Fusion Engineering and Design 112 (2016) 57–66

Contents lists available at ScienceDirect

Fusion Engineering and Design

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

Hardware-in-the-loop simulation of the EAST PF converter for PF control system upgrade

Xiaojiao Chen[a,b], Peng Fu[a,b], Liansheng Huang[a,*], Ge Gao[a], Shiying He[a]

[a] Institute of Plasma Physics, Chinese Academy of Science (ASIPP), P.O. Box 1126, Hefei, Anhui Province 230031, China
[b] Chinese University of Science and Technology, Hefei, Anhui Province 230022, China

HIGHLIGHTS

- The hardware in the loop simulation of the EAST PF system is presented.
- The control functions and the protection logic have been tested and verified.
- The major faults could be avoided and commissioning time could be saved on site.

ARTICLE INFO

Article history:
Received 7 February 2016
Received in revised form 23 June 2016
Accepted 27 July 2016

Keywords:
Hardware-in-the-loop simulation
Real-time simulation
RT-LAB
EAST PF
Control system

ABSTRACT

The EAST poloidal field (PF) control system was upgraded in 2015 and the new system has been in use for the 2015 EAST campaign. This paper presents the implementation of a hardware-in-the-loop (HIL) simulation platform of the EAST PF converter system based on the RT-LAB simulation environment, which was used to improve and evaluate the performance of the real controller. The EAST PF power supply system and its operational modes are presented in this paper. The experiments on HIL simulation platform show that the control algorithms and the over current protection of the controller meet the design requirements well. In addition, the effectiveness of the designed control system has been verified by actual application during the EAST campaign at 2015 for six months.

1. Introduction

The Experiment Advanced Superconducting Tokamak (EAST) is a non-circular advanced steady-state experimental device located at the Institute of Plasma Physics (ASIPP), Chinese Academy of Sciences [1–3]. The EAST PF power supply system consists of AC/DC converters, bi-direction external bypass, Switching Network Units (SNU), and a Quench Protection (QP) circuits [4]. Each converter operates in four quadrants to provide the slow ramp up and control of current necessary to produce the requested plasma shape and position [5].

The EAST PF power supply system was designed more than ten years ago and has been in service since then. Because of technological and cost limitations which was existed 10 years ago, the accuracy and linearity of the original power supply control system were not very good. The performance of PF converter system could not meet the plasma control requirements or improvements that were necessary in the plasma operating mode. It became necessary to upgrade the control system of the PF power supply system. Considering the complexity and variability of the control logic, it was decided to fully test the new control system before implementing it on the real main circuit so that major problems and faults can be avoided. In this paper, the HIL technology is applied to improve and verify the control system design and reduce the time for system commissioning on site, specially to test four quadrants control logic, voltage response time and over current detection function and protection logic.

The paper is organized as follows: Section 2 presents a brief analysis of the EAST PF converter system and its control system. The HIL simulation is presented in Section 3. In this part, the details in creating the real-time simulation model of main circuit are included and the monitoring interface designed by LabVIEW is presented. Section 4 shows the simulated results obtained with HIL simulation and the actual experiments on the EAST PF converter system are carried out to verify the effectiveness of the designed controller and the validity of the HIL simulation. The conclusions are drawn in Section 5.

* Corresponding author.
E-mail addresses: chenxj@ipp.ac.cn (X. Chen), huangls@ipp.ac.cn (L. Huang).

