Fusion Engineering and Design 129 (2018) 147–151

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

PWM power supply for ICRF ferrite tuner in EAST

Gen Chen*, Yuzhou Mao, Yanping Zhao, Shuai Yuan, Guang Liu, Xinjun Zhang, Chengming Qing

Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, China

ARTICLE INFO

PACS:
52.50.Qt

Keywords:
EAST-ICRF
PWM
Impedance matching
Rapid conversion

ABSTRACT

Ion cyclotron resonance frequency (ICRF) heating is a traditional auxiliary heating method applied to EAST. However, the antenna load will oscillate violently with the change of plasma parameters in the ICRF heating. But fast ferrite branch technology (FFT) can be used to achieve real-time impedance matching by controlling the bias magnetic field of FFT to adjust its equivalent electric length. So an excitation coil power supply is developed to satisfy the requirement of fast and stable change of FFT bias magnetic field. In the power supply design, the method of Pulse Width Modulation is used to achieve rapid real-time conversion of current, and to meet the needs of rapid power conversion. The paper introduces general design of PWM power supply, front DC power supply, energy storage filter circuit and constant current circuit of H bridge sequentially. And an experiment is set on the FFT excitation coil current changing with the control signal, indicating that the rapid real-time current conversion can be achieved.

1. Introduction

In the ion cyclotron resonance frequency (ICRF) heating, the antenna load will oscillate violently with the change of the plasma parameters, especially during the L-H transition state and the H state (When the power supply is in alternating current, it may come to a sudden change in power at some instant, known as the H state. But it remains at a very small power in DC state, which is called the L state.), which is a huge challenge for impedance matching system. There are many techniques to deal with this situation, such as conjugate T, 3dB coupler, real-time impedance matching. According to the EAST-ICRF system configuration, we choose the real-time impedance matching based on fast ferrite support technology (FFT). The advantage of FFT is that the differential electrical length adjustment is very fast and can be used to track load changes. Therefore, when the ICRF antenna load changes rapidly, FFT can be a very good impedance matching method [1–5].

Essentially, the structure of the FFT is a coaxial transmission line, which is filled with ferromagnetic material, so there is a bias magnetic field. The FFT bias magnetic field is mainly composed of the excitation coil, permanent magnet, and the yoke composition. The magnetic permeability of the ferromagnetic material varies with the size of the bias magnetic field, which can be controlled by adjusting the equivalent electrical length of the FFT. Therefore, the rapid and stable change of the bias magnetic field is the key to the rapid response of the FFT to the load. So an excitation coil power supply is developed for the bias magnetic field of FFT.

The output of the excitation coil must be fast response according to the variation of the antenna load, but the general constant current power supply can't be satisfied in the response time. However, the PWM (Pulse Width Modulation) technology can be used to realize the conversion of the H state and the L state. Pulse width modulation is a very effective technology to control the analog circuit using the digital output of the microprocessor. In recent decades, it has been widely used in many fields such as measurement, communication, power control, transformation and so on [6–10]. The control mode of PWM is to control the on-off of inverter circuit switching device, so that the output can get a series of equal amplitude pulse instead of sine wave or the required waveform. Therefore, the width of each pulse can be modulated according to a certain rule, so that the output of the inverter circuit can achieve the purpose of real-time current conversion.

In this paper, the general design of PWM power supply is introduced in Section 2, and the PWM control circuit is designed according to the requirement of real-time conversion of power supply current. Moreover, the working principle and process of PWM power supply are introduced, together with some technical parameters of power supply. From Sections 3 to 5, it introduces the various parts of the power supply, followed by front DC power supply, energy storage filter circuit, constant current circuit of H bridge. In the front DC power supply, an IGBT (Insulated Gate Bipolar Transistor) inverter full-bridge resonant conversion circuit is used to rectify the output voltage based on the output requirements, and to achieve the appropriate indicators. In the energy storage filter circuit, the output impedance of the front stage power supply must be impedance shifted to the load inductor in order to meet the inductor current reverse. So a 4-order Chebyshev LC energy

* Corresponding author.
E-mail address: chengen@ipp.ac.cn (G. Chen).

https://doi.org/10.1016/j.fusengdes.2018.02.043
Received 20 June 2017; Received in revised form 30 January 2018; Accepted 11 February 2018
Available online 28 February 2018
0920-3796/

