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Daily Operation of Z: An 80 Terawatt, 36 Module Pulsed Power Driver

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Core and copper loss effects on the stepped impedance transmission line pulse generator

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The effects of core and copper losses on a novel magnetic compression based stepped impedance transmission line pulse generator circuit is presented. Design equations are derived and presented which take into account the current leakage into neighboring cells, losses due to magnetizing inductance currents, losses due to saturable cores and copper losses in the saturated inductance windings. It is shown that discharging an initially charged lumped element transmission line with saturable inductor switches in each cell can result in optimized energy transfer between cells of different capacitances even in the presence of lossy circuit elements, provided the cell capacitances are in a certain fixed sequence independent of the cell inductances, but dependent on the cell losses and leakage currents. The use of pre-charge voltage in such stepped impedance magnetic compression line provides voltage multiplication in addition to pulse compression without the use of transformers, but in practice the voltage multiplication effect is limited by the losses leading to saturation and a relatively short line, containing not more than approximately 4 cells.

Keywords: Magnetic compression; energy transfer; voltage multiplication; minimum core volume, core losses, copper losses, current leakage.

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Charge trapping/detrapping characteristics and lifetime of solid dielectrics

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Solid dielectrics have been widely used as insulation in power industry and often experience degradation/aging under hostile operation conditions. Their designed lifetime may be compromised. Therefore, it is important to identify the status of the insulation. Traditionally, the lifetime of solid dielectrics has been estimated using the inverse power law without the knowledge of detailed physical processes that take place in the materials. Recently, both depth and number traps in solid dielectrics have been related to material status as both chemical and physical changes in materials can lead to formation of traps.

In the present paper, a model has been developed that links the charge dynamics with both depth and number of traps in the material. By considering the material degradation/aging as a process of trap generation, it has been suggested that once the number of traps in the material reaches to a critical value the lifetime of the material as an insulation is terminated. By observing charge dynamics it is possible to estimate depth and number of traps. The experimental results also demonstrate that the electrical performance of the materials declines when the number of traps increases. Based on the new model, it can be shown that the empirical inverse power law of lifetime of an insulation can be obtained when the number of traps has a power law relationship with both the applied electric field and the time of the electric field application. That is to say the inverse power law is a special case of the new lifetime model. More importantly, the new model has a clear physical meaning which aid our understanding of aging process.

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Design of Bipolar Pulse Generator Topology Base on Marx Generator Supplied by Double Power

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Pulsed power technology has been used for the ablation tumor. Considerable research shows that a high-strength unipolar pulse electric field can induce irreversible electroporation (IRE) on the cell membrane, which can effectively kill cells. But some scholars and doctors have found that muscle contractions occur during treatment, which are associated with the delivery of electric pulses. Confirmed by further studies that bipolar pulses have been proven more advanced in the treatment of tumor because of the elimination of muscle contractions and the effect for ablating non-uniform tissue. So the bipolar pulse generator is needed for the research on the tumor ablation with bipolar pulses. In this paper, a new type of modular bipolar pulsed-power generator base on Marx generator with double power is proposed. The concept of this generator is charging two series of capacitors in parallel by two power sources respectively, and then connecting the capacitors in series through solid-state switches with different control strategy. Utilizing a number of fast solid-state switches, the capacitors can be connected in series with different polarities, so that a positive or negative polarity pulse will be delivered to the load. A laboratory prototype has been implemented in laboratory. The development of this pulse generator can provide the hardware foundation for the research on biological effect without muscle contraction when the tumors are applied with bipolar pulse electric field.

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Two-dimensional numerical modeling of electric field and correlation to breakdown – Area scaling

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An attempt was performed to illustrate dielectric breakdown and volume/area scaling in non-uniform fields. Actual scanning electron microscopy image of electrode surfaces were used (after digitization) with an effective medium approach, where the material assumed was an representation of a composite. The digitized outline uploaded to a finite element numerical solver. Electric field calculated

and stress regions were estimated using the simulation and the results were correlated to the measured breakdown values for the composite material. The stressed area estimated were converted to cumulative distribution function (Weibull-like plot) to achieve the correlation. Data from simulations and breakdown measurements were overlapped fine for a given intrinsic breakdown threshold! The proposed method can be used in other physical property characterization such as thermal and mechanical stresses.

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Design and testing of a compact low impedance Marx generator with quasi rectangular pulse

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A compact low impedance Marx generator was designed and tested. The generator consists of twelve stages and each stage utilizes two 18 nF 100 kV capacitors and four 1 nF 100 kV capacitors. When charged to the rated voltage of the capacitors the energy density of the complete generator is 15J/L. In the Marx generator different discharge periods form the capacitors added to the main circuit and quasi-rectangular pulse was formed. The Marx generator was designed to provide a pulse with fast rise time of less than 25ns, the full-width at half-maximum (FWHM) of 100ns and width at 95% maximum in excess of 50ns. The generator can deliver in excess of 30kA at 500kV to the load. This presentation details the electrical and mechanical design of the generator. Initial characterization of the output at various voltages and various loads of different impendance also been presented in this paper.

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Energy Consumption Characteristics of Pulsed Arc Discharge in High Pressure Carbon Dioxide up to Supercritical Phase

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Recently, a pulsed power switch using supercritical fluids has been investigated due to its high insulation strength and excellent extinguishing properties [1], [2]. The supercritical fluid switch is expected as an alternating medium of SF6. But, little is known about the energy consumption characteristics, which is unignorable effect on the efficiency of switching devices. This study deals with the medium density dependence of the consumption energy of arc discharge in pressurized carbon dioxide up to supercritical phase.

A needle-to-plane electrode with gap distance of approximately several hundred μm was set inside a high pressure chamber. The pulsed voltage was applied by a magnetic pulse compression circuit (Suematsu Elect. Co., Ltd.). The peak current of pulsed arc discharge was a few hundred Ampere in gas and supercritical phases. The consumption energy in the arc channel E was calculated by the dumped oscillatory voltage and current under the post-breakdown. In the gas phase, the E increased

with medium density up to sub-critical phase. Meanwhile, the E was almost constant irrespective of medium density in the supercritical phase. Spectroscopic measurement was also carried out to confirm the local thermal equilibrium of the discharge plasma. The spectral curve was characterized by the black body radiation and line spectrums of atomic oxygen (777 and 845 nm).

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Initial Evaluation of the Load Current Multiplier Concept on the Sandia Z Accelerator

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Load current multipliers (LCMs) are specialized impedance transformers used in pulsed power generators to improve generator-to-load coupling at high power densities. These devices were recently demonstrated to increase load current by 70% on a 1 MA / 100 ns generator [1], but the concept has not been evaluated experimentally on higher current (>10 MA) generators. For example, plasma formation in vacuum magnetically insulated transmission lines [2], which was not observed in the previous 1 MA experiments, is expected to be a significant loss mechanism in these LCM devices at higher currents. We have developed a conservative LCM design compatible with the 80 TW Z accelerator at Sandia National Laboratories, utilizing a large double post-hole vacuum convolute architecture. The design consists of a combination of analytic, electromagnetic, and particle-in-cell calculations. Initial performance estimates predict a 30% increase of peak current from a 15 MA / 250 ns pulse into low-inductance, non-imploding solid targets. In this paper, we will discuss both our design methodology as well as initial perspectives for upcoming experiments to evaluate the potential usefulness of the LCM concept in high energy density physics research.

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An AC Arc Discharge Model for Ice-Covered FRP Live-Line Tools

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Four separate FRP hot-stick flashover incidents have occurred in Canada during live-line working under steady-state system conditions at the peak of the voltage negative half-cycle during cold and freezing conditions. The incidents were reported at 500-kV AC line voltage working stress (95-96 kV/m) in 1997 and 2002 in Manitoba, and at 230-kV AC line voltage working stress (71 kV/m) twice in the neighbouring province, Saskatchewan, in 2012.To the best of our knowledge, the most reliable reproduction of these incidents has been achieved at UQAC Laboratories at a voltage stress of 105 kV/m at -1.04 ℃, RH of 109 % with visible fog and 2.8 µg/cm2 ESDD during a series of "true" cold fog tests. Findings fromprevious studies could well justify the cold-fog flashover mechanism for the flashovers that occurred on FRP live-line tools especially for the two flashovers that occurred at temperatures down to -13 and -19 ℃ in Manitoba and Saskatchewan. In the present study, suitable mathematical models for predicting the AC flashover voltage of ice-covered insulators are studied by considering a 1-mm ice layer covering an FRP hot stick. To the best of our knowledge, such modeling has never been attempted so far. By adapting the Obenaus approach, the arc constant parameters in air gaps as well the arc reignition conditions for an ice-covered FRP hot stick should be determined experimentally to develop its AC arc model. However, these issues need to be determined in further research and won't be addressed in this paper. Instead, issues about the present AC arc models developed for ice- or snow-covered insulators as well as various AC arc models developed for pollution flashover are discussed. It should be noted that the arc models developed for polluted or ice-covered insulators may not be adapted adequately for FRP hot-stick flashovers due to the following reasons. The ESDD values measured on the accident sticks in Manitoba and Saskatchewan were 2-3 µg/cm2.These values are considered to be at typical background level and are ignored in polluted insulator cases. On the other hand, the thickness of ice on a FRP hot stick, e.g. 1 mm, may be much less than that for even light ice-covered insulators. Therefore, arc models developed mainly for heavy ice-covered insulators may not be adapted for FRP hot stick cases. Moreover, the most reliable reproduction of the occurred flashovers was achieved during a series of "true" cold fog tests while none of the present arc models for polluted or ice-covered insulators have been developed for cold fog conditions. Considering the mentioned points, various existing models are considered in order to examine the ones having good concordance with the experimental results obtained at UQAC laboratories.

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Characterization of Double-Positive Metamaterials for Advanced Applications

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A new type of metamaterial has been developed at the University of Missouri for use in pulsed power and high power microwave systems. These materials also have direct applications in dielectric-loaded components and nonlinear transmission lines. We present a double-positive metamaterial that incorporates high permeability, high resistivity nickel-zinc ferrite powers into a dielectric matrix. The ferrite powers were diagnosed using XRD and SEM analysis. A bimodal particle distribution was investigated with particles 5µm and 30nm in diameter. The 3D models of composites were constructed using a custom Monte-Carlo algorithm to investigate the effect of particle distribution and density on material electromagnetic properties. Simulations are compared with experimental results

in order to validate the models. Testing the electromagnetic frequency response showed materials with near equal values of positive relative permeability and permittivity that were between 3.0-6.0 for frequencies between 200MHz and 1GHz. Power handling and dielectric strength were also examined with a 100kV, 60ns pulse derived from a PA-80. A maximum electric field of 300 kV/cm was measured before breakdown using 0.2cm thick disks, 2.54cm in diameter. This work presents a statistical analysis of the dielectric strength, power handling, and electromagnetic response of the composites with varying particle distributions.

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Repetitive pulse X-rays generator based on all solid state pulsed power source

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Repetitive pulse X-rays play an important role in the investigation of various physical processes in hydrodynamic experiments. Generation of repetitive pulse X-rays requires repetitively operating all solid state pulsed power source and X-ray diode.

As the testbed for repetitively operated diodes, a stacked Blumlein line (SBL) type pulsed power source (220 kV, 1 kA, 1 kHz) based on high power photoconductive semiconductor switches (PCSSs) has been constructed at Institute of Fluid Physics, CAEP. The industrial cold cathode diode was employed to generate intense X-rays.

The blade-shaped metals or metal foils are typically used as the cathode material. In order to enhance electron emission, metal-ceramic surface flashover cathodes (spoke-shaped or not) were proposed and tested recently. The electric field strengths at triple points were calculated and used to determine the cathode parameters. ICCD images show that the spoke-shaped metal-ceramic surface flashover cathode has more uniform electron emission than metal foil cathode. The experimental results show that metal-ceramic surface flashover cathode could improve the diode performance by enhancing emission current. By employing spoke-shaped metal-ceramic surface flashover cathodes, pulse X-rays with FWHM of 40 ns were generated. This all solid state X-ray generator can be operated in the repetition rate more than 1 kHz.

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Seismic Wave Characteristic of Ground Surface Layer Produced by Pulsed Discharges in Closed Water Domain

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Pulsed discharge in water has been widely used in seismic prospecting. The spark source used in the sea or on the land has formed series of products, which is based on the pulsed discharge in

expansive water domain, such as in the sea or in the deep well. But the traditional spark source is not applicable in some places short of water, especially in the mountain region. Therefore the technology of portable spark source, independent of surrounding water environment, needs to be developed. The transfer efficiency from electric energy to seismic wave energy is the most important factor in this technology. The electrode filled with water was firstly designed to develop the pulsed discharge experiment. The seismic wave generated by pulsed discharge was measured by seismic wave detector. The relation of seismic wave amplitude and discharge parameter was observed. The electrode component is machined by stainless steel and other materials which have similar acoustic impedance with salt water to enhance the transfer efficiency from electric energy to acoustic energy. The piston-like electrodes were also designed to enhance the transfer efficiency from electric energy to mechanical energy, in which some component could be active up and down due to the impulsive force produced by pulsed discharge. The seismic wave in different electrode construction was measured and analyzed. The experiment result indicates that the amplitude of seismic wave is largest in piston-like electrodes, which also indirectly indicates that the energy of pulsed discharge in closed electrode filled with water is transferred to the ground surface layer mainly by mechanical shock.

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The Anaysis of Time to Breakdown in Various Gas Insulation Systems

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In this study,time to breakdown and breakdown voltage for GIS (Gas Insulation Systems) are performed.The assessment ofthe insulation parameters such as breakdown voltage and time-tobreakdown is always done by rapid and endurance testing.At non-uniform electrode system, pressure and gas rates like SF6, N2, CO2 are used as various parameters.It is shown how the time-to-breakdown is influenced by the applied field, the pressure and gas rates.An optimization method is developed according to experimental results. Also in order to assess the results, the Weibull distribution is employed, which, due to its inherent properties is widely used to evaluate breakdown data.

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Study of the deterioration of conductive coatings used in form-wound motor coils by fretting wear tests

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Many of the failures in rotating electrical machines can have mechanical origin. One of these conditions is the vibration of the windings, something that can occur when the coils become loose in the slot. In medium voltage form-wound coils, a small oscillating movement can lead to the wear by fretting of the conductive armor coating in contact with the stator core wall. Once the conductor armor coating is completely removed in some portions of the coil surface, partial discharges appear, either inside of the slot or at the slot end. In this work the fretting wear phenomena on conductive armor coatings is investigated by using a tribotester with a ball-on-flat contact geometry, built

for this purpose. The results show the friction force against time and friction coefficients achieved during the tests, also the surface damage caused by this phenomenon is presented for a commercial conductive armor coating.

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Influence of Impulse Waveform Parameters on the Breakdown Voltage in SF6 Highly Inhomogeneous Electric Field

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Very fast transient overvoltages(VFTOs) generated during the routine operations of disconnector switch in GIS make great threat to the insulation of power equipment such as GIS. So far, the research results of the insulation characteristics of GIS under VFTO have big dispersion and poor comparability for the waveform parameters of VFTO have not been standardized. A generating system of double-exponential impulses with front times in the range of 0.08~1.2 μs and wave tail times in the range of 1.5~50 μs was established to simulate VFTO. Using this impulse generator, the influence of impulse wavefront and wave tail time on the breakdown voltage in SF6 highly inhomogeneous electric field was studied. The results show that with the rise of gas pressure, the hump phenomenon occurs in the U50% - P curves. With the increase of impulse wavefront time, the 50% breakdown voltages change significantly and the U50% - Tf curves tend to be U-shaped. The bigger of the electric field factor f is, the obvious of the U-shaped trend is. Meanwhile, the 50% breakdown voltages decrease significantly with the increase of impulse wave tail time. Analysis reveals that the reasons for the phenomenon above may be explained by the differences of the migration and diffusion of space charges and discharge time delay under impulses with different waveform parameters.

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HIGH-FIELD EXCITED FLASHOVER ACROSS SOLID DIELECTRICS IN VACUUM: MECHANISM AND SUPPRESSION

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Surface flashover in vacuum is a great limitation of electrical and electronic system, since it typically takes place on the surface region of an insulating material at applied electric stress much lower than the bulk breakdown strength of the material. This paper gives a review of surface flashover phenomena of insulators, especially its mechanism and techniques to improve withstanding voltage. We propose that flashover is a kind of complicated surface and interface physical phenomena. Based on the concurrent optical and electrical measurements and microscopic observations, the research works of our group concentrate on the relationship between flashover and surface/interface condition of insulating materials. The experimental results reveal that, under low electric field, prior to field electron emission from the cathode triple junction, electroluminescence phenomena occur due

to the radiative recombination of electrons and holes injected into the surface states from the electrodes. We attribute the preflashover phenomena to the differences between the surfaces of solid dielectric materials. According to the results, the phenomena mentioned above are cloaely related to the trapping parameters in the surface layer of a material. This work is a contribution to the traditional secondary electron emission avalanche (SEEA) model. For improving the hold-off voltage of insulators, several suggestions are given regarding how to select the material, geometry and surface processing when designing an insulator-vacuum system. Some useful techniques are presented and discussed, e.g., reducing the shallow traps of insulator greatly improve its flashover stability and decrease its flashover scattering.

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DC Breakdown From Vacuum to Low Pressure in Dielectric-Loaded Systems*

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The purpose of this study is to characterize and order various contributions to breakdown, starting with single-surface multipactor in DC. 2D particle-in-cell (PIC) simulations will be presented for DC breakdown from vacuum through low pressure in dielectric-loaded, high-voltage systems. Simulations follow developments in [1] with a PIC model accounting for discretization errors. Models are included for space charge, dielectric charging, secondary emission, diffusive outgassed species from the dielectric, and various seed-current emission models.

Breakdown will be analyzed and presented in the context of a multiplicative anodic current. Vacuum DC breakdown is characterized by a multipactor front, defined by the saturation of dielectric-surface fields in the wake of the front, leading to a short-lived, high-amplitude anodic current. A similar front develops under low pressure, gaseous breakdown, but coupling between the (charged) dielectric surface and space charge leads to oscillatory effects in otherwise DC discharges. A novel framework for breakdown susceptibility in DC will be shown, characterizing breakdown regimes from vacuum through low pressure via $E_\perp/E_\parallel$ ratios using fields near the surface, grounding results in [2] with relations for secondary emission. Updated results for the effects of diffusive outgassed species from the surface under non-constant diffusivity will be delineated. Finally, effects of the seed current on discharge saturation will be discussed.

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Investigation Dielectric Materials at Different Frequency Ranges

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In this study,effects of frequency to dielectric parameters and problems are investigated.The various dielectrics like paper, acetate, glass, rubber, silicon are used at experiment. Frequencies range is between at 50-400 Hz.Also the thickness of the dielectrics are changed at 2 and 4 mm. The results of the experiments are given as reel and imaginer loss factor, resistance, loss power and loss factor depending on frequecy. As a result, while some dielectrics have non problem at 50-60 Hz, the problem begins at higher frequency range. At higher frequency, dielectrics may loss dielectric properties.

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Proposing Supercritical Fluids as a Replacement for SF6 in High–Voltage Circuit Breakers

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Most modern equipment in power substations applies SF6 as the working gas for insulation and arc extinction. SF6, sulphur hexafluoride, has powerful arc extinction properties and excellent insulation properties.
However, SF6 is a very strong greenhouse gas when leaked and it leaves extremely toxic oxides after operational lifetime in circuit breakers.
Researchers and companies are gradually turning their focus towards finding SF6-free solutions for circuit breakers.
Countries like Australia, Sweden and New Zealand, are already pushing users in a non-SF6 direction.
Well-known options for replacement are: vacuum, CO2, and oil, but these have their typical drawbacks which vary from insufficient current/voltage rating to deterioration of the medium itself. We have been proposing supercritical fluids as an alternative already since 2009 [1]. Dedicated research started in 2011 [2,3]. We will present a short review of research on switching plasmas in supercritical fluids, highlighting advantages such as inertness, extreme breakdown strength and fast recovery.

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High Power Microwave Pulse Compressors With a Variable Geometry of Accumulative Resonant Cavity

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This work describes a new approach for designing large accumulative resonant cavities of high power microwave pulse compressors by replacing a fixed shape (cylinder, sphere, prism) microwave compressor resonator with a variable geometry accumulative resonant system. Such a system is designed based on the standard structure element made as one mode or moderately multimode waveguide section whose ends are limited with two waveguide tees or their analogues. One arm of each limiting tee or an analogue is connected to the section; another arm is closed-circuited, and the third arm is open. The accumulative system is formed as extended linear or compact planar and voluminal structures or their compositions by alignment of standard elements through open arms of tees. The proposed approach to the accumulative system design allows adapting the system geometry according to the assembly place and integrates the microwave compressor into the working unit with saving or minimizing its dimensions.

This work provides specific schemes of possible microwave pulse compression system variants with a variable geometry of the accumulative system. The authors show that a specific architecture of accumulative system accompanied by the relevant distribution of energy output equipment may allow making microwave compressors with output pulse parameters that are discretely controlled over wide range. It is also shown that the variable geometry of the accumulative resonant cavity will enable design of compact compression cascade systems with multiplied power of the resonant cavity travelling wave. The work also demonstrates the first results of experimental study of the microwave pulse compression systems with planar accumulative resonant cavities.

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Permittivity and Permeability in Double Positive Metamaterials Fabricated with Barium Titanate

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Emerging dielectric materials have been utilized to reduce the size of antennas and advanced pulsed power systems. Metamaterial composites can replace these traditional dielectrics by providing better electromagnetic properties while also being easy to machine into complex shapes. We are presently investigating these metamaterial composites, which have an impedance that can operate at the impedance of free space or even lower and believe that the metamaterials will further reduce the size and volume of advanced systems. Previous work done at the University of Missouri has tested

a chemical process to develop a metamaterial with a ferromagnetic core surrounded by a matrix of barium titanate. Using this chemical method while adjusting the precursors in the reaction based on particle characteristics, can allow the amount of barium titanate on the particles to be tailored for the desired permittivity. The permittivity and permeability of the material is measured with a coaxial airline and an Agilent Network Analyzer. Multiple composite materials with increasing layers of barium titanate were synthesized and tested to evaluate the permittivity and permeability and the impedance versus frequency calculated. The results of breakdown measurements will also be discussed.
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Towards sub-ppm Shot-to-shot Amplitude Stability of SwissFEL Resonant Kicker

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The development of a fast electron beam switching system for Swiss Free Electron Laser[1] (SwissFEL) is in its final phase. Two high stability resonant kicker magnets followed by a septum should separate two closely spaced electron bunches (28 ns apart) and send them to two separate undulator lines. Extremely high shot-to-shot amplitude stability will ensure minimal shot-to-shot variation of the generated X-ray pulses. As previously reported, the prototype system met the project requirements, reaching 3 ppm rms shot-to-shot amplitude stability[2]. During final system optimization better than 1 ppm rms shot-to-shot amplitude stability (10e-6) has been achieved.

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[2] M. Paraliev, C. Gough, “Stability Measurements of SwissFEL Resonant Kicker Prototype”, Proc. 2014 IEEE International Power Modulator and High Voltage Conference, pp. 322-325, Santa Fe, NM, USA, doi: 10.1109/IPMHVC.2014.7287273, 2014

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Study on Bubble Evolution in Oil-paper Insulation during Dynamic Rating of Power Transformers

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Solid insulation tends to absorb moisture during the operation and maintenance of oil-immersed transformers, which could be dangerous to the insulation especially in dynamic rating conditions.As

has been reported, insulation with much moisture could cause bubble effect in turn-to-turn insulation when the load of transformer increases rapidly.
Primarily, this study theoretically analyzed the degradation of dielectric strength caused by gas bubbles generated from oil-paper insulation. The results showed that bubbles with diameter over 10μm in strong electrical field could easily lead to the partial discharge in turn-to-turn insulation under the lightning invasion. This paper mainly focus on clarifying the evolution of thermal bubble formation. The experimental platform consist of an oil-paper insulation system and an adjustable heating system was established to study the influence of water content on bubble evolution temperature, the variation of the amount of bubbles and the deformation of bubbles with temperature. Results showed that the inception temperature of bubble formation was greatly influenced by gas content and moisture content in paper, which could well explain the high probability of bubble evolution in old and wet oil-impregnated transformers. Then, a mathematical model was founded to calculate the bubble evolution temperature considering the solubility of gas and moisture in transformer oil at a certain temperature, and the probability of insulation failures was assessed. Finally, based on above results, this paper provided a strategy for managing the risk of insulation failures in oil-immersed transformers caused by thermal bubbles in dynamic rating conditions.

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Thyratron Stability Improvements of SNS Extraction Kicker System

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The spallation neutron source (SNS) extraction kicker is a high power 60Hz pulsed system used to eject a proton beam from an accumulator ring and transfer it to the target. The system has 14 blumlein PFN modulators that require timing synchronization and fast rise times, with timing jitter resulting in a modulator potentially firing outside of the ideal target time and reducing transfer efficiency. Controlling extensive jitter via reservoir and filament adjustments can also reduce the lifetime of the thyratrons that are used to switch the PFN. This paper discusses the thyratron system itself, focusing on the control of the filaments and reservoirs to eliminate line sync issues and further stabilize the grid to extend lifetime in new and aging thyratrons and the results of the improvements made.

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A 400A programmable linear current pulse generator

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As part of the LHC Injector Upgrade (LIU) project, the production of a high-intensity proton beam in the Proton Synchrotron Booster (PSB) at CERN will be achieved by injecting a beam of H- ions from the new LINAC4. During the injection process the two electrons of the H- ions are removed with a stripping foil across which the machine orbit is shifted to fill the machine aperture with beam. The process of filling the machine aperture is called ‘phase space painting’ and is accomplished with four individually-pulsed ferrite-cored kicker magnets. The magnets, two of 39μH inductance and two of 390μH inductance, will be excited by piecewise linearly decreasing currents with a maximum current of 400A for the 39μH magnets. The waveforms will comprise four different programmable

slopes, changeable from pulse to pulse in the range of 8μs to 150μs. The four kicker waveforms must be well synchronized and deviate less than 0.5% from a reference waveform. Each pulse generator contains several stages of pre-charged capacitors that one after another are switched to the magnet to generate the current with the required slopes; additional stages are present to allow fine control of the slope linearity. The performance of the first operational prototype is presented and compared to theoretical calculations.

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Multiple Voids Insulation System Response by Partial Discharge Analysis

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The purpose of the present work is to evaluate the dielectric response, in presence of multiple voids, analysing Partial Discharge measurements and simulations. Air voids are simulated inside specimens, one or two vacuoles have been taken into account in different positions and with different diameters, and partial discharges patterns have been traced. The approach combines the known circuit model of three capacitors with a model used to describe the behavior of the ionized channel inside of the inclusion during the discharge phenomenon, short-circuiting the capacity that represents the void.
The approach is based on time-variable conductance of the void, subjected to multistress conditions: voltage, temperature and pressure. Before the discharge, the electric field distribution inside the void is be evaluated solving the Laplace equation.
During the ionization phase the prevalent conductance is given by the ionized channel, as the ionized channel expires the remaining conductance is given by the surface conductivity of the resin. In the evaluation of the total electric field inside the cavity, the charge deposited on the polar area has to be taken into account. In order to consider the statistical aspect of PD, the Weibull probability function has been used. The implementation of the model is done in Simulink environment. In the first simulation are considered two voids of the same radius and the same distance from the electrodes. In the second simulation a void is moved upwards and the other downwards. In the third simulation it is doubled the radius of the first void. Finally, partial discharge measurements have been carried out in order to validate the dielectric's behavior.

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[2] Di Silvestre M. L, R. Miceli, Romano P., Viola F., "Simplified Hybrid PD model in voids: pattern validation", 4th International Conference on Power Engineering, Energy and Electrical Drives –Powereng, 13-17 may, 2013, Istanbul ,Turkey.

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GYROMAGNETIC NONLINEAR TRANSMISSION LINE WITH SEALED SPARK GAP

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This paper discusses the experimental results of a reprated NLTL based HPM source featuring a sealed, mid-plane triggered, spark gap switch. This new design feature is expected to result in more robust and repeatable performance. Previous high reprate (>100 Hz) NLTL systems employed trigatron spark gaps with high pressure flow which suffered from non-repeatable operation.

The NLTL is driven from a 2.1 nF capacitor charged to ~40 kV. The trigger generator outputs a negative polarity > 50 kV pulse with a reprate capability > 1 kHz. COTS NiZn ferrites with 8 mm ID and 16 mm OD were employed in the NLTL coaxial line. Output frequency for this size ferrite resulted in 0.7 to 1.5 GHz. The output end of the NLTL is connected directly to a simple TEM horn antenna without the inclusion of a balun. Various experimental observations are presented including spark gap voltage, in-line voltage, and radiated waveforms.

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Chopper-Marx Circuit for Application to ILC: 2. Charging and System Control

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A high power, long pulse modulator aimed at application to International Linear Collider (ILC) is being developed. The target parameters are: 120 kV (±0.5%), 140 A, 1.7 ms, and 5 pps, with consideration on compactness, reliability, and cost control. A solid state, chopper controlled pulsed power generator using Marx-topology has been proposed.

This paper focuses on the charging circuit and the control methodology. Because of the high average output power, the external power supply and charging circuitry for refilling the capacitors need special consideration, especially when a high accuracy is required. A variety of issues including voltage monitoring, voltage transforming, rectifying, and isolation have been carefully considered. In addition, an operation with feedback control scenario has been designed to ensure the output that meets the ILC requirements.

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A 100kV Nanosecond Pulse Generator Based on Magnetic Pulse Compressor

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Magnetic Pulse Compressor (MPC) is an efficient solution to obtain high compress gain, high repetition rate and high voltage output. A 100kV nanosecond pulse generator based on MPC is presented. For an improved efficiency of compress, a gas switch, a pulse transformer and a saturable pulse transformer are combined to compress the pulse width; meanwhile, the voltage output is amplified as well. Unlike the traditional magnetic switch, a saturable pulse transformer has two functions, first it works as a step-up transformer, and at the same time it acts as the magnetic switch. Thus, the overall magnetic cores volume is reduced, and it allows the pulse transformers and magnetic switches to operate at very low losses. The pulse generator consists of two compress units, while a freewheeling diode is used for reducing the reverse pulse occurred in the resistive load. The proposed pulse generator can deliver pulses of around 100 nanoseconds in width with the amplitude of 100kV, and the highest repetition frequency of about 1 kHz.

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Research on the arc of mixture using the confined space

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In order to avoid the random of the discharge paths on the polluted insulators, we make use of the capillary to form the arc in the confined space. In the capillary, the salt grains and kaolin powder are used to replace the composition of the polluted layer respectively. The voltage and the current waves of the arcs are recorded, and the photographs are presented. The experimental results show that the arc in the kaolin powder is a kind of arc including corona in a two-phase mixture (gas and solid), and the arc in the salt grains is also a kind of arc including corona in a two-phase mixture, but also with the process of phase transformation of the salt grains (solid-to-liquid) which results in the corona existing on the peak-value and the descending step of the voltage. The phase transformation of the salt grains in the arc is critical process which will influence the discharge characteristic. These results will contribute to the study of dry band discharges on the polluted insulators.

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PD Pulse Sequence Studies with model transformer insulation in Mercaptans contaminated transformer oil

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Corrosion of copper conductors in transformers due to presence of mercaptan sulfur in oil is a problem affecting the paper-oil insulations, potentially leading to failure of transformers. The mercaptan sulfur reacts with the copper conductor and forms copper sulfide on the surface. Copper sulfide also migrates from conductor surface to outer layers of paper and from there it is carried to other parts of transformer. These may become the sites for the initiation of additional partial discharges along with the existing PD which causes damage to the layers of paper in contact with conductor. Over

the last three decades computer based Partial Discharge data acquisition and analysis are common in use. The pulse magnitude and its phase position are the most commonly measured parameters. This paper presents pulse sequence studies with PD data obtained for Paper covered copper conductor (PCCC) in Mercaptans sulfur contamination in transformer oil. The paper also discusses the changes in the inter pulse time and their relation with the phase of occurrence of PD when contamination in oil occurs.

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sub-microsecond Pulse Generators Based on Magnetic Pulse Compression System

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Magnetic Pulse Compression (MPC) system is an important and efficient method to obtain high repetition rate and high voltage output. Novel MPC system which do not contain external demagnetization circuits have broadened the appliance of MPC systems. The novel MPC system mainly use magnetic switches to compress the pulse width. For improving the compression efficiency, we use both saturable pulse transformers and magnetic switches to compress the pulse width and amplify the voltage output as well. An 2n stage MPC based on the improved MPC topology is presented. The 2n stage MPC consists of 2n compress units, a freewheeling diode or an inductor to reduce the pre-pulse occurred in the load, and a resistive load. To meet the high voltage and compression gain and considering the overall system efficiency, we designed two kinds of most popular MPC system based on the improved MPC topology, which is 2-stage MPC system and 3-stage MPC system. Based on the improved MPC topology, several kinds of compact pulse generators are build in our laboratory. We named these pulse generators as MPC-AAAL(D) series. AAA means the highest voltage output in kV. Post fix L or D means the resistive load paralleled with an inductor or a freewheeling diode, respectively. These generators illustrate the improved MPC topology together with solid state switch provides an ideal way to generate pulses of around 100 nano-seconds in width with mid and high voltage of 5kV to 120kV, and the highest repetition frequency of about 20 kHz.

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Electro-Convection in Liquids in Absence of Ionization

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It is known that a nonuniform electric field can exert forces on neutral matter. In liquids, these forces may cause intense movement. The governing physics here are electrostatics and fluid dynamics.
In paper [1], we calculated heat transfer in a vessel filled with transformer oil using COMSOL MULTIPHYSICS®. This was probably one of the first attempts to analyze EC numerically. The present paper is a continuation of this investigation.
We concentrate mostly on 2-D geometries. Liquid movement and heat transfer influenced by electric forces is studied in horizontally oriented coaxial electrode systems as well as in more complex shapes. In addition, we examine oil lift and possible splash by a vertical metal electrode partially immersed in oil in a coaxial geometry. Time-resolved solutions match closely the experimental results (videos and still photos). The described approach can be useful for studying electrohydraulic phenomena. Mechanism of electrical energy conversion to heat is unclear in the performed simulations; it can be

a subject of further investigation.
[1] A. Pokryvailo, "Impact of Electro-Convection (EC) on Heat Transfer in Liquid-Filled Containers", Proc. COMSOL Conference 2015, Boston MA, 7-9 October 2015, 7pp. Available at COMSOL site.

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Liquid Dielectric Breakdown Studies using Compact Tesla Pulse Generator

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Liquid dielectric breakdown properties are studied towards the development of efficient intermediate storage devices for pulsed power applications. A Tesla based pulse generator along with suitable voltage (V-dot) and current (self-integrating Rogowski coil) sensors are indigenously developed. The experiments are performed by applying few 100 KV with few tens of nanosecond pulse under uniform electric field conditions. Preliminary experiments are carried out on deionized water (εr= 78, σ < 1 μS/cm), the experimental parameters being different electrode materials (brass and stainless steel), inter electrode gaps (3, 6, 8 mm) and applied polarity (positive and negative). Subsequently, the experiments are extended to understand the suitability of heavy water for compact pulsed power applications. In addition to the electrical diagnostics, optical measurements i.e. absorption spectroscopy and emission spectroscopy are also used for understating the breakdown properties. Further, the discharge initiation and evolution is studied using a fast camera (4 PICOS ICCD). The observations indicate significant charge holding capability in case of stainless steel compared to brass, suitability of water in comparison to heavy water for compact pulsed power applications. The experimental details and important outcomes will be presented.

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Influence of Electric Field Non-uniformity on Breakdown Characteristics in SF6/N2 Gas Mixtures Under Lightning Impulse

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In recent years, SF6/N2 gas mixtures especially with low SF6 mixing ratio was getting used as insulating medium in gas-insulated equipment for replacing pure SF6 which causes greenhouse effect. For the application of SF6/N2 gas mixtures in power equipment such as GIL, the breakdown characteristics of SF6/N2 gas mixtures in different electric field non-uniformity under lightning impulse were studied in this paper based on a fully enclosed steep-front impulse test device. The research indicates that the breakdown voltage of SF6/N2 gas mixtures increases linearly with increase of gas pressure in slightly non-uniform electric field, and the saturated trend appears with increase of the electric field non-uniformity. The reversal of polarity effect was found in SF6/N2 gas mixtures. The breakdown voltage under negative lightning impulse is higher than that under positive lightning impulse in low gas pressure, but when pressure exceeds a critical value, the result converses. The increase of SF6 mixing ratio or decrease of electric field non-uniformity would both lead to the decrease of the critical value of gas pressure. Meanwhile the change of polarity effect in SF6/N2 gas

mixtures is later than that in pure gas with the increase of electric field non-uniformity. In addition, the synergistic effect of SF6/N2 gas mixtures weakens obviously with the increase of electric field non-uniformity, and the negative synergistic effect even appears with strongly non-uniform electric field.

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Insulation deterioration of twisted pairs due to high frequency switching of power Electronic Converters (PECs)

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In Industries the motor speed are controlled with the help of PEC(power electronics converters)which are raised by the advancement in adjustable speed drive technology. This technology have paved way for dramatic changes in industrial control of motors. But the output waveforms of the PEC's are highly distorted which may affect significantly the reliability of electric motor insulation system. So the motor insulation must be designed in such a way that it can withstand these highly distorted waveforms. The cause for distortions are due to the non linear components which are used in PEC's generate harmonics and these harmonics are in turn responsible for the voltage distortion. Along with this effect the switching rates used in PEC's generate voltage overshoots which in turn leads to the premature failure of the motor's insulation. This overshoots are primarily due to the high frequency distortion, impedance mismatch and slew rate of the waveforms generated by the PEC's .Because of these reasons partial activity is accelerated ,which reduces the lifetime of the insulation, The insulation failure or breakdown in motor insulation systems are to be studied by conducting test called breakdown tests. Our experiment focuses on testing the winding primary insulation first then with the secondary insulation made of modified polyester in addition to the primary one. Twisted pair are used to investigate the winding insulation. All the breakdowns tests are performed with these twisted pairs. A twisted pair is composed by two enameled wires wound as a plait according to ASTM D 2307 standards. These specimen are subjected to stresses provided by high frequency and power frequency waveforms .First the tests are made over the primary insulation of the twisted pair then over the coated secondary insulation and the comparison are to be made. The secondary insulation is also made with epoxy resin along with filler materials like aluminium trioxide ,zinc oxide and titanium oxide of various concentrations added to base epoxy.
In our experiment ,the electrical breakdown mechanism is observed by means of pure sinusoidal wave, sinusoidal PWM with high frequency switching pulses.
The fore mentioned waveforms will be generated by experimental setup. Generated waveforms will be applied on the twisted pair samples ,the failure times will be absorbed. The above observed results will be compared with testing done with sinusoidal waveforms. The sample with secondary insulation coating was observed to have higher insulation strength compared to the sample with primary insulation, for obvious reasons. Based on the comparison factors which were found experimentally ,lifetime model of insulation will be established.
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MULTICHANNEL SIGNAL SYNTHESIS IN FREE SPACE

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A two antennae, software controllable phased array was built to study the generation and transmission of short, nanosecond, non-periodic pulses. This system allows transmitting a train of properly scaled and time-shifted non-periodic signals to generate received signals with major frequency components adjustable from approximately 600 MHz to 1.5 GHz. The main components in the system include two digital to analog converters (DACs), two data pattern generators (DPG), and two power amplifiers which drive two TEM Horn antennas. A user created data vector is uploaded to two DPGs (Analog Devices Data Pattern Generator 3) via a laptop USB connection, to be played back by attached, high speed RF DACs. The DACs chosen here are Analog Devices 9129 (AD9129), 14-bit RF DACs capable of a 2.8 GSPS data rate, that can play baseband signals up to 1.2 GHz. Two synchronized clock signals operating at 2.4 GHz are connected to the DACs, which will also provide the clock signal for the DPG3. An external trigger source connected to the DPG3 is used to begin playback of the user defined data vector.
The focus of this experiment is the transmission of a set of short, non-periodic pulses (akin to wavelets in signal theory) to create a signal of different amplitude or frequency at a specified point in space. Signals synthesized by the AD9129 are fed into a 20dB power amplifier (Mini-Circuits ZFL-2500VH+) to be transmitted by a TEM Horn antenna. Each antenna was constructed with a Chebyshev taper and a Microstrip-type balun to achieve a wide frequency response and sensitivity to fields in the time and frequency domain. Thus far, 100 ps synchronization between channels was achieved, and signals of varying shape and amplitude have been received via the shifting and inverting of Gaussian input pulses defined by the user data vectors. This paper presents an experimental evaluation of the hardware used to generate the phased array, the ability to steer the signals and generate signals of varied frequency via superposition in free space.

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The Effect of Partial Discharge on Electrical Life of Oil Immersed Paper

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Insulation paper immersed with transformer oil is used as an electrical insulation medium in transformer for its high breakdown field strength. In the normal operation state of higher voltage power transformers, the defects in insulation medium can cause partial discharge(PD) which do harm to insulation materials, resulting in a shortened life of oil immersed paper. PD activities vary according to the applied voltage, therefore the extent of shorten life is varied under different voltage.
In this paper, the average electrical life of oil immersed paper under different AC voltage is studied. The PD tests were performed on specimens of 1 mm thickness which was placed between the needle-to-plane electrodes in an oil cup. The specimen was immersed in vacuum with treatment of hot air drying in order to remove moisture. Because of dispersions in partial discharge in oil-paper insulation, the applied voltage is set according to the discharge inception voltage, such as twice as the inception voltage. Feature parameters of PD are acquired by PDCheck system and the waveform of pulses is acquired by an oscilloscope. The duration of specimen under AC voltage is considered to be electrical life of the oil-immersed paper. Relationship between average electrical life and applied voltage is evaluated using Weibull distribution, and the inverse power law as well as the exponential

law is used to find the best fitting curve between electrical life and applied voltage. Moreover, fitting curve between discharge magnitude and electrical life using inverse power law is also presented in this power, which is a novel analyzing method of electrical life of insulation material.
Test results indicated that life of insulation paper tended to decrease rapidly with increase in applied voltage. Exponential law owns a better fit degree compared to inverse power law, which indicates the existence of a threshold voltage to the electrical aging of insulation material. Electrical life is likely to have much relevance to the discharge magnitude. When the discharge magnitude is larger, the electrical life is shorter.

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Stability of thyratron switching in LCLS linac modulators

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Building from several years of study, it is determined that the dominant cause of pulse to pulse jitter in LCLS linac modulators is thyratron performance [1]. Without a stabile thyratron, all other sources of jitter are dwarfed. To achieve long term stability in this environment, a highly de-rated off the shelf thyratron was selected to upgrade critical RF stations. After a year of operation, the thyratron has demonstrated its effectiveness in reducing thyratron related jitter in a way that allows for other jitter improvements to be pursued. The thyratron upgrade study is presented in this paper.
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A High Repetition-rate Bipolar Nanosecond Pulse Generator Based on Magnetic Pulse Compression System

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Magnetic compression system (MPC) is suitable for generating (Dielectric Barrier Discharges) DBD discharge due to its capability of producing high amplitude and short pulses voltage wave. Because of the frequency limit caused by magnetic core reset, and the high DBD discharge voltage, which is often up to several tens kV under the low-frequency unipolar voltage wave, this paper proposes a high-frequency bipolar magnetic compression system to study the discharge characteristics. First, the principle of bipolar MPC is explained, which is based on full bridge inverter circuit, pulse transformer, and magnetic switch. Besides, the system is designed by calculation. Then, a simulation based on PSPICE is implemented to testify the feasibility and study the impact factors of amplitude and rising time of the load voltage waveform. Finally, the measured waveforms are obtained from experiment device and the discharge phenomena under different conditions are compared. As a result, the nanosecond pulse generator produces a pulse on a resistor load, with an amplitude of 0–10 kV, a rise time of approximately 100ns, a repetition frequency of 0 to several kHz. Although the DBD discharge is influenced by multiple factors, the pulse repetition frequency and polarity impact greatly. The preliminary experimental data show the effects of the voltage amplitude, repetition frequency, and bipolar pulse. It confirms that the generator can provide a good performance on homogeneous discharge, compared with AC, and low discharge voltage, compared with unipolar pulse.

The successful development of the system will facilitate deeply study on bipolar high frequency DBD discharge.

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Numerical analysis on the output characteristics of a linear switch array pulse modulator

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A linear switch array pulse modulator (LSAPM) including gas switches, transmission lines and matched load was proposed to produce a pulse with a L wave band pulse, the frequency of output pulse could be adjusted by changing the length and impedance of transmission line, and interelectrode capacitance. In this paper, an electric circuit model of a 12-stage LSAPM was built and analyzed, and the electric field distribution of the LSAPM was calculated. The influences of switch parameters including spark inductance spark resistance and interelectrode capacitance, on the amplitude-frequency characteristics of output voltage waveform. The results showed that a pulse with oscillation frequency of 1.2-1.6GHz, duration of 14ns and output amplitude of 130kV was generated by establishing a 12-stage LSAPM at an input square-pulse of 100kV. The output voltage decreased with increasing of spark resistance. And the pulse amplitude at above frequency band was relatively higher at the interelectrode capacitance of 6pF and the spark inductance of 1nH.

