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Design of the power supply system for the plasma current modulation on J-TEXT tokamak

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HIGHLIGHTS

- A modification scheme of heating field power supply system for plasma current modulation.
- High-power fast control power supply with multilevel cascade circuit.
- Restraining circulating current with coupled inductors in cyclic symmetric structure.

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ABSTRACT

In order to further study the influence of current modulation parameters on suppressing tearing instability, the plasma current should be modulated in a wider range. So a modification scheme is designed to improve the performance of ohmic heating power supply system on J-TEXT tokamak. A multilevel cascade circuit with carrier phase-shifted PWM technique has been proposed. Coupled inductors are connected in the form of cyclic symmetry to restrain the circulating current caused by multiple paralleled branches. The simulation proves this proposed current modulation power supply system matches output requirement and achieves good current sharing effect. Finally, a prototype is designed, and the experiment results can verify the correctness of the simulation model well.

1. Introduction

Suppressing tearing mode instabilities is one of the key physical problems in tokamak operation, so there are many ways to solve this problem [1]. An alternative way is to make the resonant surface oscillate with time by modulating the plasma current. With a modulation current which oscillates with time added on the equilibrium current, the radial position of the resonant surface can oscillate. Some preliminary experiment phenomenon shows that modulation of plasma current can not only suppress the plasma disruption, but also improve the plasma confinement [2]. However, the frequency of the oscillation should be higher than the classical growth rate of the tearing mode, and the amplitude of the resonant surface oscillation should be large enough [3].

Up to now no experimental facility has been designed or optimized specially for the experiment of suppressing tearing mode instabilities with current modulation. Because of the limit of the output capacity of ohmic heating power supply system, plasma current modulation experiment has not been further studied. The influence of frequency and amplitude of modulation current on suppressing tearing instability has not been demonstrated by experiment.

On J-TEXT tokamak, as plasma current is tightly coupled with the ohmic heating coil through transformer iron core, transformer's equivalent circuit model is used to describe the relationship between voltage of ohmic heating coil and plasma current. The ohmic heating coil of 40 turns will be as the primary winding, and plasma ring will be the secondary winding of 1 turn. The equivalent impedance, referred to primary side, of ohmic heating power supply's load is 4mH inductance and 26mΩ resistance. It is feasible to modulate plasma current by modulating ohmic heating coil current.

In this paper, firstly the construction and operation mode of present ohmic heating power supply system are discussed. Then, the designing scheme of the new power supply system is described. As multilevel cascade circuit with several branches paralleled is adopted, and that will cause large circulating current. This paper uses the coupled inductor connected in the form of cyclic symmetry to balance the current of each branch, and the advantages of the method are presented. Finally, the simulation of the

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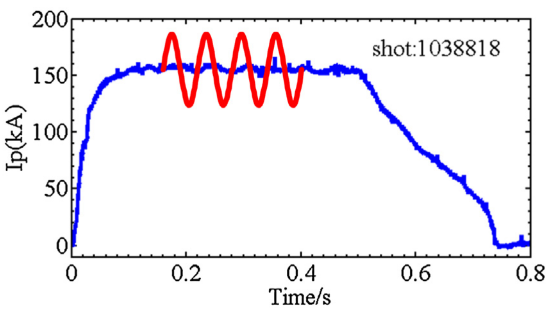

Fig. 1. The wanted modulation waveform of plasma current.

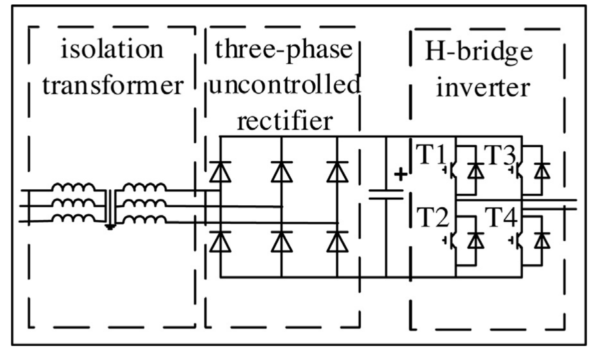

Fig. 2. Structure of power cell.

power supply system is carried out, and the simulation model is verified by experiments on a prototype.

2. Structure of current ohmic heating power supply system

The J-TEXT tokamak ohmic heating power supply system is mainly made up of four parts paralleled, including pre-magnetic circuit, ionization capacitance discharge circuit, four-capacitance banks discharge circuit, and rectifier circuit [4]. The function of first three parts is producing, driving, and heating plasma. The rectifier circuit is used to maintain the plasma. They are put into operation in turn [5]. As shown in Fig. 1, the blue line is the waveform of typical plasma discharge current of shot 1038818, and red line is the wanted waveform of modulation current. The modulation of plasma current will be conducted during the flattop of its trapezoidal wave, and in this period of time, it is the rectifier part of ohmic heating power supply that maintains the plasma current.

