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Development of Pressurizer Level Control System using Centrifugal Charging Pump and Letdown Orifices for YGN 5&6

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Abstract

The Pressurizer Level Control System (PLCS) logic for YGN 5&6 was developed to incorporate the design changes on the Chemical and Volume Control System (CVCS). The YGN 5&6 CVCS uses the centrifugal charging pumps and letdown orifices replacing the positive displacement pumps and letdown control valves in the YGN 3&4 and UCN 3&4. The purpose of this study is to develop new PLCS as well as validate newly developed control logic and its implementation method in the simulation computer code. The analysis results show that the new PLCS has adequate ability to control the pressurizer level in response to the design bases events, and the simulation computer code is useful for YGN 5&6 NSSS design code.

1. Introduction

A lot of design changes have been made on the CVCS for the Yonggwang Nuclear Power Plant Units 5 and 6 (YGN 5&6). Compared with the CVCS of YGN 3&4 and Ulchin Nuclear Power Plant Units 3 and 4 (UCN 3&4) which use the positive displacement pumps (PDPs) and letdown control valve, the YGN 5&6 CVCS utilizes two centrifugal charging pumps (CCP) and two charging control valves (CCV) for controlling charging flow and three letdown orifices for controlling letdown flow. Therefore, the current PLCS of the referenced plants (i.e., YGN 3&4, UCN 3&4) need to bee changed accordingly using the CCP and letdown orifices for YGN 5&6.

In the meantime, the new PLCS logic development requires a new simulation computer code to predict the CVCS performance and validate the new PLCS logic. However, the current simulation computer code used for the design process of the reference plants, i.e., LTC code[1], does not model the PLCS logic using CCP and letdown orifices. Therefore, the purpose of this study is to develop a new PLCS to reflect the CVCS design changes and to generate new computer code to simulate the responses of new PLCS and CVCS during design bases events. The new computer code, which is modified from the LTC code, is called KISPAC code (KAERI Integrated Systems Performance Analysis Code)[2]. Finally, this study validated the PLCS logic and simulation code by analyzing the transients behavior during the selected performance related design bases events (PRDBEs) based on the previous design and operation experiences.

2. Description of PLCS Logic

The simplified CVCS flow diagram and PLCS logic for YGN 5&6 are shown in Figures 1 and 2, respectively. As shown in Figure 1, the CVCS for YGN 5&6 consists of three letdown orifices and their isolation valves in letdown line and two constant speed CCPs and two CCVs in charging line, wherein one CCP and one CCV are redundant.

The basic idea of the new PLCS logic development is a combination of the fine control and the coarse control schemes using CCV and the letdown orifices with isolation valves, respectively. Because the CCP has its own flow delivery curve, in which the flow rate varies with the discharge pressure of the CCP, the CCV in the CCP discharge line must be adjusted to meet the required pressure drop and the charging flow at a given RCS cold leg pressure. Thus, the fine control of the pressurizer level is accomplished by adjusting the CCV opening.

The CCV opening, which is regulated by the PLCS output signal, controls the pressurizer water level closely to the programmed level which is determined based on the reactor coolant average temperature. The letdown flow control is accomplished in combination with the letdown orifices and letdown orifice isolation valves, which results in the coarse control of the pressurizer level. The letdown orifice isolation valves receive the ON-OFF control signal from the PLCS. Their control signals generated based on the pressurizer water level error between the measured and programmed levels.

As shown in Figure 2, the measured pressurizer water level and the average reactor coolant temperature are the major input parameters to the PLCS. The function generates the programed level setpoint as a function of the average reactor coolant temperature. The comparator generates the pressurizer water level error signal by subtracting the programmed level setpoint from the measured pressurizer water level. This level error signal is used as an input signal to the proportional-integral (PI) controller for the CCV control and as a control signal for the letdown orifice isolation valves. The PI controller integrates the level error signal and produces a modulation signal to the CCV in order to zero-out the pressurizer water level error by a fine control of the charging flow. The CCV control signal from the PI controller passes through a lag function, in which the signal is delayed and smoothed out, in order to prevent abrupt changes in the CCV opening and, in turn, the charging flow rate. By this function, the thermal hydraulic transient at the charging nozzle is minimized by eliminating a rapid change in the charging fluid temperature caused by a charging flow rate change.

Finally, the valve program provides an ability to control the charging flow rate proportional to the demand signal. An appropriate valve program can produce an adequate charging flow rate in response to the valve demand signal to improve plant performance. Also, the high and low limits of the valve program play a role of signal limiter which limits the maximum and minimum CCV openings corresponding to the maximum and minimum charging flow rates of 132 gpm and 44 gpm, respectively.

3. Description of Computer Modeling

As described in introduction section, the new CVCS and PLCS are modeled in KISPAC code. The new charging and letdown lines are modeled based on three conservation equations; mass, momentum, and energy balance equations. The major assumptions used for modeling the new CVCS and PLCS are as follows :

(1) The charging and letdown flows are incompressible.
(2) The acceleration pressure drop is so small that it can be neglected.
(3) The heat transfer in the charging and letdown lines except the regenerative and letdown heat exchangers is negligible.
(4) The mini-recirculation flow of the CCP is constant.
(5) The RCP seal injection flow is controlled at 26.4 gpm.
(6) The discharge pressure at the letdown orifice is a constant pressure of 460 psia.
(7) The pressure and temperature at the CCP suction line are maintained at 68 psia and 120 ^{o}F,

respectively.