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Influence of H2O on SF6 Discharge and Decomposition Characteristics Under Low Moisture Conditions

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The detection of gas decomposition products is an effective method to diagnose the partial discharge in SF6 insulated electric power equipment for its anti-interference ability and high sensitivity. However, there inevitably exists trace level of water in the SF6 insulated equipment. In order to study the influence of moisture under low volume fraction (<1350×10-6) on discharge and decomposition characteristics of SF6. An experimental and testing platform for SF6 gas-insulated electrical equipment was designed in this paper under different moisture contents (147μL/L, 347μL/L, 681μL/L, 909μL/L, and 1340μL/L). The influence of moisture on the magnitude of partial discharge caused by metal protrusions defects and content variation of SOF2、SO2F2、SO2、CO2 was observed in detail. The results indicate that average discharge amount and overall magnitude of charge decrease first and then increase with increasing volume fraction of moisture. H2O will promote the formation of all the four products, with a stronger influence on the sulfur-containing products than CO2. Besides, the value of φ(SOF2+SO2)/φ(SO2F2) maintains stable with the variation of moisture. It is about 3-4 after 9h. The value of φ(SOF2+SO2+SO2F2)/φ(CO2) presents overall increasing trend with moisture content. It ultimately increases to a stable value about 2.5-3 under low moisture condition (<681 μL/L). Thus, the detection method of SF6 decomposition products should be utilized with the consideration of moisture content.

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Construction and commissioning Xbox3: a very high capacity X-band test stand

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The Compact Linear Collider (CLIC) beam-based acceleration baseline uses travelling wave accelerating structures at a frequency of 12 GHz. In order to prove the performance of these structures at high peak power and short pulse width RF, two klystron-based test facilities have been put in operation in the last years. The third X-band testing facility at CERN (Xbox3) has recently been commissioned and has increased the number of testing slots available by 200%. Xbox3 uses a novel way of combining 4 relatively low peak power (6 MW) but high average power klystron units whose power is combined to feed four testing slots with RF to the required power with a repetition rate of up to 400 Hz possible in one slot or up to 100 Hz per slot if there are four devices under test. Besides the repetition rate, peak power, pulse length and pulse shape can be customized to fit the test requirements. In this paper we will describe the layout of the facility, commissioning experience and operation modes and results that we have achieved so far. This novel way of combining pulsed RF high power can eventually be used for many other applications where multiple test slots are required.

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Effects of Thyratron Aging on Klystron RF Pulse Stability

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The FERMI Free Electron Laser facility is based on a 1,5 GeV S Band linear accelerator. The facility operates for more than 6500 hours/year. The RF klystron modulators consist of high voltage pulse generators based on thyratron switched pulse forming networks and step up transformer technology. High output voltage stability from the modulators is required to meet the demanding specifications of RF amplitude and phase stability. An analysis of the klystron voltage stability measurement versus the RF amplitude and phase variations has been performed to evaluate the main possible contributions . Degradation of the behavior of the thyratron switch as the operating time of the tube approaches end of life has demonstrated to be one of the major reason of stability worsening with the increasing of the accumulated operation time of the plants

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Study of Nanosecond Electrical Breakdown in Perfluorinated Liquids at 140 kV

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Perfluorinated delectric liquids are perspective for using in high-voltage devices because of their chemical stability under electrical discharges. For applications like liquid spark gaps, velocity of breakdown is an important parameter. In this work the results of measurement of velocity of anode-initiated electrical breakdown at 140 kV in perfluorinated liquids of different chemical classes are presented. Experimental setup [1] comprised nanosecond generator, breakdown cell, voltage divider, and digital oscilloscope. Generator impedance is 50 Ω, stored energy 0.8 J, voltage under no-load 140 kV. Pulse duration is 8 ns under the load-matched conditions, rise time less than 0.5 ns. Point-to-plane configuration of electrodes with positive point was used. It has been shown that perfluorinated ethers have close values of breakdown velocity in wide range of gaps and demonstrate relatively low jitter in gaps for which time to breakdown (up to 30 ns) is comparable to pulse duration. Velocities of breakdown in these liquids are $5 \cdot 10^6$ – $1.3 \cdot 10^7$ cm/s for gaps up to 2 mm, which is 3–8 times larger than in transformer oil under the same conditions [2]. Differential velocity of breakdown front propagation for all tested liquids substantially decreases in gaps wider than 1.5–2 mm being about $2 \div 3 \cdot 10^6$ cm/s. Time to breakdown in wider gaps grows linearly up to 6 mm. As soon as differential velocity of breakdown remains nearly constant for wide gap range, it might be considered as an electrophysical characteristic of the dielectric liquid under these pulsed conditions.

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[2] I. F. Punanov, R. V. Emlin, P. A. Morozov, and S. O. Cholakh, "Investigation of breakdown in porous ceramics initiated by nanosecond pulses," *Russian Physics Journal*, vol. 55, no. 2, pp. 191–194, Jul. 2012.

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The influence of metal vapor deposition on the insulating materials

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The Insulating materials often work in terrible conditions with high temperature and full of metal vapor. For example, the electrical insulator of high voltage circuit breaker repeats breaking the arc frequently, resulting in electrode erosion. Electrode erosion makes the metal vapor and it will be attached to the insulator surface, greatly affecting the Insulation property. This paper mainly adopts the method of combining experiment and simulation in order to figure out the influence. In the early experiments, we can make a preliminary confirmation that the metal vapor can make the performance of insulation materials decrease, and the degree of decline is related to the thickness of metal vapor. We use electrical explosion as the way to produce metal vapor and spray it onto the surface of the insulating material. Changing the parameters in the electrical explosion can make different insulating with different metal thickness. And then, use SEM to observe and scan the surface morphology of insulation specimen. Besides, by measuring the insulating material surface resistance and flashover voltage with instrument, we can make the evaluation and compare for several kinds of insulating materials, such as Teflon, ceramics and polyimide. To make the result more persuasive, we plan to use the simulation software, FLUENT, to simulate the temperature field and velocity

field in the electrical explosion. We believe this can explain the relation between the parameters in the electrical explosion and the metal vapor deposition situation. At last, we provide the advice to reduce the influence of metal vapor deposition based on the experimental result.

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High Power Microwave Production with a Nanosecond Pulser and Nonlinear Transmission Line

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Eagle Harbor Technologies, Inc. (EHT) is utilizing the previously developed EHT Nanosecond Pulser (NSP) to drive a nonlinear transmission line (NLTL) for high power microwave production. The EHT NSP provides independent control of the output voltage (20 kV), pulse width (20 – 200 ns), and pulse repetition frequency (up to 100 kHz). EHT is using this pulser to investigate RF production with a gyromagnetic NLTL and lumped-element NLTL based on nonlinear effects in Schottky diodes. The gyromagnetic NLTL has a frequency around 2 GHz, while the diode-based NLTL's frequency is lower. EHT will present experimental, including RF measurements with D-dot probes. Additionally, modeling results will be presented for the diode-based NLTL and compared with experiment.

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A two dimensional circuit model of induction cavity

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Induction voltage adder accelerators are always employed to achieve high voltage and fast rise time voltage pulse for various research aims. The voltage pulses generated by pulse forming section are added by induction cell. Azimuthal transmission line is used to ensure current uniformity at secondary transmission line section. This results in two dimensional power flow in the induction cell. A circuit model of induction cavity has been proposed to investigate the power flow condition in induction cell. One dimensional and two dimensional transmission line elements are included which can model the radial and azimuthal directions power flow inward azimuthal transmission line and axial and azimuthal directions power flow at secondary transmission line section by this circuit model. Transient electromagnetic simulation has been employed to check out the exactness of the circuit model. The voltage waveforms at oil elbow, insulator stack, radial feed gap, secondary transmission line and dummy load acquired by the two different methods can agree with each other very well.

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SURFACE FLASHOVER CHARACTERISTICS OF GROOVED NANODIELECTRICS UNDER PULSED VOLTAGE IN PARTIAL VACUUM

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Modern electrical power industry with high voltage levels needs the investigation of breakdown characteristics of dielectrics operated at kHz pulse field in partial vacuum. Aerospace industry, like aircraft and space station applications, is also requiring much higher power nowadays. Switched-mode power supplies offer solution to overcome these challenges. Meanwhile, understanding of the effects of higher voltage levels and frequencies on insulator surface flashover under partial vacuum condition are essential. In this study, we present our research on the surface flashover phenomenon and discharge characteristics of nanodielectrics subject to varying frequencies between 20-200 kHz under pulsed voltages with different duty cycle in partial vacuum. Specifically, we investigated the grooved nanodielectrics surface potential effect on the discharge characteristics compared to untreated ones. All experiments conducted are utilized with copper electrodes at 1cm gap distance. The samples with different weight ratio of nano-particles Al2O3 and TiO2 powder into the epoxy resin are compared. It is observed that the higher the frequency is, the lower the breakdown voltage is under the same experimental conditions and electrode geometry. Besides, the breakdown voltage versus pressure curves of nanodielectrics follows the classic Paschen's Law as well. In conclusion, it is proved that the grooved samples have better hold-off voltage capacity than the untreated ones.

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Surface Flashover Properties of Polytetrafluoroethylene Modified by Ion Implantation in Vacuum

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Surface characteristics of Insulator effect its surface flashover performance obviously, appropriate surface treatment can increase the surface flashover voltage. Ion implantation technology is an effective surface modification tool, it can change the roughness, resistivity and adsorbability on the insulator surface. Polytetrafluoroethylene (PTFE) was modified by carbon ion and nitrogen ion by using a electron cyclotron resonance (ECR) ion source and a MEVVA ion source. The surface flashover voltage were measured on the experimental platforms of surface characteristics in vacuum before and after modification, Also the characteristies and microstructure of the implanted layer were studied by using the AFM(atomic force microscopy) and XPS(X-ray photo electron spectra) and find the influencing factors on surface flashover properties of PTFE modified by ion implantation.

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Effect of Electrode Composition on the Partial Discharge Characteristics of a Dielectric Elastomer Actuator System

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Dielectric Elastomer Actuators (DEAs) are electroactive polymers capable of achieving high actuation. The key to achieving these high actuation strains is to make both the electrodes and the elastomer highly compliant without sacrificing their dielectric strength or conductivity. DEAs, because they are soft materials designed to exert mechanical stress, often break down because of mechanical phenomena less common in other, rigid, high voltage systems. This work explores the use of partial discharge activity as a precursor to breakdown for DEAs. A variety of electrodes have been used, powdered electrodes and conductive greases are of particular interest because they provide negligible increases to the stiffness of the actuator, allowing greater strains. An increase in coronal discharge is seen from the use of less rigid electrodes, resulting in a trade-off between mechanical performance and electrical aging. Additionally, it has been found that the electrode's properties, such as thermal conductivity, electrical conductivity, and active area affect the electrical performance of the DEA. This paper presents a comparison of partial discharge characteristics based on electrode composition.

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Dielectric Strength Testing of 3D Printed Polymeric Materials

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Additive manufacturing techniques offer the potential to fabricate dielectric insulators with highly complex geometry; however, the relative lack of bulk dielectric strength data for many of these materials potentially limits the usefulness of these techniques for fabricating structures intended for use in high field environments. Furthermore, data suggests that the choice of printing technique may impart additional limitations in insulators by introducing anisotropic dielectric properties within the emphasized text part which are related to the original orientation in which the part was printed. The authors will present dielectric strength testing data, based on the ASTM D149 standard, for parts fabricated using the stereolithography (SLA), fused deposition modeling (FDM), and selective laser sintering (SLS) additive manufacturing techniques.

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Dielectric properties and surface flashover characteristics of Al2O3-filled epoxy resin in subatmospheric pressure under 20-200 kHz applied pulsed fields

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Nano-dielectrics are shown to have improved electrical and dielectric properties compared to the non-filled bulk material. Surface flash-over is one form of breakdown, usually occurs over the surface of insulator between the energized electrodes due to high field stress when the field stress at the insulator/electrode/ambient interfaces. Understanding the characteristics of surface flash over in sub-atmospheric pressures is more important for aerospace systems and vehicles. In space/aerospace power systems, high frequency effects on dielectric breakdown and surface flash-over are due to the switching circuits used in power systems. In this work we present surface flash-over characteristics of two different polymer nano-dielectrics filled with either TiO2 or Al2O3 nano-particles in sub-atmospheric nitrogen. A high frequency unipolar pulsed field varying from 20 kHz to 200 kHz is used in the experiments. The effects of duty cycle and frequency of the applied field, surface condition of the sample, and background pressure on the surface flash-over are presented. A 0.5 cm gap distance is formed by two rounded copper electrodes positioned on top of the sample. The plasma characteristics, such as voltage, current, and optical emission wave-forms are recorded. Dielectric properties such as volume resistivity, polarization current, and dielectric permittivity of TiO2 and Al2O3 filled samples are studied and the differences between these two samples' surface flashover characteristic are presented.

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DESIGN AND PERFORMANCE OF AN 8 LINE GYROMAGNETIC NONLINEAR TRANSMISSION ARRAY

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DESIGN AND PERFORMANCE OF AN 8 LINE GYROMAGNETIC NONLINEAR TRANSMISSION ARRAY

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This paper discusses the design, fabrication, and performance of an eight element, coaxial ferromagnetic Nonlinear Transmission Line (NLTL) used as a high power microwave (HPM) source. To start precession in the lines a 10.4 nF capacitor bank is charged to -40 kV from two 802L TDK Lambda power supplies. A center pin trigatron is used to trigger the spark-gap discharging the capacitors. The trigger generator used is optically isolated and battery powered, producing a positive polarity pulse at 20 kV with a 20 ns risetime. The spark-gap simultaneously outputs to all eight NLTL's. Preceding the 77 cm main lines are eight 32 cm lines used to delay the pulse allowing propagation speed adjustments between the lines to ensure proper phasing at the output. The lines use NiZn ferrites with SF6 insulation. Each NLTL terminates into a custom Rexolite-filled, TEM horn antenna using a zipper balun. The system is operated using a PLC control system. Experimental observations include in-line measurements of voltage waveforms and radiated D-dot field measurements.

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Relationship between the Physicochemical Properties of Materials and the Fractal Dimension of Creeping Discharges Propagating at Solid/Fluid Interfaces

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The solid/fluid (gas or liquid) insulating systems are widely used in high voltage equipment (bushings, insulators, switchgears, gas insulating lines, gas circuit breakers, high voltage power transformers, power capacitors ...) where they are exposed to different stresses and particularly to discharges phenomena that can develop within the body of insulator or at the solid/fluid interface leading respectively to breakdown or flashover (arc) of insulator and hence to the failure of the system. It is therefore imperative to understand the mechanisms and conditions of initiation and development of these discharges to avoid turning off equipment services. In this work we are interested by the propagation of discharges at the solid/fluid interface (i.e., the creeping discharges) especially their patterns and stopping length; these parameters are of great interest for the design of insulation systems used in high voltage components and systems.
The present paper is aimed at the main parameters that affect the fractal dimension D of creeping discharges propagating over different types of insulators immersed in gases at different pressures and in dielectric liquids, in a point-plane electrode arrangement. Especially, the dielectric constant, thickness of insulators, gas pressure, type of liquids (mineral and vegetable oils) and the type of voltage waveforms (lightning impulse voltage or DC) are analyzed. The considered insulators are circular samples of different thicknesses made of glass, epoxy resin and PTFE and pressboard; different types of liquid are also considered. The fractal dimension D of the observed discharge patterns is determined by the box counting method. It is shown that the fractal dimension D of these discharges depends on the thickness (e) and the dielectric constant of insulator (⊠r), gas and its pressure, type of liquid. D decreases when e increases and it increases with ⊠r; this dependency of D upon e and er indicates the important role of the electric field and capacitive effect in the propagation mechanism. Also, D decreases when the gas pressure is increased; and D is higher with lightning impulse voltage than with DC voltage. These results evidence the existence of a relation between the fractal dimension and the physicochemical characteristics of materials constituting the interface.

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Effect of hydrostatic pressure on the impulse breakdown characteristics of transformer oil

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The aim of this study was to clarify the hydrostatic pressure effect on the initiation and propagation process of oil streamers under the application of pulsed voltage with different polarities. The statistical characteristics of the impulse breakdown voltage and time lag in transformer oil were studied over a wide range of hydrostatic pressure, and the statistical discharge time lag and the discharge formation time lag were calculated by the Laue's pattern. The breakdown voltage distribution can be well fitted by 3 parameter Weibull distribution. The results show that the breakdown voltage increases with the hydrostatic pressure for both positive and negative polarity. However, the increase trend is different, linear for the positive polarity and saturated for the negative polarity. At a fixed voltage, when the pressure is increased, the breakdown time lag increases slightly for the

negative polarity, but remarkably for the positive polarity. The statistical time lag for negative polarity is much larger than positive polarity, and the hydrostatic pressure has greater influence for negative polarity. The characteristics of formation time lag are quite different: for negative polarity it decreases very slightly with the hydrostatic pressure, but increases remarkably for positive polarity. These differences are due to different initiation and propagation mechanisms, which are also discussed in the paper.

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GW-class relativistic backward-wave oscillator with pulse duration above 200 ns

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The physical idea, specific structure and main testing results of a GW-class S-band relativistic backward-wave oscillator (RBWO) with pulse duration above 200 ns are presented. To restrain the "pulse shortening" phenomenon, special attentions are paid on two aspects in our designing. One is to optimize the electrodynamic structures to decrease the electric field on the surfaces of slow-wave structures (SWSs) while maintaining relative high beam-wave conversion efficiency. The other is to increase the smoothness and cleanness on the surfaces of SWSs and improve the vacuum level to elevate the breakdown threshold. In the initial experiment, a microwave with frequency of 3.71 GHz, power of 1.5 GW, efficiency of 30%, and pulse duration above 200 ns is generated. This is the first experimental report of GW-class RBWO with pulse duration above 200 ns.

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Analysis of Peak Output Voltage and Droop from a Nonuniform Transmission Line

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Nonuniform transmission lines are widely used as impedance transformers in pulsed power systems such as Z-pinch drivers. The transmission characteristics of the nonuniform line are important issues for the system. As the characteristic impedance varies along the nonuniform transmission line, it is difficult to investigate the transmission characteristics using analytical methods.
In this paper, a mathematical expression of the output voltage from the nonuniform transmission line with an arbitrary input pulse was deduced. It is an extension of the mathematical expression we proposed two years ago[1], which is just for a half-sine input voltage wave. The peak-value of the output voltage with a half-sine input voltage wave and the droop of the output voltage with a rectangle input voltage wave were further investigated by the analytical analysis of the new mathematical expression.

[1] C. Mao, X. Zou, and X. Wang, "Analytical solution of nonuniform transmission lines for Z-pinch," IEEE Transactions on Plasma Science, vol. 42, pp. 2092-2097, August 2014.

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Space Charge Accumulation as a Contributor to Partial Discharge Activity in Dielectric Elastomer Actuators under High Voltage DC

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Space charge accumulation is theorized to be a contributor to partial discharge activity. The analysis of partial discharge (PD) activity is a method of predicting electrical breakdown in dielectric materials. Rapid aging tests of an acrylic dielectric elastomer using a partial discharge analyzer (PDA) has shown that under DC voltage application consisting of a 1 minute period of constant voltage followed by an increase in voltage step results in bursts of partial discharge activity. This paper will explore the potential cause of this phenomenon. It is theorized that space charge accumulation during the constant voltage period followed by rapid charge injection during the increase of voltage results in an impulse like stress of the elastomer causing PDs. Using the pulsed electro acoustic (PEA) method, space charge measurements are collected and compared to partial discharge occurrence data to analyze the correlation between PD occurrence and space charge presence.

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A coaxial ceramic vacuum insulator for a repetitive operated pulsed power source

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Research on the surface flashover of the vacuum interface under pulsed voltage is significant for the design and operation of pulsed power devices. The interface problem is difficult because the electrical, mechanical and vacuum issues that must be satisfied simultaneously. In this paper, a coaxial high-voltage vacuum interface based on ceramic-metal welding has been designed and tested with a repetitive pulsed power modulator. Results from electro-static and mechanic-stress calculation by the ANSYS package show that the electric field (E-field) distribution along the ceramic surface is uniform and the structure strength is under control. Key structures such as the anode and the cathode shielding rings for ceramic solders have been optimized to significantly reduce E-field stresses around the triple junctions. Aging experiments with this insulation structure were conducted in the condition of ~600 kV, ~60 ns and 1~10 Hz pulses. The statistical method was used to evaluate the reliability of the insulator performance and results show that the ceramic vacuum interface can work stably with the hold-off field of more than 45 kV/cm. Furthermore, by sampling and scanning the different surface condition of the ceramic insulator, the influence of the ceramic surface roughness on the flashover characteristics was also analytical discussed.

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Characterization and Fabrication of Carbon Nanotubes Grown on Ceramic Substrates for High Temperature RFID Applications

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Carbon Nanotubes (CNTs) are very diverse nano-scale materials that carry excellent electrical, mechanical, and chemical properties. In this study, selectively growing randomly oriented multi-walled CNTs are fabricated in-house on ceramic substrates by using thermal Chemical Vapor Deposition (CVD) technique. The fabricated samples are then tested for field emission characteristics and assembled as diodes. We used a %99.4 pure ceramic (aluminum-dioxide) as the substrate to grow CNTs on its polished surface to be used in high temperature applications. Some of the substrates are patterned by using microfabrication technology. A metal catalysis layer(s) (iron and tungsten) is deposited onto the substrate using a sputtering system, where tungsten is used as the electrical contact of the device. After the metal film deposition, the substrate with the catalyst layer(s) is transferred to the thermal CVD chamber for CNTs growth. Field emission characteristics of the CNTs are measured in vacuum at varying temperatures and are used to characterize the CNT-based vacuum diodes. Each sample is packaged so a vacuum-diode configuration is formed, then placed in a Pyrex vacuum chamber for RF testing. Two antennas, one generating pulsed RF signal and one receiving the signal are used to trigger the CNTs-based diode. Diode, acting as an RFID tag, is forward-biased to a voltage below its turn-on voltage. The voltage and current generated at the application of pulsed RF signal (the turn-on voltage and current) are measured by a high-voltage probe and a Pearson coil, and analyzed. Diode is operated at elevated temperature ranging from room temperature to 200C.

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Partial discharge measurements and IEC standards: Justification of the use for their inclusion in afterlaying test for extruded cable systems

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Partial discharges, as their name states, only partialy bridge a small portion of electrical insulation in the form of a tiny electrical arcs, which burn inside the defects that could appear in insulation system. Because of the fact that extruded cable system insulation is very sensitive on partial discharge activities detection vise, partial discharge measurements could be used as a powerful diagnostic tool in evaluating the actual condition of cable system through measuring procedures during afterlaying tests. If such procedures would be included in standards, they would provide an effective way to identify and detect the defects that might appear during the cable system installation and to forestall their appearance during exploitation, ultimately reducing the probability of failure. Very first aim of this paper is to address some shortcomings of current IEC standards related to analyses of cable systems with polymer insulation (IEC 60840 and IEC 62067). In order to justify these statements, a review of a recent alignment between IEC 60840 and IEC 62067, simulation support, using the contemporary software tool (COMSOL Mph), backed up with experimental results for two artificially induced defects in cable accessories, are provided in this paper.

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Performance improvement of a compact pulsed neutron generator with a vacuum arc ion source

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A kind of compact pulsed neutron generators with vacuum arc ion sources are widely used in neutron radiography, elemental analysis and illicit materials detection. Different modifications for the neutron generators developed at Institute of Fluid Physics(IFP)were investigated in this work. In order to increase the monatomic ions composition, a magnetic filed was applied in the plasma expanding region of the ion source. The reduction of the metallic ions in the beam is benefit for reducing the target sputtering, meanwhile increases the efficiency of neutron flux. Large amount of secondary electrons are harmful for the neutron generator operation. An idea of using a ZnO non-linear resistor with a grid to provide constant self-biased voltage to suppress the secondary electrons was introduced. Metal deuteride films as the target prepared by reactive plasma-assisted sputter deposition were investigated here. The neutron emission was measured when the neutron generator operating at 100 kV acceleration potential, ~10^-4 Pa vacuum environment and 1 Hz repetition rate. The neutron yields for different deuteride targets were measured and analyzed in the present work.

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Discussion on the Control Standards of Moisture Content in SF6 Electrical Equipment

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SF6 is widely used in high-voltage equipment due to its excellent insulation ability. However, when the moisture content in SF6 exceeds a certain value, its insulation could be damaged, threatening the normal operation of high-voltage equipment. Therefore it's of great importance to establish proper control standards on moisture content in SF6.

In this paper, the influence of moisture content on flashover voltages of cylindrical insulator models in SF6 is studied by controlling the moisture content in a specially designed organic glass chamber, and then the feasibility of three common moisture controlling methods are discussed.

The results show that controlling moisture content in the form of volume fraction can directly limit the absolute content of water vapor and prevent the formation of harmful decomposition products. However, the measured values of volume fraction at different temperatures should be rectified to a common temperature, making it inconvenient to use; the form of relative humidity can reflect the condensation margin of water vapor and could be used without consideration of temperature, but it cannot directly show the absolute content of water vapor, making it difficult to control the

production of discharge products; the dew point temperature cannot reflect the real condensation temperature of water vapor, so the method of controlling dew point temperature below zero degree is not scientific. In conclusion, 200 uL/L and 15% are suggested as the limiting values in the form of volume fraction and relative humidity according to the experimental results, which can serve as reference for the revision of the existing control standards.

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Modular Marx Generator

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This paper presents the electrical and mechanical design considerations of a compact, modular pulse forming network (PFN) based Marx generator used to drive a high-power microwave (HPM) source with a time variant load at 100 Hz. The modular Marx bank is designed to produce an open circuit output voltage of 600 kV from a 50 kV source using twelve stages. Each stage of the Marx was constructed from a PFN created with five 2.1 nF high voltage capacitors in parallel. Each Marx module was machined out of acetyl copolymer or Delrin to provide optimal strength, rigidity, and a high dielectric constant that closely matches transformer oil. These Marx modules include air supply lines that are machined directly into each block of Delrin allowing airlines to connect to each module chamber rather than every spark gap. The spark gaps are comprised of two electrode inserts placed into the sealed pressure vessel contained within the Marx modules. The electrode inserts are of a sleeve-electrode design, which allows the user to insert the electrode into the sleeve, then the sleeve into the Marx module. The benefit of this design is the ability to adjust the electrode gap spacing without compromising the high pressure seal. Two continuous charging inductors run between each PFN and underneath the Marx modules. Due to high voltages generated by the Marx, outer field shaping rings are used to reduce the field stress across the induction coils, resulting in longer lifetime. The inductors are also of modular design allowing for individual coils to be replaced in the event of failure. Output voltage and current waveforms from a 50 ohm water load are presented.

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Development of Variable Charging System for Voltage Adjustment

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Compact pulsed power generators have been used some fields such as biology, agriculture, environment and so on. Therefore, any researchers demand functions such as miniaturization, weight saving, safety and ease to use. Recently, those control systems using a microcomputer or a field programmable gate array (FPGA) has been studied for flexible changing circuits and control of pulsed

power. However, each experiment has different conditions, e. g. conductivity, pressure, temperature, humidity and so on. Therefore, different conditions are needed each energy in experiment. Our work aims the changing charge time to primary capacitor using the FPGA, and, change the output of pulsed power energy. A compact pulsed power generator is composed of a charger, a magnetic pulse compression (MPC) circuit, and a controller using the FPGA. The design specification of the controller is the Verilog HDL, Xilinx ISE 14.7, the FPGA (Spartan-3). Charging voltage is maximum 1.5 kV to the primary capacitor of 2.24 μF. Repetition rate is up to 500 pulses per second and charging energy to maximum 1.0 J/pulse. Voltages were measured a high voltage probe (Tektronix Model P6015A) for pulsed power and mid-range voltage probe (Tektronix Model P5100) for charger. The load was 500 Ω resistance. When the frequency signal becomes positive polarity, the charging signal turn off 0.5 to 1.5 ms. Them the primary capacitor is charged. At 50 μs after turning on the charging signal, the trigger signal is sent to the switch for pulsed power. The flexible control of output voltage will be very important for industry applications of pulsed power.

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Effects of mechanical pre-stress on the dielectric strength of alumina Al2O3

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The high voltage IGBT (HVIGBT) power modules are used in railways applications to build power converters. Ceramics are used in such modules because of their high electrical insulation properties even at high temperatures, coupled with high thermal conductivity.Dielectrics fail electrically when a breakdown occurs, which leads to a formation of an electrically conductive channel through the insulator. Dielectric breakdown is scarcely understood for ceramics and alumina is one of the main ceramics used.The aim of this study is to shine a new light on the understanding of this phenomena. We have focused on the effect of a mechanical pre-stress on the dielectric breakdown voltages using polycrystalline alumina substrates.Numerous works have pointed out that the dielectric breakdown of ceramics could be strongly related to their mechanical properties. More precisely, mechanical cracks already existing in ceramics would be able to grow under the electric field. The effect of the electric field's application on the cracks propagation has been previously studied either under high electric field or under moderate field. This would lead to the propagation of the cracks until the full dielectric breakdown occurs. In order to support such hypothesis, a mechanical pre-stress have been applied to commercial alumina substrates. Mechanical stresses, ranging from 20 to 140 N and using a 3-point bending test, were applied in order to increase the length of the pre-existing cracks. Then, the dielectric strength has been measured using 50Hz HV for these samples and compared to non-pressed ones.
The evolution of the dielectric strength has been correlated with the cracks evolution during the pre-stress. This shows the contribution of the mechanical properties to the dielectric breakdown phenomena in alumina.It can be concluded that the dielectric breakdown decreases when the mechanical pre-stress increases.

Keywords: Ceramic materials, High voltage power modules, Alumina, Dielectric strength, Mechanical pre-stress

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simulation and design of the multi-channel isolated charging for solid-state MARX generators

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In recent years, High pulsed power technology has been widely used in industry. In this field, MARX generators based on solid-state devices plays a most significant role during the process of energy charge and storage. This circuit structure has solved many technical problems and improves the level of pulsed power technology. With the development of the solid-state Marx generators, MARX generators derive many different types of structure. Each one has its unique advantages, but the charging mode is a general problem. In this paper, one of charging methods–the multi-channel isolated charging mode has been described. Its advantage lies in its transient Voltage balance performance such as reliability and stability. For this purpose, many simulations and analysis have been finished.

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Analysis of Insulation Failure of Polymer Composite Blocks Using High Frequency Wave Shapes

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We analyze insulation failure in polymer composite blocks using different wave shapes. We found the ratio of epoxy resin (CY230_1) and Hardener (HY951) for different samples supplised by Huntsman using a needle plane electrode configuration for different sample sizes and shapes. The polymer composite blocks consisted of a combination of epoxy resin and hardener as a neat polymer with different fractions of nanoparticles (such as Al2O3,ZnO,TiO2) added as filler polymers. We observed that aluminium oxide is transparent when compared to the other fillers. The experimental setup is constructed to emulate the realistic high field electric stress faced by insulation at different gap distances. The flashover and withstand tests were conducted at high voltage (10 kV) and either power frequency (50 Hz) or high frequency (20 kHz) to determine the breakdown voltage, breakdown time and breakdown current. The breakdown voltage, breakdown time and breakdown current were noted and plotted for various samples consisting of both neat polymer and different loadings of filler polymer for different percentage. The breakdown time increases with increasing gap distance and the breakdown time is longer for filler polymer compared to neat polymer. We also observe electrical treeing [1-2] in the sample and conduct a growth analysis, which shows that the sample breakdown in a very short duration for high voltage high frequency when compared to high voltage power frequency. We further compare and and analyze the high voltage power frequency and high voltage high frequency behavior.

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Dielectric breakdown characteristics of the rod-plane electrode system in SF6 gas under oscillating impulse voltage

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Gas insulated switchgear (GIS) has been widely used in power grid for its high reliability and small size. GIS is assembled in field considering the transportation. The AC withstand voltage testing will be taken in filed to verify the insulation condition of GIS. But only the AC withstand testing is not enough to inspect the all defects inside GIS. Impulse voltage testing is required in field. But it is difficult to carry out the impulse voltage testing for the impulse voltage generator is huge. Then, IEC 60060-3 recommend the oscillating impulse voltage waveform as the field testing waveform for its high efficiency. The breakdown characteristics of SF6 gas are not clearly under oscillating impulse voltage waveform. This paper presents the breakdown characteristics of rod to plane electrode system in SF6 gas under oscillating voltage waveform. The oscillating lightning impulse voltage (OLI) waveform with frequency 100 kHz, 200 kHz, 300 kHz and 400 kHz are adopted as the test waveform. The rod-plane electrode system with the distance of 3.2mm is used as the specimen. The standard lightning (SLI) impulse also adopted as the reference waveform. The breakdown voltage-time (V-t) curve and breakdown probability curve are illustrated in this paper. The values of 50% and 10% breakdown voltage are obtained through statistics analysis. The results show that the 50% and 10% breakdown voltage are increase with the oscillating frequency increase. The breakdown voltage under SLI is lower than under oscillating voltage waveform. The time lag under oscillating voltage waveform is longer than under standard impulse voltage waveform.The oscillating characteristics of impulse waveform have great influence to the breakdown of SF6.

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Comparison of breakdown voltage of N2, CO2, SF6, N2-SF6 and CO2-SF6 mixtures: Seeking substitutes for SF6 for high voltage apparatus

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Due to excellent and outstanding properties in both electrical insulation and current interruption performances, sulfur hexafluoride gas, SF6, is the most used gas in high voltage power equipment such as circuit breakers (GCB), switchgears (GIS), and transmission lines (GIL) since 1960s. ; SF6 is one of the best insulators gas known to date. However, by its excessive size and life span (several centuries or even thousands of years), the SF6 molecule is an agent aggravating the greenhouse effect; its global warming potential (GWP) is 23900 times that of CO2. In 1997, the Kyoto Protocol (COP 3) labeled SF6 as one of the global warming gases and began to control its use and emission into the atmosphere. Thus, the international recommendations tend to heavily restrict or even prohibit in the future, its use for preserving the environment. Since then, important researches have been undertaken to find substitutes for SF6 that have less impact on the environment, and compatible dielectric and current interrupting capabilities. Various gases have been considered. Unfortunately all these gases present a high liquefaction temperature as well as a high price. To increase the liquefaction temperature, these gases can be mixed with N2 and CO2. Among these gases, c-C4F8 has a dielectric strength 1.25 to 1.31 times higher than that of SF6 and its global warming potentia1 (GWP) is 36 ⊠ 1ower than that of SF6. However its liquefaction temperature is too high. The breakdown voltage of c-C4F8-N2 mixture increases with pressure reaching an asymptote. Other mixtures that

have been investigated include c-C4F8-CO2, C3F8-CO2, C3F8-N2, C2F6-CO2 and C2F6-N2. Of the mixtures, 20 % C3F8 - 80 % N2 shows the best performance. This mixture enables the GWP to be reduced and its dielectric properties are close to those of 20 % SF6 - 80 % N2 at 0.79 MPa. It clearly appears that it will be difficult to find a suitable substitute for high voltage power equipment even if the last years, some new gas mixtures that are under study seem interesting.
In this paper, we present a comparison study of breakdown voltage of CO2, N2 and SF6, and CO2-SF6 and N2–SF6 gas/mixtures under different types of voltage namely AC, DC and lightning impulse voltage in a sphere – sphere electrodes arrangement. The influence of percentage of SF6 in CO2 and N2 and pressure are investigated. The equivalencies between breakdown voltage SF6 and those of mixtures versus pressure are discussed. The economic and safety aspects are also analyzed.

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A Marx-Based Power Converter topology as a Current Source for Pulsed Magnets in Particles Accelerators

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In particles accelerators pulsed magnets are typically used in Linacs, transfer lines, as well as in injection and extraction areas. The required power converter current and voltage ranges can be very wide and depends on the beam energy, and the actual magnet and building configurations. This is even truer for large physics research facilities such as CERN.
It is of great importance that the powering solutions for such big facilities is standard and modular in order to reduce the cost, the maintenance efforts, and the spare parts number. Typically the power converter topology used for these applications is based on capacitor discharge and resonant principles. Magnets used in Linacs, transfer lines and injection/extraction septa, often require a current "bump" with a flat-top. Solutions combining capacitor discharge based topologies with active filter rated at a fraction of the total power are typical.
This paper presents a modular topology based on the solid state Marx generator. This topology is typically used in high voltage applications; however, it is demonstrated that a modified version of it can be used as a modular high pulsed current supply for magnets. The basic principle of charging capacitors in parallel and discharging them in series is conserved. In contrast with pulsed voltage source application, a Marx-based pulsed current source with an inductive load presents an output voltage reversal during the negative di/dt phase. The technical solution to cope with this is presented. To shape the desired current it is possible to time-shift the discharge of different Marx cells. Furthermore an active filter rated at a fraction of the converter nominal power is used to precisely tune the desired current shape. This flexible converter can be easily used for all pulsed (ms range) current converters in accelerator facilities with a high degree of modularity.

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Custom designed Dummy Loads for HV Pulsed Power Modulator Testing

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As a manufacturer for industrial, medical and scientific pulsed power applications we are frequently confronted with testing new, custom designed power

modulators, i.e. pulse generators. In their purposed applications these modulators are often intended to be used on extremely expensive RF tubes like Klystrons. Therefore, it became necessary for us as well as for our customers to develop corresponding dummy loads to avoid testing modulators on these expensive devices directly.
In order to test the modulators in accordance with the actual operating parameters (Upeak< 150kV; Ipeak< 150A; PAV< 160kW), the dummy loads need to fulfill the same requirements as the intended Klystrons. Although the Klystron's perveance is not linear and furthermore depends on the applied voltage, it is sufficient to use resistive loads as a dummy. However, such a replacement load requires an appropriate high voltage, cooling and safety design. Our basic idea was to create a modular dummy solution which can be matched easily to certain load specifications. Each module was designed as a 40kW average power, water cooled high voltage resistive load, based on commonly used standard power resistors. Depending on the specific application up to four modules can be connected in parallel or series. For protection against high voltage the full dummy was put into a surrounding grounded cage which also contains a manifold for deionized water distribution.
At first those kind of high power dummy loads were used for factory and site acceptance tests. By time those dummies also became attractive for our customers to drive long term tests on new modulator principles or to test new purchased modulators on site.

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Study on Impulse Breakdown Characteristics in Transformer Oil with Different Electrode Materials

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The bubble mechanism based on field emission has long been considered to be responsible for breakdown in liquid under impulses with duration of microseconds. Hence, it is quite reasonable to associate the breakdown voltage with the metal electrode materials.

In this paper, we took 25# transformer oil as the liquid insulating dielectric, which had been degassed and dried for 12 hours in advance. The hemispherical electrodes were made of aluminum, stainless steel, copper and copper-tungsten, respectively. The 0.12/50μs non-standard lightening impulse was utilized and the interval between each breakdown was 5min.

The 50% breakdown voltages and the discharge time delay with different electrode materials were acquired through experiments, along with the corresponding three-parameter Weibull distribution functions and the Laue plots. It turns out that the average breakdown field strength are quite different and the copper-tungsten is the highest, followed by stainless steel, copper and aluminum. Meanwhile, the shape parameters of the three-parameter time-dependent Weibull distribution functions were all around 1, making Laue plots available. Thus, the average statistical time lag and the average discharge formation time were derived from the Laue plots and the differences were discussed. What' more, the existence of the turning point in Laue plot proved the combination of two parallel initiation processes. The surface roughness and the work function were both taken into consideration to analyze the experimental results.

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Characteristics of Residual Surface Charge Distribution on Alumina under DC Voltage in Vacuum

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For dielectric-vacuum compound insulation systems, the discharges usually occur across the insulator surface with an onset voltage much lower than the breakdown voltage for vacuum gap of the same length. It is no wonder that the surface charge accumulated on the insulator plays an important role in the flashover process in vacuum, especially under DC voltage. In this paper, the off-line observation of residual surface charge on alumina under DC voltage in vacuum was carried out by a Kelvin electrostatic probe. Measured results suggested that the dielectric surface was positively charged when the tangential electric field was much stronger than the normal component, for both the positive and negative voltage. However, when the normal electric field was strong enough the dielectric surface would be negatively charged. These results clearly supported the secondary electron emission avalanche (SEEA) theory as a mechanism of surface charging of an insulator in vacuum. Besides, the flashover voltage for different electric field distribution, with adjusting the electrode radius for cathode and anode, demonstrated that the surface insulation strength could be improved by appropriately enhancing the field at anode triple junction (ATJ). This research might be of great help to make a better understanding of the role of surface charging in flashover process, and probably to put forward new measures for increasing the surface flashover voltage.

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Influence of Test Conditions on the Thermally Stimulated Current Characteristics of Silicone Rubber Used for Composite Insulators

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Composite insulators have been widely used in power system due to their perfect anti-flashover characteristics. The external insulation of the composite insulator will inevitably be aging during operation, which will affect the reliability and stability of the power network. Thermally Stimulated Current (TSC) technology has proven to be able to well evaluate aging state of composite insulator. In this paper, the TSC characteristics of silicone rubber materials under different polarization voltages, polarization temperatures, polarization times and heating rates were studied, and TSC test conditions suitable for silicone rubber material from composite insulators were explored. Meanwhile, research on TSC characteristics of silicone rubber with different thicknesses was carried out. The results indicate that the peak value of the thermally stimulated current is proportional to the applied polarization voltage. The peak current increases with the increase of the polarization time. In addition, there is a close relationship between the polarization temperature and the peak temperature (temperature corresponding to the emergence of the current peak). The current increases with the increase of heating rate, while its influence on the peak temperature is smaller. And the value of TSC increases when sample thickness increases. Based on the analysis of the results, the experimental parameters were ultimately determined as followed: the polarization temperature is 42.5℃,

the polarization time is 20min, the polarization voltage is 10kV, the heating rate is 2℃/min and the sample thickness is 1.30mm. The results of this paper are expected to provide some references for the formulation of experimental parameters in the study of aging characteristics of composite insulators through TSC technology.

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Influence of Metallic Particle on Flashover Characteristics of Post Insulator in SF6 Under Negative DC Voltage

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The flashover of insulators is a bottleneck for the development of gas insulated transmission line (GIL). The operation experience of GIL shows that metallic particle plays an important role in flashover of the insulator. An experiment platform was established to study the influence of gas pressure on the flashover characteristics of the post insulator in SF6 under negative DC voltage. The impacts that the position and size of a metallic particle had on flashover characteristics were also studied. The distribution of electric field was processed by the finite element analysis software. The results indicate that the flashover voltage reaches the maximum value with the increase of gas pressure. This phenomenon is connected with the distribution of space charge. The flashover voltage drops rapidly when the metallic particle is attached to its high voltage electrode. The reduction of flashover voltage will become slow when the metallic particle's length extends a certain value. The metallic particle will cause the greatest threat to insulation level when it is attached to the electrode of post insulator. The flashover voltage increases at first and then decreases when the distance between the metallic particle and high voltage electrode increases. The process of flashover was analyzed in the aspect of distribution of electric field.

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Flashover characteristics of metal particle contaminated GIS insulator under DC voltage

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As an indispensable part of GIS (Gas Insulated Switchgear), the cone-type insulator supports the transmission bus and separates SF6 gas chambers, which is as well the weakest link of insulation of the switchgear. The existence of metal particles, which is possibly produced during the fabrication, installation or maintenance of GIS, can lead to the tremendous distortion of local electric field, and consequently the decrease of surface flashover voltage of the insulator. In order to study the flashover characteristics of a 220kV cone-type insulator with metal particle contamination, metal particles of different lengths varying from 6mm to 12mm are stuck to the insulator surface near the bus, with the pressure of SF6 gas varying from 2 bar to 6 bar. The result shows that under DC voltage, the

flashover voltage of the insulator decreases as the length of the metal particle grows, and decreases more slowly when the particle length exceeds 10 mm. For a certain particle length, the flashover voltage shows a typical “hump effect” as the SF6 gas pressure augments, while under higher gas pressure, the flashover voltage is more sensitive to the metal particle than that under lower pressure. From the perspective of charge accumulation on the insulator surface, analyses are made to explain the experimental phenomenon.

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Chopper-Marx Circuit for Application to ILC: 1. Switching and Voltage Adding

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A high power, long pulse modulator aimed at application to International Linear Collider (ILC) is being developed. The target parameters are: 120 kV (±0.5%), 140 A, 1.7 ms, and 5 pps, with consideration on compactness, reliability, and cost control. A solid state, chopper controlled pulsed power generator using Marx-topology has been proposed.

