The Design and Testing Result of TF Power Supply System of EAST Tokamak

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Abstract

this paper analyses the design project of control system and protection system of toroidal field (TF) power supply system of EAST tokamak, and the main parameters of TF power supply system are selected. Through the first experiment of EAST tokamak, the testing curves of control system and protection system demonstrate the validity of this design project.

KEYWORDS: EAST, TF power supply, current control, quench protection

1. Introduction

EAST is a non-circular advanced steady-state experimental device to be built at the Institute of Plasma physics (ASIPP), Chinese Academy of sciences, since 1998. Its TF system, which is consisted of a toroidal array of sixteen superconducting D-shaped coils, is used to produces a maximum toroidal field of 3.5 T in the center of plasma[1]. this paper analyses the design project of control system and protection system of toroidal field (TF) power supply system of EAST tokamak, and the main parameters of TF power supply system are selected. The main parameters and requirements of the TF system are summarized in the following table.1 [2]. Through the two experiments of EAST tokamak, the testing curves of control system and protection system demonstrate the validity of this design project.

Table.1 The main parameters of TF magnet

Toroidal field	3.5 T
Inductance (L)	2.95 H
Maximum current	14.3 kA
Maximum energy	300 MJ
Ramp-up time	30-60 minutes to 80% Imax
Maximum quench $\int i^2(t)dt$ *	2.2×10^9 A^2S
Maximum discharge voltage	4000 V

*=after allowance 1 second quench detection time

2. The Design of TF Power Supply Control System

2.1. The Design of Main Circuit Topology of EAST TF Power Supply

In the power supply system of EAST superconducting tokamak, a low voltage (±20v) and high current (16KA) dc power supply that supplies for EAST superconducting toroidal magnet is required. In the design of this power supply, the two-reverse-star converter with interphase-reactor is adopted. These ratings can be achieved with thyristors or semiconductors like IGBT's or IGCT's. As there are no special requirements such as fast voltage modulation, or high switching frequency, the main disadvantages (price, great "on"-resistance) of the latter are decisive. In order to demand the requirements of lower dc voltage ripple and no parallel or serial connection, the best economical solution for the technical demands are thyristor based, 12-pulse converters according to IEC 146 type 5 as shown in Fig. 1 [3]. In this converter each branch contains only a single thyristor, whose ratings are water-cooled 800V, 4000A. In the mean time, the primary coil of one transformer is in delta connection, and another is in star connection. The circulating current is limited by the interphase-reactor between two three-phrase semi-wave converter circuits. After a analysis of the circulating current of TF power supply, A new attitude of omitting the interphase-reactor between two converters is proposed [4]. In the water cooling system of TF power supply, the total water flow rate to cool all thyristors is about 40L/min for an increase in average water cooling temperature of <10℃.

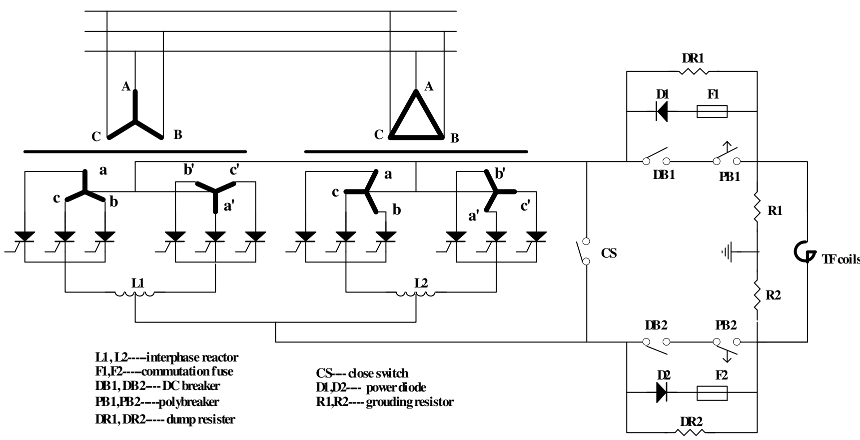

Fig.1 The main circuit diagram of EAST TF power supply system

2.2 The Design of TF Power Supply Control System

In the design of TF power supply control system, the main control is the current control, which controls the actual output current of the TF power supply to track any specified current reference of TF coils at the satisfied precision, is described in this section. The difference between the actual current (feedback signal) and the reference value is passed through a PI regulator and is processed to produce an output signal. This output signal is subtracted from the signal proportional to the current of each of two groups of 6-pulse converter and then separately connected to the firing circuit of each group of 6-pulse converter to change the output voltage of two groups of 6-pulse converter. The coils current control loop is designed to stabilized the current at any specified level. The current balance between two groups of 6-pulse converter is realized by adjusting proportional coefficients (K_1 and K_2) of two current balance control loops. The current control scheme is shown in figure 2.

