Modeling of D_2O Supply Pressure Control System for CANDU Fuel Handling System

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1. Introduction

The CANDU fuel handling system provides on-power refueling capability at a rate sufficient to maintain continuous reactor operation at full power. The D_2O supply pressure control system of the fuel handling system controls the pressure of heavy water to maintain three supply pressure levels depending on High, Medium and Low Modes. D_2O pressure regulation requires precise control but its original algorithm does not incorporate the sophisticated process characteristics.

The objective of this study is to develop a mathematical modeling of D_2O supply pressure control system including process system with MATLAB SIMULINK. The developed model was also tuned and verified using operating data of Wolsong NPP Unit 1. Finally, the developed model was used for comparing the performance of the new precise pressure control algorithm with the original one.

2. Methods and Results

This section describes some of the techniques applied for modeling the D_2O supply pressure control system using MATLAB SIMULINK software. The model includes pressure controllers and process system of the D_2O supply pressure control system.

2.1 Pressure Controller Model

The D_2O supply pressure control system is composed of three automatic pressure controllers (PC11, PC11-A, and PC11-C) which carry out the PID controls to maintain three supply pressure levels depending on High, Medium and Low Modes. PC11 is for the common bleed valve control and the others are for the series and load shunt valves control of each D_2O supply channel. Each controller functions independently to maintain its associated system output pressure.

Pressure control is achieved by simultaneously adjusting four control valves of the series valves (PCV11#1-A and PCV11#1-C) and load shunt valves (PCV11#2-A and PCV11#2-C). Provision is also included for regulation of the common header pressure (PT11). The common bleed valve (PCV11) is controlled to hold the common header pressure at a preset value. This serves as a decoupling mechanism between two output supplies (PT11-A and PT11-C), so that a major disturbance in one channel will not seriously affect the other channel.

From the original PID algorithm programmed by F-TRAN program of the controller manufacturer, the controller model is developed by MATLAB SIMULINK.

The controller model uses as input process pressure which is output of process system model. The deviation between setpoint and process pressure is used as PID input, and the calculated PID output is used as the control output for the appropriated control valve. As the controller is set as direct acting, an increase in process pressure causes the controller output to increase.

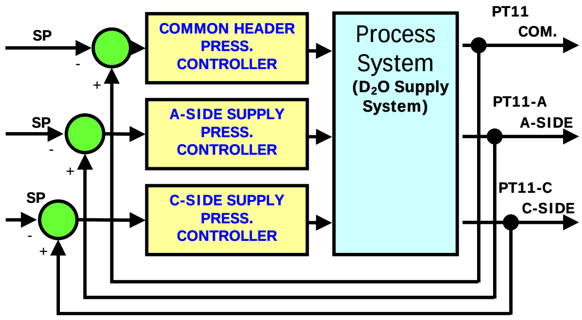

Fig. 1. The pressure controller block diagram for modeling.

2.2 Process System Model

The process system of the D_2O supply pressure control system is composed of five control valves, two D_2O supply pumps, and the other components for D_2O system as shown in Fig. 2.

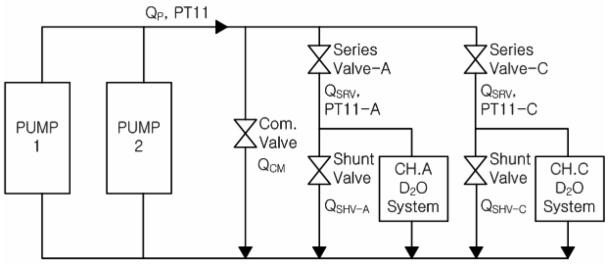

Fig. 2. The process system block diagram of the D_2O supply pressure control system for modeling.

Fig. 3. shows the developed model for the D_2O supply pressure control system using MATLAB SIMULINK. The control valve model was developed by calculating the flow through the control valve. In calculating the control valve flow, valve flow coefficient provided from the valve manufacturer, specific gravity of heavy water, differential pressure on the control valve and the controller valve control output are used.

The pump model was developed by calculating the pump flow which is the equivalent of the total flow output through the A and C channel series valves and the common bleed valve. For the calculation of the pump flow, the coefficient equivalent of the valve flow coefficient, an adaptable slewrate for the pump flow change in accordance with the pump on/off signal are considered in the pump modeling.

The other component models for D_2O system were developed by similar method as the control valve and pump modeling.

