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Modular PCB High Voltage Capacitor Bank Chargers

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I Introduction

The capacitor bank power supply is most widely applied for pulsed magnetic field facilities for its simply structure and high reliability, and the high voltage charger is the critical part of it. Thanks to the characteristics of zero switching, high efficiency and constant current charging, the LC resonant high voltage charger is usually preferred. However, the capacitor bank charger is usually rated at high power level and high voltage level, therefore,

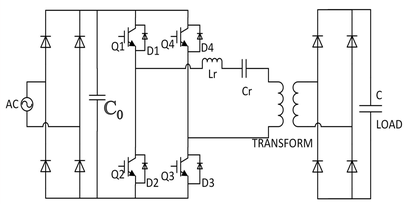
- the difficulty of design and manufacture the volume and the cost are very high,
- It is not good for promoting the application of pulsed field technology and pulsed power supply,
- The output current will not remain constant and the efficiency will decrease because of the large parasitic capacitance existed in the high voltage high frequency transformer.

To avoid the above issues, a Modular on-PCB capacitor bank charger is proposed. Based on the LC resonator principle, all the components of IGBTs with is drive and protection circuit, diodes and step-up transformer are integrated on a PCB board.

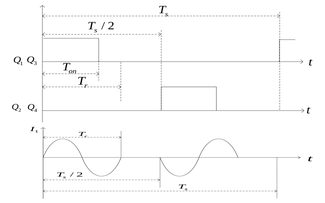
A protype modular PCB charger has been successfully developed, the input voltage is AC 220 V, and the maximum output voltage is DC 2000 V. It has succeeded to charging a 6 kV capacitor bank with 3 modules. All the specific parameters and circuit schematics will be presented as well as their experimental results.

II. Circuit Principle and realization

The circuit schematics of a LC resonant converter module is shown as fig.1, it mainly includes a IGBT bridge, a LC resonant tank, a High frequency transformer and a high frequency rectifier. As shown as fig. 1(b), IGBTs Q_1 and Q_3 turns on, the capacitor C_0 discharge through inductor L_r and capacitor C_r, after a half resonant period, the current reverse its direction to charge C_0 through diodes D_1 and D_3, and IGBTs Q_1 and Q_3 turns off without current load during this half resonant period. The switching process of IGBTs Q_2 and Q_4 is similar to Q_1 and Q_3.



(a) Circuit schematics



(b) Driving signals and resonant current

Fig. 1 The circuit schematics of a LC resonant converter module

TABLE I
PARAMETERS OF MULTI-MODULE

Parameters	Symbol	Value
Input voltage	V_{in}	AC 220V
Output voltage	V_o	DC 2kV
Output current	I_o	1A
Switch frequency	f_s	12.5kHz
Resonant inductance	L_r	136μH
Resonant capacitance	C_r	0.1μF
Resonant frequency	f_r	40kHz
Grading capacitor	C_1-C_n	2.5μF
Load capacitor	C	110μF
Primary turns of transformer	N_1	16
Secondary turns of transformer	N_2	104
Turns ratio of transformer	n	6.5

The main parameters of the developed PCB resonant charger are listed in Table I, the input voltage is AC 220 V, and the output voltage is DC 2000 V, and the charging current is 1A, and the main switches are IGBT K75T60 (75A / 600V) operated at 12.5 kHz and duty of 20%. The resonant inductance L_r and capacitance C_r are 136 μH and 0.1 μF, respectively, the turn ratio of transformer is 6.5 with a ferrite core (EE85).

Each module can work independently or together with other modules. As shown as fig. 2, the modules can be connected in serial to gain higher output voltage. There are extra voltage balance capacitors at output port of each modules to keep the voltage distribution balance between modules. When a module breakdown, it will not affect the rest modules because the output current will keep flowing through the high rectifier of the broken modules.

