PAPER

The development of data acquisition and control system for extraction power supply of prototype RF ion source

To cite this article: Meichu HUANG et al 2018 Plasma Sci. Technol. 20 085602

View the article online for updates and enhancements.

Related content

- Development of data acquisition and over-current protection systems for a suppressor-grid current with a neutral-beam ion source
  Wei LIU, Chundong HU, Sheng LIU et al.

- Development of 8 MW Power Supply Based on Pulse Step Modulation Technique for Auxiliary Heating System on HL-2A
  Xu Weidong, Xuan Weimin, Yao Lieying et al.

- Design and development of distributed control system for SST-1 Thomson scattering experiment
  V Chaudhari, K Patel, A Srivastava et al.
The development of data acquisition and control system for extraction power supply of prototype RF ion source

Meichu HUANG (黄梅初)1,2, Chundong HU (胡纯栋)1, Yuanzhe ZHAO (赵远哲)1, Caichao JIANG (蒋才超)1,2, Yahong XIE (谢亚红)1, Shiyong CHEN (陈世勇)1 and Qinglong CUI (崔庆龙)1

1 Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, People’s Republic of China
2 University of Science and Technology of China, Hefei 230026, People’s Republic of China

E-mail: zyz@ipp.ac.cn

Received 4 November 2017, revised 11 April 2018
Accepted for publication 12 April 2018
Published 6 July 2018

Abstract

A 16 kV/20 A power supply was developed for the extraction grid of prototype radio frequency (RF) ion source of neutral beam injector. To acquire the state signals of extraction grid power supply (EGPS) and control the operation of the EGPS, a data acquisition and control system has been developed. This system mainly consists of interlock protection circuit board, photoelectric conversion circuit, optical fibers, industrial compact peripheral component interconnect (CPCI) computer and host computer. The human machine interface of host computer delivers commands and data to program of the CPCI computer, as well as offers a convenient client for setting parameters and displaying EGPS status. The CPCI computer acquires the status of the power supply. The system can turn-off the EGPS quickly when the faults of EGPS occur. The system has been applied to the EGPS of prototype RF ion source. Test results show that the data acquisition and control system for the EGPS can meet the requirements of the operation of prototype RF ion source.

Keywords: RF ion source, data acquisition, control system, TCP/IP protocol, beam extraction

(Some figures may appear in colour only in the online journal)

1. Introduction

Neutral beam injector (NBI) is an effective way to heat the plasma for tokamak [1]. The China Fusion Engineering Test Reactor is under engineering design [2]. Comparing with the positive ion beam, negative ion beam still has higher neutralization efficiency with high beam energy (>200 keV). Hence, a radio frequency (RF) negative ion source test facility was developed at Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) [3–5]. The negative ion accelerator of RF ion source consists of plasma grid (PG), extraction grid (EG) and ground grid. A extraction grid power supply (EGPS) for prototype of RF ion source was designed and developed.

To simplify the structure and improve the resolution of the EGPS, the pulse step module technology based EGPS (rated voltage and current: 16 kV/20 A) was designed with 27 switch power supply (SPS) modules [6–9]. Figure 1 shows the schematic diagram of the EGPS. The 27 modules have two types, which can output voltage of 800 V and 100 V, respectively.

2. System hardware design

The schematic diagram of the data acquisition and control system of EGPS [10] is presented in figure 2. Data acquisition device mainly includes Hall sensor and resistive divider,
Figure 1. Schematic diagram of the EGPS.

The voltage and current of the EGPS are measured by resistive divider and Hall sensor, respectively. The signals are converted to optic signals by $V/F$ converter and transmitted to $F/V$ converter by optical fibers for providing galvanic isolation and shielding electromagnetic interference and electromagnetic compatibility. The signals are sampled by the PXI-9846 card. The measured current is also sent to the protection circuit board through optical fibers. The block diagram of over-current protection is shown in figure 3. If over-current signal is detected by the over-current protection circuit board, the state of optical fiber varies from light to dark. Then the hardware interlock protection will shut down the SPS modules in 5 $\mu$s and display the status of over-current for EGPS through HMI. The fault signals are latched down the SPS modules in accordance with the commands from the host computer, and provides the feedback control for output voltage of EGPS. The whole power supply system is operated and monitored through HMI.

