RESEARCH OF COMPACT REPETITIVE PULSED POWER SYSTEM BASED ON MARX GENERATOR

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Abstract

By adopting Marx generator technology, a compact repetitive pulsed power system has been developed which consists of a high power repetitive power supply and a Marx generator. By utilizing inverter, resonance, 10-stage step boost, rectification and output in series, a high power repetitive power supply has been designed and tested which can transform 300V DC to 100kV DC and charge the capacitor to 100kV repetitively. The Marx generator consists of 16 stages with integrated folder configuration. Each stage consists of three 20nF capacitors in parallel. By integrating the Marx with the high power repetitive power supply. A compact repetitive pulsed power system has been developed and tested. We have obtained 5 pulses with repetition rate of 5Hz on a 14Ω load. The peak voltage and peak power are more than 700kV and 35GW respectively.

I. INTRODUCTION

The technology of compact repetitive pulsed power source is the important development direction of pulsed power technology. It is widely used in high power microwave1-2], high power laser3], Electromagnetic launch4], material research, Environmental Protection, biomedicine, particle acceleration5] etc. Compact repetitive pulsed power source requires high output power, small volume, small weight and repetitive frequency operation which are also technical difficulties of its development.

The Marx generator has been widely used in high-voltage pulsed power system as a simple and convenient means of stepping up the voltage. An array of capacitors is charged in parallel and discharged into a load in series by means of fast closing switches.

By adopting Marx generator technology, we have designed and set up a compact repetitive pulsed power system with output power of 35GW on a 14Ω load. The pulsed power system consists of a 16-stage Marx generator and a high power repetitive frequency power supply. The Marx generator is designed with integral folder configuration which helps to reduce loop inductance and volume size. Each stage of the Marx consists of three 20nF capacitors in parallel, a convergence transmission line and a switch. By adopting technical route of inverter, resonance, 10-stage step boost, rectification and output in series, we have designed and tested a high power repetitive frequency power supply which can charge the capacitors to 100kV fast and repetitively. By system integrating and sequential controlling, we realized repetitive operation of the compact pulsed power system.

II. COMPACT MARX GENERATOR

A. Physical Parameter Design

By adopting single polarity charging, the energy-storage capacitors of Marx are charged in parallel through 150μH charging inductors by the power supply and discharge in series through the front two-stage trigger switches and the rear self-breaking switches to the load.

In order to obtain 35GW output pulsed power on a 14Ω load, we must obtain a pulse voltage of more than 700kV on the load. Considering the effects of loop resistance and other stray parameters, we design the output voltage on the load at about 800kV.

As we know that maximum power transfer from the Marx generator to the load occurs when the impedances of the Marx and the load are matched. Under these conditions, the voltage appearing across the load will be one-half of the erected Marx voltage. So, the erected Marx voltage must be 1.6MV.

The maximum operating voltage of each stage of Marx designed at 100kV, 1.6MV erected voltage can be obtained by adopting 16-stage Marx. In order to meet above requirements, we must realize impedance matching of the Marx and the load. Thus the Marx impedance must be about 14Ω which is important and also difficult for the Marx design. The most effective way to solve the difficulty is reducing the loop inductance.

According to above design requirements, 60nF capacitor is used as energy-storage element of each stage of the Marx. In order to reduce inductance of the energy-storage element, the 60nF capacitor is designed as three 20nF capacitors in parallel. Combined with a convergence transmission line and a closing switch which is made up of a circumferential orbit electrode and a plane electrode, the energy-storage and pulse-forming unit is designed. fig.1 shows its circuit.

Figure 1. Circuit of energy-storage and pulse-forming unit
In Fig 1, C is the 20nF capacitor and L1 is its inductance which is about 60nH. L2 is inductance of transmission line between two 20nF capacitors which is about 20nH. L3 is inductance of output transmission line and switch which is about 50nH. A 16-stage Marx circuit model with 150μH charging inductors and 1Ω total loop resistance is established for simulation. When the energy-storage capacitors charged to 95kV, an output high voltage pulse with amplitude of 740kV, full width half max (FWHM) of 132ns, and rising time of 43ns is obtained on a 14Ω load, as shown in Fig.2.

![Figure 2. Computational voltage on the load](image)

**B. Marx Configuration Design**

Fig.3 shows the configuration of the energy-storage and pulse-forming unit which consists of three 20nF/100kV capacitors in parallel, a convergence transmission line and a switch.

![Figure 3. Energy-storage and pulse-forming unit](image)

We have developed a new type of cascaded pneumatic synchronous trigger switch and used as the front two switches of the Marx. The principle of the switch is using gas pressure in the Marx cavity to drive the pneumatic part to move fast, thus to drive trigger needles to move rapidly between the two main electrodes. At the same time, the electric field between the two main electrodes distorts, so the switch closes and opens rapidly and can operate repetitively. The rear switches of the Marx are self-breaking spark-gap switches.

