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Development of EAST-NBI High-voltage Power Supply Chain Protection Control System

Shengmin Pan, Baocan He, Hulin Feng, Denghui Wang, Yiyun Huang
Institute of Plasma Physicas Chinese Academy of Sciences, Hefei, China

Abstract: The EAST-NBI high-voltage power supply is an accelerating power supply in the neutral beam injection auxiliary heating system. It has the features of fast rise time, short turn-off time and high voltage cut-off when the load is lighting. Especially in the load ignition, it needs to cut off the high voltage in a few microseconds, to ensure the safety of ion source load, therefore, high-voltage power supply chain protection control system is particularly important for the power supply. The chain protection control system has the advantages of higher integration, real-time, etc., especially in the temperature rise has been fully considered to ensure that the chain protection control system after a long run, due to the temperature and the protection of the safety of the system. After experimental verification of the control system is stable and reliable.

Keywords: chain protection, control system, real-time.

1. Introduction

The high voltage power supply (HVPS) is developed for the national great science engineering superconducting TOKAMAK fusion experimental device(EAST) , which is a set of high power high voltage pulse power supply for neutral beam injection(NBI). The HVPS adopted Pulse Step Modulation technology [1], which connected by 144 the same structure of 770V/70A power supply module in series (Fig. 1). Its rated output is 80kV/70A, maximum pulse width is 1000s. Due to the power supply's highest output voltage up to 100kV, therefore, between the power supply module and the control system must through the reliable isolation to ensure the safety of the controllers. And because of it worked in pulse module, there are strong electromagnetic interference when the load lighter. Based on the above consideration, this control system used optical fiber as transmission medium [2,3], which is widely used in modern communication networks, and with strong anti-interference ability and the resistance to high voltage. Through the optical fiber communication between control PC and power supply module, to control and monitor the power supply module was realized.