The optical fiber transmission is utilized for high voltage isolation, and communication between the control module and the EGPS. All the status of EGPS are collected by the CPCI-7249 card. The on/off of SPS modules are controlled by the control module through CPCI-7249 digital output ports. Each CPCI-7249 card has 48 channel digital input/output ports. Considering the number of SPS modules and the requirements of monitoring the status of EGPS, three CPCI-7249 cards are used.

To send the setting action threshold of various protection to the power supply, the CPCI-6208 card with 8 independent analog output ports is utilized. The output voltage signals of CPCI-6208 are sent to the protection circuit board through $V/F$ and $F/V$ converters by optical fibers.

3. System software design

The software of data acquisition and control system are mainly implemented on the CPCI computer and host computer. The CPCI computer runs on Linux, and the host computer runs on Windows.

3.1. Data acquisition software

As mentioned above, a CPCI computer is used for the data acquisition module. The software is implemented by C language programming on Linux. The PXI-9846 card has features of 4 independent analog acquisition channels with 16 bit resolution. The data acquisition of PXI-9846 is implemented by programming through PXI-9846’s integrated library function, which adopts the double-buffered asynchronous operation mode. The input voltage range of PXI-9846 with 512 MB on-board memory is programmed at $\pm 5$ V, and the sample frequency is set at $40$ M $s^{-1}$. Once the parameters are configured in PXI-9846 card, the PXI-9846 will collect data continuously. Then the analog signals are gathered by PXI-9846 card. The digital data of PXI-9846 are converted to value of input physical signals implemented by the WD_AL_VoltScale library function in proper order. Then the value is used for displaying and controlling.

The programming scheme of the data acquisition is shown in figure 4.

The status of the EGPS are transmitted to the CPCI-7249 cards, which are also displayed on the HMI. Each port of CPCI-7249 is connected with one signal, which can be configured through CPCI-7249’s integrated library function and easy to be read by CPCI controller.

3.2. Control module software

As shown in figure 2, the IGBT of SPS modules and the power distribution cabinet of EGPS are driven by the control module of EGPS. Depending on the NBI system requirements, the control parameters of the EGPS are set on the HMI in host computer. The controller in CPCI computer can receive the data from the host computer by network communication. The CPCI computer controls the on/off of the SPS modules in accordance with the commands from the host computer, and provides the feedback control for output voltage of EGPS. The whole power supply system is operated and monitored through HMI.

The communication between the human machine interface of host computer and CPCI controller utilizes the client/server model by using transmission control protocol/internet protocol (TCP/IP). The control module software of EGPS mainly consists of two parts: client software and server software. On the server side, server software is always in a listening status.

3.2.1. Client software implementation. The client program on host computer is developed by LabVIEW from National Instruments and runs on Windows system. The HMI of the
The client program has functions of setting operating parameters and monitoring the status of the EGPS. The parameters (voltage setting, actual voltage and current) that are read along with running time too.

After communicating to the server successfully, the client application controls the EGPS system and monitors the status of EGPS. Operators can click the buttons and set the parameters through the client application, such as voltage setting, power distribution switch-on, switch-off command. The data will be transmitted from client to server.

3.2.2. Server software implementation. The CPCI computer server software is developed by using C language and runs on the Linux to obtain fast real-time control. Its work flow chart is presented in figure 6. The voltage, current, over-voltage, over-current and on/off status of power supply module data are sent from server to client. The communication between server and client is done by the rec_command process through socket. The rec_command process saves power supply configurations from the client terminal in shared memory. Multi-process technology is used by the server software of control module. Shared memory is a fast method for multi-process communication, which can be written and read by every process. Rec_command process monitors the client requests. Once the connection is built, rec_command process receives data from the client input and saves the data.
to the shared memory. Then the rec_command process sends the collected status of EGPS to the client through TCP/IP protocol.

The ps_module process initiates the data acquisition module and collects the status of EGPS. Then the ps_module process saves acquired data to shared memory. The ps_module process reads commands from the shared memory, which are received by the rec_command process from client through TCP/IP protocol. If the received value of switch_on is 1, the power distribution cabinet of EGPS will be switched-on in soft-starting mode by programming. Then the EGPS system can be operated both by this local control module and the control system of RF ion source. If the received value of power_on is 1, the power supply will be turned-on according to the setting voltage. Once the power_on is 0, the EGPS will be turned-off, and once the switch_on is 0, the power distribution cabinet of EGPS will be switched-off.