This paper concentrates on the switching management and voltage-adding performance. The whole system is made of 20 units, each of them consists of 4 Marx-circuit boards and is designed for generating an output of 6.4 kV. The key technical issues here are the high-frequency chopping for droop compensation and the phase shift for ripple cancellation. The trade-off treatment between performance and efficiency and that between compactness and circuit cooling have been carried out by optimized design.

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The reseaches on compact repetitive pulsed power system based on Marx generator

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A compact repetitive pulsed power system based on Marx is developed. It consists of a high power repetitive power supply, a repetitive trigger and a Marx generator. By utilizing 10 inverter boost-doubling rectifier circuits to operate in parallel, we design and test a high power repetitive power supply which can transform 30V DC. to 100kV DC and charge a 0.3μF capacitor to 100kV in 150ms. The repetitive trigger based on small-sized Marx can operat at repetitive rate of 5 Hz with output pulses of about 80kV with about 30ns rising time and 200ns duration time. The 8-stage compact Marx generator contailing 8 40nF capacitors can output a peak voltage of more than 400kV on a 15Ω load when charged to 90kV. A compact repetitive pulsed power system is developed By system integration and sequential control. The pulsed power system can output single shot pulse or 5Hz repetitive pulses of more than 10GW on a 15Ω load. This work will provide technology base for us to develop compact repetitive pulsed power system with higher output power.

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A Compact High Voltage Pulse Generator for Three Plasma Synthetic Jet Actuators Synchronous Discharge

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Plasma synthetic jet (PSJ) is considered as one of the effective plasma actuators for flow control, which has drawn much attention. In this paper, a compact microsecond-pulse generator with high-voltage and three outputs is developed for achieving synchronous discharge for three PSJ actuators. The working principle of the generator is introduced and the waveforms of each part of the circuit are determined. Results show that the value of maximum output voltage of the microsecond-pulse generator is 10 kV with a rise time of about 2 μs and a pulse repetition rate of 100 Hz. Moreover, the voltage waveforms of three outputs are almost the same, indicating that the designed generator is successfully used for achieving synchronous discharge for three PSJ actuators. Furthermore, the discharge waveforms of voltage and current are tested. The effect of gap spacing on the characteristics of plasma synthetic jet is analyzed. The experiment results show that breakdown voltage increases with the increase of gap spacing and the generator can guarantee synchronous discharge for three PSJ actuators at different gaps.

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Pressure rise calculation due to an internal arc fault in HV metal-enclosed SF6 GIS

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High reliability of HV SF_6 switchgear makes an internal arc fault an extremely rare event. However, its occurrence cannot be completely avoided, and therefore, must be considered in the design process. Internal arc testing in SF_6 is not recommended due to its harmful environmental impact, but if necessary, tests should be performed only inside special containers, that will prevent the release of SF_6 into the atmosphere. Having in mind that tests in SF_6 and air are not yet fully comparable, accurate modeling of pressure rise due to internal arc faults is still the main means to evaluate required design parameters of SF_6 switchgear in respect of safety from internal arc faults.

A simulation tool, which calculates the pressure rise due to an internal arc inside a metal-enclosed SF_6 compartment, was developed and used in the design of a new HV GIS. The calculation procedure and obtained results are described and discussed. Validation of the tool was performed using experimental data from SF_6 internal arc tests, dating back several decades ago, when internal arc tests in SF_6 were not questionable as today.

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Partial Discharges in Insulation Systems Subjected to Multilevel Converters

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Ubiquitous involvement of power electronics devices in the power conversion applications on various voltage levels makes new challenges for the design of insulation systems. The fast switching processes produces complex stresses and high frequency phenomena interplaying with charge behavior in dielectric insulating materials. The converters and inverters utilize usually the most widely accepted technique based on pulse width modulation. These kinds of stresses on insulation systems result in new approach to the intensity, dynamics of working electric field strength and degradation processes being assessed mostly by partial discharges. However, most of the research studies, devoted so far to electrical insulation aspects, were based on one- or two-levels converters. Recently more and more often multilevel converters are implemented in industrial applications, due to their advantages for example in efficiency, harmonic distortion and filtering strategies. Paper presents analysis of partial discharges in electrical insulation system subjected to high voltage waveform obtained from multilevel converter. The experiments have been performed on specially prepared model samples. The programmable voltage source modular multilevel converter was used in the tests. The topology of power electronics building blocks and control approach is described. The flexible configuration allows for adjustment of the number of voltage levels and switching frequency of the modulated subperiods. Partial discharges were detected by high frequency transformer, galvanically separated from the power path. The comparison of number of levels and modulation frequency on partial discharge inception and intensity are presented. The partial discharges were acquired in form of phase-resolved patterns and correlated with multilevel voltage waveforms on the slopes and constant voltage parts. In addition partial discharges on individual levels in multilevel sequence were evaluated.

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A Repetitive Rate Pulse System Used in Lifetime Evaluation of High Voltage Ceramic Capacitors

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The lifetime evaluation of High Voltage Ceramic Capacitors (HVCC), especially the ones working under repetitive pulses, is of great importance, which influences the overall stability of pulsed power system. However rare relevant studies were made under the conditions of repetitive rate pulse. In order to realize the accelerated lifetime testing for HVCC, a high voltage, high current repetitive pulsed power system was developed.

This system consists of a repetitive pulsed power supply and a short-circuit testing cavity, whose repetition frequency and output voltage can be regulated easily. The supply is based on high power pulse forming technology with the magnetic pulse compressor as the core. The supply is composed of a primary oscillator circuit, a two-stage magnetic pulse compression network and two HV pulse transformers. For its output, the rise time is ~10μs and the amplitude is more than 70kV with the highest repetition frequency up to 50Hz. The elaborately designed short-circuit testing cavity is very compact in which SF6 gas can be charged more than 1.0MPa. A Rogowski coil is integrated into the cavity. The short circuit current is up to 20kA with the 2.5nF capacitive load. This repetitive microsecond pulsed power system is integrated and installed in a portable box which can realize the scale-up production.

With this system, the accelerated lifetime test for HVCC was conducted, and the lifetime characteristics at different voltage levels under 25 Hz repetitive rate pulse and two kinds of failure modes

were studied. Based on the experimental results, several measures were taken to improve the performance of HVCC. The lifetime was extended greatly from thousands of times to more than a hundred thousand times. Furthermore, this system, with extensive applications, is also used to test the performance and lifetime of pseduospark switches and surface flashover properties of PEEK sheets.

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Partial discharge and endurance test technologies for insulation of inverter-fed motors using impulse voltages

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The partial discharge inception voltage (PDIV) and insulation lifetime of the insulation systems for rotating machines driven by power electronics should be evaluated using repetitive impulsive voltages according to standards or technical specifications released by International Electrotechnical committee[1,2] . However, unlike the sophisticated technologies for partial discharge (PD) detection and endurance tests under sinusoidal voltage conditions, the PD measurement system design, the influence of voltage parameters on test results should be carefully considered when performing measurements at impulsive voltages. This paper introduce a generator developed for PD detection and endurance tests on the basis of high voltage solid state switchers. By using the generator, a large number of experiments were carried out on insulation models made up of enameled wires used in inverter-fed motor insulation to study the influence of impulsive voltage waveform parameters on partial discharge characteristics and insulation lifetime. Conclusions show that, the temperature, humidity and waveform parameters (rise time, full time, duty cycle, frequency) will influence the PD characteristics and insulation endurance significantly. When performing insulation evaluation under impulsive voltages, all the above influence should be carefully considered to obtain meaningful and objective results used for insulation qualification on inverter-fed motor insulation system.

1. IEC TS 60034-18-42: Rotating electrical machines – Part 18-42: Qualification and acceptance tests for partial discharge resistant electrical insulation systems (Type II) used in rotating electrical machines fed from voltage converters, 2008.
2. IEC 60034-18- 41: Rotating electrical machines - Part 18-41: Qualification and type tests for Type I electrical insulation systems used in rotating electrical machines fed from voltage converters, 2006.

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Screamer: An Optimized Pulsed-Power Circuit Analysis Tool

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Screamer was developed to solve a wide range circuits with a focus on pulsed-power systems. Screamer is a highly optimized code written in Fortran 77. We will describe the mathematical foundations of

Screamer and show how Screamer uses a wide range of pulsed power circuit elements. Screamer incorporates many physics-based models such as lossy transmission lines, dynamic loads, gas switching, water switching, oil switching, magnetic switching, and magnetically insulated transmission lines, which are important to the high-voltage, pulsed-power community. Additional circuit models or modifications to existing models can be readily implemented in Screamer. Screamer is openly available to the community without restrictions. Screamer runs on the Macintosh, LINUX, and Windows platforms.
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Evaluation of Electrical Pulsing Strategy for Optimizing Cellular Inflows Through Electroporation by Nanosecond, High-Intensity Pulses

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Applications of electric pulses to create nanopores at the membranes of biological cells can modulate the conductivity and permeabilization in a controlled manner. Applications of such membrane poration lies in the field of biomedical engineering, drug/gene delivery, cell fusion, and electrochemotherapy for cancer treatment. In principle, various different electrode shapes and geometries can be used for selecting the target areas and tailoring the spatial electric field profiles, with the over-riding goal of ensuring optimal inflows into the cell through the pores created by the external electric pulsing. The role of pulse shape (e.g., monopolar-vs-bipolar), the rise and fall times, duty cycle and duration (nanosecond versus microsecond) have been the topic of several experimental studies.
The physics behind electroporation and its quantitative analysis appears to be on relative form footing [1,2]. However, for the standpoint of a practical application, it is important to choose the pulse width and the duty cycle (since the use of multiple pulsing seems to suggest a stronger cellular uptake), while allowing for multiple electrodes for more uniform and extensive effects. What is perhaps missing is a more comprehensive predictive analysis of cellular uptake with such pulse trains using multiple electrodes. The pulse characteristics and electrode placement strategies become important issues.
Here in this contribution, we focus on a numerical study of ion inflow in to cells following poration by a pulse train. Many-pronged electrode configurations have been used for spatial flexibility, with pulse sequencing that effectively allows for phased array-like behavior. The membrane electroporation behavior and ionic inflows will be evaluated for both monopolar and bipolar nanosecond pulses. The role of pulse delay times relative to the pore resealing durations will also be analyzed, and the simulations will enable separate evaluations of the electrophoretic versus diffusive transport. Relevant comparisons to experimental data will also be provided, and the role and dependencies on diffusion rates, pore closing times, pulse durations, duty cycles and repetitive frequency will be gauged.

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High Current Switching Capabilities of a 3000 V SiC Thyristor for Fast Turn-on Applications

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Triggered solid state devices capable of holding off more than 1 kV and surging multiple kA of current are increasingly a viable alternative for pulsed power applications that previously required triggered spark gap switches or other devices based on gaseous electronics. For a number of pulsed applications requiring high surge current at low to moderate pulse repetition rates, Thyristor devices offer superior performance compared to MOSFETs or IGBTs; however, Thyristors typically feature slower turn-on time, which is governed by a diffusion limited process referred to as the base transit time. This relatively slow turn on transient results in high losses when hard-switching on timescales below 1 μs. The high saturated electron drift velocity and superior critical electric field strength offered by a wide band gap material has potential to reduce turn-on time and increase efficiency, potentially reducing losses on time scales below 1 μs to an acceptable level. Results will be presented from an investigation designed to evaluate the pulsed capabilities of a 6 mm x 6 mm, 3 kV, 35 A asymmetrical Thyristor fabricated on ultra-low micropipe density 4H-SiC 4" wafers by GE Global Research Center. Previous investigations into the pulsed capability of these devices have been focused on microsecond duration pulses at moderate peak currents of 200-800 Amperes and di/dt less than 1 kA/μs. Initial results show that these devices are capable of surging up to 3 kA at 25 kA/μs with a current rise time of 150 ns. Switching efficiencies up to 2.5 times higher than Si have been recorded, indicating that failure mechanisms related to local heating in the resistive drift layer of the device may be less prevalent compared with Si devices.

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Power Evaluation of a Cree 1200 V 50A Si-C MOSFET using the Solid State Power Emulator

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With the advancement of high voltage silicon carbide insulated- gate bipolar transistors (IGBTs) and metal oxide semiconductor field effect transistors (MOSFETs) with voltage hold-off ratings of 10kV and above and current ratings of 5A and above, possible uses for continuous power applications are being explored. Switching high voltage and high current typically requires a costly test circuit comprised of large capacitances, power supplies and elaborate loads to provide and then dissipate the power before incorporating these experimental devices in a final circuit where other components of value may be exposed to extreme stresses. The Solid State Power Emulator (SSPE) is a system in which the device being evaluated can be subjected to the power demands that it would see in its particular switching application it is being evaluated for. The benefit of the SSPE is that it reduces the needed power capability of the power supply and load by at least 80% and provides a significant reduction of the energy needed in the evaluation circuit capacitor. These benefits will be demonstrated in the evaluation of the Cree newest generation of 1200V 50A silicon carbide MOSFET by way of the SSPE. The SSPE will subject the device to hard switching application waveforms and soft switching application waveforms with various switching frequencies. The power required to perform these types of evaluations with the SSPE and typical evaluation circuits will be compared and discussed.

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High-Voltage SiC Thyristor Burst-Rate Switching

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The U. S. Army Research Laboratory has an ongoing program to develop high-voltage silicon carbide (SiC) power thyristors for future Army pulsed power systems. Previously, these SiC thyristors were switched at relatively wide pulse widths to evaluate high-current capability for single pulse events. More recent evaluations investigated minimum turn-on delay and dI/dt limitations while switching at a pulse width of 1 micro-second for short-burst and low-duty cycle applications. SiC thyristors having a 1 cm-squared chip area, and designed for 10 – 15 kV blocking, were switched for short 3-pulse bursts. A current amplitude of 1 kA (1.9 kA/cm-squared over the device's active area) was switched at a rate of 100 pulses-per-second, and 500 A was switched at a higher rate of 500 pulses-per-second. Initial switching evaluations were limited by the charging power supply and the gate circuit of the thyristor. Fast-switching capability of the 10 – 15 kV thyristors will be evaluated at higher current and pulse rate following modifications to these external components. Ultimately, turn-on and turn-off time delays of the thyristor will limit switching frequency relative to other semiconductor devices, such as SiC IGBTs and MOSFETs. However, the thyristor's low on-state losses at high current will enable higher current density and greater power delivery to the load.
This paper will explore the upper current amplitude and pulse rate limitations of the high-voltage SiC thyristors. The maximum number of burst-rate pulses achievable without external cooling will be determined. The benefits and restrictions of using the SiC thyristors in place of other semiconductor and gas switches will be assessed for applications such as thyratron replacement and compact Marx high-voltage generators.

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High Voltage Capacitors Environmental Testing

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In an era when vehicle weight is very important to mission success, non-traditional technology must be developed to provide protection without adding parasitic weight to a vehicle, such as added by heavy armor packages. Electromagnetic Armor (EMA) is one possible technology that may accomplish the goal of achieving lighter weight with equal or greater protection levels. EMA is a system that uses electrical energy to defeat threats. Electrifying these plates within a specific time frame is crucial and is highly dependent on capacitors that can store and discharge current rapidly. We conducted a 1,000 mile simulation of a combat vehicle terrain vibration test with high voltage, pulse forming capacitors at TARDEC. There were no significant changes in the capacitance and the dissipation factor (DF) of capacitors measured before and after the terrain vibration test. The test results confirmed that high voltage pulse forming polypropylene (PP) capacitors were durable and could withstand vibrations from various types of terrain in a real battlefield environment. We also conducted temperature tests with high voltage, pulse forming PP capacitors at TARDEC. We observed a reduction in the capacitance and an increase in the DF of the capacitors measured before and after the temperature test. High voltage and high frequency capacitor tests were conducted at the Army Research Laboratory. The capacitor did not have any detectable changes after the high

voltage test. The test results indicated that high voltage pulse forming PP capacitors were durable and could probably withstand environmental changes, within operational range, in a real battlefield environment.

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LED-Triggered Photoconductive Semiconductor Switches for Nanosecond Pulse Generation

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Photoconductive semiconductor switch (PCSS) is of interest to the high voltage, pulsed power technology and their applications due to its excellent properties of high hold-off voltage, fast response time, low jitter and robust stability. It is known that optical switches have advantages in electrical insulation and flexibility over electrical switches especially for high voltage pulsed power switching. PCSSs are solid-state switches but optically triggered, and thereby promise low jitter, delay, and free of electromagnetic interference [1]. The traditional optical sources for triggering PCSS are nanosecond solid-state lasers or laser diodes and the lowest optical energy of triggering was reported at about 2 nJ [2]. With the recent development of light-emitting diodes (LEDs), the optical yield of certain types of LEDs has been sufficient for potential PCSS triggering [3]. We report here a nanosecond pulsed power generation using a LED-triggered PCSS. A GaAs-based PCSS was tested to hold off up to 4.5 kV with a LED-based optical pulse. When the LED was driven by a 16.3-ns pulsed current of 110 A, with a rise time of 7.75 ns, the optical pulse was sufficient to turn on the PCSS at an energy of 0.8 nJ. A 19-ns long 4.5 kV voltage pulse with a rise time of 10 ns was generated from the main circuit.

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A Compact Faraday Cup for Nanosecond-Pulse Runaway Electron Beams

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Runaway electron beams play the dominant role in the process of nanosecond pulse discharges, which cannot be fully explained by traditional discharge theories and attracted continuous attentions. In this paper, a new collection device for runaway electrons in nanosecond pulse discharges based on faraday cup was investigated. A VPG-30-200 pulse generator was used to excite discharges and generate runaway electrons with a pulse width of 3~5 ns, a rise time of 1~2 ns and an amplitude of up to 200 kV. The measurement system consisted of metal anode, electron collector, sample resistance and signal leading body. The receiving part of electron collector device made of graphite had the shape of cup, with the diameter of 55 mm and a depth of 10 mm. The fast electrons with high energy were gathered and the induced voltage was connected to the oscilloscope through the sample resistances, consisting of ten 50Ω parallel non-inductive resistances. The experimental results showed that the runaway electron beams could be well measured by the faraday cup. The typical

waveform of runaway electron beam had the amplitude of 10 mA, a rise time of 400 ps and a pulse width of 3 ns when the applied voltage was 110 kV in atmospheric pressure air. Furthermore, experimental results with pulse sequences proved that both the voltage waveform and electron beams were stable.

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Assessing the Role of Non-Local Trap-to-Band Impact Ionization in 4H-SiC Photoconductive Switches Containing Deep Defects Aimed at Enhanced Hold-off Voltages

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The importance of non-local effects in impact ionization has been long recognized, particularly in connection with breakdown in gases, where Crooke's dark space and glow striations provide classic examples. The main point is that impact ionization is the consequence of electrons drifting down a potential gradient (i.e., in the presence of a spatial electric field) pick up energy E and can impact ionize only when this energy exceeds the ionization threshold. Ionization rates, therefore, should not depend on the local electric fields, as has routinely been used in analysis, but on the path integral.
4H-SiC is a promising material for high-power photoconductive switches given its resistance to chemical attack and radiation, stability at high temperatures, higher saturation electron drift velocity over Si and GaAs, larger thermal conductivity, and high breakdown fields in the 3-4 MV/cm range. For the same breakdown voltage, the on-state resistance of a SiC device is expected to be lower by two orders of magnitude than that for Si because smaller layer thicknesses and/or higher doping levels can be used. Such SiC material for photoconductive switches usually uses deep traps/defects to attain the desired high hold-off voltage strengths required for pulsed power applications.
Here we provide numerical studies to probe effects of non-local trap-to-band impact ionization for SiC photoconductors. We show that the non-local nature of the ionization can substantially alter the local fields, result in a pile-up of free electrons, and possibly lead to prolonged cathode injection and space-charge striations. Our modeling is based on a one-dimensional, time-dependent drift-diffusion approach, and includes multiple traps, trapping/detrapping dynamics, field-dependence of various processes, and possible hole injection. The role of trap energy level and concentration on the conduction characteristics will also be analyzed.
Work supported by Office of Naval Research and the Air Force Office of Scientific Research.

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Miniature High Voltage, High Temperature Component Package Development

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With the next generation of semiconductor materials in development, significant strides in the Size, Weight, and Power (SWaP) characteristics of power conversion systems are presently underway. In

particular, much of the improvement in Wide-Bandgap (WBG) and Ultra-Wide-Bandgap (UWBG) device efficiencies and power densities are realized through higher voltage, higher frequency, and higher temperature operation. Concomitantly, there is a demand for ever smaller device footprints with high power handling ability while maintaining ultra-low inductive/capacitive parasitics for high frequency operation. For our work, we are developing compact Gallium Nitride (GaN) and Aluminum Gallium Nitride (AlGaN) power diodes and transistors with hold-off voltages as high as 15 kV. The small size and high power densities of these devices create stringent requirements on both the size and heat dissipation capabilities of the associated packaging; e.g. die area must be balanced between larger sizing for increased current-carrying capability and smaller sizing for reduced parasitics and faster switching. To accommodate these requirements and to be able to characterize these novel device designs, we have developed specialized packages as well as test hardware and capabilities. This work describes the packaging requirements of these new devices, the development of the high voltage and high power packages, and the test capabilities needed to characterize and use the completed components. In the course of this work, we have settled on a multi-step methodology for assessing the performance of these new power devices, which we will also present. Also, specialized high voltage test facilities, constructed from commercially available laboratory equipment, were developed to support this work, and will be described in detail.

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Reserch of sweep frequency impedance criterion to determine transformer winding deformation

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The reliable running of the transformers are extremely important for the electric system. However, during operating the transformers will inevitably suffers the various impacts, such as short-circuit current and mechanical vibrate. It will lead to permanent deformation, for example warping, shifting and bulge of the windings, within a power transformer. If cannot be detected on time, the deformations may accumulate over a long period and finally lead to transformer accidents.

In order to supervise the condition of transformer windings, people developed a large amount of methods to diagnose the winding deformations. Among these methods, short circuit impedance (SCI) and frequency response analysis (FRA) had been used widely due to their good performance. However, some defects shown up according to many experiences of test: SCI is insensitive to some little deformation, and FRA has no quantitative criterion and is easily influenced by onsite condition. Therefore, sweep frequency impedance (SFI), as a new technique, is combined with the characteristics of FRA and SCI. Moreover, it has a higher signal-to-noise ratio, a better repeatability and reproducibility. That make it to be a good replacement of SCI and FRA.

Presently, SFI relies on 50Hz short circuit impedance, correlation coefficient, and grey correlation to determine the situation of transformer winding deformation. But the existing method has defects such as poor anti-disturbance ability, low sensitivity results in hard to analyze quantitatively, and incapability in identifying defects at early stage. This paper proposes a new SFI criterion to determine transformer winding deformation. It identifies the graphic shape circled by normal state and fault state to detect transformer winding deformation. This paper verifies the accuracy of the new method by testing different faults on the transformer and analyzing sweep frequency curve in different situation.

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High-voltage silicon avalanche diodes for picosecond range pulse-sharpening applications: towards optimal design

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Silicon avalanche sharperning (SAS) diodes are capable to form kilovolt voltage ramps with 100 ps risetime for pulse power applications [1-3]. Physics of these devices still remains vague and, as a result, design of the respective semiconductor structures is up to now purely empirical. Here we present the results of comparative study of specially designed and manufactured SAS structures with the same geometrical parameters and close stationary breakdown voltages Ub~1.1-1.3 kV. The devices differ in basic Si substrates, doping profiles, fabrication technique and carrier lifetime.

Original high-voltage picosecond-range experimental setup has been used for measurements. The setup allows determining both current and voltage across the diode with time resolution better than 50 ps. We use DLTS study to evaluate the effect of deep levels.

All types of diodes under study successfully form a voltage ramp in the load with kilovolt amplitude and ~100 ps rise time. Switching starts when the reverse voltage is about 2 kV. Our main finding is the drastic difference between p+nn+ and p+pnn+ structures. Namely, low residual voltage Ures ~ 150 V has been observed only for p+nn+ structures. In contrast, for all p+pnn+ structures Ures is about 1 kV hence just below Ub. Next, we reveal also different types and concentrations of deep levels: electrons traps known as Sah centers are detected in p+pnn+ structures, whereas p+nn+ are nearly clean from these levels. Remarkably, recombination centers created by electron irradiation in structures with intentionally reduced carrier lifetime have no impact on superfast avalanche switching. The question whether the observed difference in switching dynamics is caused by the difference in doping profiles or by the difference of deep levels present in the structure requires further studies. Our results show that the doping profile with abrupt pn-junction must be used for silicon avalanche sharpening diodes.

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Optimal design of a medium voltage high frequency transformer with a high isolation voltage (115kV)

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For the new linear collider at the European spallation source (ESS) in Lund, 2.88MW long pulse modulators with pulsed output voltages of 115kV and pulse lengths in the range of milliseconds are required.
For generating many pulses, a long pulse modulator based on a modular series parallel resonant converter (SPRC) topology [1] has been developed. This converter is operated at high switching frequencies (100kHz) to minimize the dimensions of the reactive components and the transformer. To achieve the required output voltage of 115kV, 8 SPRC modules each with an output of 14.4kV are connected in series [2]. Due to the series connection of the secondary windings, the insulation of the oil isolated transformer has to withstand the full pulse voltage of 115kV.

In this paper a design procedure of the medium voltage high frequency transformer using Litz wire is presented. A comprehensive insulation design method based on an electrical field conform design is explained in detail and verified by partial discharge measurements on a prototype system. Additionally, all design models, including a generalized magnetic model for the leakage and the loss calculations as well as an electrical model for the parasitic capacitance estimation for the transformer are derived and proven by measurements.

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Reversely Switched Dynistor: From Si to SiC

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The reversely switched dynistor(RSD) is proposed by Prof. I. V. Grekhov in 1980s, which is a kind of semiconductor switches applied in pulsed power area especially. Based on the controllable plasma layer commutation principle, Si RSD is famous for its good serial characteristics, low loss and high di/dt capability. It is hopeful to get higher monolithic blocking voltage and better performance for repetitive frequency by using the silicon carbide(SiC) material to fabricate the RSD because of its 10 times higher insulated breakdown electric field, 3 times higher bandgap width and 3 times higher thermal conductivity, etc.
By establishing the two-dimensional numerical models of the Si RSD and SiC RSD respectively, their characteristics are researched into comparatively. The results show that: (1) SiC RSD could get the same blocking voltage as Si RSD with about 1/10 width of the drift region. (2) It is important for both Si RSD and SiC RSD to accumulate enough electric charges in the triggering process, so as to turn on normally and reduce the residual voltage at the front edge of the pulse. With the same conditions of the blocking voltage, chip area and main circuit, SiC RSD needs higher level of the pre-charge because of shorter carrier lifetime. (3) For the quasi-static voltage drop in the turn-on process, only when the voltage rate is high enough(~>6kV) can SiC RSD have advantage over Si RSD. It is because the wide bandgap of SiC leads to high junction voltage drop, and the advantage of the bulk voltage drop reflects at high voltage rate.
In general, it is an effective way to promote the device performance to use the new material SiC to fabricate RSD when Si RSD has almost reached its limitation. The SiC RSD chip with blocking capability has been acquired by the tape-out process.

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DESIGN CONSIDERATIONS FOR HIGHER ELECTRICAL POWER SYSTEM VOLTAGES IN AEROSPACE VEHICLES

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Electrical and electronic equipment used in aerospace applications must be designed to operate over a wide range of environmental conditions that include variations in pressure, temperature, and humidity. Electrical power systems for advanced aircraft utilize voltages well above the traditional levels of 12 to 42 Vdc and 115/200 Vac, 400 Hz. Current airborne systems can contain 270 Vdc, and bipolar systems with a 540 V differential are appearing in certain applications. Higher dc potentials create increased probability of arcing and flashover compared to the risks associated with traditional ac or low-voltage dc. The low pressures of high altitude environments only serve only to worsen such concerns.

This paper summarizes the development of a guideline document containing methods of managing higher voltages in aerospace vehicles. Based upon both current and archival work, the design guidance (1) provides a basis for identifying high voltage design risks, (2) defines areas of concern as a function of environment, and (3) illustrates potential risk mitigation methods and test and evaluation techniques. The document is focused on electrical discharge mechanisms including partial discharge and does not address personnel safety. Some of the key areas of concern are power conversion devices, electrical machines, connectors and cabling/wiring, as well as interactions between components and subsystems. The document is intended for application to high voltage systems used in aerospace vehicles operating to a maximum altitude of 30,000 m. (approximately 100,000 ft.), and maximum operating voltages of below 1500 Vrms. Fundamental issues addressing some of the key areas will be presented and discussed

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Design and Test of the Trigger Vacuum Switch and its Trigger Source for the Oil Well Stimulation Device

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In order to meet the stability and high temperature working environment (above 120 degrees) requirement of discharge switch in oil well pulse discharge stimulation device, a kind of Vacuum Switch Triggered (TVS) is developed. Compared with the self breakdown switch, TVS can greatly improve the working life and stability of the whole device. The TVS is designed with multi-rod system to improve the peak current capacity and with suitable main electrode to improve the DC withstand voltage at the same time. The size of the TVS is designed and the uniformity of the electric field is studied by simulation. On the basis of the simulation, suitable main electrode chamfer is designed. Performance parameters for the designed TVS reach working voltage of 25kV, the peak current capacity of 30 kA/100 μs, the outer diameter of 68mm. Through the experiment study the triggering characteristics, the DC withstand voltage level and the life time of the TVS. After 1000 life time experiments, its triggering characteristics and DC withstand voltage level is still good. The experimental results show that the TVS fully meets the requirements of the Oil Well Stimulation Device. Aimed at the high temperature working environment of the TVS, the trigger source is studied. In that the common thyristor and diode working under high temperature is not reliable, a trigger scheme with a three electrode spark gap instead of thyristor controlling the trigger of the TVS is designed. The trigger capacitance charges from the main circuit charging capacitance, which can simplify the circuit and has no potential isolation problem. After the simulation study and experimental test for the trigger scheme, the results show that the scheme is feasible.

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Using High Voltage Nanosecond Pulses to Control Cell Functions and Treat Tumors

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Physical and Biological Implications of Capacitive Coupling for Electric Pulse Treatments

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Conventional biomedical applications of electric pulse (EP) stimulation utilize conductive coupling, where the electrodes directly contact the biological sample; however, this may contaminate the sample due to ion release from the electrodes. One such application involves activating platelets ex-vivo to create gels for wound treatment without traditional biochemical activators that may induce adverse side effects [1]. The proposed mechanism involves EP induced membrane permeabilization facilitating calcium transport into the platelets to induce activation [2]. Recent platelet activation studies have emulated capacitive coupling, a non-contact method of electrical stimulation, by placing a capacitor between the pulse generator and sample. While the calculated membrane voltage is far below the typical electroporation threshold, experiments show that capacitive coupling induces growth factor release levels comparable to conductive coupling. It is interesting that treating samples with low intensity, bipolar EPs separated by hundreds of nanoseconds by capacitive coupling was effective since applying higher intensity bipolar nanosecond EPs using conductive coupling actually induced less cell death and ion transport into the cell than equivalent high intensity monopolar EPs [3]. The presence of significant biological effects for lower intensity bipolar pulses may suggest that non-electrical mechanisms, such as shock waves, cancel biological effects at higher intensities. We further assess calcium dynamics by coupling the asymptotic Smoluchowski equation for pore formation to the Nernst-Planck equation for ion motion. The implications of these results for EP-induced mechanisms and applications will be discussed.
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DEVELOPMENT OF 3 MW DUAL OUTPUT HIGH VOLTAGE POWER SUPPLY FOR IC RF SYSTEM

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High Voltage Power Supply (HVPS) based on PSM (Pulse Step Modulation) topology has already demonstrated its ability for broadcast transmitters, accelerators of RF source, neutral beam injectors. Typical IC RF system composed of cascaded connection of Driver stage and End stage would need two power supplies. A novel concept of tapping two outputs from single PSM based HVPS is attempted for the first time. A PSM based HVPS is developed with dual output to feed anode voltage of Driver and Final Stage. This article discuss the development of HVPS, capable to provide 8-18 kV, 20 A to Driver Stage and 18-27 kV, 105-155 A to End Stage RF amplifier chain. Here dual output are controlled independently by single FPGA based PXI controller which support all pros of PSM based HVPS like low ripple , fast dynamics and fast switching off (<10 μs).

Discussed HVPS supports Non-Linear demand from IC RF system like lower current (105 A) at higher voltage (27 kV) and Higher Current (155 A) and Lower Voltage (18 kV), which developed as indoor compact solution. As an add-on specifications, HVPS facilitates 1 kHz RF power modulation. HVPS mainly composed of two numbers of Cast Resin Multi-Secondary Transformers, 48 numbers of Switched Power Supply (SPS) Modules, FPGA/Real Time based controller and other auxiliaries including passive protection devices. Present article describes technical details of HVPS Components, testing as per IEC standards. HVPS with Dual output is effective replacement, as it offers optimised solution for equipment bulk and economy as well.

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High precision, low ripple 3kV capacitor charger for future linear colliders

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A new type of particle collider in the tera-electron-volt (TeV) energy range, the Compact Linear Collider (CLIC), is currently investigated at CERN [1]. In CLIC each klystron is supplied by a separate pulse modulator, which is able to provide 29 MW of pulse energy at a repetition rate of 50 Hz. This energy corresponds to an average continuous power of 210 kW. The 180 kV pulse is generated by a pulse transformer with a primary voltage of 3kV, which also is the voltage of the capacitor bank for storing the pulse energy. Since the pulse-to-pulse repeatability is demanding (deviation<100ppm), a high power interleaved charging system with a high charging precision has been developed. The charging system is based on a 750V to 3kV boost converter with 8 series connected 650V-MOSFET constituting the main switch and with operation in boundary conduction mode. The control scheme is based on [2].

In section II of the paper, the design of the capacitor charger is outlined and in section III the central control unit including a new optical communication protocol is presented. Due to the induced delay by the communication, a stability analysis of the interleaving controller is performed leading to new optimal control parameters. For validating the new converter design with reduced input voltage, full power measurements are presented for a single module with resistive load. Thereafter, the ultra-precise charging concept is described including the adapted interleaving control. Finally, also measurements showing the interleaved operation of the capacitor charger are given.

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HV Energy Dosing dc-to-dc Converter in PWM Mode

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Energy-dosing (ED) topology was shown to be effective for capacitor charging and long- flat-top pulse generation (see [1], [2] and their bibliography for examples of implementation and for the theory of operation). The inherent advantages for these applications are zero-current switching and excellent predictability following from the ED principle of operation. As the term ED implies, the output power is proportional to the switching frequency fs. Thus, strict realization of ED is possible only when the output is frequency-regulated. At light loads, fs might become so low as to move to the audible range, which is undesirable or even unacceptable for certain applications. Then PWM control becomes necessary.
This paper extends theory of operation of ED converters into the PWM mode. Full set of equations is derived for calculation of duty cycle corresponding to a predefined load. All possible scenarios have been covered and verified with PSpice simulations and experiments with HV converters.
Having an adequate mathematical description in PWM mode is useful for the realization of predictive control as depicted in [2].

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Impact of platelet activation electric stimulation protocols on hematopoietic and mesenchymal stem cells

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Electric pulse (EP) treatment of biological cells commonly use conductive coupling, where the electrodes make direct contact with the biological sample. Alternatively, one may use capacitive coupling, where air or a dielectric separates the electrodes from the sample, to mitigate the disadvantages of conductive coupling, such as contamination from the electrodes. One critical difference is that the samples are exposed to high electric fields with conductive coupling and lower intensity, bipolar electric fields with capacitive coupling. Several studies show that electric stimulation of platelet rich plasma (PRP) with nanosecond and microsecond duration EPs can activate platelets with conductive

coupling [1] while more recent experiments demonstrated similar platelet activation efficiency with capacitive coupling. This raises the general question about the impact of electric stimulation on biological matrices containing complex cell populations, particularly non-platelet cell types in PRP. We investigated this issue by studying the growth of hematopoietic (HSC) and mesenchymal stem cells (MSC) after electrically stimulating cells contained in buffy coat separated from human bone marrow aspirate.
While conductive and capacitive coupling induced relatively similar growth factor release levels from platelets in PRP, conductive coupling adversely impacted stem cell differentiation and proliferation while capacitive coupling did not. Despite similar cell viability immediately following treatment, the coupling techniques induced dramatically different growth over two weeks. Maintaining long-term HSC and MSC viability and morphology is critical for wound treatment because their ultimate cellular function plays a critical role in healing and tissue regeneration [2].

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FILTERING OF NOISES ASSOCIATED TO THE COMMUTATION OF THE DC RECTIFIERS IN PATTERNS φ, q, n OF PARTIAL DISCHARGES

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The measurement of partial discharges is sustained in the detection and filtration of current pulses which appear in a band of frequency that include from the kilohertz up to the gigahertz, for such a reason the partial discharges detectors possess systems for the separation of this current pulses. However, partial discharges detectors also allows the pass of other signals of high frequency, denominated noises, that mix with the pulses of partial discharges and affect the measurements results, as well as the interpretation and characterization of partial discharges. To attenuate that effect, different techniques have been developed to disaggregate the noises associated to the signals, like the existent ones in the q,φ,n partial discharges patterns. In this paper is presented a procedure for identification of the noises associated to commutation of the thyristor, which could affect the q,φ,n patterns, by means of the technical of digital images processing procedure. The studied noises are vertical growths that occupy only a column of pixels and that characterize themselves for an elevated activity of DP. The interest in its elimination comes given for the influence that they can take place on the parameters that characterize the DP and not for difficulties that they introduce in the identification of these three-dimensional signatures presents on patterns q,φ,n. The procedure of developed filtering is conceived to be applied in the noises of interest that had been previously identified. The filtering of the noises of interest and random noises are also illustrated in the present article. Time of identification and filtering of every pattern does not exceed 5 seconds, indicating the potentialities of the digital processing of images in the denoising of the patterns q,φ,n as much for applications On Line as in real time. For the identification of noises it is taken as basis that the magnitude of a determined pixel is related to its nearby pixels, filtering supports itself in statistical operators and every region of interest in processed at the time. The achieved results demonstrate the effectiveness of the shown procedure.

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Vibration and Audible Noise Analysis of Power Capacitors with Constrained Damping Structure

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In a HVDC converter station, filter capacitors□specifically the can-type capacitors, are the main noise sources after transformers and reactors. It is necessary to investigate the filter capacitor vibration and noise reduction measure. Capacitor current contains fundamental and high frequency harmonics, which cause high-frequency alternating forces on the internal capacitor element, lead to vibrations of the steel enclosure of the capacitor can and thus generate acoustic noise radiated as airborne sound. A new way to restrict noise is to consume the vibration energy and decrease the oscillating amplitude of capacitor enclosures. In this paper, a composite damping structure, composed of a base steel plate, a polymer damping material layer and a constraining plate in order, was set up to damp the vibration of the steel enclosures. The damping structures were equipped on the bottom surface of a can-type capacitor in the experiments, since most of audible noise came from the bottom. In experiments, fundamental voltage and several harmonics with harmonic number 9th , 11th, and 13th were applied on the tested capacitors to simulate the actual operating conditions. The vibration velocity of the composite damping structural capacitor was measured utilizing laser Doppler vibrometry technology. Tested capacitors were set in a semi-anechoic room, and sound level around the capacitors was measure by 24 microphones. Vibration and acoustic noise characteristics of composite damping structural capacitors were studied, comparing with regular ones. It was proved that the composite structure with constrained damping layer would efficiently reduce the vibration of filter capacitors and it had a better damping effect on high-frequency oscillation. And thickness of the constraining plate used in experiments had no evident effect on damping vibration, because the two plate acted as the same constraining component in the structure.

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High power, high repetition rate, fast capacitor charging circuit

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A high power, high repetition rate, fast capacitor charging circuit is presented. The circuit uses four SiC MOSFET switches in parallel in a modified boost converter configuration. Switching losses, already reduced due to the fast switching characteristics of the SiC devices are further mitigated by an auxiliary switch enforcing zero voltage turn-on of the main switches. The charging circuit is expected to enable a nanosecond range high-voltage pulse generator to operate at 100kHz repetition rate. The optimum number of main switches is determined by the available liquid cooling area of the SiC device packages and resulting power density for an acceptable junction temperature rise of approximately 85degC.

Keywords: SiC Mosfet losses, fast charging, nanosecond pulses.

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Study of the cell viability and thermal effect under the high-frequency composite pulses

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Muscle contraction and the non-uniform distribution have become the key obstacles which restrict the development of the irreversible electroporation in clinical application. To solve these two issues, a novel type of pulses called high-frequency composite pulses was proposed by our group. The killing effect and the thermal effect were investigated by our homemade pulse generator. The high-frequency composite pulses with different amplitudes and inner frequency of burst were used to treat the human melanoma cells (Gll19) and the cell viability and the temperature rising under different parameters were evaluated. The results showed that, the cell viability would decrease with the increase of the electrical field amplitude (1kV/cm-2.5kV/cm), and the change of the temperature (4 oC -40 oC) was square of the amplitude. However, the inner frequency of burst had little effect on the temperature rising, and the cell viability had a slight decrease with the increase of the frequency. Therefore, the appropriate electric field strength should be selected to balance the killing effect and the thermal effect, while the inner frequency of the burst in the certain range have insignificant effect on both the cell viability and temperature rising. According to the requirement of the uniform electric field and the inhabitation of the muscle contraction, the optimal inner frequency with appropriate frequency content should be determined. This study revealed the relationship between the high-frequency composite pulse parameters and the cell viability and the thermal effect which was meaningful for the further investigation of the novel type of pulses.

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Electric Pulse Manipulation of Cancer Cell Population Dynamics

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While electric pulses (EPs) can control cell population in vitro [1], the ability to specifically predict the types of cells (dividing or resting) targeted and optimize the EP parameters remain critical challenges for potential cancer treatment applications. Mathematical models of cancer cell population dynamics based on coupled differential equations can predict the transition of cells between the proliferating, quiescent, and dead states to predict the progression of cell population over time [2,3]. In this study, we experimentally assess the impact of pulse duration, field intensity, and number of pulses on cell population dynamics and then fit the model parameters governing transition between proliferating, quiescent, and dead states [3] to the measured cell population to assess the cell types targeted by EPs. The potential implications of EPs on cell death, cancer treatment, and regenerative medicine will be discussed.

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The Distribution Of Lightning Striking Points On Aircraft Using The Leader Progress Method

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Lightning is one of the major natural disasters threatening aircraft flight safety. Aircraft lightning zoning is the premise of lightning protection design, and the first step in locating the lightning striking zones is determining the locations where lightning leaders may initially attach to aircraft. The lightning strike to aircraft starts with the development of a positive discharge from the aircraft, followed few milliseconds later, by the inception of a negative discharge propagating in the opposite direction. The location of the inception points of both discharges are important in order to identify the most threatened zones of the aircraft in the initial lightning phase.
For a given aircraft geometry and an given ambient field direction, the method for analyzing the distribution of lightning striking points when aircraft was struck based on the leader progress method was introduced, by which the numerical simulation model of aircraft was developed. According to SAE ARP5412"Aircraft Lightning Environment and Related Test Waveforms "and SAE ARP5416"Aircraft Lightning test methods", the key factors such as the discharging electrode, the voltage waveform, the discharge gap, flight attitude, and the number of discharge were determined. The charge simulation method were employed to simulate the lightning leader channel propagating toward the aircraft, by which analysis of numerically simulated lightning striking points on aircraft were conducted. The location of the entry points which were the starting point of the positive leader and the exit points which were the starting point of the negative leader was obtained. The distribution probabilities of the entry points and the exit points were obtained. The minimum ambient field which allows the start of the positive leader and the negative leader was obtained. The ambient field which allows a stable propagation of the positive leader and the negative leader was obtained. The research of lightning attachment experiment on scale model of airplane was also conducted in the laboratory, and the distribution probabilities of lightning striking point were basically identical to the simulation results, verifying the feasibility of the numerical simulation method, which have an important reference value for aircraft lightning protection designs.

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Measurement of electric field generated by high power burst pulse electromagnetic wave in water for using to application to bioelectrics

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Nanosecond and sub-nanosecond high voltage pulses can provide new applications. A cancer treatment by an ultra-short pulse high electric field is one of them. High power pulsed electromagnetic wave has been proposed to apply the high electric field for that treatment [1]. Therefore we are developing a high power burst pulse electromagnetic wave generator for bioelectrics application [2]. In this work, we have measured the electric field generated by electromagnetic wave in water as a phantom experiment. The electric field generated by electromagnetic wave in water has been measured by an optical method. The optical method has employed the Kerr effect of water. This method can measure the fine electric field distribution at one time by the use of a laser. As a result, we have been able to measure focused electromagnetic wave electric field of 25 kV/cm in water. This result has corresponded to a measurement result of electric field using a probe.

