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Design of the all solid high-voltage power supply for a gyrotron body

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HIGHLIGHTS

- Completed design of all solid-state high-voltage power supply for gyrotron body on HL-2M ECRH.
- Consist of 58 PSM modules and one BUCK module, controlled by DSP system.
- Fabricated full voltage 35 kV, 200 mA BPS and tested in dummy load.
- The BPS can operate in three modes: single pulse mode, multi-pulse modulation mode and the six-level preset mode.

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ABSTRACT

Gyrotron plays an important role in the research of electron cyclotron resonance heating (ECRH) on Tokomak. The high-frequency switched power supply technology and pulse step modulation (PSM) technology are used in the development of the all solid high-voltage body power supply (BPS) for 1 MW/105 GHz Gyrotron on ECRH system. Firstly, the basic structure of the BPS and its control system are introduced. Secondly, the software control algorithm of voltage stabilization and modulate method are developed. Finally, the design is verified by the experiments. The experimental results of the single pulse mode, the multi-pulse modulation mode and the six-level preset mode, are shown. The output voltage of the power supply can reach 35 kV and the current at about 200 mA, which are adjustable in the full range. The maximum modulation frequency can reach 1 kHz and the front edge of the pulse can be adjust from 0 to 3 ms and the accuracy of the output voltage is less than 100 V. The results show that the control method is feasible and can be applied to other high power microwave sources.

1. Introduction

Electron cyclotron resonance microwave source acts as plasma heating, driving, diagnosing and controling non-classical tearing mode in tokomak research [1]. A 1 MW, 105 GHz new depressed collector gyrotron was proposed for the electron cyclotron resonance heating (ECRH) system on the HL-2M, and the body power supply (BPS) is one of the key parts in the ECRH system. Its output voltage is required with wide adjustment, high stability, modulation and rapid protection, therefore it needs redesigning. At present, most of BPS gyrotron are designed into two parts to meet these requirements: the DC high-voltage platform and modulator. The high-voltage platform is composed of AC input voltage thyristor variation system, step-up transformer and diode rectifier. The vacuum tetrode is used in the modulator of ECRH on HL-2A, works in the state of amplification, and changes the output voltage with changing the input voltage of the gate drive [2]. The modulator of ECRH on the DIII-D tokomak in America which uses N-channel and P-channel transistors to construct a single power complementary symmetric amplifier, is combined with sharing-voltage circuit to let the multiple modules in series, and to isolate drive modules by using the error voltage after the voltage amplifier circuit to achieve the aim of changing the output voltage [3–5]. The BPS designed using the above method has some unfavorable factors such as large volume, low efficiency, analogy control, non full digital control [6–9]. The DC power supply (DC-PS) using multiple modules in series technology has low consistency requirement for switching devices [10]. It can vary and modulate the output voltage easily combined with the control of pulse-step-modulation (PSM). The DC-PS can output normally in the case of a small number of

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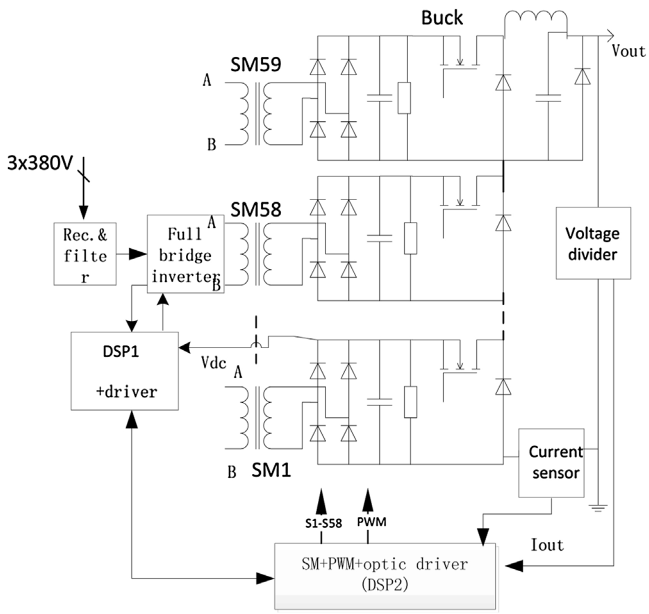

Fig. 1. Block diagram of the power supply system.

modules being in fault. The existing PSM device using multi winding transformer is with large volume and high cost and is fed by the 50 or 60 Hz AC voltage source. This paper developed a new type of solid-state BPS system for ECRH based on high frequency switching power supply technology and PSM technology, and the control method of full digital are introduced.