The 16-stage Marx generator is constructed with a low inductance structure. Fig.4 shows its side view. Each stage energy-storage unit discharges in series to the adjacent stage through the convergence transmission line and the switch. The charge inductance and grounding isolation inductance are both 150μH. The Marx is designed in a hermetically sealed metal case with volume of 0.3m³, which is pressurized with pure SF₆ to enhance insulation performance. The 3D structural diagram of the Marx generator is shown in Fig.5.

![Figure 4. Differentiating profile of Marx](image)

![Figure 5. 3-D structural diagram of Marx](image)

**III. HIGH POWER REPETITION FREQUENCY POWER SUPPLY**

**A. charging module**

High power repetitive frequency power supply is used to charge the energy-storage element of Marx, which is supplied by 300V DC power supply. The power supply adopts the technical route of inverter, resonance, 10-stage step-up, rectification and output in series. The electric schematic diagram is shown in Fig.6. The DC power supply $U_{dc}$ charges the energy-storage capacitor $C_s$ through the current limiting voltage regulator $M_{dc}$. The $C_s$ is used as the primary energy storage device of the power supply system. The resonant circuit generates a 18kHz alternating output and feeds into the 10-stage step-up and rectifying circuits $U_1 \sim U_{10}$. 
Each stage produces about 10kV DC voltage output, and 10 stages connected in series can output 100kV DC voltage. The power supply charges the energy-storage element of the Marx generator through an charge inductor.

**B. Controlling module**

The controlling module controls the timing between power supply and trigger switches, and sends trigger command to the trigger switches. The schematic diagram of controlling module is shown in Fig. 7. Using the controller, the pulsed power source can be set for single or repetitive operation and the repetition frequency can also be set in advance. According to sequential requirement, the controller sends out the charging command and trigger command respectively. The charging command controls the power supply work and the trigger command generates electrical pulse by photoelectric conversion. Drived by the electrical pulse, the monostable circuit outputs an electric pulse with duration time of more than 40ms, and drives the trigger switches to work.

**C. High power repetition frequency power supply**

The repetitive frequency power supply developed is shown in Fig.8, which is structureally designed according to high voltage and low voltage partitions seperately placed in high voltage case and low voltage case.

The primary energy-storage capacitor is placed in the lower case. The controlling, inverter and resonant circuits are placed in a hermetically sealed metal case to enhance the anti-interference ability. The step-up and rectifying circuits are placed in the high voltage case, which adopts silicone gel vacuum encapsulation to enhance insulation capability. The 100kV DC high voltage outputs to the energy-storage element of the Marx via a high voltage plug and a high voltage cable.

From the short-circuit discharge current, the period is 360ns. The loop inductance and resistance can be calculated by the current osillation period and the peak attenuation ratio according to formula (1) and (2).

\[
L = \frac{T}{2\pi} \cdot \frac{1}{C} \quad (1)
\]

\[
R = 2\ln\left(\frac{I_{\text{in1}}}{I_{\text{in2}}}\right) \cdot \frac{L}{T} \quad (2)
\]

Where C is the totle erected capacitance of the Marx, which is 3.75nF.

The calculation results show that the inductance is 876nH, and the resistance is 0.8Ω.

The equivalent resistance of the Marx can be calculated by the totle erected C and loop inductance L according to formula (3).

**IV. EXPERIMENT OF REPETITIVE FREQUENCY PULSED POWER SOURCE**

**A. Short-circuit discharge test**

The high voltage output terminal of the Marx generator is connected with its grounding terminal, and the short-circuit discharge test is carried out. The short-circuit discharge current waveform measured in the experiment is shown in Fig.9.
\[ Z_{\text{Marx}} = \sqrt{\frac{L}{C}} \] (3)

The calculated results shows that the equivalent resistance of Marx is 15.3\(\Omega\).

**B. Single-shot experiment**

In order to verify the performance of the pulsed power source, we carried out single-shot experiment with a 14\(\Omega\) copper sulfate/water resistor as the load. The load voltage is measured by resistive divider.

Fig.10 displays the load voltage waveform. The output peak power is calculated according to the formula \(P = \frac{V^2}{R}\). When the energy-storage elements were charged to 95kV, we obtained a 715kV pulse voltage with about 40ns rising time and 130ns duration time on the load. The peak power is 36.5GW.

![Figure 10. Single-shot experimental voltage on the load](image)

**C. Repetition frequency operation experiment**

In order to verify the repetition frequency operation performance of the pulsed power source, we carried out experiment by controlling timing of the repetition frequency power supply and trigger module, setting the operation frequency at 5Hz and using a 14\(\Omega\) copper sulfate/water resistor as the load. Fig.11 shows the load voltage with peak of 700kV～720kV.

![Figure 11. Load voltage measured in repetitive operation Experiment](image)

**V. CONCLUSION**

A repetitive pulsed power source based on Marx generator is introduced in this paper. It is mainly composed of a Marx generator and a repetition frequency power supply. When single-shot operating, a 36.5GW output pulse has been obtained on a 14\(\Omega\) load as energy-storage capacitors charged to 95kV. When repetitive operating, five pulses with repetition rate of 5Hz have been obtained on the load. The peak voltage and peak power are more than 700kV and 35GW respectively.

**VI. REFERENCES**