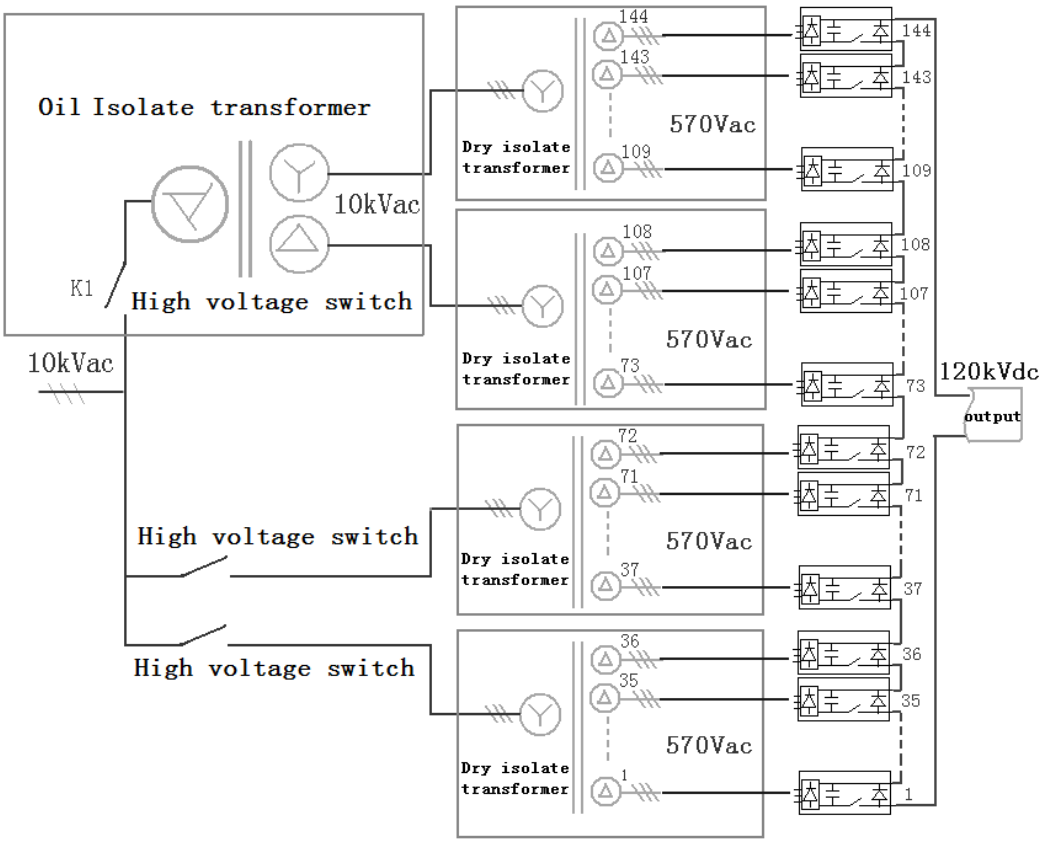


Fig.1 High voltage power supply topology

2. Chain protection control system block diagram

The integrated chain protection control system block diagram shown in Figure 2, the control system consists of power module internal intelligent controller, external protection box, IGBT drive chassis, thyristor crowbar switch[4,5] and over-current over-voltage detection module. The entire high-voltage power supply has 144 power modules in series, each power module is equipped with an intelligent controller. The function of this controller is to control the power modules in real time and monitor the internal status of the power modules. If there is an unrecoverable fault occurs (such as fan stalling). The IGBT switch is blocked and the power module is out of operation. The controller also has an over-current detection function. When it detects that the output current of the power module is more than 180A, the module is considered to be over-current, the IGBT switch is blocked, the current mode of the power module is operated, the over-current signal is reset when the IGBT driving signal is off, which can continue to run next time. The IGBT drive chassis (KIGBT O.F. in Figure 2) is used to control the optical signals that are switched on by the various power modules. The chassis is also controlled by the integrated protection chassis optical signal. The integrated protection chassis (Assorted Fault in Figure 2) is used to receive the status signal sent by the NBI master and the over-voltage fiber signal and latch it. When

receiving the above abnormal signals, the integrated protection chassis sends out the optical signal of blocking the IGBT driving chassis so as to realize the fast breaking of the power module and ensure the safety of the load ion source[6]. In addition, a CROWBAR switch is connected in parallel with the output of the power supply. The switch serves as a backup protection. When the power supply module receives the shutdown signal, if the module is not shut down in time, the CROWBAR switch is triggered to immediately drop the power output voltage to 0. All signals are achieved through optical fiber to ensure the rapidity and reliability of the chain protection system.