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Poster 2-C / 56

A Modular 200kW-25kV DC Medium Frequency Resonant Converter for RF Power Amplifiers

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The energy upgrade of existing particle accelerators, and requests for more cost-effective solutions in new large scale facilities, leads to the need of more and more compact high voltage power converters for power amplifiers. Combining this with the increasing needs in terms of reliability, modularity and redundancy (availability of large accelerators), results in challenging power converter design efforts.. Topologies based on resonant LCC DC/AC converters connected to multi-secondary step-up transformers with series connected diode rectifiers generally offer good performances for such applications. Modularity can be achieved by using several multi-secondary windings medium frequency transformers with a high number of output rectifiers. This modular approach allows degraded operation with a faulty module. Moreover, using a soft-switched LCC resonant converter allows achieving a relatively high switching frequency leading to reduced step-up transformers volume.

This work focuses on the design of the high voltage stage of a modular 25 kV, 20 kHz resonant converter used to supplying a 200 kW RF tube. It addresses:

- *The high voltage stage design.* The number of secondary windings shall consider the diodes characteristics as well as stray capacitance and inductances. Designing such a high frequency and high voltage transformer for a power of 100 kW is challenging, issues and limitations are presented;
- *The diodes rectifiers' analysis.* The high voltage requirement leads to a large number of series connected/full bridge rectifiers. Diodes parameters dispersion such as the zero bias junction capacitance and the transition time play a key role in the diodes voltage distribution during the blocking state. This analysis shows how the diode should be chosen in order to avoid destructive overvoltages. Behavioral simulations are performed to illustrate the problematic.

The design analysis is complemented and compared with experimental measurements on a full scale prototype.

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High-Current Arc Discharge (HCAD) Test System for Aeronautic Power

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High-potential DC power distribution systems such as those found in aeronautics are at risk to failures different from AC and low-voltage DC systems. Detection and mitigation of such failures, in conjunction with prevention, are of importance for not only the aerospace field but also to electric vehicles, solar power systems, and data centers.

In collaboration with the Air Force Research Laboratory, APELC has developed a high-current arc-discharge (HCAD) system for test and research applications. The development was driven by the need to understand system failures and related effects specific to high-potential DC-power distribution. The HCAD system is an instantly reconfigurable arc-discharge source capable of driving 50-Amps continuously or more than 1-kA in pulsed-discharge mode. The system can be configured for unipolar or bipolar power up to 600 VDC in both pulsed and continuous modes. The system employs 24 Farads of capacitance for pulsed discharge and uses GTO thyristors to energize and de-energize the load. HCADS features internal current limiting resistors, a hand-held fiber optic remote, calibration fixture, and voltage and current diagnostics. This paper presents the design of the HCAD system.

Poster 2-B / 340

Characterization of high voltage 4H-SiC IGBTs with wide epitaxial drift regions.

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Silicon carbide (SiC) IGBTs fabricated on wide epitaxial drift regions are desirable for pulsed-power and continuous low-duty cycle power conversion systems due to the high avalanche breakdown voltages as well as the ability to switch high currents at fast repetition rates. For mobile platforms, the use of SiC-based electronics can be advantageous as it allows for: 1) a significant reduction of volume in comparison to silicon and 2) burst/continuous modes of operation and advanced triggering in comparison to gas switches. This work focuses on exploring the long term reliability and repetitive switching capabilities of recently fabricated 4H-SiC IGBTs with epitaxial drift regions greater than 160 μm and avalanche breakdown voltages greater than 17 kV. This paper expands on previous work reported on similar devices [1-2], with an emphasis on pushing for continuous and burst mode operation.

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Poster 2-B / 58

Pulse Series Generation Based on the Resistive Load of Neutron Source Type

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There is two types of pulse neutron radiation sources:

a) accelerators generate beams:

- an electron beam interacting with the target generates photo-neutrons;
- beam of hydrogen atoms (or protons) interacting with the target generate neutrons (n1) due to the proton splitting.

b) pulse nuclear reactors are neutrons sources due to nuclear reaction.

One of the possible version of accelerator is a plasma opening switch (POS). At the mode of magnetic self-insulation the ions between the cathode and the anode of POS are accelerated through the potential difference. One of the kinds of ions is ions of deuteron (D).
The flux of deuteron ions is directed from the anode to the cathode and on the near-surface layer of the cathode the fusion reaction can occur. For example, D+D $\rightarrow$ He3+n1+3.26 MeV, where He3 isotope of helium. In other words POS can also be a source of neutrons. Thus, for generator series train pulses base on inductive storages, POS can be used as the resistive load [1].

The POS as the resistive load that is offered has a number of features:

a) the duration of the load is limited to several microseconds;

b) the amount of the load is nonlinear and can change from the mode idle run to the mode short circuit.

The paper considers a number of technical solutions which enable the generation of a series of pulse trains at the mode of D-D interaction. Besides, some possible types of loads are considered, for example, additional intensification of the neutron flux or a combination of the neutron pulse with other kinds of pulse radiations, for example x-rays.

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Research on 10kV cascade pulse power supply for discharge applications

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The cascade type high voltage pulse power supply with the magnetic isolation is used to solve the problem of floating power supply of each cascade unit. Its structure is compact and the trigger mode is simple and reliable. Using the trigger mode of magnetic coupling isolation can increase the tail branch in each concatenation unit simply and conveniently, reduce the falling edge of output high voltage pulse greatly, and improve the adaptability of cascade type pulse power. In this paper, the 10kV cascade pulse power supply is developed. Its rated working voltage of each cascade unit is 1kV, a total of 10 groups. The voltage regulation range is 0~10kV; the operating frequency is 1~10 kHz; the pulse current is 0~20A; the pulse width is 5~30us. The cascade power supply was well used in the application of microsecond-pulse discharge.

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Design and Operation of Pulsed Power Systems Built to ESS Specifications

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Diversified Technologies, Inc. (DTI), in partnership with SigmaPhi Electronics (SPE) has built three long pulse solid-state klystron transmitters to meet spallation source requirements. Two of the three units are installed at CEA Saclay and the National Institute of Nuclear and Particle Physics (IN2P3), where they will be used as test stands for the European Spallation Source (ESS).

The systems delivered to CEA and IN2P3 demonstrate that the ESS klystron modulator specifications (115 kV, 25 A per klystron, 3.5 ms, 14 Hz) have been achieved in a reliable, manufacturable, and cost-effective design. There are only minor modifications required to support transition of this design to the full ESS Accelerator, with up to 100 klystrons. The systems will accommodate the recently-determined increase in average power (~660 kW), can offer flicker-free operation, are equally-capable of driving Klystrons or MBIOTs, and are designed for an expected MTBCF of over ten years, based on operational experience with similar systems.

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Experimental Study on Variations of Rabbit Tissue Impedance during Irreversible Electroporation Ablation

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Irreversible electroporation (IRE) is a new method for tissue ablation. An exposure of a cell to a sufficiently high external electric field results in irreversible electroporation. The electrical conductivity of the cells will change during the irreversible electroporation, and the impedance of the tissue will also change. This paper uses various tissues of New Zealand white rabbits for study, which are applied high intensity microsecond pulses. We measure and analyze the change rules of the tissue impedance. The experimental results show that all the biological tissues impedance in the irreversible electroporation will decrease. And with the increase of pulses number, the impedance will decrease to a stable value. Electroporation occurs on the cells which are applied high intensity pulsed electric field and the electrical conductivity increases. Then the conductivity reaches

a maximum when irreversible electroporation takes place. When the applied pulsed electric field disappears, the impedance of biological tissues becomes larger again, and some pores return spontaneously to their pre-breakdown state. Through the study of the tissue impedance change rule, we can estimate that whether the irreversible electroporation occurs in the biological tissues. The result can help judge whether the tissues are ablated effectively.

Poster 2-B / 85

Research on Transient Junction Temperature Rise of Pulse Thyristor

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Thyristor has been widely used in HVDC transmission system and pulsed power system.The thyristor will be damaged if transient temperature rise of valve plate is too high ,and it will result in the system failure.The relationship between peak value of pulse current flowed the circuit and maximum transient temperature rise of thyristor in pulsed power system was investigated in this paper. Firstly, one circuit used to measure junction temperature rise of thyristor was designed,which was based on the theory that there is a linear relationship between the conducting voltage drop of thyristor and junction temperature rise of thyristor.The thyristor was kept on during the measuring process in the designed circuit.The junction temperature rise of thyristor was calculated through the thermal sensitive curve and the change of the conducting voltage drop of thyristor which can be measured in the designed circuit.The maximum junction temperature rise of thyristor was obtained after one heavy pulse current flowed.Then the equivalent thermal impedance model was built.The thermal resistance and thermal capacitance can be obtained by transient thermal impedance curve fitting,and parameter of equivalent current source can be calculated through the power curve.The temperature variation curve was calculated by the thermal impedance simulation model as the thyristor flowed pulse current.The maximum junction temperature rise of thyristor obtained from the simulation result was almost the same as maximum temperature rise obtained from experiment data.A method to evaluate the temperature rise of thyristor was obtained through the research.

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Evaluation of High Voltage SiC PiN Diode with Robust Field Edge Termination as an Opening Switch Device

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Silicon Carbide is a very promising material for high pulsed power and high frequency devices with ultra-fast switching requirements; however, despite SiC devices showing encouraging results that may qualify them as ultrafast switches in high power pulse systems, many more design and processing issues need to be addressed. Specifically, a premature surface breakdown at SiC DSRD (SOS)

chip edges is still a major hurdle to clear, as reported in the literature [1,2]. In this work, 6.5kV SiC PiN diodes with robust field edge termination design developed at GE Global Research Center for energy conversion systems are tested in a fast switching mode. Diode pumping circuit designed for Si opening switches were used in this test. Despite the mismatched pumping, the SiC diodes demonstrated fast switching, achieving a 10-90% risetime of approximately 5 ns.
This is an encouraging result given that these devices were designed for use as high voltage rectifiers without any design optimization and consideration given to operation as an opening switch.
Mixed mode simulations using the actual test circuit parameters and the PiN diode device structure were employed to analyze the impact of field edge termination parameters on transient characteristics of switching waveforms. Recommendations for the optimization of the SiC PiN diodes to be used in fast-switching mode will be discussed in the full paper.
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Poster 2-C / 7

Bridge topology as primary switch for magnetic pulse compression circuit

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An IGBT switch together with a blocking diode is normally used for the primary switch in a magnetic pulse compression circuit. In the presented paper a full bridge configuration as a primary switch is proposed. The configuration shows advantages especially for high repletion rate systems. It shows also higher efficacies because no special network is necessary for the reflected energy. The system can work with different kind of loads including short circuit and open loop. Design, calculations und first test results are presented.

Poster 2-A / 264

Picosecond Pulse Delivery to Biological Tissue by a Dielectric Rod Antenna

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Picosecond pulsed electric fields in the range of 20 kV/cm can affect electrically excitable cells such as neurons. A noninvasive applicator in the form of a wideband dielectric rod antenna was designed to achieve these ends in the brain. The antenna consists of three sections (a conical wave launcher, cylindrical waveguide, and conical emitting section). In a simulation utilizing a human voxel model, the dielectric rod antenna was able to deliver pulses to brain tissue. The electric field in the brain tissue at a depth of 2 cm was 11.5 V/m. To create the critical electric field for biological effects at this location, the input voltage needs to be 175 kV. The spot size at this depth is approximately 1 cm2. In order to confirm the accuracy of the simulation an experimental study of the conical launching section was conducted in free space. The results set the foundation for high voltage in situ

experiments on the complete antenna system and the delivery of pulses to biological tissue. Finally, to improve the design we show simulation results of a dielectric rod antenna which integrates a collimating lens. By collimating the rays emitted from the conical launching section it is possible to reduce the losses along the dielectric rod, decrease the scattering off of the end of the emitting section, and increase focusing. In terms of the antenna's performance, this reduces the beam width and increases the antenna gain. This allows for more efficient delivery of pulsed electric fields to the brain tissue. One can also use this device for superficial targets, such as skin.

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Design of 40kV, 300us, 200Hz Solid-State Pulsed Power Modulator for Long Pulse Applications

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This paper describes the design of a high performance solid-state pulsed power modulator for long pulse applications. Output specifications of the proposed modulator are as follows: variable output pulse voltage, 1-40 kV; width, 1-300 us; pulse repetition rate, 1-200 pps; and average output power, 50 kW. Based on the structure of solid-state Marx modulator, the proposed modulator mainly consists of high-voltage capacitor charger and IGBT stack. For simultaneous charging of energy storage capacitors, a high efficiency LCC resonant inverter is proposed with multi-stage transformer and rectifier. The IGBT stack is designed based on power cell structure that provides voltage balancing between each semiconductor device and allows reliable operation against arc condition. In addition, a novel gate driving circuit is proposed not only for applying pulse to the load but also for discharging the stored energy from the capacitive load. This active pull-down function removes additional pull-down resistor and provides fast falling time with enhanced system efficiency.
The experimental results of developed capacitor charger shows 95% and 0.96 of maximum efficiency and power factor, respectively. Finally, the performance of the developed solid state modulator is experimentally verified including rated operation (40 kV, 20 A, 300 us, 200 Hz, 2.5% Droop), active pull-down operation, and reliable arc protection.

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Fast Medium Voltage DC Solid-State Circuit Breaker

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Fast solid-state switching is an enabling technology for MVDC (Medium Voltage Direct Current) systems. Series- and parallel-connected IGBTs (insulate gate bipolar transistors) enable thousands of volts (up to 50 kV+) to switch hundreds of amps (up to 1000 A+) in less than 1 microsecond. These devices have characteristic power density of 200 MVA/m3 for a typical device rating of 4.5 kV and 600 A. The circuit breaker interfaces with generators, power converters, and energy storage devices such as batteries and capacitors. The circuit breakers are rackable and unrackable for safety and mechanical compatibility and can be uni-directional or bi-directional for load regenerating applications. A well-designed solid state circuit breaker, with inherent redundancy, can be expected to last for greater than 1 million cycles.

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Development of Compact High Voltage Power supply for -40kV Long Pulse

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This paper proposes a compact high-voltage pulse power supply consist of interleaved capacitor charging power supply (CCPS) with a series resonant converter (SRC) to drive cathode of Magnetron Injection Gun (MIG). Requirement specifications are -40 kV, -7A(280 kW) and few seconds continuous output with less than 1ms the rising and falling time and lower than ± 1% the ripple stability of output voltage at same time. To meet the requirement specifications, eight stacks operated in parallel and each stack has 45 degree phase shift switching was used. Each designed CCPS can supply the -0.9 A current and -40 kV voltage. Also, the proposed CCPS has a series resonant converter meeting simplicity of control. To prove the validity, this paper is confirmed by the simulation and experimental results of fabricated CCPS with -40 kV output.

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Tokamak Vertical Stability Coil Power Supply based on Modular Multilevel Converter

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Modular multilevel converter (MMC) has gained tremendous attention in high power applications since its introduction in 2003. It has enabled the usage of IGBT devices for high voltage applications without the need to connect a large number of switches in series. Although mostly adopted in medium voltage drives and high voltage dc transmission converter stations, MMC can be very promising solutions for pulse power supplies. The author has proposed a MMC based vertical stability power supply design previously where the design and real time simulation has demonstrated the feasibility to meet the fast dynamic requirement of Tokamak vertical stability coil [1]. However, it utilized only two groups of modules per arm with separate ideal dc power supply for each module which may not be practical for real field implementation. In this paper, a MMC with a single centralized power supply is proposed for the vertical stability coil power supply with ITER as an example. Considering the limitations of available IGBT voltage rating, the number of switches used in each arm is much increased, which then increases the controller design challenge. More importantly, with the centralized power supply, capacitor voltage unbalance and circulating current issues will arise, especially with the unsymmetrical pulse power load. Therefore, in this paper, voltage balancing strategies and circulating current suppression controller design will be presented. With the large number of switches used and complicated controller, real time simulation is preferred for more efficient and accurate design verification. The simulation results of the proposed circuit and controller with OpalRT simulator platform will be presented in the paper.

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A Uniform Electric Field Producing Microfluidic Chip for Study and Analysis of Irreversible Electroporation

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Irreversible electroporation (IRE) is a biophysical process in which electric fields applied across a cell cause extensive or permanent permeabilization of the cell membrane, which eventually leads to cell death. It has shown significant advantages in ablating prostatic tissue, such as rapid lesion creation, rapid lesion resolution, sparing of structures such as vessels, nerves and urethra for treating prostate cancer. Compared to conventional electroporation, microfluidic electroporation (MEP), because of scaling down the sizes, provides many advantages such as reducing Joule heating effect, stabilization of pH change and control of electrical parameters. Miniature devices also require very small amount of sample volume resulted in enhancement of their sensitivity and less consumption of reagent. In this paper a novel three-dimensional microfluidic electroporation chip is designed and fabricated using MEMS technology. The width and height of the fluid pathway are all 30μm. Sheath-flow technology is used to guarantee that single cell can flow through the fluid pathway one by one, not blocking at the port of the pump and the fluid pathway. Gold is chosen as the electrode material because of its low electrical resistivity and chemical stability. The structure of plate-shape electrodes can ensure the uniformity of the electric field to an extreme. The chip has been tested by electroporating human liver tumor cell (GLL19) with propidium iodide (PI) and time evolution of PI transport is also attained. Then we apply this micro electroporation chip for quantitatively characterizing the effect of electric parameters, such as pulse amplitude, pulse duration and pulse number on IRE at the single cell level.

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Design and Initial Measurements of a 12.5 kV Prototype Inductive Adder for CLIC DR Kickers

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The CLIC study is exploring the scheme for an electron-positron collider with high luminosity and a nominal centre-of-mass energy of 3 TeV. The CLIC pre-damping rings and damping rings will produce, through synchrotron radiation, ultra-low emittance beam with high bunch charge, necessary for the luminosity performance of the collider. To limit the beam emittance blow-up due to oscillations, the pulse generators for the damping ring kickers must provide extremely flat, high-voltage pulses. The specifications for the damping ring extraction kickers call for a 160 ns duration flattop pulses of +/-12.5 kV, 250 A, with a combined ripple and droop of not more than +/-0.02 % (+/-2.5 V). An inductive adder is a very promising approach to meeting the specifications. The first 20-layer prototype inductive adder has been assembled at CERN and initial measurements have commenced. This paper presents the detailed design of the full-scale, 12.5 kV, 250 A, prototype inductive adder. The prototype adder has an active analogue modulation layer to compensate droop and ripple, in order to reach ultra-low the flat-top stability. Nanocrystalline magnetic cores, Finemet type FT-3L, have also been evaluated and this data has been used to predict the output waveform with PSpice simulations. Initial measurements on the 12.5 kV prototype adder have been completed. Results are presented and conclusions are drawn concerning the flat-top stability and repeatability of the output waveforms of the 12.5 kV, 20-layer, prototype.

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Thyratron Replacement

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Thyratrons in high-power, short-pulse accelerators have a limited lifetime, making it desirable to replace the thyratrons with solid-state devices. One possibility, thyristors, are being developed for this application;, they have not, to date, demonstrated the reliability needed for installation in the short pulse, high peak power RF stations used in many pulsed electron accelerators. An alternate solid-state device, the insulated-gate bipolar transistor (IGBT), readily operates at the speed needed for accelerators, but commercial IGBTs cannot handle the voltage and current required. It is, however, possible to assemble these devices in arrays to reach the required performance levels without sacrificing their inherent speed. Diversified Technologies, Inc. (DTI) has patented and refined the technology required to build these arrays of series-parallel connected switches. Under a DOE contract, DTI is currently developing an affordable, reliable, form-fit-function replacement for the klystron modulator thyratrons at SLAC.

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A Control System for an Isolated LLC Resonant DC-DC Converter

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In this paper, a control system for an isolated LLC resonant DC-DC converter is proposed to regulate the high voltage output level. The converter uses a single stage and it is based on a full bridge structure using IGBTs as switching devices. The output stage of the DC-DC converter is assembled using series-connected lower voltage modules. The proposed topology is based on the current-fed push-pull DC-DC converter operating and controlled with PWM modulation, active clamping and zero voltage switching. The control technique PWM-Phase-Shift together with a proportional and integral controller is used to in the converter. A high voltage transformer is used to step up AC voltage and its intrinsic capacitance and leakage inductance are utilized to obtain soft-switching zero voltage and zero current switching providing loss reduction, improving efficiency and increasing the power density. The theoretical equations of the circuit operations are studied in detail and an expression for average current at the load is presented. The theoretical converter efficiency operating at the nominal output power is almost 94%. The controller proposed is being experimentally used to control the output voltage of a 1.8 kW prototype, fed into 400V, which biases a pulsed TWT with voltages of 400V in the focusing electrode, 8 kV in the one stage depressed collector and 26 kV in the cathode.

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The design of a new explosive DC breaker using electromagnetic forming technology

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In this paper, a new explosive DC breaker switch, which the electromagnetic forming (EMF) technology is used to burst aluminum cylinder in order to cut off the high DC current, is designed. The switch is upgraded from the explosive DC breaker switch of the Laboratoire National des Champs Magnétiques Intenses in France which a closed aluminum cylinder full of water is destructed by high pressure H2 which originates from aluminum wire fuse reacting with the water when the 450uF/10kV capacitor bank power supply is output into the aluminum wire.

The EMF coil powered by pulsed capacitor bank is a replacement for an aluminum wire fuse and its power supply, and the coil is installed outside the aluminum cylinder (an empty cylinder without water). The pulse magnetic field by the EMF coil will induce an eddy current on the wall of the aluminum cylinder and high pulse electromagnetic force will burst aluminum cylinder in a very short time. Compared with the French DC breaker, the EMF DC switch is miniaturization, easy maintence and the aluminum cylinder is also easy machining. The EMF coil and aluminum cylinder with optimized distance and fashion of the fracture can meet the requirement of DC breaker with maximum pulse current 120 kA and isolation voltage in the fracture up to 20kV.

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Analysis of Fault Characteristics of Converter in VSC-HVDC

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The voltage source converter is an important part of VSC-HVDC (Voltage source converter based high voltage direct current) system which has low over-voltage and over current bearing ability and thus prone to various faults. In this paper, based on the VSC-HVDC system PSCAD/EMTDC simulation model, the mathematical model of DC voltage and current fluctuation component caused by AC single-phase break fault is established. Also, the mathematical model of fault AC current on both-side converters is built. Based on the research mentioned above, two VSC fault harmonic transfer patterns is studied. It is proved that n-th harmonic positive sequence on AC side of one-side fault converter will lead to (n-2)-th harmonics negative sequence and n-th harmonics positive sequence on the other VSC, and that n-th harmonics negative sequence on AC side of the fault converter will cause n-th harmonics negative sequence and (n+2)-th harmonics positive sequence on the other VSC.

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Experimental Study on Reverse Recovery Characteristics of High Power Thyristors in HVDC converter valve

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The high power thyristor is the basic unit in HVDC converter valve, and its transient performance has a tremendous influence on the reliability, stability of the whole power system and designs of thyristor control unit. For this reason, each thyristor needs to be tested routinely before the operation of the power system. However, there is no specification for the routine test of thyristor valve. The test methods of thyristors are associated with the relationship between reverse recovery characteristics and external operating conditions. Therefore, to provide a reference and basic datum for the routine test of thyristor valve, it's necessary to investigate the reverse recovery characteristics of high power thyristor in converter valve. In this paper, we focus on the evaluation of thyristor reverse recovery time by forward current, namely forward current amplitude, conduction pulse width and rate of change of commutating current. The influences of thyristor reverse recovery time have been investigated to determine the parameters of thyristor testing based on testing the reverse recovery process of thyristor and analyzing the influence mechanisms. The results show that the reverse recovery time mainly depends on peak forward current and commutating di/dt, where reverse recovery time decreases with the increase of the commutating di/dt and is directly proportional to peak forward current; the commutating di/dt relative to peak forward current is the main influence factor of reverse recovery time; the ration of turn off time and reverse recovery time is less than 1.2, which is particularly significant for the evaluation of thyristor reverse recovery ability by impulse test in thyristor testing.

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SILVACO BASED ELECTRO-THERMAL ANALYSIS OF 4H-SiC TIV-JFET STRUCTURE UNDER EXTREMELY HIGH CURRENT DENSITY RESISTIVE SWITCHING

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Electro-thermal analysis of SiC power semiconductor devices is crucial for its suitability in high power pulsed application. The relative stability of the threshold voltage and the absence of surface conduction in a Trenched and Implanted Vertical JFET (TIV-VJFET) structure gives it an inherent advantage over SiC MOSFETs especially in high current density pulsed applications like high voltage DC - DC converters, high voltage laser power supply and other pulsed power circuits. Technology Computer Aided Design (TCAD) modeling of SiC power semiconductor devices provides a simulation-based approach to predict and understand device behavior under extreme electrical conditions. In this research, a 2D model of a 1200 V 4H-SiC TIV-JFET cell structure was designed and simulated using Silvaco ATLAS TCAD software to investigate and understand the effects of

extremely high current density pulsed switching on the device characteristics. The JFET cell was designed for an active area of 2 μm² and a threshold voltage of -7 V. Physics - based models were included to account for impact ionization, recombination effects, band gap narrowing, mobility and lattice heating. The electro-thermal simulation was performed using a resistive switching circuit at an ambient lattice temperature of 300 K. The circuit was designed for an ON - State drain current density of 5000 A/cm². The device was simulated using a 100 kHz 50% duty cycle gate signal consisting of four switching cycles considering the simulation time bottleneck. The analysis of lattice temperature profile revealed the formation of thermal hot spot in the channel area close to the gate P+ regions in the JFET structure. Further analysis showed an increase in the minority carrier concentration in the vicinity of the gate implants which affected the switching characteristics of the JFET at extremely high current density.

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Driving Circuitry with Active Voltage Clamping across IGBTs in a Marx Configuration

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For a device for treatment of food by pulsed electric fields a modular semiconductor-based Marx generator has been designed. Each stage comprises a parallel configuration of inexpensive IGBT switches forming together the pulse switch. A control signal allows synchonized switching of the stages. It is distributed to the stages inductively via ferrite core transformers. Separate gate drivers have been implemented at each stage next to the IGBTs. Such a design enables fast switching and, hence, low switching losses, without the need for the control signal to transfer the total power required for switching. The gate drivers are powered continuously by a rectified AC current sharing its signal path to the stages with the control signal for synchronized switching. For the mentioned application, the switches are operated mainly as closing switches. However, in case of a flash-over at the load fast opening of the switches is required. For protection against inductive over-voltage across the switches instead of free-wheeling diodes a circuit for active clamping has been added. The driving circuitry has been tested successfully in a Marx configuration. The paper describes selected details of the driving circuitry and presents results of tests.

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Electric Pulse Parameter Exploration for Lipid Extraction from Microalgae

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A desire to limit CO2 emissions and overall energy demands has motivated the search for alternative energy sources. The first approach involved the development of plant biofuels for a greener, renewable solution; however, crop-based biofuels grew unpopular because they were expensive and used foodstuffs. Using microalgae can avoid these issues and are now an increasingly popular source of

liquid fuels. One area in microalgae biofuel production that requires improvement is the extraction process for lipids or other biofuels. The most common lipid extraction method, Bligh & Dyer [1], is costly and toxic. Treating microalgae with electric pulses (EPs) induces electroporation, which can lyse the cells to increase the extraction efficiency of safer, greener biofuels [2]. Thus, EPs can intensify biological effects to provide a safer and less expensive renewable solution than the Bligh & Dyer method. This study explores the optimization of EP parameters and green solvents to improve lipid extraction efficiency. While preliminary research has shown EPs are an effective pretreatment, the extent of their effectiveness remains unknown. We report a comprehensive analysis of EP parameters for treating microalgae, both cyanobacteria and green algae, with nanosecond and conventional electroporation parameters.

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15-Stage Compact Marx Generator Using 2N5551 Avalanche Transistors

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In this contribution, we present a 15-stage, avalanche transistor Marx generator using inexpensive 2N5551 transistors. It can be used in low-power biomedical, environmental and food applications where compact circuits to generate high-voltage pulses are required. We characterized the avalanche transistors and built a test setup with 15 stages which provides 1.3-kV pulses into a 50 Ohm load and over 4-kV into a small capacitive load (such as a small plasma reactor). Furthermore, by optimizing placement of starting capacitances, the rise time of the circuit could be adjusted to just under 2 ns, which can still be further optimized.

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Experimental study of a helical coil operating mechanism for future switchgear applications

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The replacement of the strong greenhouse gas sulphur hexafluoride and the emerging installation of multi-terminal HVDC grids also lead to significantly changing requirements for future switching devices. On the one hand, the application of alternative insulating and arc quenching gases requires

higher opening velocities of the contacts to compensate the reduced dielectric strength of these gases. On the other hand, fast switching devices are needed due to the fast increase of the fault current in DC grids. In this contribution a compact helical coil operating mechanism is set up for replacing conventional mechanical spring drives in circuit breaker and switching applications. The total stroke is selected to match typical contact distances in state-of-the-art gas-insulated switchgear. Nevertheless the operating principle can be easily extended to higher moving distances. In order to achieve an intrinsic breaking effect, the winding direction of the stator is reversed after half of the moving distance. In a first approach, the operating mechanism is tested in the high current part of a synthetic test circuit with a sinusoidal current. The initial position of the sliding anchor on the stator is varied to experimentally determine the acceleration and breaking performance of the operating mechanism. Furthermore, the amplitude of the sinusoidal test current is varied up to values of several kilo-amperes. The movement of the anchor is observed by measurements of the travel curve and video camera recordings. In addition the wear of the stator windings as well as the sliding contacts of the anchor are investigated yielding a statement with regard to the durability of the operating mechanism. The results also indicate the applicability of the mechanism for future DC switching devices.

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A New soft Switch Circuit to improve the efficiency of a solid-state Marx generator

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Nowadays, it is important to improve the power efficiency with the growing variety of environmental, biological, medical, and especially for homogeneous dielectric barrier discharges (DBD) industry application using a repetitive high-voltage solid-state Marx generator. However, most solid-state pulse generators are action at hard switching on or off, such as a huge current for the DBD load, which will increase power loss, enlarge thermal stress and have to enlarge the heat sinks or decrease their repetitive rate.

In order to improve the power efficiency of the repetitive high-voltage solid-state Marx generator applied in DBD, a series resonant soft switch technology is proposed in this paper. It is series in an inductor matched to DBD capacitor, where series resonant for soft switching will be happened. The influence of the Q-factor and the value of the series inductor will also be analyzed. Studies have shown that the new circuit will provide us a quasi-zero current switching on and off. If we select a high Q of the inductor will improve the radiant power and system efficiency of KrCl* lamp, a typical DBD load.

A laboratory prototype pulse generator is implemented operated with the voltage range 0-10 kV, the repetition rate from 0.1 Hz to 10 kHz, pulse width from 1 μs to 5 μs and the rise time less than 100 ns. The efficiency of the Marx generator improves over 30% and the radiant power improves over 25%.

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Novel GSSA Modeling of Switching Functions and Control of High Power Voltage Source Inverters (VSI) for Advanced Aircraft Electric Power Systems

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The growing complexity and nonlinear structure of modern aircraft electric power systems with extensive nonlinear loading made available state-space averaging models inadequate for accurate analysis and characterization of such systems. In this paper, the Generalized State-Space Averaging (GSSA) model is applied for the analysis, control, and characterization of SPWM twelve pulse inverter in advanced aircraft electric power systems. The proposed GSSA model has been applied to derive the corresponding averaged model of the reduced-order system for the voltage source inverter, while taking into consideration the interaction with the entire aircraft electric power system. An accurate model of the switching function approximations has been derived by developing average duty cycle intervals over several regions of the PWM switching pulses. The first order approximations of the modulated signals are subsequently generated and the inverter's input and output profiles have been captured according to the GSSA model. Moreover, the proposed approximated model can be employed to generate real-time control signals using available hardware. Furthermore, the developed model and the results obtained are presented and discussed.

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Research on Calibration Method for Single High Pulse Voltage for Semiconductor Devices Test Instruments

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Power IGBT module is widely used in high power conversion applications in various fields because of the advantages of high voltage and high current applications. In order to avoid the influence of temperature rise to the device measurement, pulse test method is widely used to test its static and dynamic parameters, So there are single high pulse voltage source and single pulse high current source in power IGBT modules test instruments. For now in the metrology field, how to calibrate its Single High Pulse Voltage source is a difficult problem. Now the amplitude of single high pulse voltage source is above 7kV with the pulse width as 50 microseconds. Based on detailed research on the test principles of the power IGBT modules test instruments, the pulse high voltage divider and the data acquisition unit are used to setup a calibration device for Single High Pulse Voltage source to calibrate the amplitude of Single High Pulse Voltage source. We use the resistors to develop the pulse high voltage divider, and did carefully research on the pulse response time, voltage dispersion, voltage regulation of the pulse high voltage divider. Also the data acquisition unit with 20MHz bandwidth and 100MS/s acquisition rate is evaluated through tests including vertical accuracy test, bandwidth test, rise time test, comparison test and etc.. Through above relevant test results, with the comprehensive consideration of the influence of each measurement uncertainty component, we have finished the evaluation of the uncertainties of the amplitude measurement for Single High Pulse Voltage source. The uncertainty of measurement is better than 2% with the coverage factor as 2.

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EFFECT OF CONDUCTIVE SCREENS ON THE STABILIZATION OF PLASMA CHANNELS WITH CURRENTS OF HUNDREDS kAmps

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The problem of plasma structure stabilization recently has received considerable attention for low and high temperature plasma applications, in particular in fusion experiments, and in order to cope with the problem different special configurations of current and magnetic systems are developed and deployed. However, the available solutions require construction of complex magnetic fields and consume considerable amounts of energy. With respect to TDI-type thyratrons, which are widely used in recent years in Pulsed Power applications installations, this issue has not been studied thoroughly.
Normally TDI-thyratrons (pseudospark switches) are operated in circuits with grounded grid and, in fact, represent an arc gap, the life of which is mostly determined by erosion of its electrodes. However our experience shows that TDI-thyratrons, operated on the left branch of the Paschen curve, feature certain essentials in the motion of arc channels when switching charge transfer of more than 0.1 C per shot with peak currents exceeding 10 kA. Besides, the way how the switch is connected in the circuit, affects greatly on the service life of the tube.
In a report analyzes the behavior of the discharge in the known switching devices, including ignitrons and vacuum gaps, the influence of their design on the discharge stabilization, which made it possible to determine ways to enhance the reliability of thyratrons.
Based on experimental data, we analyzed the results of the influence of external conductive shield on stabilization of plasma channels in high-power pseudospark switches with reentrant and classic design.
Both no-ferrous and ferrous shields have been tested. The preliminary calculation of the magnetic field distribution is presented. This research is a part of a work on improvement of switching capabilities of thyratrons used for transferring currents up to hundreds kA with switching energy more than 50 kJ.

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Optimized Small Scale Hydropower Generator Electrical System Design & Modeling Based on Real-Measurements

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This paper proposes design and implementation of a small scale micro-hydro power electrical system capable of supplying a house near flowing water with sustainable power. A small scale hydropower turbine system and a larger system using a DC power supply generator are built. Real small hydrogenerator associated with electric generator is used with a simple load, rectifier, and dc-dc converter. Larger system will use programmable power supply attached with rectifier to act as the larger hydroturbine system is used. DC to DC converter is used to regulate the voltage level. Instead of using a battery to store energy, a Supercapacitor and static capacitors are used to store the energy. Smart dc load equipment is used to act as the compatible dc loads for smart homes. Full-wave bridge rectifier, and inverter after the storage devices are designed and implemented. A caparison between the two different types of capacitors static and Supercapacitor one is introduced. Artificial Neural

Network (ANN) is used with feed forward back-propagation technique to implement Charging and discharging ANN models for load range up to 150 W with Time and Voltage as inputs and Energy and Current (Watt) as outputs. These models are checked and verified by comparing actual and predicted ANN values, with good error value and excellent regression factor to imply accuracy. Finally, the algebraic equations and Simulink models are generated and deduced to use them without training the neural units each time. Optimized genetic process for the discharging models of both types of capacitors is adopted. A genetic algorithm is formulated to maximize the energy with respect to the time and load range. Energy is the objective function with bounds for voltage as optimizing variable. All results are simulated with MATLAB, and Genetic Optimization Toolbox. A noticeable improvement is appeared in performance parameters.

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A Comparison of Piezoelectric Transformer Technologies for HVDC Converter Applications

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Piezoelectric transformer-based power converters are ideally suited for uses in applications where compact form factor and high voltage isolation are major considerations. Piezoelectric transformers are resonant electromechanical devices that use mechanical vibrations to induce polarization throughout the bulk of their constituent material. Two types of piezoelectric transformer, one type composed of lithium niobate and the other composed of a lead-zirconate-titanate, were operated into a multi-stage voltage multiplier for a side-by-side comparison. The performance characteristics, including input impedance, output voltage and current, and power conversion efficiency were investigated and reported. The lead-zirconate-titanate transformers exhibited wider input bandwidth, making them suitable for tandem operation from a single source of stimulus, whereas the lithium niobate was able to produce higher voltage with lower losses.

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Investigation on discharge mechanism of a particle beam triggered gas switch

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A transient optical diagnostic system for studying the discharge characteristics of the particle beam triggered gas switch was built, the temporal and spatial evolution of particle beam was observed in real time, the velocity curves of particle beam under different gas pressures were obtained. And at the lowest working coefficient of 47.2%, the discharge processes of the two spark gaps were photoelectric diagnosed and analyzed respectively. The results showed that, particle beam moved forward in a bullet mode, and the speed of which increased with the decrease of pressure, and decreased with the increase of time. At the initial time, the speed was fastest. The positive and negative streamer was occurred in the trigger gap and jet gap respectively, and the delay time of the two gaps was 34.2ns and 42.1ns, which was basically same as optical diagnostic results. The particle beam triggering was

a non-penetrating induced discharge method, the electric field of the head of discharge channel was enhanced through injecting electrons to the spark gap, and discharge process was accelerated from electron avalanche to streamer, and it was conducive to the rapid closure of the switch.

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A ZCS AC/DC Converter with LCL

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Abstract—This paper studies an inductor-capacitor-inductor(LCL)voltage-source converter(VSC) which can be implemented by zero current switches(ZCS). The ZCS has potential applications in improving the efficiency of high-voltage high-current system, such as servo power supplies at over 10 MW for the compressed plasma suggested in[Li, G. High-gain high-field fusion plasma,Scientific Reports, 2015, 5]. This converter is composed of an ac/dc/ac insulated-gate bipolar transistor-based VSC converter and a passive LCL circuit designed for matching the conventional PWM converter. The converter parameters are tested for designing LCL circuit to have optimal response during the faults, realize ZCS control,and minimize converter losses.The simulation model is built based on the MATLAB platform.The simulation results show that the rectifier has good controllability and testing rig is being built.The simulation confirms the capability to control the load current for the compressed plasma .

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Fuzzy Logic Control of a Hybrid Energy Storage Module for Naval Pulsed Power Applications Using a Hardware-in-the-Loop Testbed

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As the Navy transitions to a more electrical fleet, the electrical architectures must adapt to the changing load profiles. With the introduction of electrical propulsion, new types of electrical energy based weapons, and energy storage backups for these devices, load profiles have become higher power and more transient than ever seen before – especially during directed energy weapon operation. One issue that has become apparent with the introduction of these transient loads is the ability of traditional generation sources, such as fossil fuel generators, to power them. Although generators are stiff sources of power, they suffer efficiency losses when they deviate from operating at a constant maximum load. Previous research has shown that it is possible to integrate hybrid energy storage modules (HESMs) in order effectively filter out the power transients seen by the generators while preserving the lifetimes of the energy storage devices used in the module. Although the topology has been verified, there still exists some concern about the method of controlling the system level power flow in order to meet the unique demands of this naval application while preserving energy storage device lifetimes. This paper proposes to utilize fuzzy logic control in order to intelligently

govern the flow of power throughout the system. A small-scale testbed has been constructed using a custom designed power converter capable of bi-directional power flow between a battery and supercapacitor to feed a dynamic pulsed power load through several operational scenarios. The system utilizes a PC104 running Simulink RTOS to impose fuzzy logic control on the system. This testbed will demonstrate the effectiveness of fuzzy logic control to act as a system level controller for a HESM in naval pulsed power applications.

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Modeling and Experiment Research on Turn-off Characteristics of Pulse Power Thyristor

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Pulse power thyristor has been widely used in pulsed power system for its numerous advantages, such as good controllability, large through-flow capacity and high repetition frequency. To study the device's electrical characteristics and the circuit transient process, a marco model of pulse power thyristor applying to MATLAB software platform was established in this paper,based on research of reverse recovery process of pulse thyristor. This model combined ideal thyristor model in MATLAB with reverse recovery current module, which was designed to describe the reverse recovery process of thyristor after the conducting current rapidly decresed to zero. In the model, reverse current increased with a constant di/dt when accumulated carriers rapidly decreased; and then when space charge region started to recover,the thyristor's recovery current curve was described by two hyperbolic secant curves with different time constant. This established model achieved the smooth transition of current curve from storage time to dropping time, and thus improving the precision of thyristor model comparing with the original one. In addition, experiment was designed to verify the marco model. According to the experimental data, the reverse recovery voltage and recovery current curve calculated by the marco model fitted well with the experiment results.

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Design of High-voltage Nanosecond Fast Repetitive Pulse Generator Based on Avalanche Transistor

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A high voltage, nanosecond pulse generator is designed to get the high resolution and accurate results in Pulse electro acoustic (PEA) equipment to measure space charge test. There's more and more requirement for fast rise time pulse generator especially with high repetition frequency and high voltage. Several technologies are being used for generation of nanosecond pulses such as spark gas, draft-step-recovery diode (DSRD), semiconductor opening switch (SOS) and fast-ionization device(FID), photoconductive semiconductor switch. Mostly are limited by its life time and low repetition frequency. The semiconductor switches such as FID, DSRD and SOS are hard to manufacture and expensive. Serial avalanche transistors technique is used in this design. By carefully designing

the serial transistor circuit and PCB, the stray inductance and voltage reflection are reduced effectively, which make the output rectangular pulse obtain 2.5 ns rise time. The amplitude output pulse can reach up to 2.5 kV with 12.5 ns width. The pulse time jitter is less than 100 ps even in10 kHz high repetition frequency output mode. The high voltage DC power supply can provide high voltage in the range of 0 to 6000V for the rectangular wave forming line. The serial avalanche transistors connected to the rectangular wave forming line can discharge to the 50Ω load under the control of triggering signal. Then a rectangular pulse with amplitude of the half DC charging voltage is formed on the load by the shaping effect of the rectangular wave forming line. The pulse width is determined by the length of the forming line. The avalanche operation mode can ensure the fast turn-on speed, therefore obtaining fast rise-time pulse. The series of avalanche transistors can enhance withstand voltage and make the pulse amplitude reach to several kV.

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Evaluation of Long Term Reliability and Safe Operating Area of 15 kV SiC PiN Diodes during Ultra-High Current Pulsed Conditions

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Silicon Carbide (SiC) is a leading wide bandgap semiconductor for increasing the power density of high power applications. This paper overviews the long term reliability and safe operating area of 15 kV SiC PiN diodes during pulsed current conditions. An automated system is used to stress these devices with ultra-high current pulses and monitor degradation with in-system characterization. The system is capable of a 100 μs full-width half maximum pulse width up to 15 kA, with a repetition rate of 0.5 Hz. Periodic in-system characterization measures device forward conduction and reverse breakdown. The devices in this paper are pulsed at current levels from 1.5 kA to 3 kA. Over 100,000 pulses at 1.5 kA have been performed with no degradation. The long term reliability and failure mode results for the 15 kV PiN diodes will be reviewed.

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THYRISTOR BASED SWITCHES TRIGGERED IN IMPACT-IONIZATION WAVE MODE

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The process of triggering thyristors by an overvoltage pulse with a short rise time was implemented. Low-frequency commercial thyristors of tablet design with diameters of silicon wafers of 32 to 56 mm and an operating voltage of 2 to 2.4 kV DC were used in the experiments. An external overvoltage pulse was applied across the thyristor main electrodes, which ensured a voltage rise rate from 0.5 to 6 kV/ns within a few nanoseconds. Under such conditions the thyristor closing process occurred due to initiation and propagation of a fast ionization front across the semicon-ductor structure. The

time of switching the thyristor from the blocking state to the conducting state was within 200 to 400 ps. The thyristor based switches contained 2 to 9 series connected thyristors and operated in this triggering mode in different discharge circuits. Operating voltage was 5 to 20 kV and capacitance of discharge capacitors was 2 to 800 μF. The experimental results obtained covered the following range of discharge parameters: discharged current amplitude of 10 to 150 kA, current-rise rate of 15 to 130 kA/μs, current rise time (0.1-0.9 level) of 0.4 to 5 μs, pulse duration (FWHM) of 1 to 20 μs, and switching efficiency of 0.85 to 0.96.
The paper will discuss the experimental circuitry, tested switches design, and results obtained. The results of numeri-cal simulations of the thyristor switching process will also be given.