To achieve accurate current control for TF coils, current measurements is of great importance. In our scheme, as shown in figure 1 or figure 2, we select four current sensors of 5 kA LEM module to measure the currents (I_{11}, I_{12}, I_{21} and I_{22}) of four 3-pulse converters (Conv_11, Conv_12, Conv_21 and Conv_22). So the unbalanced current between two 3-pulse converters of the 6-pulse midpoint converter can be detected. The current of each group of 6-pulse midpoint converter is the sum of the currents of its two 3-pulse converters.

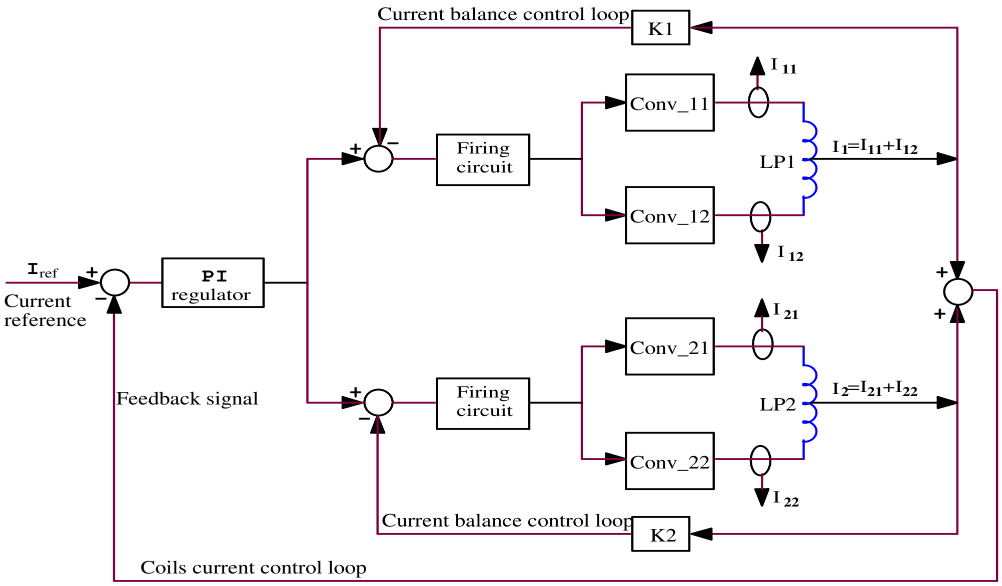

Fig.2 Feedback control scheme for TF power supply

3. The Design of TF Power Supply Protection System

The TF power supply protection system has two fundamental functions: the protection of TF power supply towards internal failures and the quench protection to avoid damages to the TF coils. Internal failures only affect the TF power supply system, and so are mainly cleared by changing the converter to inverter operation and closing close switch (CS) after opening QF. In general fast discharge of the TF coils is not initiated.

The most important function of the TF power supply protection system is protection of the TF coils in the event of a quench. Quench protection circuit, as shown in figure 3, must be capable to provide a safe and fast discharge of the TF coils stored energy to the external dump resistor. 16 TF coils are connected in series, and the stored energy is extracted by a single discharge circuitry. The discharge rate of the coils stored energy depends on the time constant of the discharge circuitry. According to the $\int i^2(t)dt$ constraint, during a quench occurring at 14.3 kA of maximum operating current, the TF coils current must decays rapidly with a time constant of <19.5 s to protect the TF coils from exceeding the upper temperature limit of 150K. This decides the minimum value of the discharge resistors, and the maximum permissible resistance is limited by the maximum discharge voltage. We take total 0.2Ω (each 0.1Ω) as the quench protection resistance value [5].

According to the first experiment in March, 2006, when other systems, such as vacuum system, cryogenic system etc., has fault and the magnets do not occur quench, if we adopt quench protection, the fast discharge may result in the instability of EAST device, so we add a new discharge system, named as fast demagnetization system, its current ramp-down ratio is about 60-100A/s, as shown in Fig.3.