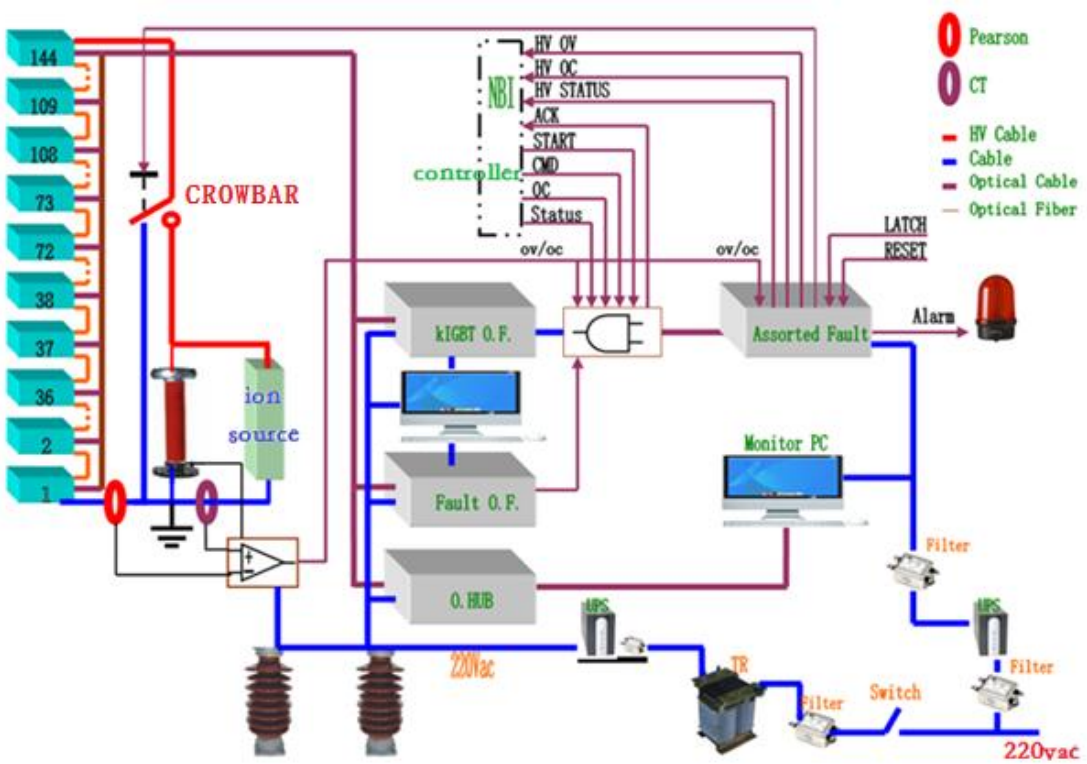


Fig.2 Chain protection control system block diagram

3. The power supply module internal intelligent controller

The principle diagram of the internal intelligent controller is shown in fig.3. The core control chip of the internal intelligent controller is single chip microcomputer 89C51[7,8], which control the power module IGBT, fan and vacuum contactor by logic control circuit, while detecting the power module output voltage, current and the fault signal.

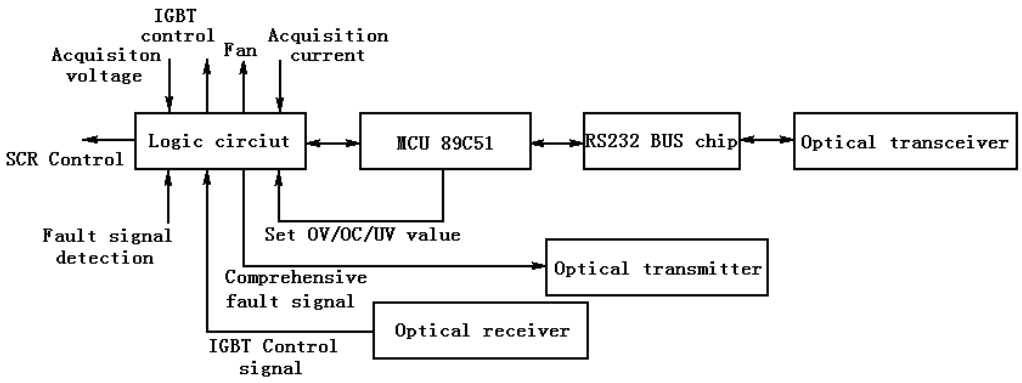


Fig.3 The principle diagram of the power supply module internal intelligent controller

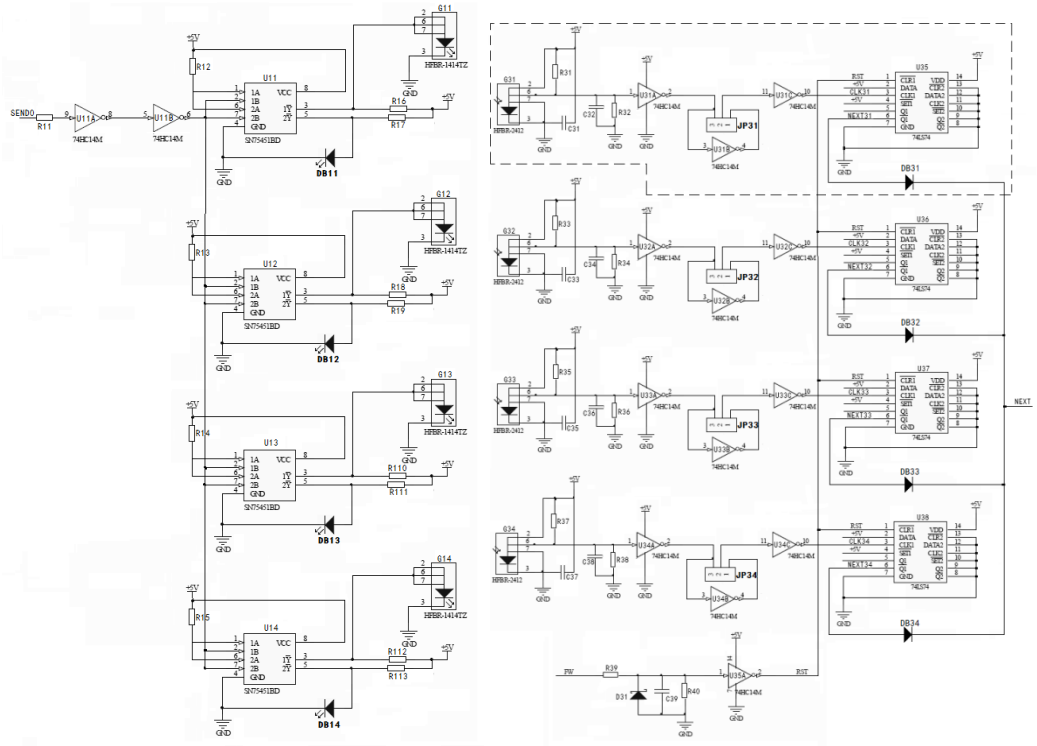
The microprocessor is responsible for processing the command from control PC through RS232 communication. The logic circuit is used for receiving IGBT drive signal and judging the internal state signal of the power module, and making proper protection control.