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A High-current, IGBT-based Static Switches for Energy Extraction in Superconducting Power Circuits

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The steadily increasing demand from the particle physics community for higher energies and higher integrated luminosity has reinforced the need for new accelerator equipment, often breaking with conventional technologies. One of the fields where new and innovative engineering is required and where interesting developments are on-going, is the domain of fast switching of high DC currents, such as it is recurrently required for rapid extraction of large quantities of stored energy in superconducting circuits.
The 30 kA opening switch, development at CERN within the global HL-LHC project, is an illustrative example of an innovative engineering required to satisfy the demands related to circuit protection. The paper presents the integration into an IGBT-based static DC switch of a variety of different, new design principles, such as a triple-busbar layout for optimized circuit symmetry, the extensive use of laminated, water-cooled busbars, and an optimized capacitive compensation of the parasitic inductances as well as a complete analysis of the thermal budget management of the individual IGBT modules. Results from direct liquid cooling of the IGBT's will also be presented.
The paper will also include a presentation of a bipolar, redundant 1 kA IGBT switch which features an all-laminated busbar concept, elaborated for energy extraction in superconducting corrector circuit.

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Energy Storage Modeling Library (ESML) for DC NANO- GRID

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When renewable energy introduces the term "energy storage" automatically comes. Because electric power is consumed the instant it is produced so electrical energy storage technologies are designed

to absorb electrical energy directly and release it as electrical energy (act like a generator) at a later time. To mitigate the problem of intermittency of renewable energy as well as to improve the controllability of transmission and distribution systems, energy storage is an important factor. It can be used from a very small scale to large scale such as cell-phone, pumped hydro storage (PHS), compressed air energy storages (CAES) and so on. For medium or high power applications, micro grid can be used to provide power to its local area. But when there is need of a medium scale or large-scale energy storage, and PHS and CAES are unavailable, the only solution is to integrate small-scale energy storage systems together to form an energy storage DC Nano-grid. So, modeling of different types of storage devices and techniques is very important issue to figure out more about various characteristics of each one before starting the control, management and implementation process. Different storage devices and techniques are modeled and simulated in this work as the following: Lead-acid battery, Nickel-Cadmium (Ni-Cd) battery, Nickel-metal hydride (NiMH) battery, Lithium-ion (Li-ion) battery, ZEBRA battery, Sodium-sulfur battery, Ultra-capacitor, Flywheel energy storage (FES), Super-conducting magnetic energy storage (SMES), Vanadium redox flow battery (VRB), Zinc bromine flow battery (ZnBr), Compressed air energy storage (CAES) and Pumped hydro storage (PHS). MATLAB software, Simulink and Power System toolbox are used in modeling and simulation process. Then the concept of energy storage DC Nano-grid based on the different results characteristics is illustrated. Finally, a comparison of energy storage technologies for power Applications is presented.

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CHARGE-TRANSFER BASED SENSORLESS VOLTAGE FEEDBACK IN HV CAPACITOR CHARGERS

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Rapid capacitor chargers are typically used to charge a bank of capacitors with the purpose of discharging it into a pulsed power load [1,3]. Previous research shows that the charging voltage of the load can be accurately calculated in real-time using microcontroller software algorithms [2]. The objective of this paper is to report a hardware based approach to measure the charge transfer into the load capacitor and implicitly the capacitor charging voltage. The proposed circuit uses operational amplifiers in order to integrate the input charge. A microcontroller receives the integrated signal to compute the output voltage and stop the charging process when the target voltage has been reached. Failure to accurately detect the end of charge time could lead to an excessively large capacitor bank voltage. For this reason, the proposed method can be utilized as a backup for end of charge detection. A comparison is performed between the proposed mechanism and the method described in [1].

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Study of Effects of Nanosecond Pulsed Electric Fields on Cancer Cell by using in Vivo and ex vivo Assay.

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Treatment approach of malignant neoplasm (cancer), which has high probability to death, has been actively studied. Although there are several current cancer therapy as radiation therapy, surgical therapy, and chemotherapy (anticancer drugs), these therapy have some disadvantages such as radiation to patient and critical side effects. The goal of this study was to establish a new cancer therapy, using nanosecond pulsed electric fields (nsPEFs), so as to lead to regression of these disadvantages. 2ns-PEFs were applied on solid tumors obtained by embryonic chick assay. The tumors were dissected from the eggs in a few days after the PEFs application and were weighed. It was confirmed that the mean weight of the pulse-treated tumors was significantly smaller than that of controls; tumor growth was constricted by nsPEFs application. The nsPEFs were applied subsequently to the tumor cell suspension to examine the effect of nsPEFs application in detail. The viability of tumor cells was measured by the WST-1 assay (water soluble tetrazolium salts) in advance. In increasing the charging voltage and the number of times, the viability of pulse-treated cells was significantly smaller than that of controls which were not exposed to nsPEFs. By using a flow cytometry with Apoptotic/Necrotic/Healthy Cells Detection Kit, it was confirmed that apoptosis was induced and necrosis was slightly occurred in cell by nsPEFs application. In addition, it was confirmed that equal or more apoptosis in cells were induced by nsPEFs application than Anisomycin application as a positive control. In other words it was also confirmed that apoptosis was induced. In the same way, an ex vivo assay was performed on pulse-applied solid tumors obtained by embryonic chick assay. The discussions will be presented in detail.

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Electric Pulse Manipulation of Stem Cell Proliferation and Differentiation

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A single 2.5 or 5.0 V/cm electric pulse (EP) of 90 s duration induced changes in cardiomyocyte differentiation, increasing the number of beating foci with the higher field strength increasing intracellular reactive oxygen species [1]. Similar field strengths can also induce cytoskeletal stresses that facilitate manipulation of osteoblasts and mesenchymal stem cells [2]. While effective, these treatments often require relatively long application times and the mechanisms may be challenging to apply consistently and the physical interactions may conflict with long-term physiological effects. We hypothesize that intense nanosecond electric pulses (NSEPs) can overcome these side effects while additionally leveraging additional physical mechanisms that they introduce, such as plasma membrane nanoporation, ion transport, and intracellular structure manipulation [3]. Through their ability to control growth factors and provide both mechanical and electrical stresses [4], appropriate tuning of EP parameters facilitate adequate microenvironment control to manipulate stem cell function. We experimentally assessed the impact of pulse duration, field intensity, and number of pulses on muscle stem cell population dynamics by examining increased proliferation using a photospectrometer

and enhanced proliferation for various energy ranges using fluorescent microscopy. The potential implications of these results to regenerative healing and tissue repair will be discussed.

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Down Hole Pulse Generator Must Survive 300 C at 9 km Depth: Low-cost Access to Ubiquitous Geothermal Heat Worldwide

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The answer to Humanity's energy emergency is beneath our feet: ubiquitous, abundant, baseload geothermal heat -is - if only we could afford to bore deep enough to reach it, anywhere on Earth. The average geothermal gradient, anywhere on Earth, is about 30 C per km depth. At 9 km, at almost 300 C, with enough contact area, abundant energy may be extracted, forever, if the borehole system is managed well. Brought to the surface by water or other working fluid, in a closed system, electricity generation via steam Rankine or Organic Rankine Cycle (ORC) generators plus district heating and / or cooling continuously available. Affordable access to deep geothermal heat eliminates the prospecting risk of finding geothermal fluids and / or "hot spots" in Earth's shallow crust.

Since 2005 a collaboration among Norwegian University of Science and Technology (NTNU, Trondheim, NO), Technical University of Tomsk (RU) and SwissGeoPower (CH) has been investigating Electro Pulse Boring (EPB), a novel rock-breaking process using very high voltage, high power, short pulses of electricity, (500-700 kV, 10 ns, 10 pps; average power ~ 25 kW) applied to an electrode array on the borehead. Sedimentary or crystalline basement rock is fractured to chips, which are removed to the surface with conventional mud-driven "hose return". The Down Hole Pulse Generator must be situated directly above the borehead, suspended from the surface via a power and controls umbilical, and must survive 300 C and the pressure at 9 km depth. This is a pulsed-power challenge that must be met before deep boring testing may proceed and succeed.

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Nano-Grids: Future Power Grids – Concept and Review Paper

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This paper proposes reviewing the recent advances and new technologies for NanoGrids systems. It aims to make a point of view on the Nano-grid as a future promising electric power system grid. It tries to reply some questions like what are the Nano-grids, how they are related to smart-grids and what is the difference between them and Micro-grids. Microgrids are building blocks of a Smart-grid. Nanogrids are building cells of a Micro-grid. They should be efficient, reliable, self-sufficient, and fault tolerant to contribute to a healthy smart grid. A Nanogrid may not be directly connected to a grid. It should stably operate in clusters (in a Microgrid). It should be able to operate in an islanded mode. Nanogrid should be operationally independent to make the Smart-grid reliable and fault tolerant with reduction of converters number in Nanogrid. This work addresses, discusses and reviews the following aspects related to this kind of grid: Basic Architecture, Modern Domestic Loads, DC Compatibility, Nanogrid: Present Technology, Energy Control, Efficient Design Strategies, Transformer-less Single topology for Multiple jobs, Battery life, Optimal charging circuits, Special Converters for Nanogrid, Multi-Control Single-Input, Nano-Grid Construction, Interconnecting Nanogrids and Conceptual power electronics based electric power system in future sustainable home. Moreover, Communication within the Nanogrid system, Future DC Nanogrid, Conceptual dc nanogrid in a future home, a contemporary vision of "smart" electrical system nano-grid in residential buildings, Solid State Lighting, Grid-connected mode, Grid-connected to stand-alone mode transition, Static Operation of a DC Nanogrid and The Main Characteristics of the DC Nanogrid System are also investigated. AC Nano-grid and DC Nano-grid within Contemporary Smart Grid Concepts are also presented. Overview about Modes of Operation: grid-connected and stand-alone are also introduced. Communication within the Nano-grid system plus some Characteristics of the DC Nanogrid System and Static Operation of a DC Nano-grid are presented in brief. All the previous items are supported with comprehensive reviews from other researchers work in the review part of the paper. Finally, Nano-grids' Benefits and Challenges with possible Research Topics are addressed.

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Effect of the Number of Inner Wire Electrodes on Surfactant Treatment Using Nanosecond Pulsed Powers

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Recently, water pollution has come to an issue around the world. As a new water treatment technology, advanced oxidation processes (AOPs) has attracted attention. We have studied an efficient wastewater treatment using nanosecond pulsed power as one of the AOPs. In this system, effects of not only the active species but also electric discharges are expected. A nonionic surfactant was selected as a treatment target because much nonionic surfactant occupies to domestic and industrial wastewater. The surfactant solution was circulated in a water treatment equipment with a coaxial cylindrical reactor by a pump. In previous research, 0.5 L of surfactant solution was mostly treated for 120 minutes using the nanosecond pulsed power system.
In order to shorten the treatment time and increase the treating capacity, another treatment system was developed. The number of inner wire electrodes was increased from one to eight. In addition, internal diameter of the outer electrode became larger. As a result, the treatment time of 1.0 L surfactant solution became shortened to 80 minutes. The treatment by reactor having the eight inner electrodes was compared with that having two inner electrodes. Although both foam heights in water reservoir were approximately same after 80-minutes treatment, UV absorption of the solution treated by using eight inner electrodes were larger than using two inner electrodes over the observed spectrum. It seemed that the increase of UV absorbance was caused by more amount of active species dissolved in the solution because more ozone was also produced. In addition, increase of interfacial area between the solution and streamer discharges was expected. Therefore, molecular structure of hydrophilic group of surfactant treated by using eight inner wire electrodes could be decomposed into smaller structure.

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Impact of Pulsed Power Loads on Advanced Aircraft Electric Power Systems with Hybrid Fuel-Cell/Battery APU

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Pulsed power loads such as electromagnetic guns, electron lasers, high-power radars, electromagnetic launch and recovery systems can cause significant stress on aircraft electric power systems. In this paper, the performance characteristics of a fully integrated advanced aircraft electric power system (AAEPS) with a hybrid fuel cell-battery auxiliary power unit and connected pulsed power loads are investigated. Connected pulsed power loads on aircraft electric power systems may cause the power generator to undergo transient behavior which in turn can cause significant stresses in the shaft and the actuator. Moreover, pulsed power loads can also affect the power quality and voltage stability of the aircraft electric power system. Drawing short-duration high power in an intermittent fashion by the pulsed loads can cause frequency and voltage fluctuations which may lead to sensitive load malfunctioning and instability of the aircraft power distribution network. In this paper, the impact of pulsed power loads has been studied with different scenarios and case-studies. The results obtained stresses the need develop and install compensating devices to maintain the stability of the AAEPS in the event of severe pulsed power load operation.

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Simulation and Design Trade-Off Analysis of 15 kV SiC SGTO Thyristor during Extreme Pulsed Overcurrent Conditions

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Silicon carbide Super Gate Turn-OFF (SGTO) thyristors are an advanced technology for increasing the power density of high voltage pulsed power or power electronics. However, the transient characteristics and failure modes of these devices have to be further understood. This paper presents the Silvaco Atlas simulation of a 15 kV SiC SGTO thyristor during extreme pulsed overcurrent conditions. The device is simulated with various operating conditions that include pulsed current amplitude, pulse width, and temperature, and the simulation results are validated against experimental results for a 100 μs, 2.0 kA pulse. In addition, tradeoff studies for the device structure region widths are performed. The simulation model developed in Silvaco Atlas is detailed, and the results for the various operating conditions and device region widths are presented.

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Special Purpose Power Electronics Converters for Nano-Grids & Smart Homes Applications

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A Nano-grid is a model version of a smart grid with the ability to function as separate power generator. The power electronics converters are playing very important roles in smart homes. So this paper proposes three important converters as the following: Single-Input Multi-Outputs (SIMO) DC-DC Converter, Multi-Inputs Multi-Outputs Converter (MIMO) and Multi-Level Cascaded Inverter (MLCI) Design, Simulation and Implementation. A DC-DC converter is designed effectively and precisely to suit its function in a Nano-grid. The converter is a single-input-multi-output converter (SIMO) which is taking one dc voltage from alternative energy sources like solar photovoltaic panel and applying it to two dc output voltages. This boost converter takes the input and increases its voltages level, leading to the outputs respectively based on the customer' needs. This single input- multi output converter is designed, simulated and tested using MATLAB/SIMULINK. The input and output characteristic are well depicted in figures form. The Multi-Input-Multi-Output (MIMO) converter, in this work, is a type of switch-mode power supply. The alternative power supplies are in many different operating modes. Finding the right operating mode is key to the MIMO converter fulfilling the needs of design. Simulation and experimental results for rectification, conversion modes are presented with the switching criteria and control characteristics. The modeling, design and simulation are done with the aid of multi-sim software and Simulink. The implementation is done using printed board, power diodes and MOSFETs. Finally, this paper proposes design, modeling and implementation of a multi-level cascaded inverter for a single-phase connected photovoltaic system. The cascaded inverter consists of two full bridge topologies and AC outputs in series. Each bridge has the ability to produce three different voltage outputs. In this work, a single level, three level, and nine levels are proposed using MATLAB/Simulink with circuit implementations. The proposed configuration reduces the complexity in design and modularity when compared to conventional method which also provides reduced switching losses and harmonics.

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Auto-Tuning Oscillator for the Generation of Nonthermal Plasma as a Therapeutic Treatment for Melanoma

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Nonthermal plasma is an emerging treatment method of Melanoma cancer cells with promising results. Implementation of nonthermal plasma for Melanoma cancer cell treatment is hindered by the need for precise setup and constant manual reconfiguration. This work presents a new automated approach for the generation of nonthermal plasma that can maintain a stable plume with no user intervention, while reducing form factor and cost. In contrast to expensive impedance matching plasma generators that operate at higher frequencies, this work employs a closed loop feedback algorithm, which utilizes AC amplitude and DC current measurements to adjust the frequency to produce a stable plume.

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Test Results of a 7.5 kA Semi-Conductor Prototype Switch as Modular Switchgear in Energy Extraction Systems for the HL-LHC Magnet Test Bench Circuits

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The superconducting magnets, intended for use in the LHC High Luminosity (HL-LHC) project at CERN are based on Nb3Sn technology. Powering of prototypes of such magnets with up to tens of kilo-Amperes are required for detailed studies of the quench behavior, as well as an evaluation of the associated quench protection equipment. For this purpose an ultra-fast energy extraction system is needed to prevent any overheating of the magnet conductors during the quench process which is being analysed. No commercially available opening switch is capable of rupturing a DC current of 30 kA in a highly inductive circuit, within one millisecond and under development of up to 1 kV. This has been the incentive for undertaking the development of such a switch. The choice was to use high-current IGBT's as static switches. This paper presents the arguments for the different choices of topologies and component selections for the 7.5 kA basic module of which four units are composing the final switch. Specific features related to the design, the compensation techniques and the thermal considerations are highlighted. In particular, the paper offers a detailed presentation and analysis of all test results from type testing of the first module, including a comparison with the design-phase calculations and the simulation results.

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Treatment of Aqueous Pollutant by a Discharge Plasma Reactor Using a Porous Membrane

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Over the past ten years, a number of studies using the discharge plasma, such as the surface discharge over water, the discharge assisted by bubbling and so on, have performed for the treatment of contaminated water. The aim of these researches is focused on the improvement of the energy efficiency. The input energy supplied into the discharge is used preferentially to produce discharge plasma in atmosphere gas. From the viewpoint of the energy consumption, it is apparent that plasma production in gas phase is superior to that in liquid phase. We considered the water treatment process by a pulse discharge plasma reactor of coaxial cylinder using a porous membrane in order to reduce energy consumption. It is important for this method to confirm the dependence of the controllable parameter of pulsed-power generator in order to realize higher energy efficiency. The pulsed-power generator developed in our laboratory is composed of a high-voltage direct-current power supply and a MPC (Magnetic Pulse Compression) circuit with the embedded system control. Each pulse discharge voltage and frequency can control by not only changing the input DC high voltage but also the rewriting of the embedded system of the MPC circuit. Thus, the pulse power generator can control the injection energy per unit time, and the injection energy per pulse of one shot. In this study, in order to confirm the advantage of this plasma reactor, we report the energy dependence of the phenol decomposition efficiency, and the effect of selection of active species, by changing both of input energy and atmospheric gas which is poured in into a reactor.

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Stacked Multi-Level Long Pulse Modulator Topology for ESS

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The European Spallation Source (Lund, Sweden) is an under construction multi-disciplinary research facility to be based around a Linear Particle Accelerator which is to provide 2.86 ms long proton pulses at 2 GeV at a pulse repetition rate of 14 Hz, representing an average beam power of 5 MW.

To accommodate the requirements of the proton linac, a large number of klystrons driven by power electronic modulators will be needed. Conventional long pulse modulators are pulse transformer based and commonly exhibit poor efficiency, low power density, large footprint and cost. In addition, these topologies due to their nature in combination with the above cited high peak power requirement for short periods of time commonly produce prohibitive levels of flicker and harmonic content while operating at suboptimal power factor, problems usually corrected by both costly and spacious external grid compensators.

This paper presents the stacked multi-level (SML) klystron modulator topology, a novel, modular concept based on high-frequency transformers and rectifier bridges stacked in series, believed to better suit the application and better satisfy ESS requirements, directly addressing the mentioned shortcomings of conventional topologies.

The development of this new klystron modulator topology has included the design and construction of a reduced scale prototype with the potential of delivering long (3.5 ms) high quality dc pulses (0-99% rise time of less than 100 μs and flat top ripple less than that of 0.15%) of high voltage (115 kV) and high power (peak power > 2 MW) while on its own maintaining excellent AC grid power quality (low flicker operation < 0.2%, sinusoidal current absorption with total harmonic distortion < 3%, and unitary power factor).

The paper in detail describes the essential features of the topology and outlines the working principle, presenting results from both simulation and experimental work.

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Investigation of Harmonic Distortion in Multi-Pulse Rectifiers for Large Capacitive Charging Applications

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The United States Navy is transitioning its fleet to utilize more high power electrical loads. Many of these loads are not only higher power than previously seen aboard ships, but also operate in a transient nature with loads that are much more capacitive than previously seen. In this transition, efficiency in power conversion has become more important than ever before. Converting AC power to DC power can be very inefficient due to the presence of harmonics. Previous work investigating multi-pulse rectifiers has shown that it is possible to reduce these harmonics through the artificial

fabrication of additional phases to input to a rectifier, but in all of these publications, the load has been assumed purely resistive, or slightly inductive in nature. This work presented here investigates the harmonic content of multi-phase rectifiers with large capacitive loads. Six, twelve, eighteen, and twenty-four pulse rectifiers have been simulated using Simulink to predict the reduction of harmonic distortion in each rectifier. Model validation will be carried out using a hardware implementation of each rectifier using a 1 kW three-phase synchronous generator source. This work provides insights into critical issues, such as efficiency, that arise when converting AC power to DC power in order to charge a large capacitive load. The simulations and hardware implementations will be discussed

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Evaluation of Rotational and Vibrational Temperature of Nanosecond Pulsed Surface Discharge on Water

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In recent years, surface discharge on water has received attention as one of the wastewater treatment method. Discharge plasma can produce OH radicals without secondary product, and the electrode setup of the surface discharge allows a reduction in water pollution from electrode by erosion. Generally, the heating of discharge channel is suppressed by application of short pulse width voltage. Therefore, nanosecond pulsed surface discharge leads to effective generation of OH radicals. However, up till now relatively few studies have been reported on temperature evaluation of the surface discharge on water. In this study, we focused on the temperature of nanosecond pulsed surface discharge on water, and evaluated rotational and vibrational temperature of the discharge from its emission spectrum.

The air gap between the needle electrode and the water surface was set at 1 mm and water depth was set at 10 mm. The distilled water was used in this experiment and the initial value of conductivity of the water was 1.47 uS/cm. The voltage with pulse width of approximately 70 nanoseconds by Blumlein line was applied to the needle electrode. The emission spectra from the discharge was observed by the multi-channel spectrometer. The measurement position of the emission spectra was set just below the needle electrode. The rotational and vibrational temperature were evaluated from the N2 second positive system band (1) (2). The simulation results were in good agreement with experimental results. As a result, the rotational temperature was about 1000 K and vibrational temperature was about 3000 K.

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Pulsed power as the main tool of energy-efficient non-thermal microbiological decontamination

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We demonstrate that application of the pulsed power is an indispensable condition for realization of microbiological decontamination in an energy-efficient (respectively, non-thermal) manner.
There appear two distinctive (characteristic) cases of microbiological decontamination: the case of non-selective, tough sterilization, and the case of selective, obligatory non-thermal, chemically neutral sterilization (usually applicable for foods and other thermo-labile products).
We consider that the best solution for the first case is chemical method of oxidation in non-equilibrium ("cold") plasma, combined with UV. Continuous microwaves (MW) - applied for the generation of non-equilibrium oxidative plasma - is a good method of generation, but it is usually applicable in rarified conditions. Pulsed power offers several advantages for optimal process of cold plasma sterilization. First of all, the respective reduction of the duty cycle (at the same average power!) ensures breakdown (plasma generation conditions) at normal atmospheric (or, eventually, higher) pressure conditions - it is the factor of substantial practical importance. Then, the decrease of the duty cycle causes the increase of the grade of plasma non-equilibrium, amplifying its density and oxidative activity - practically without the rise of the gas temperature (non-thermal action of plasma is the base of energy-efficiency of the decontamination process).
For the generation of the non-equilibrium (non-thermal) plasma it is not obligatory to use pulsed harmonic high frequency oscillations. The same effect can be obtained as a result of application of the short (nano-second) high voltage impulses. In this case plasma parameters can be controlled through the amplitude, duration and duty cycle of impulses.
For the second case (of selective non-thermal action upon vegetative microorganisms in aqueous medium) is indicated sterilization due to application of the high voltage, special form impulses. We propose the theoretical analysis of the processes in the electrolyte medium (as juices, milk etc.), subjected to high voltage impulses' action. Optimal regimes of such sterilization are proposed.

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Closed Transition Transfer Switch based on Multi-mode Photovoltaic Inverter for Preventing Power Outage

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This paper proposes a closed transition transfer switch (CTTS) based on a photovoltaic inverter which is capable of transition between grid-connected and island modes. The proposed system consists of the CTTS, utility grid and photovoltaic inverter connected to each input, respectively, an active load with power factor correction, and a system controller. According to the grid condition, the system controller manages the closed transition between the two inputs and determines the inverter operation mode.

Unlike the traditional CTTS switching to a diesel generator by a prior notice of outage, the proposed CTTS and inverter have the following two advantages. In case of the normal grid condition, the inverter provides current in the grid-connected mode using a perturb and observe algorithm for maximum power point tracking (MPPT) while the grid supplies voltage, so both of the switches are closed and used for different purposes. Moreover, in case of the unexpected grid failure, they also prevent the power outage through the sudden breaking of grid switch and the simultaneous fast transition to the island mode owing to no start-up delay. When the grid is returned, the voltage source is switched to the grid again after the synchronization of the phase to the grid for the closed transition.

The inverter has an LC filter optimized to both modes and an additional inductor for the safe closed transition. Above all, the current controller predicts current flowing through the filtering capacitor and applies it to the control for the fast transition and stable operation.

The performance was verified by the PSIM simulator. In addition to the closed transition by the prior notice, at the time of the unexpected grid failure, the inverter went into the island mode rapidly in less than 1 ms, so it was verified to prevent any power outage effectively.

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Development of high power burst pulse generator based on magnetic switch for bioelectrics application

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Nanosecond and sub-nanosecond high voltage pulses can provide new biological applications. A cancer treatment by an ultra-short pulse high electric field is one of them. High power pulsed electromagnetic wave has been proposed to apply the high electric field for that treatment [1]. This work focuses on the design of a compact high power pulsed electromagnetic wave generator using a nanosecond pulsed power generator for the cancer treatment [2]. In this study, we have developed the pulsed power generator that outputs the multiple pulses continuously by NLTL (Nonlinear Transmission Line) using magnetic switches. The NLTL consists of the ladder of capacitors and saturable inductors. The NLTL makes the pulse train by delaying the propagation of the pulse through the magnetic switch of each ladder. The frequency of repetition of the burst pulse is 14 MHz. The peak output voltage is 7 kV at the charging voltage of 28 kV. The number of pulses in the pulse train can be varied by the number of the units of the magnetic switch.

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Impact of Wind on Pollution Accumulation Rate on Outdoor Insulators Near Shoreline

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The present work is an experimental work to investigate the impact of wind speed on pollution accumulation rate on outdoor insulators near coastal area. The outdoor insulators near shoreline are suffered from rapid saline accumulation due to heavy wind coming from the seashore, which is more dangerous in foggy weather conditions. A method was developed in laboratory to find the impact

of wind velocity and wind direction on the pollution accumulation rate on outdoor insulators and subsequently to determine a suitable mitigate method to overcome these problems. To replicate the seashore conditions on outdoor insulators an experimental setup was developed and installed inside an environmental chamber and was functioned with a wind generation and shoreline specification slats (NaCl, CaSO4) and kaolin powder injection system. The equivalent salt deposit density (ESDD) and nonsoluble deposit density (NSDD) were measured on the top and bottom of insulator surfaces at different wind speed. Useful observations were stated, with the wind speed and salt deposit density on energized and unenergized insulators. It was found that the pollution accumulation rate increased with the increase of wind speed up to 8 m/s but it decreased when the wind speed more than 8 m/s. Moreover, the pollution accumulation rate was different in energized and unenergized states.

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Characteristics of GaAs PCSS Triggered by Laser Diode array

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Photoconductive semiconductor switches (PCSS) have an excellent performance in the field of pulse power, especially the one made of GaAs does. Since PCSS can be operated in non-linear mode, laser diodes, which are small in size，low-cost and easy to be driven compared to traditional laser devices, can be used to trigger it in low power. In this condition, pulse width of the radiation is always larger than the delay time, thus, it is more important to investigate the influences of laser power than energy. In this paper, an array of laser diodes which emits laser pulse with a dominant wavelength of 905nm and an optical fiber with 7 branches are used to trigger a semi-insulating GaAs PCSS. By changing the driving current and the quantity of fiber branches that connected to LDs, power of laser pulse is changing in a range of 45-1250W. It's found that the power of LDs largely influences the output characteristics of the PCSS. The related experiment results are presented, and further discussions are given in this paper.

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Study on inducing apoptosis and stimulating the irreversible electroporation effect for tumor treatment based on high frequency nanosecond pulsed electric field

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To solve the problems involved in tumor treatment using pulsed electric fields (PEF), we presented a novel tumor treatment method using high-frequency nanosecond pulsed electric fields (nsPEF) modulated by microsecond pulse based on both apoptosis and irreversible electroporation, also aiming at direct killing effects of microsecond pulsed electric fields (μsPEF) and indirect modulating effects of nsPEF. In order to verify the validity of the method which we presented, the human melanoma cells A375 were used to carry out some vitro experiments. And the self-developed unipolar high frequency nanosecond pulse generator was used to produce the pulse. To find the optimal values of the pulse parameters, ensure that still has a good effect in the case of low field strength, a series

vitro cell experiments were carried. The pulse string number was fixed to 100, and changed pulse width (100ns、250ns、500ns), electric field amplitude (1, 2, 3, 4 kV/cm), and burst frequency (1, 10, 100, 1000kHz), respectively. The tumor cells survival rate after 0h and 24h which handled by pulsed electric field was detected by MTT and CCK-8, and the tumor cells apoptosis rate after 4h and 24h was detected by Annexin V-PI double-staining method. The experimental results show that this method can effectively kill tumor cells and induce its apoptosis, it is obviously that the feasibility of this method is verified. And the condition of electric field intensity and frequency is more suitable for the human body, which can solve many problems in future practical application.

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Thermal and Efficiency Study of a solid-state dual Marx generator combined a pulse transformer

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A solid-state dual Marx generator combined a pulse transformer is proposed in this paper, which can obtain a bipolar pulse and increase the output voltage. While, its input current will many times of the ratio of the pulse transformer, which will increase the difficult of the system thermal stress for its compact footprint. The power loss, power efficiency and thermal stress will be studied for a 40kV, 10kHz and 150A system. Its circuit action will be analyzed under different damping conditions with resonance characteristic build by the pulse transformer and load. And its every stages power loss and power efficiency will be quantitative. The thermal model of the Marx generator is also established to the heat sink design. Studies have shown that it can be applied to DBD load with under-damping and the leak inductance of the pulse transformer can make solid-state dual Marx generator worked at soft switching, which can improve its power efficiency and decrease thermal stress. Some practical measurements with a thermal imaging instrument have conducted for experimental demonstration. Through the above equivalent circuit model theory analysis and the experimental measurement, a feasible method for loss analysis, efficiency analysis and thermal design is proposed in this paper.
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CONTINUOUS SWITCHING OF ULTRA-HIGH VOLTAGE SILICON CARBIDE MOSFETS

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Silicon carbide power semiconductor devices are capable of increasing the power density of power electronics systems[1,2]. In recent years, devices rated to block voltages up to 20 kV have been demonstrated[3]. These research grade devices must be fully characterized to determine operating characteristics as well as failure mechanisms. The purpose of this paper is to demonstrate the continuous switching performance of ultra-high voltage MOSFETs rated for 15 kV / 10 A. A high voltage

boost converter was developed to evaluate the continuous switching performance where the high-voltage MOSFET is utilized as the main switching element. During operation, the on-state voltage, gate leakage current, and dc characteristics are monitored to determine device degradation. Measured device degradation is presented as a comparison of initial and final dc characterization.

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Effects of Algae on the Flashover Performance of Insulators Covered with RTV-Coating

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In the humid areas like Sichuan Province of southern China, algae often grows abundantly on the surface of porcelain insulators covered with room temperature vulcanized silicone rubber (RTV), which may increase the risk of pollution flashover. In order to solve the potential threat to the safety of power grid, study on the growth conditions, the species, the growth habit and the distribution status of the algae was carried out by collecting and investigating the algae pollution layer on the surface of RTV-coated insulators in various transformer substations all around Sichuan basin. Besides, the influence of algae layer on the hydrophobicity of RTV-coating was tested by water spray classification. At last, the switching impulse flashover performance and pollution flashover performance of the algae polluted insulator were tested by up and down method. The results indicate that the algae layer mainly covers the top surfaces of the insulator umbrella skirts, and the mainly type of algae is apatococcus lobatus of chlorophyta. The algae pollution layer will lead to obvious decrease of hydrophobicity and surface conductivity of the RTV-coating covered with algae pollution layer, thus the pollution flashover voltage declines significantly. However, the switching impulse flashover performance is seldom or never affected by the algae layer, the reason is the arc propagating along the tips of umbrella skirts of insulator, rather than developing along the surface of insulator during the impulse flashover process, hence the surface condition can't affect the switching impulse flashover performance of insulator. The research about the influence of algae pollution layer on the insulation performance of RTV-coated insulator provided a reference for the operational maintenance of composite insulation.

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Molecular Dynamics Based Assessment of Electric Pulse Enhancements of Cell Membrane Poration by Pressure Waves

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Applications of electric pulses is known to create nanopores at the membranes of biological cells, which can then modulate the intracellular conductivity and permeabilization in a controlled manner. Applications of such membrane poration lies in the field of biomedical engineering, drug/gene delivery, cell fusion, and electrochemotherapy for cancer treatment. However, in addition to external voltage pulses, pressure transients (typically in the MHz range) have also been shown to create pores in plasma membranes by imparting mechanical stress due to these ultrasonic shock waves [1]. Sonoporation experiments show that the collapse of bubbles in water by ultrasound generates membrane pores, thereby allowing the intracellular delivery of drug or gene payload.
Here we focus on poration of lipid bilayers of cell plasma membrane by the interaction of transient shock waves through atomistic Molecular Dynamics (MD) simulations. The Gromacs simulator is used, with a simple point charge SPC model for water molecules incident on a nanometer-sized patch of a dipalmitoylphosphatidylcholine (DPPC) phospholipid membrane bilayer. The simulations were performed by having a sheet of water molecules with a pre-determined velocity (representing an incident shock-wave) impinge on a section of a DPPC bilayer. The simulations were carried out systems containing over 1 million atoms with dimensions of the corresponding MD cells taken to be 34x34x82 nm3.
In addition to simple shock, we have include the presence of an external electric field as an additional stimuli in concert with the pressure transient. With this superposition, the requirements on the electric field intensity were reduced. In principle such a dual mechanism would make it possible to spatially tune membrane poration effects. Besides, using electric fields alone can potentially slow the electrophoretic driving force for ions and dipolar molecules once pores have formed due to the reduced voltage drops associated with the high local conductivity. Hence, a dual strategy would likely have practical advantages. In this contribution, details of our simulation results along with the enhanced potential for cellular throughput at reduced fields will be discussed.

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Delayed avalanche breakdown of high-voltage Si diodes: scenarios and mechanisms of picosecond-range switching

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Delayed avalanche breakdown of reversely biased high voltage Si diodes, known as Silicon Avalanche Shapers (SAS), leads to ~100 ps switching and has found important pulse power applications. The widely accepted model of delaye d breakdown is a TRAPATT-like ionizing wave that propagates faster than the saturated drift velocity vs. and leaves dense electron-hole plasma behind (see Ref. 1 and references therein). However, both analytical theory and numerical simulations show that TRAPATT-like wave in Si at typical electric field of ~300 kV/cm is roughly 3 times slower than it is needed to explain 100 ps switching [1].

In this presentation we point out flaws of the TRAPATT-like wave concept in application to SAS diodes and discuss alternative mechanisms of ultrafast avalanche switching. These are scenarios

of filamentary back-stroke ionization [2], the concept of non-TRAPATT-like ionizing wave in low-doped structures [3] and, finally, straighforward but efficient mechanism of quasi-uniform avalanche breakdown. First, we argue that experimentally observed switching time of ~100 ps can be explained assuming that only part of the device cross-section is modulated. We show that such current localization results in qualitative difference in switching dynamics. Second, we describe ionizing waves that differ from TRAPATT-like waves in propagation mechanism and formulate physical conditions for their excitation in SAS diodes [3]. Finally, we demonstrate that avalanche switching with rise-time below ~100 ps may occur in spatially uniform manner even in pin-diodes where front propagation is impossible. These results are also applicable to optically activated switches. The critical parameters for successfull ps-range switching are the ratio of the maximum electric field to the ionization threshold and the ratio of the RC-time (determined by the intrinsic device capacitance and the external load) to the inverse impact ionization rate.

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Research on the Working Gas Pressure of Spark Gap Switch in High Power Laser System

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Laser inertial confinement fusion will be a kind of new energy supply in the future. As a drive source of inertial confinement fusion, the large laser equipment is used to afford the high power laser beam for thermonuclear fusion. A high-current closing switch is an important component in pulsed power systems. High-energy switch and its trigger system are required for the discharge applications of capacitor bank, such as electromagnetic rail, coil, and electro-thermal guns. In a high–energy laser system, a two-electrode spark-gap switch is used as the main one in this paper. The static breakdown voltage of switch is determined by the working gas pressure. Graphite electrodes will erode during the discharge operation of the system and the erosion of electrodes results in an increase in the gap width, causing the DC breakdown voltage to rise. In the fixed triggering mode, it is essential to make sure that the under-voltage rate is relatively stable when changing the switch's gas pressure. When the under-voltage rate of switch is low, the rate of stable triggering and self-breakdown will decline. In this paper, the relationship between the breakdown characteristics and the working gas pressure of a spark gap is studied. A comparison was made from the DC breakdown voltages of various switches under different gas pressures and the triggering reliabilities were tested. It is shown that a controlled reduction in pressure can compensate for the gap widening effect and thus ensure switch operation even with electrode erosion. By determining the under-voltage rate which ensures switch conductions, a gas pressure regulation method was devised to ensure the stable operation.

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Research of Muscle Contraction and the Effects of Tissue Ablation in Vivo Exposed to High-Frequency Electric Fields

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The irreversible electroporation has the advantages of non-thermal, minimally invasive and visualization for the ablation of tumors which has been research and applied extensively. The technique involves delivering a series of unipolar electric pulses to permanently destabilize the plasma membrane of cancer cells through an increase in transmembrane potential, which leads to the development of a tissue lesion. Clinically, muscle contractions will emerge with the delivering of the electric pulses, which will make the patients painful and also may affect the location of implanted needle electrodes. In this paper, the researches of muscle contraction and the effects of killing liver tissue in vivo exposed to high-frequency electric fields were performed by changing the frequency of the pulses. The IRE, Monopolar high-frequency IRE and Bipolar high-frequency IRE were applied to rabbits' leg muscles to research muscle contraction of animals respectively. And then filtrate the pulse parameters which cannot cause the muscle contraction for the rabbits liver tissues ablation experiments. The experiment results show that the muscle contraction can be seen during the Monopolar high-frequency IRE and IRE pulses delivering. However Bipolar high-frequency IRE can inhibit muscle contraction very well, and the Bipolar high-frequency IRE with a certain intensity can ablate the liver tissues without muscle contraction.

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An explosive pulsed power source based on ferroelectric generators and electrical exploding opening switches

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As a primary power supply, the explosive-driven ferroelectric generator (EDFEG) has high energy density, can autonomously produce more than 100 kV high voltage with a few microseconds pulse duration, but hundreds nanoseconds rising time. In our experiments it can output the current of over 10 kA on an inductance load of about 2μH. It is believed that EDFEG should be an ideal primary supply for the pulsed modulator with the inductance energy storage and the electrical exploding opening switch (EEOS). In the tradition of the pulsed modulator with EEOS, there is a high voltage pulsed capacitor or an explosive magnetic generator as the primary power supply. Based on EDFEG and EEOS we have designed an new explosive pulsed power source without external power supply. The EDFEG in our pulsed power source designed can output equivalent constant current of 7.5 kA with pulse duration of 4μs, and generate about 15kA oscillating current through an inductance of 2μH and an EEOS designed specially. A capacitor of 1μF is connected in parallel to the EDFEG in order to reduce the voltage on the EDFEG close to 11kV. In this design the ferroelectric blocks of PZT95/5 endure lower pulse voltage of only 11kV. When metal wires of EEOS explode at the time near peak value of the oscillating current, higher pulse voltage of more than 300kV will be produced on a resistive load of 50Ω with rising time of 10ns and pulse duration of 65ns. The power density of the explosive pulsed power source is expected to exceed 500GW/m3 which is more than twice as much as the traditional pulsed power source with EEOS.

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Effect of brine and temperature in sterilization using nanosecond pulsed electric field for packaged fresh foods

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We have investigated sterilization of packaging foods. In sterilization methods of the packaging foods, there is pulsed discharge sterilization and high frequency pulsed electric field sterilization[1][2]. The pulsed discharge sterilization is suitable for solid fresh foods. The high frequency pulsed electric field sterilization is suitable for liquid fresh foods. However, many liquid fresh foods are difficult to sterilize by the pulsed electric field for having high electrical conductivity like containing salt. In this study, sterilizing properties of the brine of the high conductivity by nanosecond pulsed electric field have been investigated. Target microorganism was Saccharomyces cerevisiae that is detected generally in foods. In experiments, the salinity and temperature of the brine with S.cerevisiae was changed as parameters. As experimental results, by applying the pulsed electric field in the sample temperature of 50℃, processing time to reduce the number of S.cerevisiae two digits has been about one-fifth of that of the room temperature. In the evaluation of the sterilization ratio by difference of the salinity, the sterilization ratio at the salinity of 3% has been more than that of 0.3%.

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Observation of Discharges in NOx Treatment Reactor Using Nanosecond Pulsed Powers and the Reactor Improvement

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In recent years, environmental problems as acid rain and air pollution have become more serious. Nitrogen oxides (NOx) are one of causative agents of them. Currently, NOx treatment technology has been established, but they have some disadvantages as high cost and large-sized equipment. Because the NOx treatment equipment did not become widespread, there is a need in the art for a cost-effective and compact NOx treatment system. We have studied the NOx treatment by a nanosecond pulsed power. Streamer discharges are produced in the treatment reactor by adopting nanosecond pulsed power and effective NOx treatments are expected as a result. In the previous study, while NO removal ratio increased after start of the treatment, it decreased after the peaking. It is found that the decrease was caused by curvature of the inner wire electrode and occurrence of spark discharges in the treatment reactor. In a preliminary experiment, the phenomena were suppressed by a tensioned inner electrode by a weight. A tensioned inner electrode by a spring was introduced to control the phenomena and it improved the treatment efficiency in this study. In addition, appearance of discharges in the reactor was observed to consider a dependence of the discharge appearance on NOx treatment. The spark discharges was not observed and streamer discharges were produced uniformly and stably in using the spring system. As a result, the temporal decrease in removal ratio was not observed and the removal ratio was righted. The removal ratio was improved at each pulse repetition rate in using the spring system. When the initial NO concentration was 100 ppm, the removal ratio reached up to 100 %.

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Electric Pulse Modification of Mammalian Cell Suspension Conductivity

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Variations in the electrical properties of biological cells elucidate how intense electric pulses (EPs) can alter mammalian cell structure, intracellular organelles, and plasma membrane integrity [1-2]. Time domain dielectric spectroscopy (TDDS) can characterize these changes by measuring the electrical properties of the plasma membrane, cytoplasm, nuclear envelope, and nucleoplasm [1-2]. Because TDDS uses sensitive electronics involved, it is impractical for measuring changes during EP exposure [1]. This study examines the conductivity of the cell suspension during EPs by measuring the voltage and current pulse for pulse durations ranging from 10 ns to 300 ns for buffer solutions of various conductivities while keeping the energy density applied to the cellular suspension constant. We observed increased suspension conductivity following EP exposure to lower conductivity solutions, indicating membrane permeabilization and ion transport out of the cells. Previous models indicate ion motion during an EP is driven by electrophoresis while diffusion through long-lived pores dominates motion on the order of hundreds of microseconds after the EP [3]. Coupling the asymptotic Smoluchowski equation for membrane pore formation with the Nernst-Planck equation for ion motion permits assessment of calcium transport to assess the impact of EP parameters and suspension conductivity on electrophoresis [3]. The implications on short-term and long-term behavior, including dielectric measurements [1-2], will be discussed.

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Basic design and results of Regulated high voltage power supplies utilized for heating systems at IPR for SST-1

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Regulated high voltage power supplies (RHVPS) at an 80kV/10 MW level are designed, developed in-house and patented by Institute for plasma research (IPR) and are being utilized for different heating systems within steady state tokomak (SST-1). These are main power sources for NBI, LHCD, ECRH

and ICRH heating systems for running an SST-1.
In this presentation, different subparts of these RHVPSs like power electronics, power supply control and multi megawatt transformers are described in brief. A procedure of commissioning and erection issues for these power supplies with their dynamic load like accelerator, gyrotron and klystron are also discussed. Fast turn off capabilities (2 micro Sec) and actual short circuit tests (wire burn test for 10 J fault energy) with test results are shown to certify their capabilities, since these type of power supplies must have these characteristics for fail safe operation of their dynamic loads which might have breakdowns within themselves. These HVPSs were operated with several loads e.g. a large ion source for NB, a Klystron and a Gyrotron. All loads have different dynamics but the HVPS was found to be capable to cater to all. Results of RHVPS testing with dummy load and with actual heating systems (NBI, LHCD, ECRH) are presented with reference to their load characteristics.