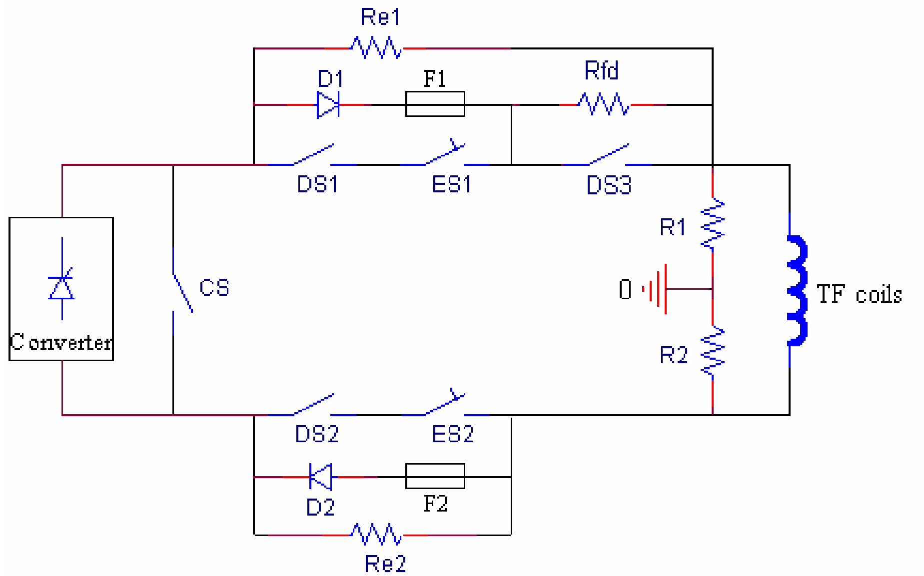

Fig.3 Quench protection and fast demagnetization Circuit Diagram

4. The Result of Experiments

Through the first and second EAST tokamak experiments, TF power supply system has excited to TF coils, the maximum current reachs 14.56A, and a quench protection is carried out at this current value. From the testing waves we know that the current may ramp up and ramp down smoothly, and the quench protection is reliable.

4.1 The exciting wave of TF power supply

In March and September, 2006, EAST device has two campaigns, especially the latter campaign, all the magnets were excited to the full parameters, TF magnets were excited to 14.56kA (the rating value is 14.3kA), From the testing waves we know that the current may ramp up and ramp down smoothly, as shown in Fig.4. When the current ramp up to about 7500A, TF power supply received a disturbance so that power supply was in inverter and current was ramp down. After about 1 minute the disturbance signal disappeared and the current ramp up again.

4.2 the testing wave of quench protection

When the current reach 14.56kA and maintain about 800 seconds, we carried out a quench protection in order to validate the reliability of TF magnets. In the curse of quench protection, the quench protection system of TF power supply perform this protection perfectly according to the design parameter, the DS1 and DS2 breakers are opened, the fuse F1 and F2 are blew, in the mean time two back up breaker---polybreakers are not opened. The testing wave is shown in Fig.4, Fig.5 and Fig.6.