The ohmic heating rectifier circuit consists of two 6-pulse rectifier sets connected in series, and it works in a 12-pulse manner. It has the capability to provide a current of 10kA at 300 V (DC) within a duration of 0.5s to the ohmic heating coil. However, its 300 V DC voltage is unable to produce the modulation current of enough large amplitude or enough high frequency to further study the relationship between plasma current modulation parameters and the effect of suppressing tearing instability. Thyristor is the Switch device in the power supply, and it can not operate under a high frequency to quickly track and control the plasma current, because it will cause large switching losses and the failures of power switches. Therefor the scheme of multilevel cascade fast control power supply is designed.

The new power system should still provide a rated current of 10 kA within duration of 0.5 s to the heating coil like the original one. But it should provide a maximum voltage of ±2000 V, because the ohmic heating coil's maximum acceptable voltage is 2000 V. New switch device should be chosen to get higher switch frequency.

3. The design of the power supply

3.1. Main circuit of the power supply system

Fig. 2 shows the power cell composing the power supply system. It is made up of an isolation transformer, a three phase uncontrolled rectifier module and an H-bridge inverter module. The main circuit topology of the power supply is shown in Fig. 3. It is made up of a step-down transformer, power cells and current-sharing inductors. The transformer converts input high voltage 6.9 kV of the flywheel energy storage system to 740 V. Its capacity is 1000 kVA. The isolation transformer of power cell is connected between step-transformer and uncontrolled rectifier. Its capacity is 80kVA. Each H-bridge inverter has its separated DC voltage source. A medium filter (15 mF capacitor) is used in three-phase uncontrolled rectifier module to remove voltage pulsating. H-bridge inverter is chosen, because it can realize four-quadrant operation and its control method is simple. There are a total of twelve power cells assigned to six paralleled branches and two cells in series on each branch. In order to make the parameter meet the design requirement of original power supply, the new power supply should output rated current 10kA. If current is averagely distributed, each branch only withstands 1.67 kA current. For the wider range the modulation current, increasing di/dt requires higher voltage of the inverter's DC side. However, the ohmic heating coil's maximum acceptable voltage is 2000 V. Each branch only withstands 1000 V voltage. To meet the requirements, SKiiP 2403 GB172-4DL (1700 V/2400 A 2-pack-integrated intelligent Power System) is adopted. With CPS-PWM (Carrier Phase-shifted PWM), the power supply can achieve equivalent higher switch frequency under the lower switch frequency condition, and can also remove lower harmonic effect.

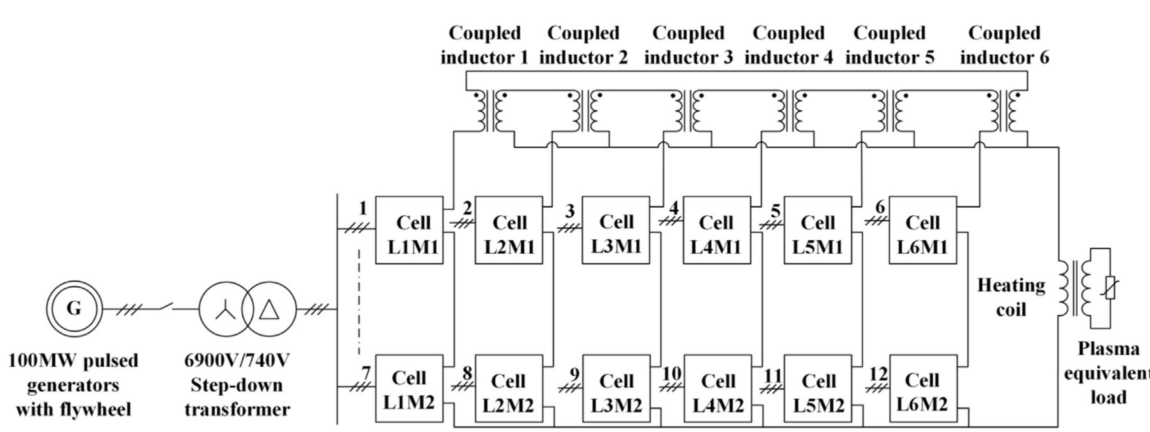

Fig. 3. Main circuit topology of the power supply.