4. Comprehensive protection of the chassis

The integrated protection chassis is the core component of the chain protection control system. The real-time performance and reliability of the chassis are particularly important for the safe and reliable operation of high-voltage power supply and load ion source. In order to ensure the real-time performance and reliability of the chassis, all the circuit boards in the chassis adopt the CPCI pluggable structure[9,10], which can adjust the logic operation of optical signals in each channel in real time. In addition, all signal operations are performed by using chips, and all final logic operation of the fault signal has a latch function.

Comprehensive protection of the main circuit board inside the chassis shown in Figure 4, including the fault signal sending board A and fault signal latch board B. Fault signal latch board is mainly composed of optical signal receiver chip HFBR-2412T, D trigger chip 74LS74, NAND gate chip 74HC14 and some capacitor resistors. Work process is as follows, when any way HFBR-2412TZ received no light signal (normal light, you can set the jumper, JP31 in Figure 4 to set the jumper), that received a fault signal, 74LS74 chip the fault signal lock Save and send to the optical signal sending board through the bottom connecting board. Fault signal transmission board is mainly responsible for the received fault signal (electrical signal), through the optical signal transmission chip HFBR-1414TZ conversion sent to the various subsystems and the need to control the chassis, the control board 4-way optical signal synchronization signal. Through the jumper on the backplane, the fault signal latch board and the fault signal sending board can be used in combination. For example, two fault signal latch boards and one fault signal sending board, or one system requiring more fault signals can use one fault

signal latch board and 3 fault signal send boards. Through the comprehensive protection of the chassis can fault signal real-time latch display, and give the required system or chassis, real-time protection of power and load requirements.



A. Fault signal sending board B. Fault signal latch board

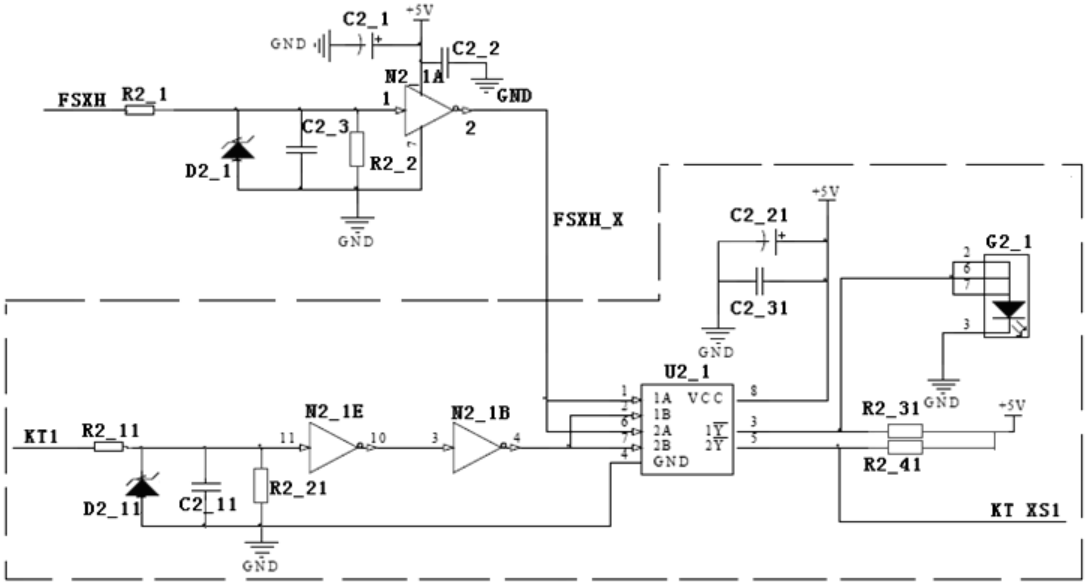
Fig.4 Comprehensive protection of the chassis circuit