2. Hardware structure of BPS

The basic structure of the BPS is shown in Fig. 1. Three AC sources is fed to the rectifier and capacitance filter circuit, and then the full-bridge inverter circuit to convert DC-bus voltage into high-frequency AC voltage signal with the frequency of about 25 kHz and amplitude of about 540 V. The high-frequency AC voltage is fed to the primary of 59 step-up transformers from the points A and B, the secondary of the transformers are applied to 59 PSM modules. Every PSM module consists of rectifier, filter, free-wheeling diode, MOSFET switch and gate driver. About 600 V DC power is obtained after rectifier and filter in every module. That means the primaries of 59 transformers are connected in parallel and the outputs of these modules are connected in series. If the MOSFET switch is on, the output voltage of the module is 600 V. So the total output voltage is decided by the number of modules turned on. The full-inverter can realize the output voltage of each module in closed-loop control by feeding back the voltage of the first module's (SM1) filter, the voltage is about 600 V.

The MOSFET switches can turn on or off via controlling the fiber optic drivers. So the output voltage can superpose by the output voltage of the 58 modules, which is an integer multiple of the 600 V, and can change every time and modulation. Because of modulation these modules are with load or with no-load, the spike will be appear in the rising edge of the output voltage waveform. To overcome this problem, the 59th module is used. It is designed by the BUCK circuit, and is driven by the optical fiber, which is directly controlled via PWM signal generated by DSP1. So the output voltage of the 59th module can adjust from 0 to 600 V. The regulation accuracy of the output voltage can be realized with less than 100 V. So the output voltage of the BPS can be expressed by the following equation:

$$V_{out} = 600n + 600d$$

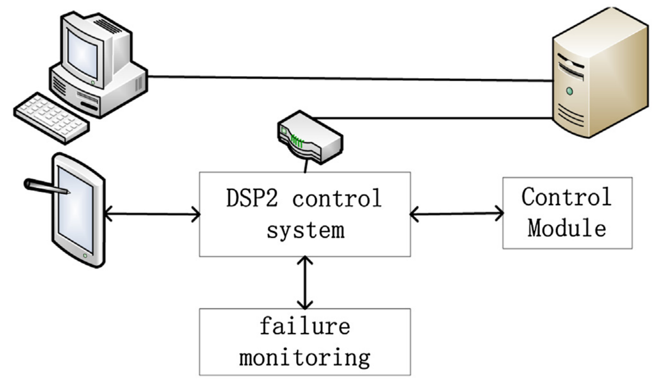

Fig. 2. The structure scheme of BPS control system.

where n is the number of turn-on module, d is the duty of the PWM control signal for the 59th module.

Fig. 2 shows the basic block diagram of PSM power supply control system [15]. DSP2 controls 59 modules through 59 optical fibers. When the system is in remote control mode, DSP connects to the router by the serial Ethernet module, transmits and receives the data with PC. While in local mode, DSP2 ignores the control information coming from the router, the control parameters can be set only by local touch screen. In order to ensure that the control system has fast fault response ability, the digital signal can be sent to DSP2 control system from the higher level fault at any time. If it does not receive fiber signals within 5 μS, it would switch off all modules.

DSP2 not only needs to control the modules, sample the input and output voltage and current information, but also communicate with touch screen and ECRH control PC system. Because of the limited number of IO ports, it is impossible use 59 IO ports to control 59 modules directly one by one. Therefore, the front 30 modules are controlled by three IO port, each IO port controls 10 modules. The 31th to 59th modules can be controlled independently. Thus controlling 59 modules requires 32 IO ports only.

3. Control algorithms and control flow

3.1. Control thought

In order to meet the complex requirements of the experiment, we hope that the BPS has the ability to output any six level waveforms as shown in Fig. 3. These values from V1 to V6 can be set to any voltage from 0 to 35 kV, and the time from t1 to t6 can be set to any time from 500 μs to 1s, so BPS can generate any six level waveforms, the period is no more than 5 s.

In the process of designing the program, the six level voltage control value and control time are put into a control array Voltage [6] and Time [6], respectively. The 12 values can change in the local

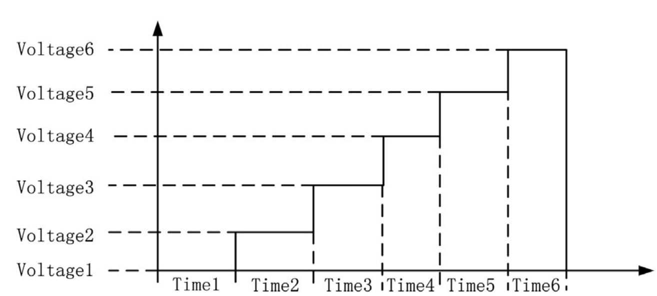

Fig. 3. A scheme of waveform control parameters.