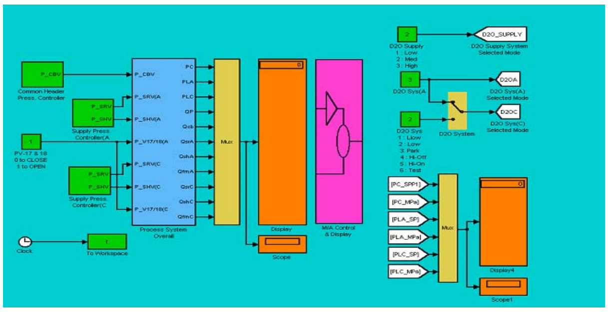

Fig. 3. The developed model of the D_2O supply pressure control system by MATLAB SIMULINK.

2.3 Verifying the Performance of the Model

For verifying the performance of the developed model, static and dynamic characteristics of the model were compared with operating data of Wolsong NPP Unit 1. Table I provides the comparison of the static characteristics at Medium and Low pressure modes.

Table I: The comparison of static characteristics

Source of Data	Mode	Load Flow	PT11 [MPa]	PT11(A [MPa]	PT11(C [MPa]	CBV11 [%]	SRV-A [%]	SHV-A [%]	SRV-C [%]	SHV-C [%]
Wolsong NPP#1	LOW	23.69	16.03	3.828	3.828	45.31	48.97	41.5	42.11	42.61
SIMULATION	LOW	21.06	16.03	3.828	3.828	45.29	45.5	42.01	45.5	42.01
Wolsong NPP#1	MEDIUM	22.55	16.09	8.556	8.594	34.11	59.97	34.03	53.08	34.31
SIMULATION	MEDIUM	22.93	16.09	8.556	8.594	34.17	61.42	34.4	61.42	33.85

For the comparison of the dynamic characteristics, the same PID parameters and control commands were applied at Medium pressure mode. Fig. 4 shows the comparison of the dynamic characteristics with Auto mode for the common valve, Manual mode for the series valve, step change for the channel A shunt valve and auto mode for the channel C shunt valve.

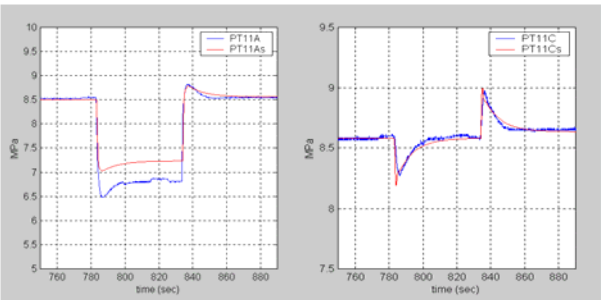

Fig. 4. The comparison of the dynamic characteristics (Left: Ch. A Supply Pressure, Right: Ch. C Supply Pressure). Red is simulation data.

For our application of the model tuning, we found an adaptable lag filter on the valves and some pressure drop on the pipe were necessary for accurate modeling.

2.4 Verifying the Performance of the new control algorithm with the developed Model

For the pressure control during mode change, the series valve is controlled by the controller with constant slewrate or constant speed [%/sec]. This original pressure control algorithm generates an excessive pressure disturbance in the process system during mode change operation which makes the common pressure come close to the setpoint of relief valves.

A new algorithm is developed to reduce pressure disturbance during mode change. This new algorithm adopts a control feature which controls a series valve to make the constant flow through the series valve during the mode change.

For verifying the performance of the new algorithm, simulation using the developed model was performed on the original and new algorithm as shown in Fig. 5.

The new algorithm is showing good performance as predicted and has been applied to Wolsong NPP Units 1, 2, 3 and 4.

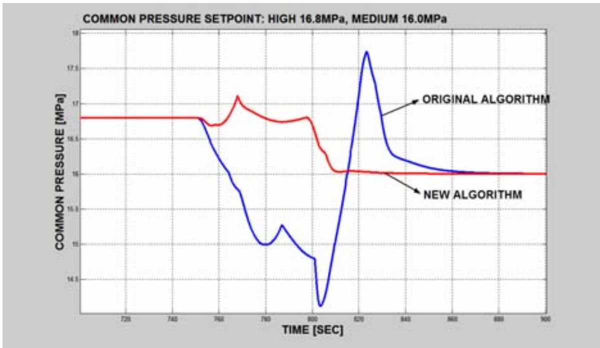

Fig. 5. Simulation results for the mode change from High to Medium mode. Common Pressure SP at High mode: 16.8MPa, SP at Medium mode: 16.0MPa.

3. Conclusions

The model of D_2O supply pressure control system is developed using MATLAB SUMULINK and the analysis using operating data has been performed to verify the performance of the developed model. The new algorithm was verified by the developed model and has been applied to Wolsong Units 1-4. The developed model can be used for predicting the dynamic behavior by changing the process parameter, developing new control algorithm, and a training tool for plant operators to understand the process system.

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