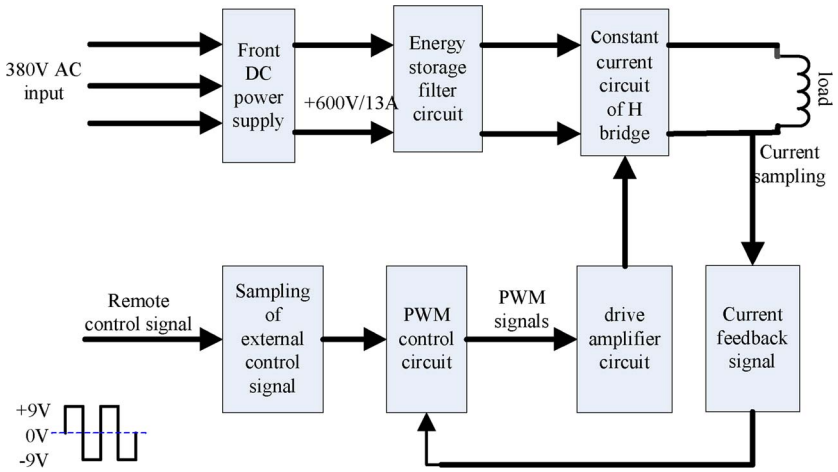

Fig. 1. Schematic diagram of bipolar power supply system.

storage filter circuit is developed to achieve the requirements of impedance conversion, and to complete the conversion from the voltage source to the current source to meet the requirements of the inductive load. And the constant current circuit of H bridge is used to achieve real-time current conversion by controlling its switch in Section 5. Then an experiment is set on the FFT excitation coil current changing with the control signal in Section 6. Finally, there is a summary of the full text in Section 7.

2. General design of PWM power supply

According to the measured parameters, and the requirements for rapid response to the antenna load, a bipolar power supply is designed and shown in Fig. 1.

As shown in Fig. 1, the 380 V AC power is input from the front-class power supply, and turned into 600 V DC through front DC power supply, and then completed the impedance conversion and voltage source to the current source conversion in the energy storage filter circuit, so as to fulfill real-time current conversion in the constant current circuit of H bridge finally. At the same time, the remote control signal is compared with the current feedback signal in the PWM control circuit, and then the contrast value is processed to form the PWM signals. Immediately, the PWM signals enlarged by the drive amplifier circuit are accepted into constant current circuit of H bridge. In the end, it achieves real-time current conversion by controlling its switch in the constant current circuit of H bridge, so that it can reach agreement between the output current value and the specified value of remote control signal.

Actually, DC resistance of the load (about 0.45 Ω) is much smaller than AC reactance of the load (about 600 Ω), so the instantaneous output power (referred to as the H state) of the power supply is much greater than the output power of the steady current state (referred to as the L state). In the H state, it needs 600 V high voltage output for the power supply in order to ensure the current change speed. However, according to constant current value given by the remote control signal, it needs only about 45 V or less in the L state. So it needs to make a quick response to the power output and it is not less than 40A/ms for the rate of current change, since the remote control signal frequency is unchangeable. However, the general constant current power can't meet the requirements for the response time. In this conduction, Pulse Width Modulation can be used to achieve it by changing the duty cycle of remote control signal, that is, to increase the duty cycle in the H state, and to reduce the duty cycle in the L state. By this way, the power supply can respond quickly between the H state and the L state.

In this system, since the load is similar to an inductor of pure inductance, so the power supply is mainly current feedback, and control of current tracking is used. Generally, the sampling value of the load is used to compared with the reference value of remote control signal. And the on-off time of each power device is determined by the instantaneous value gained from the comparison, so that the actual output current follows the reference value. In the H state, it is adjusted to increase the output duty cycle by the PWM control circuit based on the comparison value, so that to ensure the output power rapidly raises to the maximum in a short time. However, when it is switched to the constant current L state, it is adjusted to narrow the output duty cycle so that the output power quickly reduces to a suitable steady value.

3. Front DC power supply

The front DC power has been designed with an output power of 6500 W, and its output voltage is no less than 500 V. And it mainly composes of 3 sub circuit modules, which are rectifier filter circuit, full bridge converter circuit and filter circuit. The full bridge converter circuit virtually is an IGBT inverter full bridge resonant conversion circuit, with advantages of high efficiency, easy to debug, high reliability, high output power and so on [11,12]. Firstly, the three-phase four wire AC380 V input is rectified and filtered to obtain the 510 V DC voltage. Then it is processed by the full bridge converter circuit and the filter circuit. Finally, the DC 600 V/13A is obtained and the overall efficiency is 85%. The detailed schematic diagram is shown in Fig. 2.

4. Energy storage filter circuit

Since the voltage and current are 600 V/100A after the load coil current reversed, the output impedance of the front stage power supply is 6 ohm, but the impedance of the load inductance is 50 ohm.

In order to achieve the reverse of load current, the output impedance of the front stage power supply must be changed by impedance

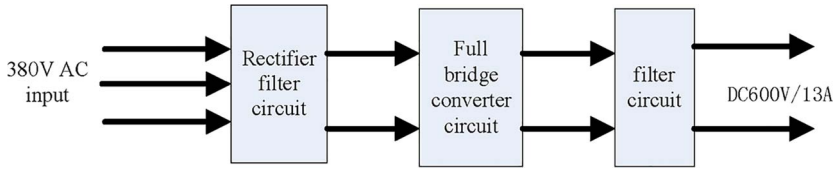

Fig. 2. Schematic diagram of front end DC power supply.