Computational Analysis of Controlled Power Source for Transient Fusion Reactor Power Conversion

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1. Introduction

Supercritical carbon dioxide is one of the prospective working fluids for power conversion system of fusion reactor. The Optimized Supercritical Cycle Operation (OSCO) apparatus is being designed at Seoul National University (SNU) to simulate the power conversion system. The main goal is to obtain experimental data of the supercritical carbon dioxide cycle power conversion system, particularly in transient states. OSCO adopts a controlled alternating current (AC) power supply for its heaters which can generate various transient power patterns to represent the transient heat exchangers or heat sources.

A simulator of transient direct current (DC) power supply for nuclear applications was proposed [1, 2]. A computational analysis is presented of the AC power supply source to generate various transient patterns. A three-phase line commutated power electronic converter is adopted to control the output power.

2. Systems Design

The power supply is designed to deliver controlled power for a set of heaters representing the heat source.

2.1 System Description

OSCO has been extended from the existing Pressure Applied CO_2 Operation (PACO). PACO aims to obtain a collection of thermophysical characteristics of SCO_2 using a vertical small circular tube to guide the upward flow [2]. Originally, the PACO apparatus was equipped with a variable AC power source. Due to the lack of the existing variable AC power source to simulate transient states, a programmable AC power source is designed for OSCO as shown in Fig. 1. The OSCO test section has six heater rods for controlling the heat flux on the test section. A three-phase AC-AC converter is adopted to control the output power to all test section heaters. A variety of the transient pattern power references are generated by a dedicated personal computer (PC). The International Thermonuclear Experimental Reactor (ITER) operation scenario and standard step function are chosen as the basic patterns to generate transient conditions.

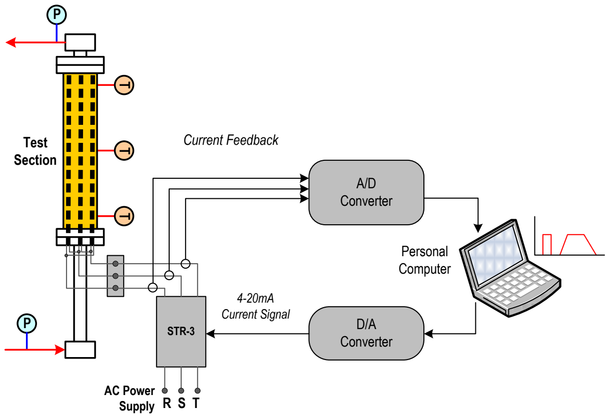

Fig. 1. OSCO power source system.

2.2 Power Converter

A thyristor three-phase AC-AC converter is used to control the power of the heaters as shown in Fig. 2. All the heaters are connected in a delta configuration. This converter can be categorized as a naturally commutating converter since their thyristor switches are naturally commutated by the AC supply.

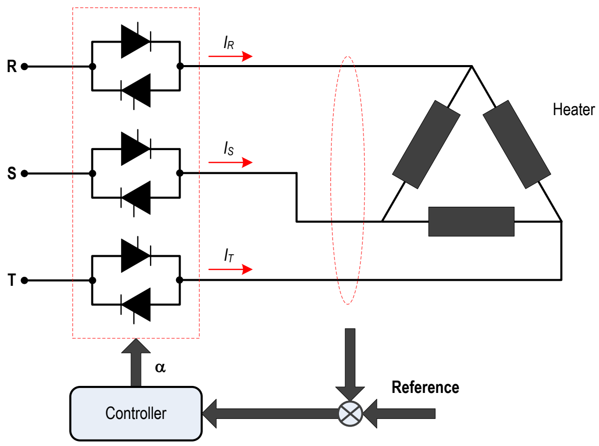

Fig. 2. Three-phase AC-AC converter.