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On the Circulating Current Control of a LCL Converter for Tokamak

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Abstract-This paper suggests a four quadrants converter System for tokamak CPSS, such as ITER-like CFETR. The converter is composed of insulated-gate bipolar transistor (IGBT) and an internal passive LCL circuit. The resonant frequency characteristics of the LCL circuit are analyzed, and a parameter design method on the base of voltage stepping and the current regulation under extreme external dc faults is also presented. a control method for circulating current control is proposed. The salient features of the proposed converter System are 1) the circulating current can be controlled in such a way that it never become zero, and load current can change polarity without any discontinuity and dead zone, even if in the case that the total reference voltage of converter changes rapidly; 2)A transformer is not required since LCL circuit can achieve voltage stepping; 3) fault current of the converters with LCL transformer will be close to or below the rated value in the short circuit fault conditions occurring in AC or DC sides; 4) the converter is controlled by PWM, the reactive power can be absorbed by the grid. The effectiveness of the proposed four quadrants converter System is substantially confirmed by the simulation.
Index Terms—LCL ; four quadrants ; fault-current; circulating current; CFETR

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Multi-Parameter Analysis in Single-cell Electroporation Based on the Finite Element Model

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Pulsed electric fields have recently been the focus of considerable attention because of their potential application in biomedicine. However, their practical clinical applications are limited by poor understanding of the interaction mechanism between pulsed electric fields and cells, particularly in different effect of electroporation exposed in different parameters, and the optimal pulsed parameter is still vague. A multi-shelled dielectric model considering the inner membrane was established by

the finite element software COMSOL in this paper. Different shock protocols (different pulsed duration/strength/frequency/polarity) was exposed to the cell model respectively to simulate and analyze the influence of pulse parameters on varying degrees of electroporation by comparing the dynamic development of the pore radius and electroporation region (include the distribution of recoverable, non-recoverable, and non-electroporation areas on the cell). Results showed that the conventional pulses have better efficiency in electroporation than high frequency pulses; The monopolar pulses with cumulative effect have much better electroporation effect than the bipolar pulses which have weakening effect when duration of single pulse reduced to nanosecond; and electric field strength was the major factor that induced electroporation, particularly in the recoverable pore, but it had minimal effect on pore expansion. However, pulse duration affects the non-recoverable pore, such that the high-intensity wide pulse is more useful in the field of irreversible electroporation. The high-intensity short pulse can increase permeability and maintain cell viability. This work done by this paper maybe exploited further to investigate the behavior of more complicated cell systems and to promote the optimized application of pulsed electric fields in clinical.

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Review and Recent Developments in DC Arc Fault Detection

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With the development and implementation of dc based power systems, dc arc fault protection becomes an inevitable challenge for the safe operation in various applications. This paper presents a brief review of dc arc fault modeling and detection methods. The goal is to examine state-of-the-art technologies and to identify future research and development needs of dc arc fault protection in modern dc networks. For dc arc modeling, the focus is given to external characteristic equation which models the arc with electrical parameters. This type of model, normally in the form of V-I equations, can be used to simulate and analyze the impact of an arc fault to the dc network. Moreover, models of the random high frequency components in arc current and their applications will be reviewed and discussed. Then, selected dc arc fault detection techniques based on time, frequency, and time-frequency domain analysis are reviewed and compared.

It is crucial to differentiate high-impedance, series dc arc faults from normal operating conditions such as load changes or switching-related noise. Thus, preliminary results from a robustness study of a wavelet based detection algorithm under noisy environments is presented. The noises studied include wideband noise, impulse noise from system transients, and frequency specific noises such as harmonics and switching-related noise, all of which are commonly seen in dc power systems. Current industry standards on dc arc detection are more focused on photovoltaic systems for terrestrial applications. The status of a draft SAE standard being developed on 270 Vdc arc fault detection and validation tests for aircraft is briefly discussed.

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The high voltage pulsed current supply based on Solid-state devices

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The output current of a Marx generator will be affected by the value of different loads even though the output voltage has been fixed. A special kind of current pulse generator is needed in experiments and industrial applications, which can generate a current pulse of constant amplitude regardless of the impact that the resistive load fluctuates in a certain range. A novel current pulse generator based on inductive intermediate storage has been constructed. The generator is equipped with a solid-state Marx adder for charging the inductive intermediate storage, an inductor to obtain an expected current which can be controlled by the charging voltage and charging time. The structure of the basic unit in the solid-state Marx adder is redesigned in order to ensure the continuous path of the inductive current and release the current to the loads. There is a total of four steps in a complete discharge process that are determined by the movement of two kinds of solid-state switches, Insulated Gate Bipolar Transistors (IGBT) and thyristors. In this paper the design principles are described in detail and the control method is also given. The designed current pulse generator is able to produce short current pulses of amplitude within 10 A and pulse length from 1 μs to 10 μs when driving variable resistive loads of kΩ scale. The current pulses have a good flat (amplitude fluctuation <5%), a fast-rising edge (<600 ns) and a fast-falling edge (<500 ns). The experiments have verified the characteristics of the new generator, stable, reliable and simple.

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Repetitive High Voltage Pulse Modulator Using Bipolar Marx Generator Combined with Pulse Transformer

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All-solid-state Marx generator is mature approach to obtain repetitive high voltage pulses and many topologies have been proposed. However, due to limited rated voltage of semiconductor switches, a large amount of switches is required. Too much switches, in addition with high repetition rate, lead to severe stray parameters and heat dissipation. It increases the difficulty of structure design and reduces system reliability. Moreover, the inconsistency of massive switches slows down rise and falling edges of pulses. Therefore, how to enhance reliability of repetitive high voltage modulators has always been the research hotspot and difficulty. Marx topology combined with step up pulse transformer is proposed in [1]. But only unipolar Marx combined with pulse transformer is discussed.

In this paper, a pulse modulator which consists of a bipolar Marx generator combined with a pulse transformer is proposed. The bipolar Marx generator is composed of a series connection of full bridge switch-capacitor cells (SCCs) [2]. A ten-SCCs stage Marx generator can output ±8 kV voltage pulses. A step up pulse transformer with a ratio of 1:5 is connected to the output of Marx generator. Thus, the amplitude of output voltage pulse at load can be 40 kV. The use of pulse transformer also enables zero current switching of IGBTs. Therefore, switching losses are reduced. Higher turn ratios, such as 1:40, will further reduce the amplitude of primary voltage. However, it will lead to larger leakage inductance and parasitic capacitance, and degrade the shape of voltage pulses.

A laboratory prototype of the proposed pulse modulator is implemented. It operates with a voltage amplitude in the range of 0-40 kV. The repetition rate can be adjusted from 0.1 Hz to 10 kHz and pulse width can be adjusted from 2 μs to 5 μs. The rise time of voltage pulses are less than 400 ns. Over voltage, short circuit, and temperature protects are taken into account. Experiments with homemade DBD shows that the pulse modulator can work in rated parameters reliably. Electrical model of pulse transformer and DBD reactor are developed and simulation analysis is carried out. The simulation results agree well with experiment results.

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Using an Integrated Design Approach for the Compact Linear Collider (CLIC) Klystron Modulators

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Space charge and its role in electric breakdown of solid insulation

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Workshop 1 / **355**

Particle Swarm Optimization Techniques for Pulsed Power Systems

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20 minute talk, 10 minute Q&A

Workshop 1 / **356**

(Moderated Discussion) Optimizing Power Converter Design at the (RF Power) System-Level

Moderated Discussion

Plenary 3 / **358**

Pulsed power at Loughborough University

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Oral 9 / **253**

Recent Experiments on the Recirculating Planar Magnetron*

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The recirculating planar magnetron (RPM) [1] is a crossed-field device that combines the advantages of high-efficiency recirculating devices with the scalability of planar devices. Experiments using the RPM-12a, the first L-band prototype, have successfully produced 150 MW microwave pulses, 50-200 ns in duration, with instantaneous efficiencies of up to 30% at approximately 1 GHz [2]. The device is driven using MELBA-C, which delivers a pulsed cathode bias of 300 kV for 0.3-1.0 μs. Axial magnetic fields of 0.15-0.3 T are utilized. The microwave extraction system employs coaxial outputs from each side of the cavity structure.
Recent RPM experiments have demonstrated the use of two asymmetric anode structures for generation of multiple frequencies, successfully generating multi-MW at 1 and 2 GHz simultaneously from a single RPM. Other experiments have demonstrated the first 3-D printed structures to be used in a high power crossed field device. Using a stereolithography process, two RPM anodes were fabricated. These anodes demonstrated comparable performance to the solid aluminum anode.

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[2] M. A. Franzi, G. B. Greening, N. M. Jordan, R. M. Gilgenbach, D. H. Simon, Y. Y. Lau, B. W. Hoff, and J. Luginsland, "Microwave Power and Phase Measurements on a Recirculating Planar Magnetron," IEEE Transactions on Plasma Science, vol. 43, no. 5, pp. 1675–1682, May 2015.

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Oral 10 / 180

Effect of High Voltage Impulses on Change of Partial Discharge Characteristics in oil-Impregnated Paper for Online Diagnostics

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An important signature of degradation is usually linked to the onset of Partial Discharge (PD) activity within the insulation. The change in the PD pattern can concern the insulation degradation level. High voltage transients such as lightning and switching impulses are inevitable phenomena that happen in power systems. They can impose electrical stresses on the insulation system of power components such as power transformers and their bushings which may lead to their failure. In this paper, the effect of HV impulses on the change of surface and cavity discharges of oil-impregnated paper has been investigated. With resemblance to the real situation, superimposed impulse on the AC voltage has been applied to the samples. The probability of initiating partial discharges in oil-impregnated paper due to the impulses has been studied. The PD initiation depends on the status of the insulation, the impulse magnitude and the AC phase angle at which the impulse occurs. Behavior of the partial discharges before and after the impulse on the healthy samples has been compared to the samples with aging defects such as papers with moisture content or carbonization. The possible physical phenomenon behind each behavior has been discussed.
The results show the correlation of PD characteristics with the insulation degradation level and HV impulses. Recording the voltage signals with incident of high voltage transients can be used for assessing the insulation condition of power transformers and their bushings. These measurements can be done through test tap of the bushings to be used for the online diagnostics.

Oral 10 / 147

The mechanism of SF6 decomposition characteristics Under Partial Discharge at Different Gas Pressures and Voltage

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SF6 is widely applied in gas insulated switchgear (GIS) due to its excellent insulating and arcing performance. However, the partial discharge often is caused by some insulation defects because of the production, installation and operation of the GIS. Under partial discharge, The decomposition products including SO2F2, SOF2, SO2, CF4, CS2, will be formed. The types, content and change trend of products will encounter serious disagreements due to the difference of discharge type. The partial discharge can be detected by the analysis of the decomposition products of SF6. In recent years, because the method to detect the partial discharge is of a greater reduction of interferences and a higher sensitivity, the researchers pay more attention to the decomposition characteristics of SF6. In this paper, the decomposition characteristics of SF6 under partial discharge at different gas pressures and voltage level were studied. In the experiments, gas chromatography was adopted to quantitatively determine the characteristic components of decomposition. The results show that SF6 decomposition products include CO2, SOF2, SO2F2, SO2 under the needle-plate defects. The total concentration of (SOF2+SO2) and SO2F2 vary with the pressure increasing according to the rule of negative exponent, and the concentration of CO2、SOF2、SO2F2 increase linearly and gets saturated at last as the voltage increases. Then, characteristic parameters of SF6 dissociation rate is put forward to explain the SF6 gas decomposition mechanism under different pressures and voltage level. Under partial discharge, first, SF6 will decompose into SF5, SF4, SF2, etc, by electron impact-induced dissociation. The low fluorine sulfides will then react chemically with insulating material, and oxygen in SF6 to form the decomposition products. And dissociation rate affected by gas pressures and voltage controls to form stable decomposition product rate. Finally, by calculating dissociation rate, the conclusions that dissociation rate at different gas pressures and voltage level influenced the decomposition product concentration were drawn.

Oral 10 / 11

Partial Discharges in Synthetic ester-pressboard Dielectric

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Purpose/Aim
We need to understand one of the breakdown mechanisms of transformer dielectrics i.e. partial discharges (PD) in oil-pressboard composite insulation. In this study we conducted a PD experiment. Experimental results may be useful for online condition monitoring of large power transformer.
Experimental/Modeling methods
Effect of various impurities (i.e. Moisture in pressboards, and in oil, conducting particle (Cu) in oil as well as in pressboard surface, artificial bubbles in oil) on PD behaviors of synthetic ester –pressboard insulation system using needle –plane electrode has been investigated.
Results/discussion
PD behavior of artificial bubbled sample has similar effects of PD as compared to moisture in synthetic ester sample. It means moisture in oil and bubbles in oil had experienced same local electric field. These PD pattern results of differently modified sample may useful for better understanding of PD behaviors of synthetic ester-pressboard composite system. The same field configurations existing in power transformers.

Conclusions
Moisture in pressboard itself does not make big impact in PD pattern and PD inception voltage as compared with fresh pressboard, but in moisture variations in synthetic ester have rise in PD behaviors i.e. apparent charge (pC) and phase shifting in PD pattern. Outcome of this experiment study is an impurity in synthetic ester is contributing more the initiation of localized electric field as compared to pressboard conditions.
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Oral 9 / 86

Development of a Compact Narrow-band High Power Microwave System

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We describe a very Compact High Power Microwave system which is under development at CEA Gramat.
The electric pulses generation is provided by a compact and innovative 400 kV, 100 Hz Marx PFN. Its specific design provides a very fast rise time and its U shape agrees with severe geometry constraints.
A specific compact 45 kV capacitor charger for the Marx has been developed by TECHNICS Company [1]; double resonance technology, very low leakage inductance of the transformer and oil tank used as a heat sink provide low volume and weight.
The HPM source is an optimized X-band sub-gigawatt relativistic resonant BWO using low magnetic field (0.6 T); Starting from a preliminary study [2], it makes use of an optimized geometry for compactness constraints.
The antenna is a vacuum radial line helical circular array antenna providing high gain (>28 dB) and circular polarization. A TM01-TEM mode converter is build-in and the antenna presents a very small volume (11 cm length and 42 cm in diameter including mode converter).
We have experimented and characterized the entire assembled system (except batteries) in the MELUSINE test area in Gramat. We have shown the possibility to integrate all the system, including batteries and vacuum pumps into a virtual 65 x 65 x 65 cm cube.
Next phase will be the final integration, including prime power, into the virtual cubic volume.

[1] Willy Debache & al., “Compact high power capacitor charger” in 2012 IEEE International Power Modulator and High Voltage Conference, San Diego.

[2] V. V. Rostov & al. “Simulated parameters of subgigawatt relativistic BWOs with permanent magnetic systems” in IEEE 18th International Pulsed Power Conference, Chicago, 2011

[3] S. Pottier & al. “High Pulsed Power Compact Antenna for High-Power Microwaves Applications” IEEE Transactions on Plasma Sciences, vol. 42, no. 6, June 2014.

⊠⊠Work supported by the DGA (Direction Générale pour l’Armement).

Oral 9 / 205

DEVELOMPENT OF A PORTABLE, HIGH POWER MICROWAVE SYSTEM

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This paper presents the design and operational characteristics of a compact, portable, high power microwave system. The system is capable of operating at various pulse repetition frequencies (PRFs) > 100 Hz for short bursts. The microwave source is tunable between 2-6 GHz with varying power. The system utilizes several main subsystems. These subsystems include a Marx generator, Marx air flow system, a rapid capacitor charger, trigger generator, a Lithium-Ion polymer battery, and control system. The complete system was designed to fit on a movable cart that incorporates a hydraulic lift system and dimensions to fit through a standard entry way. The Marx generator is a Trigatron driven 10 stage, 500 kV, 105 J, spark-gap based device. The Marx is charged via the capacitor charger and then trigged by the trigger generator. The trigger generator is of modular design and is capable of a 20 kV pulse with a pulse risetime of 20 ns. The charger is an H-bridge design built to have an output voltage of 50 kV and a power rating of 90 kW. The portability of the system comes from the on-board air and energy systems. The air system is capable of moving 100 SCFM through the Marx generator to allow fast charging and operation. The energy system is divided into two separate systems; a 24 V and lead acid battery for powering ancillary equipment and a 380 V Li-Po battery for charging the Marx generator. The system is controlled by various microcontrollers and all communications are done via fiber optics to prevent EMI problems. Circuit topology, experimental data, voltage and current waveforms, and the overall system is discussed at various PRFs.

Oral 10 / 36

Investigation of model transformer insulation behavior during PD activity in Di-Benzo-Di-Sulfide Sulphur contaminated transformer oil using online tanδ measurement

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Sulphur can be present in mineral insulating oil and can manifest in stable, highly reactive and corrosive form. The corrosive sulphur reacts with the copper conductor in transformer and forms semi conductive copper sulphide at the surface of the copper conductor. The paper insulation used on the copper conductor may get damaged due to copper sulfide deposits which also affect the partial discharge activities prevalent in the transformer paper-oil insulation. The affect of Sulphur on model transformer paper-oil insulation is studied with online measurement of Dissipation factor (tanδ) and partial discharges (PD). The paper presents results of the investigatory work carried out with on-line tanδ and PD measurements made during experiments with Paper covered copper conductor (PCCC) in presence of Di-Benzo-Di-Sulfide contamination in transformer oil.

Oral 9 / 256

Study of the Electric Field Screening Effect on Nine Carbon Fiber Field Emitters with Non-uniform Height

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Field emitter arrays have the potential to provide high current density, low voltage operation, and high pulse repetition for radar and communication. It is well known that packing density of the field emitter arrays significantly affects the emission current1. Previously we conducted experiments using two- and four-cathode configurations with same height. With all the fibers having uniform height, it was found that the fibers at the outer edge always dominate the emission, since they experience the least amount of shielding. Here we extend our previous work and present experimental results for nine cathodes in a square and cylindrical configuration. The experiments used nine cathodes with variable spacing and non-uniform height to investigate the effect of electric field screening on current emission. With non-uniform height (i.e.fiber in the middle taller than the rest), the edge effect should be less severe, and each fiber should contribute to the overall emission more equally. Emission characteristic and voltage-current profile are compared to the case of two and four field emitters with same height and variable spacing.

Oral 10 / 151

Electron stimulated gas desorption of some dielectrics in vacuum

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Surface flashover in vacuum across dielectrics usually happens in many pulse power devices, high power microwave (HPM), which seriously limits the transmission of HPM. Up to now, Secondary electron emission avalanche (SEEA) model is generally accepted to analyze the phenomena. The mechanism of SEEA is characterized into four continuous steps: (1) generation of initial electrons; (2) secondary electron emission avalanche; (3) accompanying with gas desorption subjected to secondary electron impact and collision ionization, and (4) gaseous plasma breakdown across dielectric window. Gas desorption stimulated by electron irradiation plays the dominant role. Accurate measurement of the gas composition and quantity of electron-stimulated desorption is very helpful to study the flashover mechanism and theoretical simulation.
In this paper, we set up an ESD device with a modified quadrupole mass spectrometer (QMS) surround with a cooling shroud. The incident electron energy varies from 2keV to 8keV in pulse method. First, residual gas species in the experiment chamber are analyzed. Then, a pluse electron beam impacts the sample surface to stimulate gas release and the mass spectra analysis of desorbed gas is carried out by QMS. The differences between mass spectra before and after electron irradiation are regarded as the amount of desorbed gases. We measure some typical HPM window dielectrics, such as polytetrafluoroethylene (PTFE), polyethylene (PE) and alumina ceramic (Al2O3). It is found that main desorbed gas components are similar, i.e. H2(m/e2), H2O(m/e18), CO(m/e28), CO2(m/e44), etc.

H2 gas accounts for the majority of desorbed gas components. Organic materials (PTFE, PE) have higher desorption gas than that of Al2O3.

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Ferrimagnetic Material Testbed for Coaxial Nonlinear Transmission Lines

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Ferrimagnetic-based nonlinear transmission lines (NLTLs) are actively researched as potential compact, phaseable sources of high power microwaves for various applications. The performance of the nonlinear microwave conversion process in gyromagnetic NLTLs is heavily dependent upon the properties of the ferrimagnetic materials and line geometries. A test bed for NLTL development has been constructed to support ferrimagnetic material and line geometry evaluation. The test bed has been designed to support rigorous testing sequences of each material to determine optimal operating efficiencies and power handling capabilities for incorporation into NLTL-based systems. The test bed is driven by a parallel plate Blumlein generator capable of 15ns pulse width, 100kV amplitude, and tuneable risetimes from 1 to 20 ns. Evaluation of pressurized gasses, oil, and solid dielectrics for high voltage line insulation has been conducted. Additionally, several custom electrical diagnostics have been developed to support the high voltage (>60 kV) and high frequency (100 MHz – 6 GHz) requirements. This presentation will discuss the test bed topology, custom diagnostic construction and evaluation, and preliminary results.

Oral 10 / 130

Stability Characteristics of Gas Filled Surge Arrester in Gamma and X Radiation Field

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Breakdown (dc and pulse) of noble gases at low values of the product of pressure and inter-electrode distance (pd) is investigated in the paper theoretically and experimentally. This range of the product pd is particularly important since the work point of gas filled surge arresters (GFSA) is found in it. The influence of gamma and X radiation on the volt-second characteristics of breakdown will be considered in well-controlled conditions. Experimental parameters will be the type of electrode material, configuration of electrode surfaces and gas pressure. Experimentally obtained results will be processed statistically. Special attention will be devoted to comparison of the influence of ionizing radiation and the influence of design solutions on the pulse characteristics (volt-second) of GFSA during the analysis of the experimentally obtained results. The effect of the long-term deconditioning will also be considered from the same aspect.

Oral 9 / 128

600 kV BIPOLAR OUTPUT TESLA-BLUMLEIN GENERATOR WITH FREQUENCY BANDWIDTH >1 GHz

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The paper describes the development of a repetitive 10 GW, Tesla-driven Blumlein pulsed power generator that produces a bipolar voltage output in excess of 600 kV peak-to-peak, with an initial rise time of about 300 ps and a frequency bandwidth larger than 1 GHz. The design of the system required PSpice simulations to be combined with three-dimensional analysis using the Computer Simulation Technology (CST) electromagnetic microwave studio software. Technical details, together with experimental results will be provided.

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Evaluation of Hybrid Bouncer Systems for High Precision Klystron Modulators

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Recent advances in the development of linear particle accelerators bring back new challenges regarding the design of pulsed power converters. On one hand, pulses quality (e.g. flat-top ripple, stability and repeatability) becomes more and more important because it directly influences the beam acceleration parameters. On the other hand, the need of reliable systems often requires a capacitor discharge topology in association with a bouncer circuit in order to perform a pulse shape correction by compensating the main capacitor bank voltage droop.

This paper presents a complete study of a novel hybrid topology of such a bouncer circuit. This topology allows to merge the advantages of the open loop passive resonant bouncer topology and the active bouncer one. The principle consists in using a closed loop controlled linear current ballast associated with a well-known parallel LC-based resonant bouncer circuit. This association leads to improve the pulse shape correction made by the passive bouncer alone and leads to a stronger robustness against the parameters deviation (closed-loop operation). Additionally, the losses created in the linear ballast are limited since only a fraction of the modulator current flows in it. First, the merits of such a bouncer topology are established through an analytical study and a comparison with other topologies. The latter is then completed by numerical simulations in order to show the trade-offs between the passive elements size and the linear ballast losses. Key points of the design, including the choice of passive elements and control strategy are provided and the implementation of a reduced scale prototype is described.

Oral 10 / 78

Experimental study on oil well stimulation by dynamic shock wave induced by liquid pulsed current discharge

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This paper aimed at investigating the dynamic shock wave induced by liquid pulsed current discharge to increase the intrinsic permeability of the cement sheath and rock in the oil well. It is believed that the blockage at the oil well perforation can be broken and removed from the bore-hole wall, and the fracture to increase the permeability of the hole-bottom region can be formed under the repetitive dynamic shock waves. Then the oil production of the well is improved. In this paper, an equipment of the oil well stimulation based on the electrohydraulic shock waves is designed and constructed. In order to study on the performance of the oil well stimulation, some preliminary experiments are carried out on some hollow cylinder concrete specimens. The liquid gap voltage, main discharge current, and shock wave pressure as well as the time-resolved photographing of the plasma channel development and bubble formations were observed and presented during the experiments. The spectrum analysis of the shock wave is carried out and presented. In the small specimen test, the blockage on the holes, which simulates the well perforations, are damaged by the shock waves. During the large specimen test, the fractures are overserved as 4 shots discharge applied. As the shots increases, the cracking is extended, and then the specimen is damaged in pieces. The influence of the injected electrical energy and the applied shock wave shot number on the fracture of the specimen is investigated. The experimental results show that the shock wave can increase the permeability.

Poster 3-B / 131

Measurement Uncertainty of Fast Pulse Voltages Measurements with Capacitive Divider

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The influence of measurement uncertainty of type A and B as well as combined uncertainty during the measuring of fast pulses by using capacitive divider will be considered in the paper. A budget of measurement uncertainty will be formed for that purpose, the one that is characteristic for measuring fast pulses with a capacitive divider. Several types of capacitive dividers will be designed and used (with different types of high-voltage capacitor, low-voltage capacitor and with adjustable resistance) that provide minimization of certain measurement uncertainty budget components. Measuring of pulse voltages under well-controlled laboratory conditions will be performed for each type of capacitive divider. The parameter of these experiments will be pulse rising time (in the ranges of ms, μs, ns). Measuring results will be processed statistically. On basis of the obtained results, it will be possible to conclude which components of the voltage divider (construction, materials, capacitance, inductivity etc.) influence the measurement uncertainty. It will enable recommendations for choosing the optimal type of capacitive divider in accordance with minimal measurement uncertainty.

Poster 3-C / 193

Separation of Mixed PD UHF Signals in GIS by Using Cumulative Energy Function Feature Extraction

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ABSTRACT: Multiple PD sources may occur simultaneously in power equipment, and cause the interpretation problems such as pattern recognition and risk assessment. The separation of mixed signals is of importance for reliable interpretation. The separation features in most of the methods are with fixed mathematical equations, which may not applicable to the variable experimental conditions such as power equipment, measurement circuit and coupler performance. In this paper, a mixed PD signals separation algorithm based on feature optimization extraction of cumulative energy function is proposed. Cumulative energy functions in time domain (TCE) and frequency domain (FCE) are calculated to characterize the PD waveforms and their FFT spectrums, respectively. Mathematical morphology gradient (MMG) operation is applied to the TCE and FCE, and the energy rising steepness features are extracted. The standard deviation of extracted features is adopted to evaluate their separation performance. In order to obtain effective separation results for various experimental conditions, the length of structure element in MMG is optimized with the goal of maximum separation performance. Experiments on three multi-defect models in a GIS are performed, and the separation performance of the proposed algorithm is tested with the acquired mixed UHF signals. Finally, the separation algorithm is successfully applied to the separation of UHF signals detected from an on-site 1100kV GIS multiple PD UHF signals. The separation results indicate that the proposed method is effective for both internal and external sensors, and the method shows robust performance for UHF signals separation.
KEY WORDS□gas insulated switchgear, partial discharge detection, signal separation, cumulative energy, feature optimization extraction

Poster 3-A / 137

The Movement of Bubbles on High Repetition Discharges in Tap Water

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Pulse discharge in water has many applications, such as cleaning water at dams and lake, creating chemical active species and so on. In the study of discharge in water, application and generation mechanism have been studied in recent years. However, the mechanism has not been made clear completely yet. In high repetition discharges, it has not been cleared yet. In high repetition discharges, we can see interesting phenomena. Each discharge gathers many bubbles around tip of electrode, and bubbles come together. This paper reports bubbles movement at repetition discharges. It was focused the distance between electrode and bubbles, and the shape of bubbles around electrode tip. A maximum output of 1 J/pulse was applied to an electrode of 0.8 mm in diameter covered by an insulator of 2 mm thickness. This water conductivity was 110 to 170
μS/cm. The process was taking movies of state of discharge on 500 pps (pulse per seconds) in tap water, analysis of the movie to show the movement of bubbles using the image processing software,

and calculation of the distance between electrode and bubbles to show the movement. The result has four points. These are distance between electrode and bubbles, before gathering bubbles around electrode, before gathering bubbles around electrode, and bubble's size. As the result of calculation, each discharge pulled bubbles after pushing the bubbles to the far area from electrode. Before gathering bubbles around the electrode, far bubbles from electrode are pulled stronger than near bubbles by each discharge. After gathering bubbles around electrode, it was not able to use all situations about the distance data. Therefore, bubbles around electrode affect other bubbles. Also, big bubbles come near the electrode stronger than small one.

Poster 3-B / 341

High Energy Density Power Supply Development at NSWCDD

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Directed energy applications exist in which pulsed power systems are required to operate repetitively with average power in excess of 100 kW for a short duration followed by a relatively long period of inactivity. The small duty-factor of such systems allows for size, weight, and power optimization of power electronic systems. This paper presents the development of a high power density, low duty-factor series resonant CCPS operated from a 250 V super-capacitor prime power source. Analytical and numerical analysis of a low-leakage inductance, nanocrystalline cored high-voltage transformer will be presented. Also, FEM analysis of duty-factor limitations brought on by thermal stress will be discussed. Finally, experimental test results of the converter will be presented. This work is supported by the Air Force Research Laboratory (AFRL).

Poster 3-A / 20

DEVELOPMENT OF HIGH-POWER GAS DISCHARGE AND ELECTRONIC VACUUM DEVICES FOR PULSED ELECTROPHYSIC. CURRENT STATUS AND PROSPECTS

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In the paper the most recent results of research and development efforts made by Pulsed Technologies ltd are presented. Design and essential characteristics of more than 36 types of high-power high-voltage switches TDI- and TPI-thyratrons (pseudospark switches) [1], TGI- thyratrons at 250 MW pulse and 0.5 MW average power, spark gaps, as well as X-ray tubes of the new generation are described.

High power pulse thyratrons contribute the major part of production volume of our company. Thyratrons used to be the most important switches for Pulsed Power applications, as indicator of which

serves the fact that from volume 1 (1950) to volume 10 the titles of IEEE International Power Modulator Conferences involved a phrase “Hydrogen Thyratron”. Currently, solid state switches keep replacing plasma switches in the most of pulsed power applications. However, there are some important niches in which thyratrons and pseudospark switches are still out of competition.
The report contains a list of publications and examples of emerging applications of these switches in the innovative equipment of leading world institutions, including high-power Pulsed Electrophysics, colliders [2] and accelerators of various types [3], in medical equipment, industry and etc..

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Poster 3-C / 176

Partial Discharge under PWM stress-type Conditions

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In recent years, the increasing use of AC-DC converters, especially in the field of renewable energy sources, has led to the implementation of new modulation techniques, in particular the ones based on the pulse width modulation, PWM. The purpose of the present work is to evaluate the presence of partial discharges that occur when the supply is a PWM stress-type. In particular the goal is to validate a previous work in which the measurements of partial discharges has already done [1]. The aim is to carry out further measurements in order to confirm that the measurement set-up for testing IGBT modules, is able to distinguish the pulses due to the dv/dt, present in the PWM trend, and the partial discharges.
The setup used for the realization of the corona discharges is constituted by an electrode section 30 μm, which was powered with a PWM waveform, and a counter electrode placed at a distance of 2.8 cm consisting of a copper plate and connected to the ground terminal. The power supply of the sample is carried out through a power cable connected to the amplifier voltage. The measurement is made by means of a field probe.
By feeding the system with the PWM waveform, additional pulses are due to a dv/dt of rise time and fall time of the carried signal. Increasing the voltage of the PWM waveform it is possible to note the triggering of the corona partial discharges.
Analyzing the discharge pulse, it is possible to distinguish partial discharges from other type of discharges. In this way it is made clearer the measurement of partial discharges when the PWM type source is used. Is then confirmed that the pattern carried out in a previous work represent a real partial discharges.

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Compact, Battery Powered Supply and Control Integration for HPRF Systems

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The Naval Surface Warfare Center, Dahlgren Division (NSWCDD) is developing a low duty factor High Voltage Power Supply (HVPS) optimized for power density and specific power. This HVPS employs state-of-the-art components and topologies that are highly optimized to the "burst mode" operation typical of high power directed energy systems. The reduced duty factor, thermal, and life-time requirements allow for significant Size, Weight and Power (SWaP) optimization over traditional, continuous HVPSs. The presented material will outline the design, implementation, testing, and incremental improvement in the HPVS and its associated control systems. This work is supported by the Air Force Research Laboratory (AFRL).

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GENERATION OF INTENSIVE DIRECTED CONTROLLED X-RAY RADIATION DURING CAVITATION OF FAST LIQUID STREAM

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In the report the results of investigation of intensive directed controlled X-Ray radiation connected with bubble cavitation phenomena in fast oil jet and supersonic water jet [1] are presented and discussed. The total activity of X-Ray generation was about $Q \geq 0.1$ Ci.

The mechanism of X-Ray generation is connected with the sequential tandem of cavitation and shock-wave processes inside liquid jet and in the volume of output channel. We have investigated bubble cavitation and X-Ray generation phenomena at high pressures of machine oil (P=30-90 atm) and at super-high pressures of water (P=200-2000 atm). The soft part of X-Ray radiation (Ex=0.8-1.1 keV) was generated by the surface of supersonic free water jet in the area of cavitation at any pressure. The energy of radiation from the surface of oil or water output channel (made of plexiglas or stainless steel) was Ex=1.5-2.0 keV. In the case of additional lead cover on outer surface of a channel the energy of X-radiation was Ex=4.5 keV.
It was shown also that the formation of shock waves and X-rays is accompanied by generation of undamped high frequency thermal waves [2].

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MINIMUM-INTRUSIVE DIAGNOSIC SYSTEM FOR SF6 HIGH VOLTAGE SELFBLAST CIRCUIT BREAKER NOZZLES

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Circuit breakers are important components in the electrical power supply grid. The maintenance of high voltage gas circuit breakers requires high personal as well as monetary efforts for the asset operator. Furthermore, a faulty reassembly of the circuit breaker during maintenance can lead to a circuit breaker failure during operation. For this reason the maintenance strategy changed from a periodic schedule to a condition-based strategy. One possibility to realize condition-based maintenance strategies as well as to reduce the failure risk is the use of minimum-intrusive diagnostic techniques. This research work examines such techniques for assessing the wear of the insulation nozzle inside the switching chamber of a circuit breaker. The approach applied here is based on the measurement of the transient pressure signal at the main filling valve of the circuit breaker during a switching operation without electrical load. The pressure signal is investigated regarding characteristic features which yield information for the determination of the switching chamber condition. Characteristic features be identified in the pressure waveform and are used for further analysis. In this process the nozzle condition, as the most influencing factor is varied. Additionally the influence of electrode ablation and filling pressure variations are analyzed as well. In addition, the nozzle ablation on multiple poles is considered. A machine learning algorithm applying the k-nearest-neighbor-method is used for the determination of the nozzle and electrode condition, while the characteristic features are utilized as input parameters. Thus it is possible to classify new, unknown measurements with an already known data basis. The classification is successfully applied with a high reliability for different circuit breaker types. For the validation of the method field measurements from different circuit breaker types are evaluated.

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Partial Discharge Pattern Recognition Based Artificial Neural Network

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The purpose of this paper is the identification and classification of different sources of partial discharge (PD). These PD sources are due to artificially introducing defects, which are carefully designed in the power cable insulation. PD data is collected from the experimental work in high voltage laboratory with the aid of a conventional phase-resolved PD analyzer LDD-6. After that, the partial discharge pattern recognition (PDPR) which uses as a diagnostic tool is applied to the collected data to determine the partial discharge source as well as get information about the deterioration degree level of the insulation failure. The PDPR with artificial neural network (ANN)is applied to PD data to extract the appropriate features of each pattern of the PD source. These features are the fractal dimension and lacunarity which generate from the three-dimension PD pattern raw data.The ANN is used to improve the performance of PD classification systems which is the most priority of this work. The results indicate that the fractal dimension and lacunarity are sufficient to recognize the different PD patterns.

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Nanosecond Pulse Discharges in an Inhomogeneous Electric Field in atmospheric air

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Nanosecond pulse discharges in air and other gases at atmospheric pressure can behave various forms of discharges, such as corona, diffuse, spark or arc. In this paper, characteristics of three typical nanosecond pulse discharges, including diffuse discharges, gliding discharges and synthetic jet, in an inhomogeneous electric field are presented.
Diffuse discharges can be obtained at atmospheric pressure with high pulse repetition rate in a point-to-plate. It can be identified as an intermediate state between corona and spark streamer discharges in an inhomogeneous electric field. The corresponding conduction current was unipolar and had amplitude of several amperes, which had the similar amplitude with the displacement current. Furthermore, discharge area of diffuse discharges could be increased by using a multi-needles-plate electrode configuration, a coaxial electrode configuration with a diameter of 5 cm or a knife-plate electrode configuration with an axial length of 30 cm.
Gliding discharges are created in pin-to-pin or a hollow electrodes atmospheric pressure with an air flow. A non-stable stage would appear some time after the discharge go into the stable stage, in which the gliding discharges transitioned from repetitive sparks to diffuse discharges. Furthermore, high flow rate will lead to the spark-to-diffuse transition in pin-to-pin electrodes, and the repetitive sparks are more likely to obtain at high repetition rate, which is benefit to the applications for ignition and combustion. In addition, evolution of the nanosecond-pulse gliding discharges is observed by using a high-speed camera.
Plasma synthetic jet is exited by a home-made pulsed generator in pin-to-pin electrodes. The breakdown voltages for different discharge capacitors keep the same when the gap is fixed. Furthermore, large discharge current can be produced when the discharge capacitor is used. The discharge current increases with the value of the discharge capacitor. The ratio of dissipation energy is higher in the case with discharge capacitor than that in the case without discharge capacitor.

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High Voltage Radio Frequency Test Facility for the characterization of the dielectric strength in vacuum of RF drivers for Neutral Beam Injectors Ion Sources

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PRIMA (Padova Research on ITER Megavolt Accelerator) is a large experimental facility under construction in Padova, Italy, aimed at the development and test of the full scale prototype of Neutral Beam Injectors (NBI), called MITICA, for ITER, the world's largest experiment to prove the feasibility of fusion as a source of energy.

MITICA is foreseen to accelerate a beam of 40 A of negative deuterium ions up to 1 MV, in order to deliver a power of about 17 MW to the plasma with a pulse length of one hour. All these requirements have never been reached before at the same time and this is the reason for PRIMA test facility and MITICA experiment.

The negative ions are produced by means of an ion source composed of 8 radio frequency (RF) drivers working at 1 MHz each generating a cold plasma at a pressure of 0.3 Pa with a power of 100 kW. A set of grids at different electrical potentials, extracts and accelerates the negative ions producing a negative ion beam which is then neutralized in order to enter and heat the plasma.
The production of the negative ions by means of RF driven ion source and their extraction is a feature which needs to be developed separately before MITICA operation, since these requirements are not satisfied in any of the existing NBI for fusion devices. Therefore a second experiment called SPIDER will be hosted in PRIMA and it is the full scale prototype of ion source for ITER NBI.

To fulfill the demanding operational condition of the RF drivers and the need to gain experience on the RF voltage holding in vacuum, a necessary experimental investigation is needed. Thus, the High Voltage Radio Frequency Test Facility (HVRFTF) is being built in Padova, at Consorzio RFX. The HVRFTF scope is to reproduce the operating conditions of the RF coils used in the ITER NBI ion source, in particular the voltage up to 15 kV at 1 MHz and the operating pressure in the range of 1E-3 – 0.3 Pa.

The paper will present the specific features and issues related to the design, construction and first operation of the HVRFTF.

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Preprocessing method of online oil chromatographic data based on adaptive wavelet analysis

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Due to the influence of external environment and the error of measuring equipment, on-line oil chromatogram data contains obvious noise and the signal oscillates. The monitoring data is difficult to be directly applied on analysis of the equipment state. In this paper, a novel wavelet based de-noising method is proposed for preprocessing the on-line oil chromatography data. By analyzing the characteristics of on-line oil chromatographic data, the method of determining the decomposition level based on the probability distribution of wavelet coefficients and the method of determining the threshold value based on outliers conservation were proposed. The improved wavelet de-noising method is applied on analyzing the on-line oil chromatographic data of a defective UHV reactor. The results show that the proposed method is feasible and effective.

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Study of the Silicone Rubber Used at the External Insulation of High Voltage with Laser-induced Breakdown spectroscopy (LIBS)

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RTV coatings and composite insulators had been widely used in electric insulations to prevent pollution flashover. Many methods of materials analysis were used to get more information about the content, the elements components, and the structures such as IR spectrum, XPS, EDS and XRD.
Laser-induced breakdown spectroscopy (LIBS) was an effective technique, unlike other conventional

surface analysis techniques which require cumbersome sample preparation. LIBS measurements can be performed under ambient conditions, with no sample preparation and measurements can be taken in times on the order of one second.
In this paper, we show that the LIBS with a nanosecond pulse laser can be used to measure the elements content of the silicone rubber composites. The plasma properties of the silicone rubber was investigated. Several elements of the compositions in silicone rubber was found such as C, O, Si, Mg, Al and so on. And also we found that the depth of the laser ablation was linear relationship with laser pulses.

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Effect of Distance between Electrodes for Water Treatment by Plasma

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We have studied the water treatment by spraying into a pulsed discharge space in air, to decompose refractory organic compounds included in industrial waste water. In practical application, reactors of large scale are required to treat a large quantity of water. For that, electrodes with diameter of long distance is needed. Hence, the effect of the distance between electrodes was investigated. Three coaxial electrodes generating plasma was prepared. These diameter was 40, 77, and 115 mm, respectively. High pulsed voltage is applied at electrodes to generate plasma, and the water treatment was carried out by spraying in to that space. The pulsed voltage of higher peak was applied if the diameter of the electrode was longer to adjust electric field of three electrodes. In this presentation, the difference of the plasma and the water treatment efficiency of three reactors is shown.

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A New Approach for Optimal Design of Corona Ring

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Polymeric insulators are largely used in electrical systems. However, these equipment still present serious problems, mainly related to their polymeric material layer. When the polymer is exposed to intense electric fields, insulation failure and loss of hydrophobicity may occur.
These problems are caused due to non-uniform electric field distribution along the insulator, which tends to intensify the electric field on the sheds near to the phase terminal. Non-uniform electric field distribution can be minimized using suitable corona rings.
Issues involving bad corona rings design were found out at 230 kV transmissions lines of a Brazilian energy company. Insulators have presented failures after only 5 years of use, such as core tracking and fiberglass mechanical rupture. The company's suspicion was that the corona ring provided by the manufacturer was ill-designed. After some study, Ferreira (2007) proposed a new corona ring design, although no optimization method was used by the author.
Therefore, in this paper several optimization methods were used to determine the optimal corona

ring design. The following methods were utilized: Nelder-Mead, COBYLA and BOBYQA. In addition, a software based on the Finite Element Method was used to performer the simulations.
Results show that the optimized corona ring provides a reduction of 79.6% on the electric field when compared to the manufacturer's ring. When compared to the design proposed by Ferreira (2007), the reduction was 63.5%.
With respect to the performance of the optimization methods, the Nelder-Mead method was found as the most suitable for the problem solution, due to its smaller computational effort and great convergence speed.
The method presented in this paper, can be generalized to any insulators with different voltage levels. Moreover, the method has some advantages over other available methods, such as those presented by Sima et al. (2004) and Murawwi et al. (2013).

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Temperature investigation of electric arc discharges in medium-voltage switchgear

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The purpose of this study is to investigate temperature profiles of electric arc discharges in a medium-voltage switchgear. This project aims at Validation of simulations of electric arc discharges temperatures. Therefore a simple contact geometry was applied under 150 A and 550 A of alternating current at normal atmosphere. The contacts were made up of both copper and copper-wolfram.

To discover the off-switching process the contact pairs initially were closed. They opened briefly after zero-crossing of the alternating current voltage. A spectrometer was installed orthogonal to the contacts axis. Its space-resolution observed a cross section of the arc discharge in 3 mm distance parallel to the cathode surface. Spectrograms were taken at two points. Firstly at the currents maximum and secondly 1 ms later.

To determine temperatures the Bolzmann-plot method was applied to the intensities of Copper I spectral lines[1] at 510.5541nm and 515.3235nm wavelength. Therefore the broadband spectrogram was analyzed with a sum function of multiple Pseudo-Voigt profiles. Fitting was done via non-linear least square algorithms. The mathematics will be part of this talk.

So far the results of measurements under 150 A alternating current were analyzed. Thus the temperature at the first point in time is investigated to about 14.000 K at its maximum and down to about 8.000 K at the edges of Copper I availability. At the second point in time higher temperatures are estimated. After validation of the off-switching process an experiment concerning the on-switching process is planned.