5. IGBT drive chassis

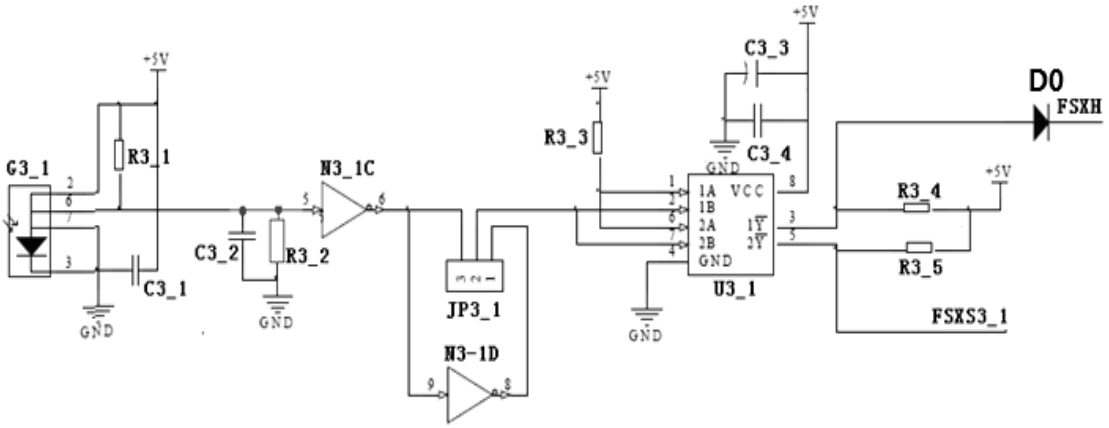
The IGBT drive chassis is the communication link between the control computer and the power module. The control card PCCI-7248 is connected to the IGBT drive chassis via a connection cable. The capture card controls the optical signals of the drive chassis and controls the power module input resection. IGBT drive chassis circuit diagram shown in Figure 5, which includes 12 light drive signal board and a light lock signal board. 12 optical drive signal board composed of the same structure, are composed of 12-channel optical drive signal, each optical drive signal circuit shown in Figure 5, A shown. The circuit is mainly non-gate chip 74HC14, optical driver chip SN75451, optical transmission chip HFBR-1414TZ and some capacitor resistors connected. FSXH signal in the figure is block signal connected with No. 1 pin and No. 6 pin of each optical driver chip SN75451, which can block the IGBT driving optical signal in real time (144 optical signals are blocked at the same time) when the blocked optical signal is received.

B circuit in Figure 5 is circuit board schematics, it also has 12 road, each road functions are the same, when any one receives the fault blockade signal can block the IGBT optical drive signal. The circuit is mainly light reception signal HFBR-2412TZ, light-driven chip SN75451, NAND gate chip 74HC14 and some capacitance resistors.

Which JP3_1 used to set the status of blocked optical signals, that is, light normal or no light normal. Its main function is to receive the optical signal into electrical signals, and then sent through the backplane to each light drive signal board, to achieve rapid protection.