3. Simulation Results

Three-phase delta connection 21 ohms heaters which are supplied by a three-phase AC-AC converter is simulated by a standard power simulator software. The converter is supplied by standard 380 V_{pp} 60 Hz AC power source. The system can generate a maximum power of 20 kW. The maximum reference is set equal to 80% of this maximum power in this simulation. Figures 3 and 4 illustrate simulation results for ITER operation scenario and step function, respectively. In the per unit (pu) system, the power slopes of the ITER operation scenario are 0.02 pu/s and 0.01 pu/s for heating and burn termination operation, respectively [3]. This reference 80% of the maximum power can be reached in 40s for simulating the burn phase of the ITER operation scenario. In this simulation the burn phase is started from t =10s. The 80% maximum power is reached at t = 50s. The termination phase is simulated from t = 90s to t = 170s. As shown in Fig. 3, the actual power can track the power reference very well.

To investigate the control system capability with an extreme transient condition, a standard step reference is applied to the simulation model as well. This reference is simulated by applying a step function suddenly from 0 to 0.8 of the maximum power at t = 10s as shown in Fig. 4. The actual power can still track the step power reference well enough.

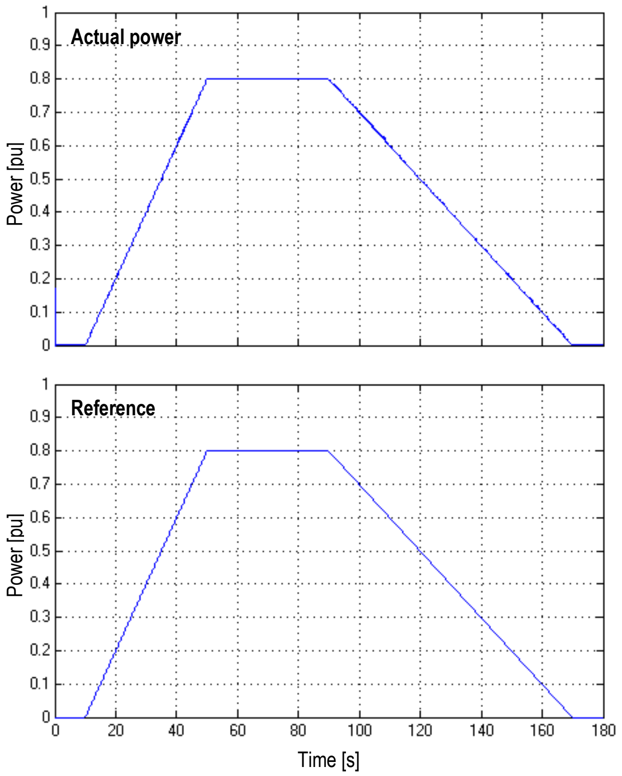

Fig. 3. ITER operation scenario simulation.

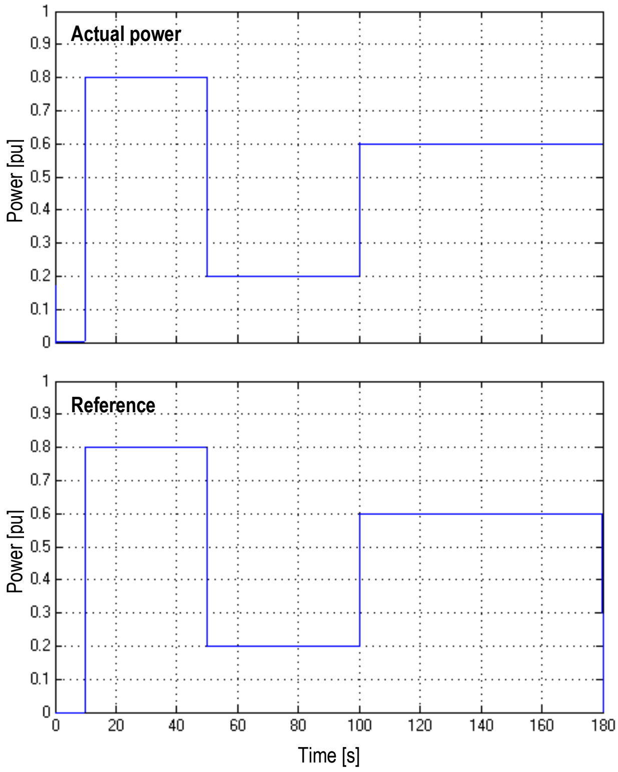

Fig. 4. Step function simulation.

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