[1] http://physics.nist.gov/PhysRefData/ASD/lines_form.html

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The partial discharge inception and breakdown voltage distribution of metal protrusion in SF6 gas

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Gas insulated switchgear (GIS) is the most important equipment in grid. It has been widely used in power system for the merits of small size and high reliability. Especially for the city substation, GIS is the preferred power equipment. GIS has the compact structure and it is difficult to repair once there are defects inside the GIS. It is the important step to monitor the defects inside GIS. PD is the pre-breakdown phenomena and it always be seen the key monitor parameter for the insulation condition assessment. The metal protrusions are common defect and it will appear on bus bar or shell of GIS in the process of manufacturing, transportation and assembling. The metal protrusion will lead to partial discharge (PD) and breakdown (BD) in the GIS operation process. This paper presents the PD and BD voltage distribution in different distance triggered by metal protrusion in SF6 gas. The electric field simulation of metal protrusion is carried out and the electric field distribution is obtained. The need-plane electrode systems with different gap distance are adopted as the specimen. The PD inception voltage and BD voltage are obtained through lab test. The test results show the PD inception and BD voltage increase with the distance increase. But for the electric field strength, the BD electric field strength increase with the distance increase and the PD inception electric field strength change a little with the increase of distance. The mathematic model is established to explain the experimental results.

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Advanced Method for Detection of Partial Discharge in Oil-paper insulated Transformer Bushings and Current Transformers

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Objective: Oil-paper insulation is widely used in transformer bushings and current transformers, and the detection of partial discharge (PD) in this type of insulation has been paid attention. However, current methods for PD detection in these apparatus usually do not have satisfying performance in either sensitivity or noise rejection capacity. In this paper, an advanced method for PD detection in oil-paper insulated bushings or CTs is proposed using a simplified coupler attached to the tap of the bushing, in order to solve the problems the conventional methods faced.

Method: The principle of the proposed method and the effect of the introduction of the coupler to the apparatus is first analyzed. PD experiments were then carried out on 110 kV transformer bushings and CTs to test the effect of the proposed method, with defects preset in the test objects during production process, including the protrusion on the grading ring of the bushing, voids in the oil-paper of the bushing and the CT. PD signals were also detected by the UHF method as contrast.

Results: The theoretic analyze shows that the introduction of the coupler will cause little influence to the apparatus. The experiments results show that the proposed method has satisfying performance in detecting typical defects in oil-paper insulation, and the frequency band of the coupler can help to eliminate interference effectively, especially when amplifiers are introduced. The test results indicate the good application prospect of the proposed method for on-site PD detection.

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The Effects of Lightning Discharges on Control & Communication Cables and Antenna Systems

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In this work, lightning discharges and their effects on control & communication cables and antenna systems are investigated. The mechanism of lightning is described in detail and electric and magnetic fields created by lightning discharges are examined. An experimental test setup is designed and implemented in order to observe induced voltages on cables or antennas caused by lightning discharges. Test results are compared with each other and discussed in detail. Also, they are compared with theoretical findings. Effects of induced voltages on certain systems are studied. Moreover, some precautions to avoid the harmful effects of lightning are suggested.

Keywords: Lightning, lightning discharge, induced voltage, control cables, communication cables, antennas

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High temperature carbon nanotubes (CNTs) based diode turn-on with a pulsed radio frequency signal

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In this paper, a CNT diode was tested at elevated temperatures to be used in high temperature RFID sensor. The diode was made from CNTs that were grown on a silicon-substrate that made up the cathode and an anode was positioned at a set distance away from the CNTs. A voltage was applied to the diode at a voltage level just below the diode's turn on voltage. An external RF pulse is sent from an antenna. The diode receives the RF pulse and field emission from the CNT begins. The test system consists of a Radio Frequency Identification (RFID) tag (CNT diode), a transmitting (TX) antenna, and a receiving (RX) antenna. A square nanosecond pulsed signal is transmitted. The current and voltage data are is captured for each temperature. The diode is tested at temperatures, ranging from room temperature to 300C, with 100C increments to see how the changes in operation with temperature.

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Study on the characteristics of the shock wave induced by underwater pulsed current discharge

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A dynamic shock wave induced by underwater high pulsed current discharge has a wide potential applications in industrial and civil fields, such as rock fragmentation, electrohydraulic cleaning, and

oil stimulation, etc. In order to promote the application of the dynamic shock wave, a test stand of underwater pulsed current discharge is designed and constructed. The main capacitor is 3 μF, and the charging voltage is 30 kV. Under the needle-needle electrode system with the gap distance of 10 mm, the intensity of the dynamic shock wave induced by the electrohydraulic effect is measured by a pressure sensor of PCB 138A01. Based on the electrical parameters and time-resolved observation of the arc and bubble development from a high speed camera, the factors that affect the shock wave intensity are analyzed. It is showed that the arc length has a great effect on the intensity of shock waves. As the arc length increases, the main discharge current decreases. However, a more intensive pressure is observed. It is concluded that the development of arc length is inconsistent, and arc expansion speed is not uniform. Moreover, the intensity of shock wave is closely related to the power and energy dissipated into the discharge arc channel. The longer arc and the quicker arc expansion can lead to a higher power and energy deposited into the arc channel, which can activate a stronger shock wave. Finally, a hydraulic fracturing is carried out to analyze whether the dynamic shock wave can achieve the fracture creation of a cement sheath. Results show that the shock wave can result in the increase of the permeability. The intensity of shock wave can determine the fracturing pattern and the number of pulsed discharges.

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Research of Airflow Control Using Surface Dielectric Barrier Discharge Plasma at Atmosphere Pressure

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This paper presents experiments carried out on atmospheric pressure surface dielectric barrier discharge plasma actuators. Two parts concerning these actuators are addressed in this work: First, the effect of a DC bias on the electrohydrodynamics force induced by the AC discharge actuator for airflow control is investigated. A special designed corona like discharge potential probe is used to measure the surface potential due to charge deposition at different DC biases. From the surface potential data, the plasma electromotive force is shown not affected much by the DC biases except for some reduction with negative DC bias near the exposed electrode edge for the sheath-like configuration. Meanwhile, the temporally averaged electric wind velocity, the mean thrust production and the schlieren visualization are measured. The results show the airflow and thrust force induced by the actuator can be influenced by DC bias. The direct thrust force is almost a linear relationship to the potential voltage at the exposed electrode edge; the velocity profiles with different DC biases are gradually diversified in the further downstream area as well as the upper space away from the discharge plasma area. In the second part of the paper, a new electrode configuration, i.e., a row of needle is taken as an exposed electrode for the plasma actuator, and the electrode height is adjustable. The different effects of the electrode height on the airflow acceleration behavior are experimentally investigated by measuring the same electrical and mechanical characteristics. It is demonstrated that the airflow velocity and thrust increase with the electrode height and the best actuator performance can be obtained when the exposed electrode is adjusted to an appropriate height. The difference, as analyzed, is mainly due to the distinct plasma spatial distributions.

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Optical diagnostics of single-wire electrical explosion in vacuum

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PPG-3 is a small-scale pulsed power device built to study the physical process of single wire electrical explosion (EEW). It is composed of a capacitor bank of 10nF charged to 0-60kV, a laser-triggered switch, a 50 ohm transmission line and a discharge chamber housing the exploding wire. The voltage and current waveforms of the exploding wire were measured with a capacitive divider and a current shunt, respectively. A Mach-Zehnder laser interferometer as well as a high-speed camera with 4ns exposure time is applied to capture the pictures of the exploding wire. Tungsten wires with 10-25μm diameter have been tested and ~13μm diameter turns out to be a maximum for energy deposition. In order to get a direct knowledge of the surface breakdown process during EEW, an optical fiber array probe is applied to collect the self-radiation from different part of the wire; the optical signal is then converted to voltage waveform by photoelectric detectors with response time less than 1ns. This helps identify the initiation location and the progressing direction and speed of surface breakdown.

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Design of a Compulsator to drive a Railgun

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Compulsators are AC synchronous generators designed to maximize the short circuit current that could be delivered by the generator. Compulsators have certain advantages over capacitor banks such as higher energy density, occurrence of natural current zero and flexibility in current shaping. Hence, they have become an attractive choice as a power source for the Electromagnetic Launch (EML) applications.

A capacitor bank driven railgun was built and tested earlier in the Pulsed Power Laboratory of Indian Institute of Science, Bangalore, by one of the authors. The scope of the present work is to design a compulsator for the above mentioned railgun. The resistance and inductance gradient of the railgun are calculated using a FEM based commercial code. The effect of varying the different parameters of the compulsator on the performance of the system has been studied and is discussed in this paper. By means of the parametric study, the necessary background for the design of the actual compulsator has been achieved.

A single phase, 2-pole, rotating field, passively compensated, iron core topology has been selected for the design of the compulsator. The compulsator is designed based on mainly two conditions: (1) The instant of projectile exit is synchronized with natural current zero instant. (2) For the given mass of the rotor, the projectile exit velocity is maximized. The system has been analyzed as three magnetically coupled circuits, considering the effect of the magnetic saturation of the machine. The performance of the railgun has been analyzed for different sizes and shapes of the rotor, number of turns, switch resistances and rotor speed ensuring that the thermal and the mechanical stresses in the machine remain within the specified limits. Based on the above analysis, the compulsator is designed for the above mentioned railgun and results will be published in the final manuscript.

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Study of Accelerating Surface Charge Dissipation on Epoxy Treated by Dielectric Barrier Discharge

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Epoxy is used in the manufacture and electricity industry for a wide range of applications. However, it will easily form three-pronged and accumulate a lot of charge on the epoxy surface under high field strength. In this paper, dielectric barrier discharge (DBD) with a plate-in-parallel configuration was used to generate non-thermal plasmas for the surface modification of epoxy. The distribution of surface potential is measured by a Kelvin electrostatic probe which is connected to an electrostatic voltmeter. The water contact angle (WCA) and surface roughness are measured by contact angle measurement and atomic force microscopy, respectively. In addition, measurement of surface resistance is conducted before and after the plasma treatment. The experimental results show that surface potential decay on the treated material is much faster than that on the untreated ones. Moreover, the process is sensitive to relative humidity (RH) of ambient air. It can be observed that the decay rate increase with the increase of RH within the tested range. AFM shows that surface morphology is changed by plasma treatment, which causes the enhancement of surface roughness. The WCA shows that the treated surface is completely hydrophilic when the treating time reaches 60 s. Furthermore, surface conductivity for treated samples increase by one or two orders of magnitude compared to that for untreated samples. Such behavior is attributed to the increase amount of water absorbed and thus leading to stronger leakage of charge on the sample surface. The results can provide a reference for surface modification of epoxy in industrial applications.

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Experimental Investigation on Humidity Effects on the Variations of Positive DC Corona Discharge

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Corona effects and its related electromagnetic environment on the operated conductors are important problems for high voltage transmission lines. The climate environment is quite complex in China, HVDC transmission lines may go through many high relative humidity areas,consequently, the corona performance of HVDC transmission lines will be greatly affected.
In the present paper, a corona effects testing system with the wire-to-plane electrode was built in the outdoor environment, the purpose of which is to study the influence of relative humidity on corona performance of DC conductors. Based on the testing system, the photon counting rate, the electric field strength and the ion current density at the ground level were measured by the UV imaging detector, the rotating DC electric field mill and the Wilson plate respectively. The relatively humidity during the experiments was kept within the range 40% to 80%. Moreover, the effect of relative humidity on the measurement accuracy of the field mill was also investigated in artificial climate chamber within the relative humidity 40% to 90%.
The outdoor experimental results indicated that the corona discharge intensity increased with the raise of relative humidity; hence, the corona inception voltages reduced while the photon counting rate and the total electric field increased. The change of relative humidity had slight effect on the ion current density, which kept invariant basically. It was also found that the original value of the field mill would be affected by the change of relative humidity, the higher the relative humidity was,

the greater original value of the field mill would be.
On one hand, the water molecule around the DC conductor will be charged as a result of the ionized field, which will affect the electric field in the neighborhood of the conductors. On the other hand, due to being charged or airflow blowing, the water molecule deposit on the surface of the conductors, which may change the conductor surface conditions. The influences of relative humidity on space charge distribution and the surface roughness degree of the conductor are the main reasons for the variations of corona performance.

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Self-sustaining conditions for nanosecond pulsed volume discharges under airflows

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The research of nanosecond pulse discharge has received extensive attention, it is important to study on self -sustaining condition of gas discharge in atmospheric air flow. In this paper, we are focus on the initiating and extinguishing boundaries of nanosecond pulse discharge under different air different airflow conditions.
An DBD volume discharge is generated between two parallel stainless steel plates (80×30×1.5 mm3) which were covered by the mica sheets(150×60×1 mm3). The discharge gap is 3 mm. The stainless electrodes are connected to a nanosecond pulsed power supply (voltage amplitude U: 0-30 kV, pulse repetitive frequency PRF: 0-3.8 kHz). The voltage and current are measured by a capacitive divider (bandwidth: 200 MHz, divider ratio: 2200) and a Pearson current probe (Pearson 6585). Both the waveforms are recorded by an oscilloscope (DPO 3014 2.5 GHz). The discharge current signals, obtained by total currents minus displacement currents, are used to identify the initiating and extinguishing of volume discharges. With a regulating valve and a throttle orifice, the airflow velocity can be changed between 0 and 100 m/s. Under such airflow velocities, the airflow is always considered as under incompressible state, and the airflow velocity can be measured by a pitot tube based on Bernoulli equations.
There are two important excitation factors for initiating and extinguishing conditions of volume discharge under airflows. At a give voltage amplitude, the needed PRFs for discharge initiating and extinguishing both increase with the increasing airflow speeds. It can be explained with the transformation actions of metastable particles and active particle to the downstream region. At lower voltage amplitude, the needed PRF of initiating and extinguishing discharge boundary are mostly not affected by airflows. While at a higher voltage amplitude, the needed PRFs of initiating and extinguishing discharge boundary are hardly affected by airflows.

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Introduction to non-magnetically confined fusion plasma torch-device.

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The plasma generators consists of a circular orifice anode and an inner cathode enclosed in a chamber and positioned in line with the nozzle. The otherwise closed chamber has a vortex-stabilizing gas inlet, and gates in the region of arc column and is heated and accelerated. By adjusting the flow of gas, one can force the arc column to contract anode-bore, outside of the chamber, flame-like phenomena of high enthalpy, high temperature and high velocity appear. My US Patent [1] has been described the fundamentals of non magnetically confinement of the self-set DC Arc Plasma Torch with the vortex's Arc stabilization. This Patent is based on results of my personal research of this phenomenon, in a frame of my life span project of pulse modulation Plasma in DC Arc generators. Method of location of an arc plasma torch in the center of arc channel by superposition the pulses of frequency modulation νm onto plasma arc could sustain thermo nuclear synthesis in the center of plasma arc channel without being confined by magnetic fields.

1)"Thermal nucleus fusion torch method",US Patent # 8,436,271, filing data is 04/14/2010, Patent issue is May 7,2013

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Study on Diagnosis of Power Transformer Winding Deformation through Vibration Signal

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As one of the most important equipment in power system, the safe and stable operation of power transformer is of great importance and the condition maintenance and fault diagnosis can avoid breakdown of power transformer as well as save investment. Since 1980s, lots of method, such as Frequency Response Analysis, Low Voltage Impulse has been put into winding deformation detection. Among these method, Vibration Analysis from oil tank has gain much attention through its advantage that it is closely related with the mechanical condition of winding and core and it can be used in on-line monitoring. This paper based on the principle of transformer vibration and Fourier Transform, choose odd and even harmonic ratio, the ratio of 100Hz, the ratio of maximum amplitude and complexity of spectrum as vibration eigenvalue to indicate the vibration change under different fault of transformer. What's more, the alert threshold for diagnosis was got through 78 power transformer vibration signals. Through the above two steps, the diagnosis method of power transformer is concluded and put into filed test. Among the test results, vibration eigenvalue from one 220kV power transformer which has suffered several short-circuit impact shows that the winding of phase C has the bulge and buckling deformation. The conclusion and diagnosis results are proved to be correct after the transformer was sent back to the manufacturer and the core and winding was hang out of the oil tank. The diagnosis method for power transformer in this paper based on tank vibration can make contributions to condition monitoring.

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The impact of airborne particulate matter concentration on Negative DC ground synthetic electric field in spring season

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In recent years, with the deterioration of nature climatic, haze occurred frequently in Beiijng, China, especially in spring and winter seasons. During haze weather, the concentration of airborne particulate matter will turn higher, and it may have significant effects on high voltage power systems.
When the electric field intensity on the surface of the HVDC conductors exceeds a critical value, corona discharges and produces a large number of ions. If airborne particulate matter, exist at this time in the vicinity of HVDC conductors, ions would adhere to these particulate matter, becoming charged particles, suspending in air and affecting the ionized field of the conductors.
In order to investigate the impact of airborne particulate matter concentration on ionized field of HVDC power lines, a simulated overhead transmission line was constructed outdoor near our laboratory. During March to May (spring season in Beijing), the negative dc experiments were carried out in fine and haze weather for several times. The concentration of airborne particulate matter was monitored by laser dust monitors LD-5C (B), which was in the range 20μg/m3 to 400μg/m3. The components and particle size of the collected airborne particulate matter sample were studied by means of scanning electron microscope (SEM) and energy dispersive X-Ray Spectroscopy (EDX). The state of corona discharge was observed by an ultra violet (UV) imaging detector, therefore, the corona inception voltages could be obtained. The negative DC ground synthetic electric field was measured by three filed mills.
Through a large number of observations and measurements, it is found that the airborne particulate matter has little effect on negative dc ground synthetic electric field before corona discharge occurred; however, the negative dc ground synthetic electric field became higher with the increase of the concentration of airborne particulate matter when the applied voltage exceeded corona inception voltage.

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Research on a New Type of Lightning Protection Device for Distribution Network Based on the Principle of Multi-Short-Gaps

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The arc quenching device with multi-short-gaps introduced in this paper has the advantages such as quick and reliable action, good performance of self-restoration in insulation and low cost. The device allows the arc to be established by a lightning strike, and then the device extend arc with the high temperature and high pressure produced by arc until arc extinguishes. The duration of the arc quenching process is very short and act trip caused by relay protection devices would not happen. So the device can be widely used in distribution network to reduce the lightning trip-out rate.
To test the lightning protection performance of the device, a series tests such as impulse withstand voltage test, power frequency withstand voltage test and volt-second characteristic test have been taken. The results show that the impulse breakdown voltages of the samples are between 35~50kV, the power frequency withstand voltages are about 30kV, the volt-second characteristic curves are all above the 10kV insulator, and the device can quench the arc very quickly. In the course of the experiments, it is found that the impulse breakdown voltage value of the device decreased after the first breakdown when the device repeatedly suffered from impulse voltage. That is, the discharge characteristic of the device is not stable. Moreover, with the increasing of the gaps number, although the power frequency withstand voltage of the device grow linearly, the impulse breakdown voltage did not have a good linear relationship with the number of the gaps. To solve the problem, a large gap is connected in series. Tests show that the discharge characteristic of the improved device is more stable.
Therefore, a conclusion can be drawn that the arc quenching device with multi-short-gaps has good capability for lightning protection of distribution network.

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Mode Transition in Microsecond-Pulse Gliding Discharges at Atmospheric Pressure

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In an inhomogeneous electric fields, there is several kinds of discharge mode existing in microsecond-pulse gliding discharges, which could be widely used in different fields. In this paper, in order to investigate mode transition among different discharge modes, effect of gas flow, pulse repetition frequency (PRF), and electrode distance on microsecond-pulse gliding discharge was studied by the measurement of the voltage-current waveforms and discharge images. Experimental results showed that both the breakdown voltage of spark and ignition voltage of diffuse decreased with the increase of the PRF, which was closely related to the memory effect of the residual particles in the time interval. Moreover, all other things being equal, breakdown voltage of spark also decreased with the increase of the gas flow, while ignition voltage of diffuse remained uncharged, which could be explained by the state of the air flow. Increasing the gap distance led to the increase of the breakdown voltage for spark mode. Furthermore, the diffuse discharge might appear when the electrode gap exceeded or equaled 5 mm. Such variation was closely related to electric field strength. In addition, when the applied voltage was 18.5 kV, diffuse-to-spark transition occurred when the PRF increased and the gas flow decreased. When the applied voltage was 12.1 kV, diffuse mode could transit to corona or spark mode when the electrode distance changed in atmospheric pressure air.

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TANDEM FREE ELECTRON X-RAY LASER ON CHANNELING RELATIVISTIC PARTICLES

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One of the optimal ways of generation of coherent hard radiation is connected with Free Electron Laser on relativistic particles. Unfortunately, the effectiveness of "usual" FEL is very low ($dN/dn < 0.001$ quanta/particle). The possibilities of optimization of FEL and creation of tandem short wave laser with extremely high efficiency ($dN/dn >> 1$ quanta/particle) are discussed. The main role in such system plays the full Doppler effect in extreme area of Cherenkov parameters $\beta n(\omega) cos(\theta) \approx 1$ that was investigated for the first time in 2006 [1].

For such laser the very effective process of consecutive generation of two types of photons with different frequencies $\omega_{1,2}$ on the same radiating transition is possible and this double photon generation leads to the restoration of the initial state of quantum system. This effect allows predicting the possibility of multiple repeat of radiation cycle on the same pair of energy levels $\varepsilon_{n,m}$

$\varepsilon_n \to \varepsilon_m + \hbar\omega_1 \to \varepsilon_n + \hbar\omega_1 + \hbar\omega_2 \to \varepsilon_m + 2\hbar\omega_1 + \hbar\omega_2 \to \varepsilon_n + 2\hbar\omega_1 + 2\hbar\omega_2 \to \ldots$

This closed loop can be repeated many times, leading to the possibility of multiphoton generation at two-level transition of the same particle [2]. The pumping source for such laser is the kinetic energy of moving particles. In tandem FEL there is no need for inversion.

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Pre-ionization roles of upstream discharges for downstream discharges under airflows

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Airflows always bring the change of the distribution of charged particles, and also induce the discharge mode transitions. With a specific arrangement of discharge electrodes, this work focus on the interaction between discharges and airflows, and present the pre-ionization actions of upstream discharges for downstream discharges under airflows
The DBD reactor consists of two pair of plane-parallel ITO electrodes. Both upstream and downstream electrodes are made of 2mm thick glasses covered by 130nm ITO film. The size of glasses and ITO film are 180*60mm and 60*30mm, respectively. The ITO electrode was symmetrical along the horizontal and vertical position, the distance between the upstream and downstream electrodes can be adjusted. The gap distance between barriers was 5mm. The discharge system is installed after a wind tunnel, and with the flow direction perpendicular to the electrode surface. A nanosecond pulsed power is supplied to discharge excitation with the voltage amplitude U of 0-30 kV and the pulse repetitive frequency PRF of 0-3.8 kHz. The voltage and current are measured by a capacitive divider (bandwidth: 200 MHz, divider ratio: 2200) and a Pearson current probe (Pearson 6585). Both the waveforms are recorded by an oscilloscope (DPO 3014 2.5 GHz).
In static air condition, the discharge signals were same between the upstream and downstream. With the increase of airflow velocity, the second discharge current in downstream was significant higher than in upstream. The metastable particles generated by upstream discharge are transferred to downstream by airflow, and such transformation played a pre-ionization actions of of upstream discharges for downstream discharges, which can be enhanced and controlled with airflow speeds.

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Life Expectancy Determination of Form-wound Coil Isolation of High-voltage Motor

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Isolation capability of organic and inorganic isolation materials is considerably different in respect to time. There is a relatively poor dependence on time in case of inorganic isolation materials. It is very significant in case of organic materials (that are more often in use). This paper will consider life expectancy of form-wound coil isolation of high-voltage motor depending on the part of form-wound coil where it is located. Namely, although the form-wound coil of a high-voltage motor is uniformly isolated, it appears that breakdown in a form-wound coil happens mainly in certain points. The paper starts from the presumption of Weibull distribution of random variables breakdown voltage and breakdown time. Certain relation between parameters of these distributions and life expectancy exponent will be specified on basis of this presumption. Expectancy life exponent of form-wound coil isolation of high-voltage motor will be determined on basis of this relation and adequate experimentally determined parameters of Weibull distributions (depending on the position on the form-wound coil). Quantile dependence of breakdown probability on form-wound coil depending on the position on the form-wound coil will be determined on basis of knowing the expectancy life exponent.

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The characteristics of repetitive frequency discharge of Plasma Synthetic Jet Actuators

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Characteristics of plasma synthetic jet (PSJ) actuators driven by repetitive pulsed discharge have drawn much attention. In this paper, the PSJ actuator is composed of a pair of tungsten electrodes and a boron nitride cavity without a cap. The cavity has a diameter of 8 mm and volume of 400 mm^3. The distance between two electrodes ranges from 1 mm to 4 mm. A homemade generator CMPC-40D is used to excite the PSJ actuator. It can provide a pulse with an amplitude of 30 kV, a rise time of 0.5 μs, a pulse width of 8 μs, and a repetition rate ranges from 0 to 5 kHz. Effects of pulse repetitive frequency (PRF) and air gap spacing on the discharge characteristic of a single actuator are investigated. Experimental results show that the breakdown voltage increases with the increase of the gap spacing, but decreases with the increase of the PRF. During the ignition time, the discharge voltage falls to zero in a few nanoseconds and the current discharge is damped sinusoidal oscillation. We observe that the energy dissipation oscillates in time, for total discharge energy of 2 to 10 mJ. The energy decreases with the increase of the PRF, but increases with the increase of the gap spacing. Furthermore, three actuators in series connection are studied. Experimental results show that synchronous discharge could be achieved for three actuators, the actuator closed to ground breakdown first, and then the middle one, and finally the actuator near the anode. The delay time is about 50 and 10 nanoseconds, respectively.

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Electric Pulse Parameter and Electrode Geometry Impact on Plasma Formation

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Mutliple theoretical and experimental studies have investigated the species generation„ ignition, flame stability, and combustion enhancement due to nanosecond electric pulses (NSEPs) for potential applications in plasma assisted combustion (PAC) and ignition (PAI) [1,2] . While many experiments use standard pulse generators with fixed pulse duration, rise- and fall-times, and peak voltage, parameter modification may enhance flexibility by facilitating control of species or discharge characteristics (e.g. glow vs. arc). Here, we explore the impact of NSEPs on species generation and discharge evolution with various electric fields and pulse durations from 10ns to 50ns. We present optical emission spectroscopy (OES) results of species generation and images demonstrating discharge formation and evolution under various NSEP conditions. Furthermore, novel electrode geometries may induce nonuniform electric fields to possibly facilitate the generation of cold plasmas at high pressures and create other species useful for PAC and PAI. Mathematical models of the electric fields for various geometries will enable comparison to the more homogeneous electric fields of conventional geometries and provide inputs for future modeling of species generation as a function of pulse parameters and electrode geometries for future PAC and PAI experiments. We will present OES and imaging of the discharges with various electrode geometries and compare these results to electric field models to assess the impact of nonuniform electric fields on performance. The potential implications for PAC and PAI and future work for system development and design will be discussed.

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MODELING AND SIMULATION OF MULTIPACTOR DISCHARGE ON DIELECTRIC WINDOW UNDER HPM IN VACUUM

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Multipactor discharges on dielectric window seriously limits the generation and transmission of high power microwaves (HPM), which blocks the development of microwave technology. In order to understand its physical mechanism deeply, a simulation model based PIC Monte Carlo is built in this paper. The influences of microwave electromagnetic field and dielectric surface electrostatic field are considered in this model. During simulation, the realistic secondary electron yield curves as input are used, and the distributions in the emission velocities and emission angles of the secondary electrons are also took into account. The movement trajectories of electron under complex field are obtained by simulation. The influences of different emergence angles and microwave electromagnetic parameters to electron movement are also considered. It is found that the emergence angles of electron have significant effect on the movement of electron, and impact energy will be increased and return time will be reduced as the increase of electric field amplitude, and the impact energy and return time will oscillate with cycles for the change of the phase of electric field. The change of multipactoring electrons number and electrostatic field are also studied by simulation. The result shows that electrons number and electrostatic field both oscillate with twice microwave frequencies periodically for the change of time. The reason of this phenomena is explained.

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A linear transformer driver based on capacitive coupling self-triggering mode

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In the future, the fast linear transformer driver (FLTD) will include a mass of gas switches. Normal triggering technology is hard to match the increase of switches through the expansion of external triggering system. Although some triggering sequences are conductive to generate better outputs, the control system is hard to realize. Actually in a certain range of the triggering sequences, the difference of the output is tiny, so simplification of the triggering system is very important to the performance of FLTD. Taking the Marx generators for example, a lot of gaps should be triggered synchronously too, the high voltage triggering pulses come from the capacitive coupling between the electrodes and the ground. In the FLTD, because the triggering electrodes of the gas switches are “virtual ground potential”, some capacitive coupling paths also exist between the central pole and the triggering electrodes of the system. In this paper, a linear transformer driver based on capacitive coupling self-triggering mode has been described, and the preliminary circuit analysis and simulation have been completed.

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polytetrafluoroethylene films Surface treatment of atmospheric pressure three-dielectric-layer barrier discharge plasma driven by sub-microsecond repetitive pulses

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Low temperature plasma surface processing is one of the most effective ways to improve the hydrophily of polytetrafluoroethylene(PTFE) films. In order to increase surface treatment area and research the processing effects, a three-dielectric-layer barrier discharge device is used in this experiment. That is, one more dielectric layer is inserted into the gas gap between the primary dielectric layers. And the gas gap between every two layers is equal. Therefore, non-thermal plasma forms between the two gaps. At least one film sample can be treated in every gap. A sub-microsecond repetitive pulsed power generator with maximum repetitive frequency up to 1kHz , voltage amplitude up to 100kV, fall-width-at-half-maximum(FWHM) pulse duration 230ns and with pulse rise time 120ns and, is used to drive the discharge device. The discharge device is inflated with Ar/air mixture gas or others. Through the high speed photographs of discharge plasma with exposure time 5ns, it is shown that the discharge is very homogeneous. The PTFE film samples are fixed on one or double sides of the dielectric layers tightly. With a 30s surface treatment time, The water contact angle of PTFE after plasma treatment was measured at an average of 85 degree. Which indicates that the water contact angle decreases obviously compared with a 118 degree value before plasma processing. Besides, some other analytic measure ways, such as atomic force microscope (AFM) or X-ray photoelectron spectroscopy (XPS), will be carried out to acquire the surface morphology or chemical changes of PTFE films.

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Experiments about discharge in water with changing conductivity and applied voltages

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A large volume plasma with streamers is generated around an electrode with a sharp edge when a pulsed high voltage is applied to the electrode in water. Discharge in water is applied to the industry such as improving water quality. However, some of discharge mechanism in water has not been cleared. In this study, we generated the discharge in water with changing the water conductivity, measured waveforms and took pictures of discharges. Plasmas in water were generated around a copper electrode of 0.8 mm in diameter covered by an insulator of 2.2 mm. Plasmas were positive polarity. The current and voltage waveforms of the discharge were measured by a high voltage probe (Tektronix Model P6015A) and current monitor (Pearson Model 101). The conductivity was changed from 110 to 1500 μS/cm for analysis of plasma formations with current and voltage waveforms. Pictures of the discharge were taken by a single-lens reflex camera and a high speed camera. Our work has two purposes for analysis of plasmas in water. First, the current was proportionally increased when the conductivity was increased and shapes of plasma were also changed. The progress distance of streamers was shorter when the conductivity is larger. However, the emission of light on plasma was increased. Next experiment was change the applied voltage, and considerations how to generate discharges. The applied voltage related to the discharge probability. In the low applied voltage, discharges had like grain of light at the tip of streamer in almost all pictures. The grain may be small babbles in the water, and the progress of plasmas grew to small bubbles. Our experiments about changing conductivity and applied voltages will be fundamental data for some applications of discharge in water.

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Optical and Illuminant Characteristics of Nanosecond-Pulse Diffuse Discharges in a Point-to-point Gap

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Diffuse discharge sustained by nanosecond pulses can generate volume discharge at atmospheric pressure, which has been widely studied since 2010s. Although the fast rising time limits the formation of spark stream under certain condition in nanosecond-pulse discharges, the pulse repetition rate and gap spacing may also affect the discharge mode. Our previous work showed that nanosecond-pulse discharge in an inhomogeneous electric field could generate various discharge modes (corona, diffuse and spark discharges) in air and other gases at atmospheric pressure. In this paper, the optical emission spectra and discharge images are investigated to analyze the optical and illuminant characteristics of nanosecond-pulse discharge at different discharge modes.
The emission spectra were used to analyze the optical characteristics of nanosecond-pulse discharge. The experimental results showed that the emission spectrum of diffuse discharge ranged from 300 nm to 425 nm. Typical spectral lines, such as OH, N2, N2+, are observed, among which the spectral lines at 337.1 nm had the largest intensity. The emission spectrum of spark discharge ranged from

200 nm to 950 nm. The spectral lines included NO, OH, N2, N2+ and O, among which the spectral lines at 777.1 nm had the largest intensity. Moreover, the intensity of spectral line for N2 in spark mode was larger than that in diffuse mode, which indicated the existence of large discharge intensity in spark mode.
The grey-scale method was used to estimate the illuminant characteristics of different discharge modes in nanosecond-pulse discharges. The experimental results showed that the maximum grey values were 60, 180 and 255 when the discharge modes were corona, diffuse and spark, respectively. Three regions, such as near-anode region, central region and near-cathode region, could be distinguished according to the grey scale values in diffuse mode. Furthermore, effect of the pulse repetition rate and gap spacing on the diffuse mode was studied.

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Computer Simulation Evaluation of an Electric Current Impulse generator

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The lightning are natural phenomenon of extraordinary complexity that has significant influence on life on Earth in many ways. Discharges cause risk of potential effects on the safety of living beings and are capable of causing damage to the integrity and operation of electric power and communications systems. Therefore, many researches are focused to understand the phenomenon, but there is some difficulty in working directly as it occurs in nature. Thus, alternatives used to study lightning are either by computer simulation or by simulation from capacitor discharges. By exposed, this paper presents a computer simulation of a simulator of lightning, better known as current impulse generator. Resistor, inductor and capacitor (RLC) represents the electric circuit of generator. Moreover, it was considered that generator consists of three capacitors in parallel and test object to impulsive current injection is a grounding grid represented by its earthing resistance. Then, with the objective to evaluate the response of the simulated event, it was used the variable capacitance, inductance, capacitor charging voltage and ground resistance such that they obtain different current curves as a function of the generator discharge time. The simulations were performed with four different configurations of impulse generator and each variable was used separately while the others were held constant. The evaluated parameters were amplitude, front time and half-wave time of the current signal generated in the test object. As a result it was observed that: the charging voltage had no significant influence on the variation of front times and half-wave times of generated signal; raising the capacitance caused no significant variation in the magnitude of the current; the higher the inductance, the lower the front time of the injected current; and the amplitude of the applied current vary significantly when it was changed the resistance value of the simulated ground system.

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Improvement of Ozone Producing Coaxial Reactor by Tensioned Inner Wire Electrode in Using Nanosecond Pulsed Power

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Ozone is a strong oxidizer and becomes low environmental load because ozone is composed of oxygen atoms. Therefore, ozone is expected to be utilized in many fields, and high concentrated and efficient ozone producing method is desired. Although the ozone production using dielectric barrier discharges is generally used because of obtaining high concentration, the production efficiency is not high in consideration of cooling energy for the system. In contrast, streamer discharges generated by pulsed power produce ozone with high efficiency but not high concentration.
Nanosecond pulsed power has been introduced to produce ozone efficiently and we attempted to increase concentration by adopting the thin coaxial reactor with short electrode separation. In previous studies, temporal downturn of ozone concentration was observed and the peak concentration was not maintained. Then, it was observed that the inner wire electrode curved and spark discharges frequently occurred around where the electrode gap narrowed. These phenomena were considered as a cause of decreasing ozone production. In this study, we experimented with two approaches to suppress these phenomena. One was an adoption of a thicker inner electrode. The diameter of the inner electrode was altered among 1, 8, and 14 mm as a preliminary experiment. Although the curvature of inner electrode was constrained, ozone concentration decreased. This would be because reduction of electric field strength on electrode surface decreased occurrence of streamer discharges. There is, however, a room of study because decreasing of ozone concentration was small in using 8-mm electrode. Another was an adoption of tensioned inner wire electrode by a spring. The curvature of inner electrode was constrained. As a result, the downturn of ozone concentration was not observed and the concentration increased in stable state. In addition, the effects of increasing number of reactors and the others will be discussed in presentation.

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PLASMA-ASSISTED COMBUSTION TECHNOLOGY USING NANOSECOND PULSED POWER

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Next generation type of ignition system has been developed in a gasoline internal combustion engine called as “Plasma-assisted combustion technology” [1]. This technology is considered to improve an engine performance through increasing the lean burn flammability and reducing emissions by applying non-equilibrium plasma to gasoline. However, the detailed effect of non-equilibrium plasma on gasoline is poorly understood. In this study, the reforming mechanism of gasoline by non-equilibrium plasma is investigated using gas chromatography.

At first, a nanosecond pulsed power generator using fast recovery diodes was developed to generate non-equilibrium plasma. This pulse generator supplied 9 ns rise-time, 17 ns FWMH, 32.5 kV amplitude pulses into a 1 kΩ load. A non-equilibrium plasma can be produced at a pressure between 0.1 MPa to 0.5 MPa, limited by a vessel.

The pulsed power from this pulsed generator is applied to the spark plug used at conventional ignition system in a gasoline engine. The gasoline is reformed by non-equilibrium plasma at 0.1 MPa. After non-equilibrium plasma is applied to gasoline, the component of reformed gasoline is investigated using gas chromatography. As a results, lower-hydrocarbons, such as methane, ethylene, ethane and propylene, are produced newly. Applying more pulses increases the amount of generation of these lower-hydrocarbons.

It is concluded that the lower-hydrocarbons my be produced by the active species generated by the non-equilibrium plasma. It is well known that lower-hydrocarbons are easier to ignite than higher-hydrocarbons. Plasma-assisted combustion technology could improve the engine performance. We

are currently investigating the credibility of our hypothesis and the effect of non-equilibrium plasma to generate lower-hydrocarbons, considering the features of applying pulses.

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STUDY OF THE CORONA EFFECT : APPLICATION TO THE IONOCRAFT

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An ionocraft is an asymmetrical capacitor that uses high voltage (> 20 kV) to produce thrust in the air without requiring any combustion or moving parts. The high voltage ionizes the gas present between the two electrodes by corona effect and moves this ionized gas in a direction defined by the shape of the electrodes. The principle of ionic Wind propulsion with corona-generated charged particles is the Biefeld-Brown effect discovered by Thomas Townsend Brown in 1928.
This paper presents a parametric study on the corona effect. The empirical Peek law predicts the threshold appearance of the corona effect on a wire. This law is studied and compared to experimental measurements. These results allow an optimistic design of an ionocraft (weight = 5 g) working in the range of 20 kV and 1 μA.

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Spatial resolved observation of repetitive nanosecond volume discharges under airflows

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Repetitive nanosecond discharges have received considerable attentions for their wide industrial applications. Among these plasma applications, a large volume discharge in atmospheric pressure is currently one of the most widely proposed methods. This paper presents nanosecond volume discharge behaviors under high-speed airflows. ICCD pictures and discharge electrical characteristics are obtained and used to study the effects of airflows on the volume discharges.
The experimental system includes a subsonic air wind tunnel, a nanosecond pulse generator, discharge systems, and measurement systems. The airflow speed can be adjusted with a maximum value of up to 250m/s. The plate-plate electrodes separated by a 6 mm vertical distance are set in a horizontal and parallel manner. The two electrodes are composed of stainless steel plates with the sizes of 40 mm ×100 mm and a thickness of 2 mm. The discharge system is installed at the downstream of the wind tunnel exit, and with the flow direction perpendicular to the electrode surface. The voltage and current are measured by a capacitive divider (bandwidth: 200 MHz, divider ratio:

2200) and a Pearson current probe (Pearson 6585). Both the waveforms are recorded by an oscilloscope (DPO 3014 2.5 GHz). A high resolution ICCD is used to observe discharge development and discharge mode details.
The ICCD plasma images indicate that the volume discharge modes vary with airflow speeds, and a diffuse and homogeneous volume discharge occurs at the speed of more than 50m/s. With different ICCD exposure times, the discharge modes have detailed definition as filament discharge or diffuse discharge. The role of airflows provides different effects on the 2-stage pulse discharges. The 1st pulse currents maintain consistency with airflow speeds, and the 2nd pulse currents always first decrease and then increase. The inhibited effect caused by airflows begins to dominate at higher flow speeds. The pulse repetitive frequency should be high enough to generate stable plasma for high-speed airflow applications.

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High Voltage, Fast Kicker Power Supply

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Short-pulse dielectric Two-Beam Accelerators (TBAs) have the advantage of producing high accelerating gradients near GV/m at significantly lower cost and complexity over traditional superconducting accelerators, which could significantly reduce the overall cost of accelerators for both scientific and industrial applications. One challenge is the development of a high voltage fast kicker system for the staged dielectric TBA. Kickers are electromagnetic devices that create very fast fields to deflect charged particles to divert a portion of the beam away from the accelerator for use. In general kicker systems require fast rise times and precision flat-top for uniform beam deflection. The requirements for the fast kicker system for dielectric short-pulse TBA are very demanding, and there is currently no power supply that can meet the all the necessary requirements. Eagle Harbor Technologies, Inc. has developed unique high voltage nanosecond pulse technology that can be utilized to meet the requirement for future TBA systems. EHT has demonstrated an 80 kV modular power supply system with fast rise time capability (~16 ns). To reach the desired output voltage of 160 kV EHT proposes to combine two of the 80 kV systems to enable the fast kicker power supply.

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PIC/DSMC Simulation of Radiation Transport Dynamics in Helium Gas Discharges

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Largely absent from kinetic, low-temperature plasma simulations is the capability for simulating radiation transport. It is largely acknowledged that self-produced radiation from gas discharges may have an impact on plasma formation and there is a need to include this physics into modern simulation codes. As such, there has been some effort in including photon dynamics into plasma simulations although they are generally only applicable to a single gas mixture such as air or focus

on a small subset of transitions. In this work, a thorough kinetic description of Helium is included into a massively parallel Particle-in-Cell (PIC) utilizing Direction Simulation Monte Carlo (DSMC) for electron-neutral interactions. Additionally, a method for radiation transport is included that includes both natural and Doppler line broadening as well as self-absorption mechanisms. This method demonstrates the capability of modern PIC simulations to simulate temporally and spatially-resolved emission spectra and include energy-dependent photon dynamics such as photo-emission from the electrode surfaces. One-dimensional simulations of a Townsend discharge at various pressures in pure helium depict the evolution of the excited state densities and subsequent spontaneous emission. It is shown that high-energy photons emitted from the ground state transitions of helium (41P -> 11S, 31P -> 11S, 21P -> 11S), while heavily self-absorbed by background neutral particles, are capable of reaching the cathode causing additional electron current due to photo-emission.

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Research on 24MJ PFN for electromagnetic launch discharged in sequence

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ABSTRACT: Electromagnetic launch technology(EML) is a prime candidate for furture long range artillery systems. Pulse thyristor is one of the key components in pulse power supply(PPS). Mutiple modules are fired sequentially to generate flattop waveform for the load. However, in the circumstance, thyristors are easy to fail. In this paper, the pulse thyristors' reliability was researched when the pulse forming network(PFN) was fired sequentially. The reverse recovery over voltage in discharge process is the main reason of thyristors' failure. Based on a 24MJ Electromagnetic launch system, a macro-model of scr was eatablished, in which, the reverse recovery process was taken in consideration. The change of reverse recovery over voltage was fitted by hyperbolic secant function. Experiments showed that the model could precisely predict reverse recovery over voltage of pulse thyristors in the 24MJ Electromagnetic launch system. On the other hand, this paper studied the inhibition of inductance on the reverse recovery over voltage of scr in PPS. It was showed through simulation that an appropriate increase of induntance value could effectively inhibit current drop rate so as to inhibit the reverse recovery over voltage of scr. Meanwhile, the overall efficiency of PPS would not decline significantly. This paper took 24MJ Electromagnetic launch system as test platform. In the first round of testing, 13 pulse forming units(PFU) was fired sequentially. The thyraitors failed when the inductance value was 10uH. Then, 120 inductor was added to each PFU through converting parameters. After that, The 24MJ Electromagnetic launch system operated reliablely when it was triggered in different time sequence.