http://dx.doi.org/10.1016/j.fusengdes.2016.07.020
0920-3796/

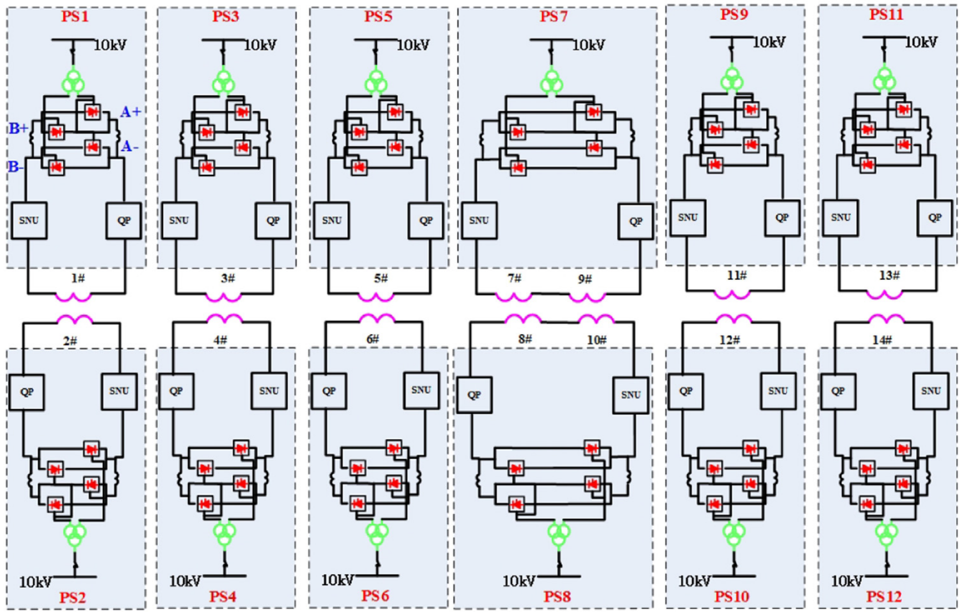

Fig. 1. The architecture of the EAST PF power supply system.

2. The EAST PF converter system

There are 12 PF power supplies that feed 14 PF coils (including the central solenoid coils). The power supplies have voltage ratings range from ±0.35 kV to ±1.1 kV with a common current rating of ±15 kA. The architecture of the EAST PF power supply system is shown in Fig. 1.

2.1. The operational modes of the EAST PF converter system

The operational modes of the EAST PF converters comprises of parallel mode, single bridge mode and circulating mode. The circulating mode facilitates smooth current zero crossing and avoids open circuit and high voltage on the coil. The PF converter system operates using parallel mode when a large load current is required. In this case, two six-pulse bridges oriented in the same direction and work together to supply the current to the load and produce a twelve-pulse output voltage. Single bridge mode is used during the transition period between circulating mode and parallel mode. Operational modes are switched according to the load current value as explained in Table 1. The A+, A−, B+ and B− are the six-pulse converters, as shown in Fig. 1.

2.2. The control system of the EAST PF converter system

Fig. 2 shows the architecture of the EAST PF control system. A Master Controller (MRC) receives reference voltage signals from the Plasma Control System (PCS) and dispatches it to the local controllers (LCC). Each LCC controls two set of converter units. The LCC calculates the firing angle according to the reference signals from MRC and sends it to the alpha controller. The alpha controller sends the fiber optic signal at the appropriate time to the pulse generator.

Table 1
Operational mode.

Id/Imax	<−15%	−15%∼−10%	−10%∼10%	10%∼15%	>15%
Bridge Operational mode	A− B− Parallel	B− Single	A+ B− Circulating	A+ Single	A+ B+ Parallel

The pulse generator transforms the fiber optic signal into an electrical signal to trigger the thyristors. The three operational modes and the switching between modes are controlled by LCC while the coil current closed loop control is realized in the PCS. The hardware configuration of the LCC is given in Fig. 3 which is composed of CPU board, alpha controllers, AI board and DI/DO board and the relative interface, based on CompactPCI bus [6,7].

2.3. The design requirements for the EAST PF converter system

According to the plasma control requirements, the design requirements for the EAST PF converter system are as follows:

(1) The circulating current value should be 2 ± 0.5 kA;
(2) |(ID1-ID2)/ID1|<10% in parallel mode (If Id > 0, ID1, ID2 represent the IA+ and IB+, else if Id < 0, ID1, ID2 represent the IA− and IB− respectively);
(3) The PF converter shall provide the symmetrical voltage response not more than 20 ms for full scale change.

Due to the complexity of the control system and the high power rating of the EAST PF converter system, any misoperation of the controller might damage the equipment. By connecting the real controller to high-fidelity simulation of the main circuit, the HIL

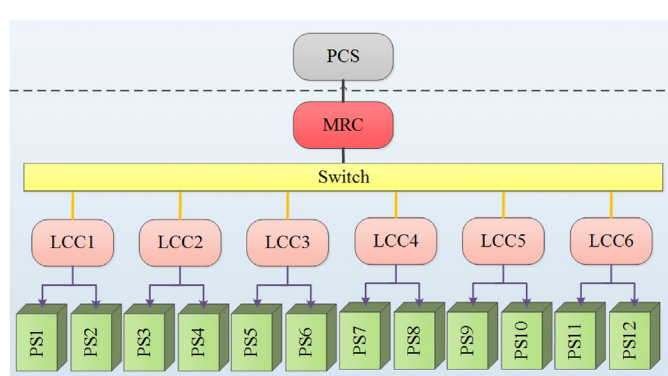

Fig. 2. The architecture of the EAST PF control system.