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 prototype 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.

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 Q1 and Q2 turns on, the capacitor C1 discharge through inductor L1, and capacitor C2, after a half resonant period, the current reverse its direction to charge C2 through diodes D1 and D2, and IGBTs Q3 and Q4 turns off without current load during this half resonant period. The switching process of IGBTs Q1 and Q2 is similar to Q3 and Q4.

![Circuit schematics](image1)

II. Circuit Principle and realization

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 1 A, and the main switches are IGBT K75T60 (75A / 600V) operated at 12.5 kHz and duty of 20%. The resonant inductance L1 and capacitance C1 are 136 μH and 0.1 μF, respectively, the turn ratio of transformer is 6.5 with a ferrite core (EER5).

Each module can work independently or together with other modules. As shown as fig. 2, the modules can be connected in series 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.

![Circuit schematics](image2)

III. Control and Protection

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 demultiplexes 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.

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 220 V 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 μs.

![Experimental results](image3)

IV. Experimental results

- 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 prototype 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.

![Experimental results](image4)

Conclusion

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