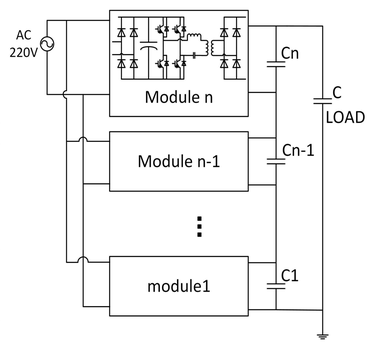


Fig. 2 modules in serial

III. Control and Protection

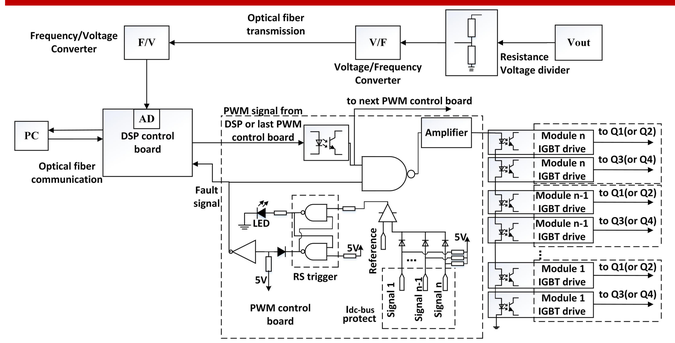
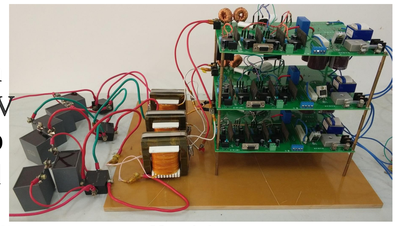


Fig. 3 Control and protection circuit schematics

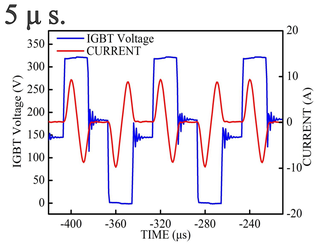
The main challenge of multi-modules charger is to design a reliable and accurate control and protection signals. The control system is based on the DSP28335, which will receive the command from and upload the measured current and voltage to the PC computer through 2 optical fiber cables. The DSP chip generates 2 PWM signals and pass them to the local control unit through high speed optocoupler TLP250. The local control unit receives the PWM signals from DSP and demultiplexs to each IGBT's driver, the demultiplexer base on high speed amplifier and optocoupler, it has smaller than 20 ns time delay, high voltage isolation ability, and it is strong to EMI. And it has fast protection function (μs level), such as the bridge short-circuit protection and report the fault signal to the DSP.

IV. Experimental results

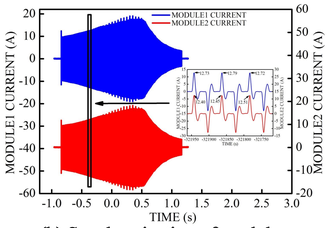


All the power IGBTs with driving circuits, diodes, inductor and capacitor, current sensor and voltage sensors are integrated on a PCB board as shown as the right picture. Each modules is rated at 2 kV /1A output and AC 220V input. Three modules connected in serial (as fig .2) work synchronously to succeed to charge the 110 μF capacitor bank to 6kV within 2 s. The overall size of each module is 300mm*200mm*80mm. The resonant current and voltage of IGBTs in each modules is shown as fig. 4(a), it shows that the IGBTs turns off with zero current. Fig. 4(b) shows that the resonant currents (output current) between modules are perfectly synchronized, so the proposed PWM signal demultiplexer scheme in this paper is effective and available.

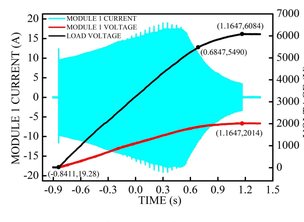
The experiment results of three modules in serial is shown as fig. 4(c), the black curve is the total voltage (up to 6084V) and the red curve is the output voltage of a modules (2014V), so the voltage balance between modules is good. Fast protection is very important for the safety of many modules work together, the fast protection function is integrated in the local control unit by using hardware. Fig. 4(d) shows that it can shutdown the PWM signals in 2 μs after the bridge short-circuit fault occurs, it is smaller than the required 5 μ s.



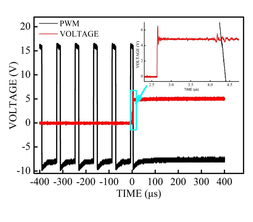
(a) Resonant current and voltage of IGBTs



(b) Synchronization of modules



(c) Output voltage and resonant current



(d) Fast protection

Fig. 4 Experimental results

Conclusion

- **Resonant charger is a key part of the capacitor bank pulsed power supply, the traditional charger has a large volume and high cost, and it is not good for prompting the application.**
- **Modular PCB resonant chargers are proposed, all the power device and control/ protection units are integrated on a PCB board to be more compact and reliable.**
- **A protype of 3 modules PCB charger of 6 kV /1A is developed, all 3 modules can work synchronously and reliably with fast and complete protection system .**

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PRESENTATION ID NUMBER

Tue-Af-Po2.04-07