A.Light drive signal circuit diagram



B. Light blockade signal circuit diagram

Fig.5 IGBT drive chassis circuit diagram

6. Over-current detection circuit

Over-current protection is one of the main fault protection of high-voltage power supply, the ion source to be subjected to exercise during normal work, in this process will make the high-voltage power supply over-current, high-voltage power supply should be quickly cut off the high voltage, high voltage power supply over-current protection detection is very important. Over-current detection device installed in the low voltage output of the high voltage power supply, the schematic shown in Figure 6, the circuit board divides the power supply and over-current detection of two parts.

220V AC power supply through the step-down rectifier to get ± 15V DC, supply to electronic components. The input signal of the over-current detection is the current of the main circuit, which is measured by the current Hall (LT-308S of LEM Company) or PEARSON (101)[11,12], and then sampled, followed and compared to obtain the over-current signal and directly sent through the optical fiber to Comprehensive protection of the chassis.

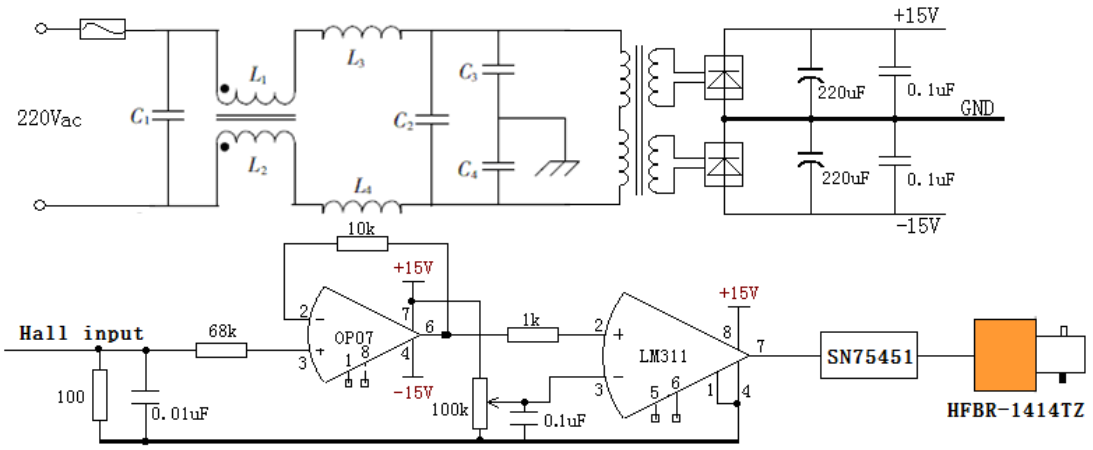


Fig.6 Over-current detection circuit

7. Crowbar switch

When the load is on, the high-voltage power supply must shut off the power within 5us. If some high-voltage power supply can not be shut down in time, the high-voltage power supply will continue to release energy to the load. When the load is short-circuited, the absorbed energy must be less than 5J[13]. Therefore, a short-circuit switch needs to be connected in parallel with the high-voltage power output. When some modules can not be shut down in time, the high-voltage power output is short-circuited by the switch to protect the safety of the load ion source. This switch we call the crowbar switch.

Taking into account the use of high-voltage power supply output short-circuit switch conditions[14], and the selection of the device can be used, and ultimately determine the use of high-power thyristor series operation, synchronous trigger mode, improve device reliability. When the high-voltage power supply is short-circuited, the inrush current of the switch is about 2kA, so the thyristor can be used as a crowbar switch[15,16].

Crowbar switch as shown in Figure 7, which has 24 pulse thyristors in series, the thyristor parameters: rated voltage 6500V, pulse repetition capability 3kA @ 400A / us. 24 thyristor in series composite the 156KV crowbar switch. The switch is turned on by a fiber optic signal, each thyristor with overvoltage conduction, and each thyristor drive circuit using a separate power supply mode.

Fig.7 Crowbar switch physical map

8. Conclusion

The EAST-NBI integrated protection system is one of the most important systems to ensure the safety of the power supply and load ion source. It consists of integrated protection chassis, IGBT drive chassis, crowbar switch and other devices. For fast protection, the device has hardware implementation. Through the experimental test, from the detected over-current to power off the module is about 3.7us, to achieve rapid protection of the power supply. After two rounds of EAST experiments, it is verified that the system is stable and reliable.

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