The ps_module process calculates the numbers of modules to be turned-on/turned-off according to the setting voltage $U_S$ sent by client, that will be sent to the CPCI-7249 card by programming. Feedback control (output voltage of EGPS) is adopted in this control system. The actual output voltage of EGPS is $U_0$. If $U_0 - U_S > 100$ V, other modules will be turned-on through the operation of the CPCI controller. Until $U_0 - U_S < 100$ V, the ramp-up of voltage for EGPS are over. When EGPS is in operating condition, and if one of the SPS modules is turned-off due to some fault, the difference between the setting voltage $U_S$ and the actual output voltage of EGPS $U_0$ is detected by the feedback CPCI controller. Then the redundant modules are turned-on to operate the EGPS in stable mode.

### 4. Results

The data acquisition and control system has been employed in EGPS operation. The EGPS system has been operated at different output voltage. Figure 7 shows the response of control signal of SPS module. Blue is the control signal and red is the output voltage of SPS module. The control signals of switching on and off are transmitted to the modules, which have delay of about 1 $\mu$s. The process of switching on and off has about 5 $\mu$s delay in theory. As shown in figure 7(a), after receiving the control signal, the module works in about 4 $\mu$s. The module with fast dynamic response can accomplish high frequency switch. Figure 7(b) shows the response of switching-off module. This result is the response of no-load test for SPS module. When the module is switched-off, the energy of power supply is absorbed by the parallel RC circuit of IGBT, which leads to the voltage of module dropping slowly.

The tests of system for EGPS with resistance dummy load are shown in figure 8. Blue and red are the output voltage and current of EGPS, respectively. It shows that the EGPS works one by one until reaching the setting value of output voltage at the beginning, and turned-off step by step in the reverse order at the end. The output voltage of EGPS can reach to 16 kV with 450 ms. The output voltage of EGPS uses the feedback loop control and meets the requirements of negative ion source on the EGPS. The results show that the data acquisition control system can adjust the rising/falling time and setting the voltage, measure/display the voltage and current, control the output voltage of the EGPS, etc.

The testing of over-current behavior is one of the important parts in EGPS system. The response of the EGPS after short circuit is shown in figure 9. An instantaneous rise of current is detected by over-current protection circuit board. Then fault signal is sent to the interlock protection circuit board by optical fiber. The interlock protection circuit board shuts down all control signals of SPS modules after receiving the over-current signal. It shows that the switching-off time of voltage of EGPS is less than 5 $\mu$s. Due to the feature of load, the switching-off time of current at output is longer.

As shown in figure 10(a), the EGPS system has been applied to the prototype RF ion source of NBI, which feeds the voltage difference between PG and EG. The data acquisition
Figure 5. The HMI of data acquisition and control system.

Figure 6. Flow chart of server software.
Figure 7. Response of control signal of SPS module. (a) Turned-on, (b) turned-off.

Figure 8. Output of the EGPS. (a) the test of the EGPS system, (b) output of the EGPS.

Figure 9. Short circuit response of the EGPS.
and control system is also used on EGPS. Figure 10(b) shows one shot waveform of the output voltage and current of EGPS at 4.2 kV. RF power is about 35 kW, the pulse width is 0.5 s.

5. Conclusions

The development of data acquisition and control system for EGPS on RF ion source has been reported in this paper. The results proved that the optical fiber transmission, protection circuit board, hardware circuit of interlock protection, multi-process technology, and TCP/IP protocol improve the efficiency of system operation. The test results shown that the data acquisition and control system of EGPS works well with good performance, the system meets the requirements of RF ion source on EGPS.

Acknowledgments

This work was supported by National Natural Science Foundation of China (Contract Nos. 11505225&11675216), Foundation of ASIPP (Contract No. DSJJ-15-GC03), and the Key Program of Research and Development of Hefei Science Center, CAS (2016HSC-KPRD002).
ORCID iDs

Meichu HUANG (黄梅初) @ https://orcid.org/0000-0002-8222-2365

References