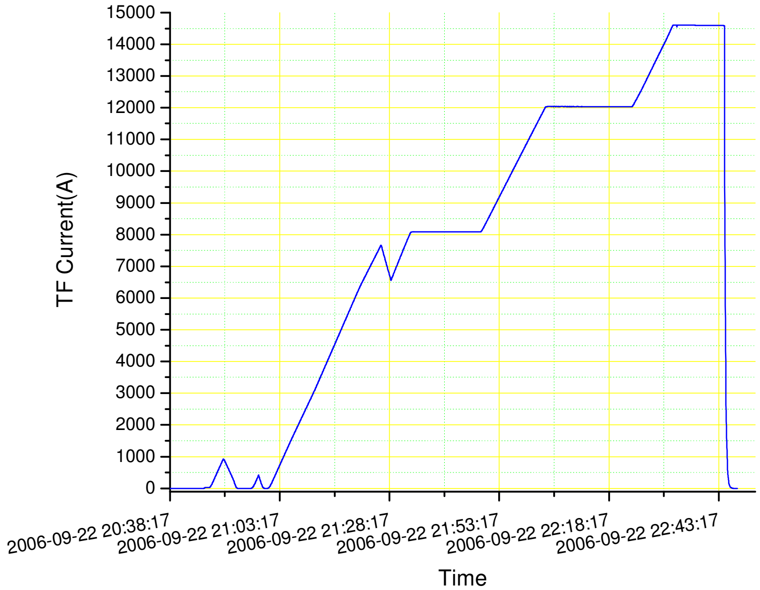

Fig.4 the exciting wave of TF power supply

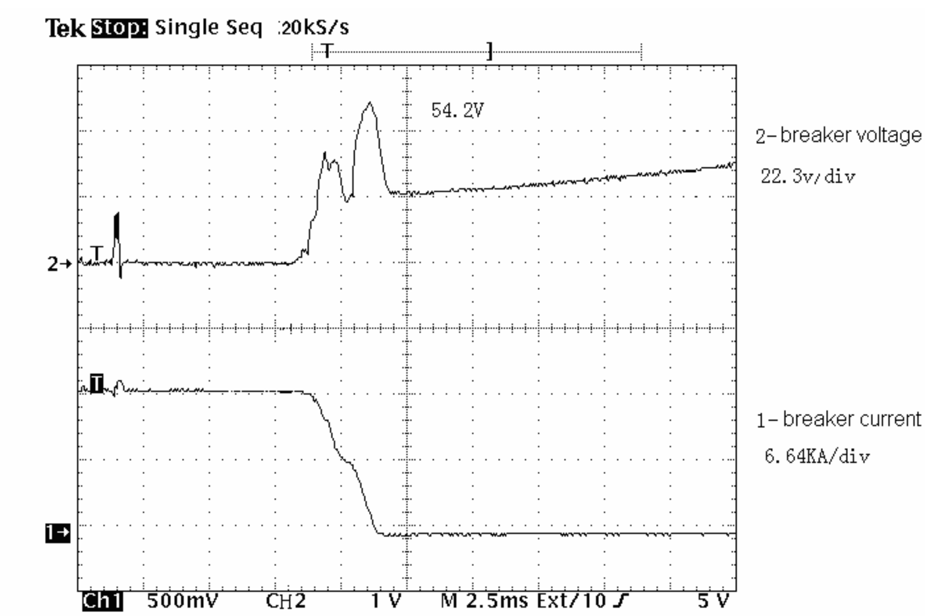

Fig.5 the voltage and current wave of breaker

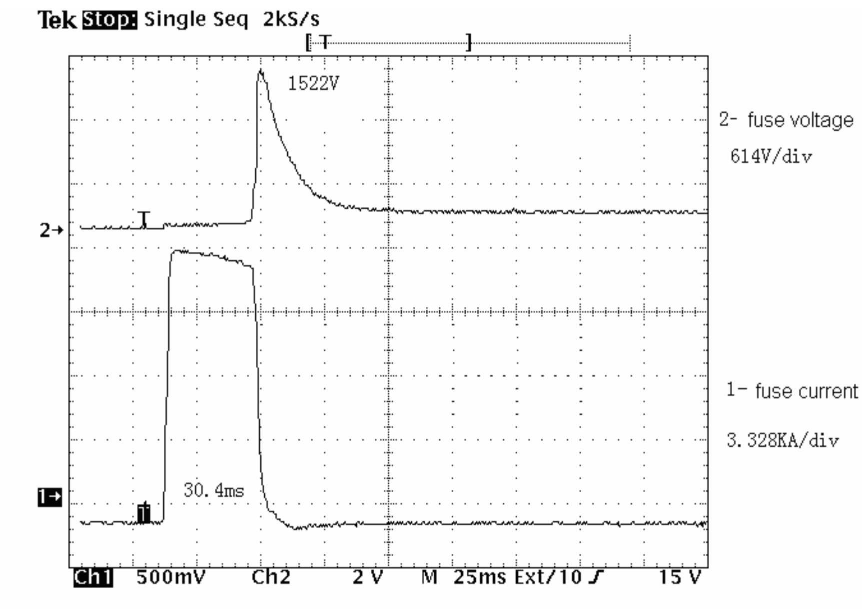

Fig.6 the voltage and current wave of fuse

5. Conclusion

In a word, testing result shows that the design of TF power supply system is correct, and The TF power supply has achieved the required specifications. The operation sensitivity and reliability of the quench protection circuit have been experimentally confirmed.

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