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Influence Factor on Sweep Frequency Impedance to Detect Winding Deformation within Power Transformer

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As a device of power transmission and distribution, a power transformer is considered to be the heart of a power system, and its safe running is important. The rate of transformer failures caused by the winding deformation remains high, therefore the study on detecting the transformer winding deformation is of great significance to avoid unexpected accidents and improve the reliability of the operation in power systems. To detect the winding deformation within a power transformer effectively, people develop lots of non-destructive methods, such as frequency response analysis (FRA), short circuit impedance (SCI), sweep frequency impedance (SFI), low voltage impulse (LVI), and so on. As a novel detection technique, the SFI method is widely used on onsite test due to its well anti-jamming ability and definite standard code, but its characteristics still need be studied further. In this paper, a fast, economical, and nondestructive testing system was established to study influence factors, which included the length of the grounding line, the cross-sectional area of the outside short circuit line, and the shape of the inside short circuit line, on SFI method during detecting winding deformation within a power transformer. The experimental results show that: 1) the change of the grounding line length leads to the change of the SFI curve at high frequencies, which results in the misjudgment of the transformer winding deformation. 2) the cross-sectional area of the outside short circuit line impacts on the SFI value at 50 Hz. 3) the shape change of the short circuit line between two disks does not affect the tendency of the SFI curve during simulating a short circuit fault within a power transformer.

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Simulation of the transient overvoltage in HVDC scheme during the operation of MRTB

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During the transfer from monopolar ground return mode of HVDC to monopolar metallic return mode, Metallic Return Transfer Breaker (MRTB) will cut a large current and induce transient overvoltage on dc output and converter transformer. It is challenging to simulate this electromagnetic transient, because the arc procedure of MRTB is usually ignored in traditional simulation. In this paper, a simulation model of a±800 kV HVDC scheme is established in PSCAD to investigate the transient procedure. The MRTB is simulated with three branches, including SF6 breaker branch, arrester branch, and a series branch of a reactor and a capacitor. When the MRTB start to open the ground return circuit, an arc initials at the fracture of the breaker. Nonlinear resistance of the arc forms a resonant loop with the reactor and the capacitor, and the resonant current will cross zero and create a break condition for the breaker. The dynamic resistance model of the arc generated in MRTB is built based on Mayr's arc model. The MRTB model is able to simulate the dynamic performance of the switch operation procedure, and then is applied to analyze the overvoltage in the HVDC scheme. Once the resonant current is suddenly cut off, the energy stored in the reactor will be transferred to the capacitor and then absorbed by the arrester. Thus, the voltage on the MRTB increased abruptly and then decreased slowly. The highest voltage appeared on the MRTB is over 100 kV. Besides, the overvoltage at inverter side is over 1.1 p.u. The DC bias voltage from the converter side windings to the earth also varies with the operation of the MRTB, but the winding voltage remains unchanged.

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SEPARATION PROCESS OF PLASTIC AND METAL FROM CD-R USING PULSED POWER

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We are investigating a new method to recycle metal and plastic from metal-coated plastics used as components of automobiles and electronics using pulsed power. In this study, we used CD-R as an example and investigated the separation of metal (silver layer) and plastic (polycarbonate basis) from CD-R using pulsed power. The pulse power from a magnetic pulse compression generator having the maximum storage energy of 40 J/pulse was applied to the gap between two ring electrodes on CD-R. The progress of the removal of metal layer and the state of discharge are observed every time of pulsed voltage application.

As a result, almost all of the silver layer was separated from polycarbonate basis by the 25 shots of pulsed power having storage energy of 35.3 J/pulse. In addition, the discharge was observed in every shot.

The light emission from the discharge at the first shot was measured using a spectroscope. As a result, spectrum related to silver was observed. It means that the discharge occurs between the ring electrodes and the silver layer and the protection layer of insulation material was punctured.

In the second and the following shots, one or two peaks were observed in the voltage waveform. The value of the first peak in the second and the following shots increased with the number of shot. As shot number increases, metal layer around the ring electrode is removed gradually and the gap length between the ring electrode and the exposed silver layer also increases gradually. Therefore, the value of the first peak in the second and following shots is supposed to correspond to the discharge onset voltages in air gap between the ring electrodes and the exposed silver layer.

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Motion Behavior of Free Conducting Wire-type Particles in SF6 Gas under DC Voltage

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Based on a large number of engineering practices, free conducting particles are unavoidable in GIS, which is largely threaten the security operating of GIS devices compared with fixed conducting particles. Scholars chose sphere particles and air as medium for easy analysis and calculation, which is not agree with practice situation. Therefore, the free conducting particle experiment device and observation system are specially designed and the motion behavior of free wire-type conducting particles in SF6 gas is studied in this paper. Firstly, the strength model of free wire-type conducting particles and lift-off law are discussed. Furthermore, lift-off electric field strength as a function of gas pressure, shape of particles are researched. The result shows that lift-off electric field strengths are unchangeable with gas pressure; when lengths of particles increase, lift-off electric fields strengths increase slightly. When radius of particles increases, lift-off electric field strengths increase exponentially. Finally, the cohesive strength between particles and electrode, which has an inconvenient effect on particle lift off and often be ignored before, increases as the radius of particles decrease.

When the radius of particle is 0.65mm, the cohesive strength is little and even can be neglected in the case of length of particles shorter than 3mm, which makes the calculation value of lift-off electric field strength is similar with the experiment value.

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Spectral mapping of the corona discharge

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High voltage equipment like transformers, circuit breakers, etc. are vital for reliable power supply. Condition monitoring of these equipment is essential to avoid loss of revenue and unscheduled outages that happen because of catastrophic failures. Usually, these failures are a result of sustained corona or partial discharges and may also be due to system conditions that stress the equipment insulation. Generally, corona discharges occur at the asperities of the metal conductors and are a precursor for flashovers. The corona and its characteristics are well studied and reported in the literature. The objective of this work is to report investigations in the pre-corona region processes that are precursor to a corona discharge. The paper presents experimental results along with corresponding mapping with the VI characteristics of corona discharge. The pre-corona and corona are generated in the laboratory with point-plane geometry of the electrodes. The instrumentation designed for measurement consists of collecting ultra-violet optical signatures and transferring them to a spectrometer for further analysis. Corona discharge in the air produces optical signals in the ultra violet region and electromagnetic waves in the ultra high frequency range. Thus, opening the possibility of mapping these on the electromagnetic spectrum. The corona discharges are also associated with audio signals that can be mapped on the longitudinal spectrum. These pre-corona processes with its corresponding signal can provide valuable insights for development of instruments that can detect and forewarn about impending failures.

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Effect of Solution Electric Conductivity on Surfactant Treatment Using Nanosecond Pulsed Powers

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Development of the treatment technology of household effluent and industrial wastewater is imperative for environment conservation. In recent years, water treatments with electric discharges have been studied as one of the water treatment technologies. We have studied the decomposition of organic compounds, as indigo carmine and surfactant, in the water by streamer discharges generated with nanosecond pulsed powers. Streamer discharges not only generate active species such as ozone and OH radical but also effectuate direct actions such as shock waves and ultraviolet rays. Because surfactant was contained in household effluent and industrial wastewater, and was persistent, the surfactant was chosen as a treatment target.

In this study, a solution of persistent surfactant: nonylphenol ethoxylate was treated by using streamer discharges generated with nanosecond pulsed powers. The effect of electric conductivity of the surfactant solution on the treatment was investigated. The conductivity was changed by adjusting added KCl (potassium chloride) amount in the surfactant solution. The foam, which is a typical characteristic of surfactant, in water reservoir disappeared faster when the conductivity was

higher. Because measured ozone concentration was approximately same after 80 minutes in all conductivities, it was considered that increase in conductivity due to addition of KCl could not affect the ozone production but surfactant degradation. In these experiments, streamer discharges might directly act on surfactant treatment or potentiate the reaction of ozone to surfactant. Increase in absorption around 200 nm with conductivity was observed by spectrophotometric analysis for the solution. It was suggested that nonylphenol was generated by decomposing nonylphenol ethoxylate.

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Design of a 5.5MJ Charge Dump Power Supply for the PPPL FLARE Experiment

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The Facility for Laboratory Reconnection Experiments (FLARE) [1] is an intermediate laboratory experiment currently under construction at Princeton University by a consortium of five universities and two Department of Energy (DoE) national laboratories, located at the PPPL. The goal of FLARE is to provide experimental accesses to new regimes of the magnetic reconnection process and related phenomena directly relevant to heliophysics, astrophysics, and fusion plasmas. The device comprises a vacuum chamber and 9 coils sets that are independently programmable to provide the poloidal and toroidal magnetic fields required to form plasma and study the effects of magnetic reconnection. Each of these 9 coil sets requires a separate pulsed power system, it is the design of the power systems that is reported here. The 9 separate pulsed power systems combine to produce over 5.5MJ of energy to the experiment and each presented their own unique challenges. The most energetic power system is a 3.4MJ, 19.2mF capacitor bank charged to 20kV that provides the guide field, with a rise time of approximately 12ms it delivers an average peak current of 40kA over 5.3ms to 12 coils wired in series. The poloidal field coils consist of two separate coilsets each requiring 540kA peak current which is produced by two 20kV, 2.64mF capacitor banks. The design of the two driver coilsets each charged to 60kV will also be presented. Work supported by NSF Grant Number: PHY-1337831 Title: “MRI Consortium: Development of a Large Plasma Device for Studies of Magnetic Reconnection and Related Phenomena” under subcontract from PPPL under PO94088 [1] H. Ji et al Status and Plans for the Upcoming FLARE, Bulletin of the American Physical Society DPP 2015

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Effects of pulsed magnetic field on performances of semiconductor devices

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The electromagnetic launch system generates strong magnetic field radiation when discharging, which may degenerate or even destroy the function of semiconductor devices. Based on fundamental theory of Electromagnetics and Semiconductor Physics, this paper established magnetic injury effect model of typical semiconductor devices, such as diode, transistor and etc. The relation equations of magnetic induction density and these devices' output parameters, which involving forward voltage drop and electrode current, was abtained through the derived equations between magnetic induction density with semiconductor mobility and scattering rate. To test and verify the model, experiments was designed to study effects of pulsed magnetic field on characteristic parameters of typical semiconductor devices. In addition, the relation curve between magnetic flux density and these parmeters was abtained in accordance with the experiment data. Finally, the equation of scattering rate was corrected according to the relation curve to improve the theoretical model, and the improved model approximately agreed with the experimental results.

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Design and Implementation of a Hierarchical Control System Architecture for a Modular Pulsed Power Supply System

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Using generalized building blocks for the design of power electronics converters is advantageous in terms of scalability, modularity, power density, and reliability. For the control of those power electronic converters composed of Power Electronics Building Blocks (PEBBs), an easily scalable and modular control system should also be integrated. In this paper, a hierarchical control system architecture together with both communication and protection means is proposed for a modular Pulsed Power Supply (PPS) for the implementation of Electromagnetic Launcher (EML) system. An isolated interface between high voltage control system elements on each PPS module and main control system is recommended and implemented for the EML system. The proposed control system architecture is formed via modular PXI based control hardware of National Instruments. The proposed hierarchical control system architecture is an industry application of the control system architecture suggested in IEEE Standard [1] to the PEBB based modular PPS with some application specific contributions of authors to the subject.

Keywords: Hierarchical Control System Architecture, Power Electronics Building Blocks (PEBB), Pulsed Power Supply (HAPF), High Voltage Isolated Control System

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The development of three stage electromagnetic forming facility and its timing control system

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A Space-Time-Controlled Multi-Stage Pulsed Magnetic Field (Stic-Must-PMF) forming and manufacturing technology is introduced in Wuhan National High Magnetic Field Center, the technology is based on spatially strategically placed multiple coil systems and each coil can be addressed individually by its associated power supply with precise timing control. Such well-designed space-time distribution of electromagnetic force could lead to the forming and manufacturing of sheet and tube parts and components with controlled materials properties.
Based on Stic-Must-PMF a Three Stage Electromagnetic Forming Facility is developed. The designed facility is composed of three capacitor power modules. The total energy of each power module is 1MJ, 200KJ, and 14.4KJ respectively. The power modules can be freely selected or utilized for driving multi-stage coils under its timing control system. The precise timing control system is designed for power modules configuration and discharge control. By generating precise and synchronous triggering signals according to the requirement of forming, the multiple power modules could be discharged to multi-stage coils synchronously or in a preset time sequence.
With the application of the designed and fabricated triple-stage electromagnetic forming system, an approach of radial Lorentz force augmented electromagnetic forming is proposed to realize the deep drawing with large drawing ratio. The forming depth of aluminum alloy sheet (1060-H24) has been dramatically increased from 8.44 mm to 20.28 mm.

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Effects of increasing the repetition rate in nitrogen oxides treatment using pulsed discharge plasma

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Nitrogen oxides (NO_X) and particulate matter (PM) emitted from diesel exhaust causes awfully problem to the atmosphere. Current processing techniques are using the catalyst with a precious metal. By contrast, treatment of diesel exhaust using non-thermal plasma (NTP) might reduce the amount of the catalyst that the system uses. Topic of diesel exhaust treatment by NTP has been investigated by many research institutions to date. Nevertheless, it's not realized yet in motor vehicle pollution sources. Nitric oxide (NO) accounts for a large percentage of NO_X in exhaust. Fluctuation of the engine load, it significantly changes both NO and PM concentrations. Therefore, the system using NTP must cope with abruptly change of concentration. We investigated the effects of increasing the repetition rate under the same energy density in simulated gas. The temperature of gas included room temperature in order to simulate the time of starting the engine. The NTP was generated by applying a high voltage pulsed power supply to a dielectric barrier discharge (DBD) reactor. In this work, power supply having the magnetic pulse compression (MPC) is used to obtain a pulsed high voltage. Charge and discharge controller is improved for the purposes of experiment and became high-speed response. The experimental results show that the dispersion of NO removal rate is suppressed by increasing the repetition rate under the same energy density. The stability of NO removal rate by NTP contribute to the stability of the whole system.

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Behavior of Pulsed Streamer Discharges in Flowing Water

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Underwater streamer discharges produced by pulsed power have applications for water treatment such as an algae treatment at dam, clean of water and sewage and so on. Streamers propagation, bubble formation along streamers, bubble collapse, generation of shock waves and extinction of bubbles were observed by previous work. In this work, a target situation is flowing water from a moving rod electrode. The moving rod electrode in water is used to simulate flowing water. This water conductivity is 100 μS/cm. A pulsed power generator using MPC (Magnetic Pulse Compression) circuit generates a maximum output of 5 J/pulse and maximum repetitive rate is 250 pps (pulses per second). The high voltage electrode is needle tungsten, and the ground is plate copper. The high voltage electrode is moved by a robot at rates up to 1 m/s, and the moving distance is 30 cm along the longitudinal direction. The voltage and current waveforms were measured by a high voltage probe and a current monitor, respectively. Pictures of plasmas form moving rod electrode were taken by a single lens reflex camera or a high speed camera. Research methods were generation of plasmas or not from pictures. The results and conclusions, electrode velocity was important condition for generation of plasmas, discharges depend on the applied voltage also applied energy, and small bubbles were important for generation of plasmas. Those experiments showed 0 cm/s of electrode velocity is 100 % of discharge ratio and 100 cm/s is around 70 %, and 22 kV of peak voltage is 0 % of discharge ratio and 29 kV is 97 to 100 %.

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Lightning strike discharge simulation test research on shielding characteristic of lightning rod

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The negative high-voltage switching voltage impulse with long wavefront time was employed to conduct lightning strike discharge simulation testing research on shielding-protection characteristic of lightning rod. In order to simulate the leader attachment and the protection process of lightning rod, the rod to rod discharge electrode arrangement was applied, the upper rod electrode was used to simulate the natural lightning downward leader while the lower one simulated the scaled tested lightning rod; meanwhile, a scaled conductive bar was placed around the tested lightning rod to simulate protected object. By conducting repeatedly the lightning discharge simulation test at different height and different distance of the protected object (conductive bar) for the tested lightning rod, the attachment probability and the protection range of the tested lightning rod can be statistically figured out. According to the method described above and contraposing the 30 meters protection radius, using 1:7.5, 1:10, 1:12.5 scaled-down models, the shielding-protection characteristic of a 12 meters height lightning rod was investigated by employing the lightning strike simulation test. Based on the discharge attachment probability of lightning rod to be greater than the value of 90%, the protection curves (areas) of the tested lightning rod were obtained for each scaled model, and compared with the rolling sphere method with radius of 30 meters. The results showed that the influence of the scaled ratio is small for the protection curve testing and all the tested curves are well consistent with the rolling sphere method, when employing an about 2.5 meters long bar to bar discharge gap arrangement and negative switching voltage impulse with wave front time of 125 ± 20 microseconds. The consistency seems indicating that it would be reasonable to use the negative switching impulse voltage with long wavefront time to conduct the lightning strike discharge simulation test, and this would be instructive for experimental testing of the lightning protection performance of new-type lightning protection devices.

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Coupled Thermal-Electrical Simulation Analysis for Carbon Fiber Composites Exposed to Lightning Current Impulse Based on Deleting Cell Process

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Carbon fiber reinforced composite materials are widely employed on aircraft because of its superior structural and weight performances. Carbon fiber composites possess a much lower electrical conductivity as compared to traditional metallic materials, which lead to serious damage when subject to lightning strike. In order to protect the carbon fiber composites, metallic mesh are used to cover the materials. While the lightning strike damage mechanism of metallic mesh protected carbon fiber composite panel is not explicit, which demands further research. In this paper, simulated lightning current impulse was employed to strike on copper mesh protected carbon fiber composite specimens. Then ultrasonic detection was applied to inspect the damage characteristics of tested composite panels. Based on deleting cell process, coupled thermal-electrical simulation model of carbon fiber composites exposed to simulated lightning strike was established, and lightning current impulse damage mechanisms of composite specimens was discussed. Furthermore, Considering the electrical conduction of carbon fiber composites following its temperature was revealed to be a key parameter for accurate numerical simulation, a modified simulation model was established. The modified model utilize a hypothesis of the electrical conductivity of carbon fiber is inversely proportional to its temperature from decomposition to sublimation. In order to further reveal the damage mechanisms of carbon fiber reinforced composite materials caused by the lightning strike, comparisons were conducted between the numerical simulated results and the experimental results. Research results showed that assume negative correlation between the electrical conductivity of carbon fiber and its temperature from decomposition to sublimation acquire reasonable numerical results, joule heats generated by lightning current was main factor lead to lightning strike damages of carbon fiber composite panels. The research is helpful for understanding the complicated damage phenomena caused by lightning strike, and optimize lightning strike protection for carbon fiber composites.

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Observation of Underwater Pulse Discharge and Influence of Deposited Energy on Shock Wave

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The shock wave generated by underwater pulse discharge has been used in many industrial applications such as electrohydraulic forming, oil stimulation and rock fragmentation. From an industrial point of view, how to achieve high electrohydraulic transformation efficiency is one of the main focus. To solve this problem, the comprehensive understanding of the sophisticated phenomenon is required.

In this paper, an optical observation system for underwater pulse discharge system is established to study the shape variation and the movement of arc and bubble. Needle to needle electrodes are used in experiments, of which the discharge gap length is from 10 mm to 25 mm. The charge voltage of the main capacitor (3μF) is 30 kV. A fast camera (FASTCAM SA-X) with multiple ND flitters (ND 1000 + ND 400) is equipped to capture the shape variation and the movement of arc and bubble. The arc voltage, current and the pressure of the shock wave are acquired by Tektronix P6015A,

PEM CWT600 and PCB 138A01 respectively, all signals are stored in a 350MHz oscilloscope (Agilent HD4034). The method of calculating deposited energy and average arc resistance is proposed as well, in which the time variation characteristic of the arc is taken into consideration. Finally, the influence of deposited energy on shock wave is analyzed.

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Generation and Characterization of a Pulsed Dense Plasma with Helium*

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This contribution is about characterization of a Lorentz-drift based plasma accelerator in preparation for a colliding plasma experiment. The aim is to investigate the basics of a high energy density collision zone by accelerating two or more plasma sheets simultaneously against each other. A possible application for this device is the production of high densities for a plasma stripper.
The experimental setup has a total capacitance of 27uF at maximum voltages of 10kV. The maximum discharge current of 147kA is switched by a thyratron. Due to a low inductive setup of 130nH high current slew rates in the 10^{11}A/s range are achieved. These are necessary to form a plasma sheet. All measurements have been performed in a vacuum chamber at 3 to 100mbar pressures with a 2% hydrogen in helium gas mixture.
For dynamic characterization and optimization of the acceleration process velocity and kinetic energy of the plasma sheet have been determined. For velocity measurements an array of six photodiodes has been used. Up to 80km/s velocities have been verified by the comparison to image of a fast framing camera. Moreover the images show the shape of the plasma sheet. The kinetic energy has been qualitatively examined by a piezoelectric element.
Additionally the results of spectroscopic measurements will be presented. The Stark broadening of the h_\beta-line has been measured by a 0.5m monochromator. The mean temperature has been determined via He I and He II line intensities. Electron density and temperature of the single accelerator are of great interest for the upcoming comparison to the collision experiment. In combination with the dynamic investigations the presented device is sufficiently characterized for collision.

*This project is supported by BMBF.

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Quasi-Analytical Derivation of Parallel-Plate Multipactor Trajectories in the Presence of Higher-Order Mode Perturbations

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Multipactor [1] is a resonant phenomenon in which an electromagnetic field causes a free electron to impact a surface, resulting in the surface emitting one or more secondary electrons. If the surface geometry and electromagnetic fields are appropriately arranged, the secondary electrons can then be accelerated and again impact a surface in the bounding geometry. If the net number of secondary electrons participating in multipactor is non-decreasing, then the process can repeat indefinitely.

This phenomenon is of considerable practical interest in the design and operation of radio frequency (RF) resonant structures, windows, and supporting structures.

Multipactor is frequently studied either experimentally or via numerical simulations. In the case of numerical simulations, frequently the particle trajectories are determined by calculating the force on a particle at any given step in time, and stepping the particle through many time steps. In this work, the particle position is expressed as a linear time-dependent system of equations, and the equations are solved for the case of a multi-mode time-harmonic excitation. The resulting solution is expressed in terms of an explicitly-defined integrand which in practice must be evaluated numerically. This quasi-analytical method could in principle provide an explicit integrand for any excitation in which certain intermediate quantities in the time-invariant system are analytically integrable.

This work provides an additional way of examining how various parameters affect multipactor trajectories, and could be used for further perturbation analysis. Some comparisons in a parallel-plate geometry are shown between results using this method and results from a full numerical solver that was previously used by the authors in the context of coaxial-geometry multipactor simulations [2], [3].

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This work supported by a Michigan State University Foundation Strategic Partnership Grant on Accelerator Technology.

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Analysis of Motion and Discharge of the Free Conducting Wire Particle in DC GIS

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Aiming at restraining the free conducting wire-type particles that are common but dangerous within DC GIS, a more realistic platform of coaxial cylindrical electrode is set up using high-speed camera and PD monitor, in the meanwhile, as to observe the motion, PD and breakdown of the particles. The research work starts from analyzing the charging behavior of the particle under DC voltage, then gives a quantitative analysis and an experimental verification of the particle's lifting voltage. Two different motion patterns of standing and bouncing are observed, and the relations between the probabilities of the two states' occurrence and the length of the particle are studied through experiments. Particle's Corona images are recorded, also, the impulse current method is used to monitor and extract the PD signals which are triggered by the wire-type particles. The breakdown images are also taken, and mechanical analysis of the air–gap breakdown with free conducting wire-type particle is conducted based on the stream theory. The proposed research has shown that, the lifting voltage of the wire particle is almost irrelevant to the length of the particle but has strong correlation with the radius of the particle. The length of the particle has an impact on the motion patterns, i.e. the shorter the particle, the greater the probability of bouncing, and vice versa. There exists micro-discharge corona at the particle's standing point, and the corona at the top of particle

renders polarity effects. The intensity and frequency of partial discharge increases with the wire-type particle's length. The micro-discharge gap increases with the length of the wire-type particle, while the breakdown voltage decreases with the length.

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Evaluation of Epoxy Coated Resistors in High Voltage DC Surge Environments

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The performance data of high voltage resistors in specific pulsed power applications is limited. A series of tests were performed on epoxy coated high voltage ceramic composite resistors. With the implementation of these resistors in unique applications that result in their exposure to high energy surge environments such as air conditioners and electric vehicles, there is a need for a better understanding of performance metrics under these conditions. Thermodynamic data and resistance parameters were experimentally determined with fully and partially coated epoxy resistors. This paper will explore the added benefits of the epoxy, beyond the mechanical strength and aesthetics. The potential gains include a stability of resistance and thermal surface radiation. Data collected indicates that complete epoxy coated resistors show increased performance, maintaining the pretested resistance 54% more accurately and decreasing the radiation temperature exposure to other components by 12℃.

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TO 50-YEAR ANNIVERSARY OF PULSE METHOD: FROM A STORM IMPULSE TO THE ONE-STAGE ON-LINE REGIME

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This paper is devoted to further development of pulsed method for transformer winding diagnostics. Power transformers are key components of any electrical power systems. A big amount of the power transformer population all over the world being in service at the moment, have been reached an age of 30 – 40 years and more. Timely state control of transformer winding is necessary step to provide a stability of electric energy system. Experimental results of winding state control on real transformer have been given. Ways of sensitivity increasing have been determined. "Classical" diagnostics, which means two stages - probing pulse input and response signal control - could be improved by using short probing pulse. It is shown that, sensitivity of state control is increased with smaller pulse duration (up to 25 ns) and more rapid front pulse (no more than 5 ns). Combination of places of giving of the probing impulse and a response signal measurement is also important. Depending on when a fail is – high or low voltage winding – combination of diagnostics signal influences to sensitivity.
Other approach is "one-step" state control. To check a winding state just one probe pulse is used and investigated. It is established that, winding fault could be revealed by just probe pulse analyzed.

An efficiency of "one-step" diagnostics increases at reduction of probing pulse duration. It is promising way for winding state control at on-line regime and lead pulsed method to new level. This is especially important so as pulsed method has its 50-year Anniversary in this year.

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Influence of HVDC Converter Operation on Partial Discharge Characteristics

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This paper presents an investigation of the influence of different operating conditions of HVDC convertors on partial discharge behavior occurring within cables on the DC side of an HVDC system. Cables at the DC side undergo different stresses due to transients and harmonics, which affect their insulation integrity and may result in an intensified level of partial discharge (PD) activity. Most DC schemes, nowadays, are bidirectional with the valve firing angles at the heart of power conversion and power flow control. Depending on the mode of converter operation and the properties of the interconnected AC systems, varying levels of harmonics, either characteristic or non-characteristic, appear on the DC side. By reproducing a down-scaled version of the DC output of conventional HVDC converters under controlled laboratory conditions, PD signals occurring under an HVDC applied voltage generated at different converter firing angles have be measured. PD was produced using a range of insulation samples containing known defects and measured using an HFCT sensor with a bandwidth of 19 MHz. Characteristics of the acquired PD signals have been analyzed using statistical methods with the aim of finding a promising condition monitoring tool to identify the influence of the generated harmonics on PD activity. The results will aid HVDC network operators in identifying incipient cable faults by contributing to diagnostic knowledge rules for interpretation of PD parameters under known operating conditions.

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Thermal and Mechanical Analysis of Electromagnetic Loading on Stainless Steel Structures

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In high voltage applications that require a resistive load or shunt, one must turn to non-traditional resistor construction techniques to satisfy electrical power absorption and load matching requirements, handle thermal loads, and resist distortion and destruction due to generated Lorentz forces. A readily available material that meets these requirements is 304L stainless steel. Pipes constructed of 304L stainless are available in multiple diameters and lengths which allow one to satisfy electrical design considerations; in a coaxial configuration that minimizes the electromagnetic fields exterior to the shunt. Because of Ohmic heating during high current operation of the shunt, it is important to thoroughly analyze and evaluate the structure's temperature distribution relative to system integration and operational requirements. In addition, while electromagnetic fields are constrained to the interior of such a shunt, these fields give rise to very strong Lorentz forces on the inner and outer

conductors. These forces must be evaluated from a safety and fatigue perspective to make sure that system operation with such shunts does not endanger the system or personnel.

In this presentation, the author proposes a readily constructed, resistive, coaxial shunt from commonly available 304L stainless steel and yellow brass. This shunt is fed by multiple 350 MCM coaxial cables and is amenable to quarter symmetry analysis for numerical efficiency and to reduce computational runtime. The shunt is modeled in a commercially available multiphysics package and excited by current sources that drive each coaxial cable equally. Analysis of the thermal and electromagnetic loading will be presented. Modifications to the shunt to extend operation to higher current levels or duty cycle operation will be discussed.

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Effects of temperature dependence of electrical and thermal conductivities on the heating of a one dimensional conductor

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Joule heating limits the operation of most current carrying components and devices, especially in nanoscale circuits such as carbon nanofiber based field emitters, graphene electronics, and nanolasers [1]. For many materials of interest it is important to consider the temperature dependence of the thermal and electrical conductivities when calculating the effects of Joule heating. We examine the effects of linear temperature dependence of the electrical and thermal conductivities on the heating of a one-dimensional conductor by solving the coupled non-linear steady state electrical and thermal conduction equations. We find that there are conditions under which no steady state solution exists. In the special case in which the temperature dependence of the electrical conductivity may be neglected, we have obtained explicit expressions for these conditions. The maximum temperature and its location within the conductor are examined for various boundary conditions. We note that the absence of a steady state solution may indicate the possibility of thermal runaway [2].

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Oral 12 / 178

Tailoring High-Voltage, High-Current Thyristors for Very High Frequency Switching

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Many applications exist requiring high voltage switching in the tens of kilohertz rates with peak currents at the thousands of amps and blocking voltage at the thousands of volts. High-voltage, high-current thyristors provide low forward voltage and high peak current rating versus active area but suffer from long recovery times. To achieve high frequency operation would have required the use of gate turn off thyristors. Switch modules using series connected gate-turn-off thyristors require additional circuitry and isolated power floating at each device gate potential rather than the more compact thyristor based switch modules operating at lower frequency which do not need to use gate-turn-off. Tailoring the thyristor for faster turn-on also achieves a device with faster recovery. Using these devices we have developed a compact thyristor based switch module capable of achieving greater than 20 kHz pulse rates using only a single low voltage, low power trigger.

In present form the module is designed for a maximum blocking voltage of 7.5 kV and a peak current of 3 kA. However, this concept could be easily used to generate higher voltage switches using more devices in series. Also, higher current devices are in development which would increase the peak current rating to 14 kA without a significant increase in the size of the module. Higher current can also be achieved using devices in parallel. This paper will discuss the tailoring of the thyristor, the design of the switch module, and test results showing fast turn-on of greater than 100 kV/µsec and 25 kA/µsec as well as recovery times of less than 10 µsec.

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An All Solid-State Inductively-Driven Radiation-Resistant Modulator For Fast-Kicker Magnet Applications

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In many accelerator applications requiring a fast-kicker magnet, radiation generated by particle beams can limit the physical proximity of the modulator to the magnet. It is typical that the modulator be located hundreds of feet away from the radiation environment, increasing the complexity and cost of the modulator and cabling.

The main susceptibility of the modulator to radiation-induced failure are the solid-state switches when they are in an open-state holding off high-voltage. By using an inductively-driven topology to switch DC current flowing through a considerable inductance into the kicker magnet, the time that high-voltage is across the solid-state switch is minimized and equal to the current rise-time and fall-time in the kicker magnet, thus increasing the MTTF of the modulator in the radiation environment.

The complexity of the primary energy source is also reduced to a low-voltage high-current supply that can be located with the controls away from the radiation and linked by simple high-current DC cabling. This method allows for an arbitrary pulse width and rep-rate as well as unlimited DC current in the kicker with no droop after the initial fast-rise.

Stangenes Industries has developed and installed the system described above to divert a proton beam in a medical application. This paper presents experimental data describing the systems' operational parameters as well as a novel switch protection scheme which prevents over-voltage failure of the switches.

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Transient Electromagnetic Field Reconstruction from Sets of Non-Periodic Oscillations

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Arbitrary transient electric field shapes are generated in free space utilizing a set of transient signals with proper shape, amplitude, and time shift. Akin to wavelets in signal processing, brief, non-periodic oscillations are superimposed at a pre-selected location in space to effect destructive and constructive interference. With a properly chosen signal set, an entirely different frequency or shape is generated. Two methods have been employed to find optimum signal sets, the Discrete Wavelet Transform (DWT) and Particle Swarm Optimization (PSO). While the DWT approach dictates constant time step and rectangular matching between wavelets, PSO is not restricted in this manner, allowing for more flexibility in choosing amplitudes and signal delays.

Using PSO, a signal may be constructed that closely matches a desired shape in time or frequency domain through time shift and amplitude modification of a number of non-periodic oscillations. This previously postulated approach has been experimentally verified utilizing a Transverse Electromagnetic (TEM) Horn Antenna array, which has been designed and implemented due to its wide frequency response necessary to transmit and receive short non-periodic signals. The frequency response of the transmitting horn antenna was exploited by applying a Gaussian input pulse, which was a-priori simulated and is now confirmed to produce a desired bipolar output. For ease of control, the pulse is generated digitally, run through a data pattern generator, and converted to an analog signal driven by a clock. This pulse is then amplified and transmitted from multiple synchronized antennas, added in the far-field, and superimposed.

As expected, the resulting received signal has been found to increase in amplitude by a factor relative to the number of transmitting antennas. To date, a synchronization accuracy of better than 100ps between individual channels has been achieved. The generation of arbitrary signals in the 100 MHz to GHz regime is demonstrated.

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The Design and Testing of an Inductive Voltage Adder for ALS-U Kicker Magnets

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A 6kV inductive voltage adder has been designed to drive 50 ohm stripline kicker magnets for an upgrade to the Advanced Light Source at Lawrence Berkeley National Laboratory to a diffraction limited light source. Several features were included in the design to allow damping of potential oscillations and optimizing the rise and fall times. A prototype of this inductive voltage adder has been fabricated and tested into a 50 ohm resistive load to characterize system performance. The design and test results will be presented.

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Electric field analysis of different compact electrodes for high voltage pulsed electric field applications in liquid food

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A 2D and 3D electromagnetic simulation has been performed on compact electrode designs aimed to obtain higher electric field distribution between the high voltage and ground electrode, which ensures high bacterial inactivation in liquid food. The electric field simulations are performed for applied voltages of 1kV to 5kV. For the round edged design, the transmembrane potential of 1V is achieved with the spherical cell, modeled between the high voltage and the ground electrode. And for the novel torus tube design, simulation is performed and the electric field values are taken based on deciding the location of bacteria, between the two electrodes. The dimensions of the electrodes are maintained in mm and cm suitable for laboratory scale, continuous pulsed electric field treatments. In both the designs, efforts have been put forth on simulation to achieve higher electric field application between two electrodes. From the observed results, it is understood that greater electric field application between the two electrodes is achievable even using small efficient electrode designs, which in turn assures i) A greater bacterial inactivation in the liquid food and ii) A compact pulsed electric field experimental prototype.

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SOLID-STATE MARX GENERATOR FOR CLIC BREAKDOWN STUDIES

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A new semiconductor based Marx generator converter, using SiC discrete MOSFETs (Metal Oxide Semiconductor Field Effect Transistors), has been designed to meet specifications for carrying out high electrical gradient RF breakdown research for the Compact Linear Collider (CLIC) study: CLIC is an international collaboration working on a concept for a machine to collide electrons and positrons (antielectrons) head-on at energies up to several Teraelectronvolts (TeV). For this experimental research, the load of the Marx generator is a spark gap. The load can generally be considered to be capacitive in nature: normally the load will not conduct, however it will occasionally breakdown (when there is high voltage across it, it can transition into an electrically conducting state). The purpose of the high-gradient breakdown studies is to determine the long-term breakdown rate of the spark gap under different test conditions. Thus the Marx generator must be designed to operate reliably with both a capacitive load and following an electrical breakdown of the load.
The requirements for the Marx generator include applying positive voltage pulses to a 150 pF capacitive load, at a repetition rate from 1 Hz to 1 kHz, with a flattop of up to 10 kV pulse amplitude and 500 ns to 100 μs pulse width, having rise and fall times of 100 ns, from 5% to 95%. Ideally there will be no ripple during the flattop: the equipment is used for breakdown studies and, for a given geometry of the sample under test (i.e. the load), the breakdown rate is approximately proportional to Voltage^30 (i.e. a small ripple can give a large change in breakdown rate). To minimize ripple the circuit inductance is kept to a reasonable minimum.
Preliminary experimental results from the Marx generator connected to this load will be presented and discussed in view of the proposed application and initial requirements.

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Pulsed plasmas for two environmental applications: Power-to-Methane and pollution control

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Nanosecond pulsed plasmas at ambient conditions can be tailored to energize chemical processes that help to cure environmental problems. We report here two application areas: industrial emission control and fuel synthesis.
A short review will be presented of the development and industrial performance of a pilot size installation for on-site emission abatement [1]. The pilot installation has been built around a pulsed power driven streamer-corona reactor. The power source is a high-efficiency spark-gap based device which can operate autonomously for long periods of time. It is a self-controlled system operating at up to 10 kW average power, and at pulse parameters of 100 MW peak power, 1 kHz pulse repetition rate and 100 ns pulse width.
Next, we present the development of a plasma-catalytic reactor for methane synthesis. The feedstock is CO2, water vapor and renewable power. This research originates from first ideas and results that we presented in a recent paper [2]. The paper showed that 400 ppm of Methane was synthesized by a pulsed corona discharge around a Nicrothal 80 wire in CO2 above a water surface. A new device is in development to optimize this process. It combines a dedicated catalyst, a corona reactor, humid CO2 gas and nanosecond pulsed power. First results will be presented. Technology developments in this direction are needed to be able to convert the surplus renewable power of the near future.

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Improvement on the Ionization Rate of Hall Thruster with High Voltage

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With the development of spaceflight mission, high special impulse becomes significant trend of Hall Thruster. Improving the discharge voltage is the most effective way to achieve high special impulse. Because of the limit of total power, the increase of voltage means the decrease of mass flow rate of neutral propellant, and ionization rate is significantly related to the neutral density. Decreasing the mass flow rate will decrease the neutral density, which leads to the decrease of collision frequency, and ionization rate. At the same time, when increasing the discharge voltage together with reducing

the mass flow rate to maintain the constant discharge power, the acceleration layer widens mainly towards the anode, the ionization zone increases in both directions and shifts towards the anode. That means the overlap of ionization region and acceleration region, which also decreases the performance of thruster. To improve the ionization rate of Hall Thruster with high voltage, this article advances a gas distributor with azimuthal gas injection technique such that the propellant enters the discharge channel with azimuthal velocity and thus longer neutral residence time. That increases the electron-neutral collision rate, and thus higher ionization rate. Experimental results show that a gas distributor with azimuthal gas injection technique can effectively improve the ionization rate at high voltage and low mass flow rate.

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Discharge properties of microsecond pulse driven Argon plasma jet arrays

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Atmospheric pressure plasma jets (APPJs) have attracted much attention due to their flexibility, low cost and ability to treat remote objects. By grouping individual jets together to form jet arrays is a good solution for large area treatment. Most of the reports generated plasma jet arrays using He as discharge gas. However, Ar is more economic than He. But, due to its high breakdown voltage and easy glow to arc transition, little research have been done by using Ar as feeding gas.
In this paper, the discharge properties of Ar plasma jet arrays (with six individual jets) driven by an in-house developed microsecond pulse generator is studied. The single plasma jet is composed with a needle-ring electrodes structure. The discharge properties of plasma jet arrays are studied by short exposure time pictures, current and voltage measurements, optical emission spectroscopy, ICCD camera and schlieren flow visualization. The influence of gas flow rate, pulse repetition frequency (PRF) and discharge gaps on the plasma jet arrays discharge uniformity is observed. The results show that the discharge starts from the outside of the plasma jets, followed by plasma jets in-between. The uniformity, bullet speed and reactive species intensities (OH, N2, Ar) of plasma jet arrays increases with the increase of gas flow rate and PRF. The best uniformity is achieved under a discharge gap between 10 mm- 12.5 mm. The bullet speeds of each plasma jets get the closest value under a gas flow rate of 6 L/min. This study provides useful information for design of homogenous plasma jet arrays for various potential applications.

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PERFORMANCE ANALYSIS OF AN ALL SOLID STATE LINEAR TRANSFORMER DRIVER (LTD)

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The performance of an all solid state linear transformer driver (LTD) is evaluated based on experimentally verified behavior of a single stage. While the majority of high voltage pulse generators for HPM generation and industrial food processing applications rely on high voltage spark gap switches¹, an all solid state LTD is presented as a possible alternative for this pulsed power regime.

The single-stage LTD utilizes a low-profile design² with robust thyristor switches and high energy density mica capacitors to minimize overall system inductance. Sub-nanosecond jitter is achieved with simultaneous thyristor triggering. The stage is magnetically coupled to a secondary winding through a central Nanocrystalline core. A DC current source, decoupled with a large inductance, actively resets the core during pulsed operation. The overall result is a low-impedance (<1 Ω per stage) pulse generator that rivals the performance of traditional Marx systems with the improved reliability, increased lifetime, and fast rep-rate capabilities of solid-state switches.

The single-stage LTD is constructed in a cylindrical arrangement with a radius of 60 cm and height of 2.54 cm. The stage is tested with charging voltages up to 8 kV into various loads and compared with simulations based on an analog behavioral thyristor switch model previously developed³ at Texas Tech University. The simulation is expanded into a full-scale, 40-stage LTD simulation and analyzed for viability in driving HPM sources, such as a vircator.

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Analysing a gate-boosting circuit for fast switching

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A challenge in fast switching of voltage-controlled power semiconductor devices such as MOSFETs and IGBTs is fast charging of the gate capacitance. As gate drive circuit and device leads both involve stray inductance, the rise rate of the gate current is limited. To achieve higher current rise rates, an overvoltage might be applied to the gate leads (so called gate-boosting) [1]. In this work, a simple gate-boosting circuit has been investigated. It allows using a gate drive voltage in the order of 100V whereas the voltage across the internal gate capacitance is kept well below the limit for the gate-emitter voltage as given in the datasheet. Hence, damage to the gate oxide layer is prevented. For the design process, it is of advantage to verify the voltage across the internal gate capacitance in the TO-247 package by measurements in addition to simulation results. For such measurements, the protective plastic housing around the die has been partly removed by means of an etching process. With a probe specifically modified for low inductance, measurements of the voltage across the gate capacitance in direct vicinity to the die have been performed. This work presents steps towards achieving

a fast rising voltage across the gate capacitance within permissible limits, whereas the voltage across the device leads outside of the housing exhibits high inductive peaks. As result, improvements of the load current's rise rate in hard switching conditions by a factor of around 8 up to 4.2kA/µs at a rise time of 50ns for a commercially available TO-247 IGBT have been demonstrated.

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Evolution of Partial Discharge of Oil-paper insulation under Long-term AC Voltage

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Internal insulation defects of oil-immersed transformers are common because of flaws in both manufacturing and transportation process. Partial discharge (PD) activity caused by insulation defects may occur at rated voltage condition, leading to deterioration of material, which results in breakdown of insulation. Feature parameters of PD are closely related to the performance of insulation materials. Therefore, the parameter changes under long-term AC voltage due to the decrease in electrical properties of material. It is effective to acquire insulation condition of materials by analyzing changes in the parameters of PD.
The present thesis studied partial discharge in insulation defect of oil-paper insulation under long-term AC voltage. The PD tests were performed on specimens of 1 mm thickness which was placed between the needle-to-plane electrodes in an oil cup. The specimen was impregnated with oil in vacuum with treatment of hot air drying in order to remove moisture. Feature parameters of PD, such as phase-resolved partial discharge analysis and average discharge magnitude, were recorded during the test process. When the feature parameters of PD are significantly changed, some specimens were removed. The surface appearance of these specimens was studied by scanning electron microscope and infrared spectrometer, and the insulation parameters such as surface resistivity was also measured. These measurements provide a theoretical basis for the analysis of the changes in the feature parameters of PD, which is helpful for the estimation of remaining life of insulation material.
Test results indicate that as the AC voltage applied, cellulose depolymerisation continuously happened at the surface of paper. Cellulose in some area is carbonized by PD, and particulates are created. The surface resistivity of paper decreases, resulting in a higher repetition rate of PD. As the PD developed, the discharge magnitude is increased at the beginning while decreased rapidly just before breakdown of the paper, and the distribution phase of discharges is almost unchanged.

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Power Modulators are Still Cool

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I really like power modulators.

Exhibitor Breakfast / 351

I'm submitting a late abstract!

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I am testing how to submit a paper!

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Development of a test platform for high voltage ceramic capacitors based on magnetic compression

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Abstract: The long lifetime, fast charging and discharging capabilities of high voltage ceramic capacitors are important for their application in pulsed power facilities. This paper presents a rep-rate platform for testing capacitors at several tens kilovolts with charging and discharging time in microsecond region. The platform consists of a high voltage power supply, a primary unit, a core-type pulse transformer, a magnetic compression network with reset unit and a test cavity. A detailed circuit model including the reset unit is presented to optimize the electrical parameters of each component. Then, the test platform is built and experimented based on magnetic compression technology. One pseudo-Spark Switches (PSS) is used as control switches in the primary unit for pulse charging and another PSS is used for discharging in the test cavity. Test results of the platform with dummy load and test cavity are presented to verify the design and capabilities of the platform.

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Power Modulators are Cool

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I like power modulators.