The initial conditions used in the evaluation of the new CVCS and PLCS logic are the steady state nominal conditions at full power except for the event initiating at power other than full power. Tables 1 and 2 lists the major initial conditions and the PLCS control setpoints for the YGN 5&6, respectively. The PLCS control setpoints are determined based on the setpoints of the reference plants as well as preliminary parametric analysis results. With the above assumptions, initial conditions, PLCS control setpoints, and design data, the three conservation equations are solved explicitly using the Half-Interval search method[3].

4. Analysis Results

Among PRDBEs, the following two events which have significant impact on the pressurizer level control are selected and analyzed to validate the new PLCS performance and the new modeling for the CVCS design changes using the KISPAC code:

(1) Total loss of load (Full load rejection).
(2) Load change from 20% to 100% power with +5%/min rate.

Among the calculated system parameters, the reactor and turbine powers, the RCS temperatures, the measured and programmed pressurizer levels are plotted as a function of time and shown in Figures 3 through 10.

(1) Total loss of load (Full load rejection)

As shown in Figure 3, the turbine power initially decreases to 0%, causing the reactor power immediately decreases to about 75% due to a drop of the Control Element Assembly (CEA) bank #5 into the core by the Reactor Power Cutback System (RPCS) action, and the Reactor Regulating System (RRS) further inserts CEA bank #4 to match the reactor power to the turbine power until the reactor power reaches 50% on which the Automatic Motion Inhibit (AMI) is set and further CEA insertion is prohibited. As the reactor power decreases, the RCS temperatures follow the reactor power and results in a slow decrease in the programmed pressurizer level (see Figures 4 and 5). The decrease in the programmed pressurizer level causes a deviation from the measured pressurizer level and, hence, triggers the PLCS control action. Initially, the level error sharply increases and results in a slight closure of CCV and a decrease in charging flow. However, this level error decreases slowly and reverses, resulting in a lower level compared to the programmed level setpoints. Therefore, the PLCS starts to open the CCV in order to increase charging flow (see Figure 6) until balancing the measured pressurizer level to programmed level setpoint. During this transient, the new PLCS controls the pressurizer level to the programmed level in a reasonable manner and is considered to be adequately designed and functioned.

(2) Load change from 20% to 100% power with +5%/min rate

In this event, the reactor power gradually increases and follows the turbine power, and the RCS hot leg temperature also increases to match with the programmed RCS average temperature as shown in Figures 7 and 8. Due to the increase in RCS temperature, the programmed level setpoint increases as shown in Figure 9. Initially, the level error increases slowly and results in a slight opening of CCV and a decrease in charging flow. Due to the increasing charging flow, this level error reduces slowly and reverses, resulting in a higher level compared to the programmed level setpoints. Therefore, the PLCS starts to close the CCV in order to decrease charging flow (see Figure 10) until the measured pressurizer level balances to the programmed level setpoint. The charging flow reaches to the minimum flow of 44 gpm and is maintained for a while until the measured pressurizer level matches to the programmed level (see Figure 9) and returns to the normal charging flow rate of 88 gpm. During this transient, the new PLCS controls the pressurizer level to the programmed level in a reasonable manner and is considered to be adequately designed and functioned.

5. Conclusions

The simulation results of selected performance related design bases events show that the new Pressurizer Level Control System suggested in this study can achieve a proper control of pressurizer level and RCS inventory. Also, the simulation results demonstrated that the KISPAC computer code model for the new CVCS design for YGN 5&6 is adequate to evaluate its performance in conjunction with the new PLCS logic. However, further study is required for obtaining the optimized PLCS control setpoints and for validating the KISPAC code with other design bases events and/or plant test data.

6. References

1. ABB-CE, "LTC User's Manual", December 1986.
2. KAERI, "Software Verification and Validation Report for KISPAC Code", 00000-PA-VV-001, 7/14/95.
3. B.Carnahan, H.A.Luther, J.O.Wilkes, "Applied Numerical Methods," PP. 178-179, 1969.

Table 1. Initial conditions

System parameters	Value	Unit
NSSS power(at steam generator outlet nozzles)	2825	MWt
Core power	2815	MWt
Pressurizer pressure	2250	psia
Pressurizer level	52.6	%
Cold leg temperature	564.5	°F
Hot leg temperature	621.2	°F
Steam generator pressure	1070	psia
Steam generator level(narrow range)	44	%

Table 2. Pressurizer Level Control System control setpoints

Preliminary setpoints for the new PLCS	Value	Unit
Proportional gain of the PI-controller	20	%/%
Integral time constant of the PI-controller	480	sec
Lag time constant	150	sec
Letdown isolation valve CH-110Y open/close setpoint	-5.0/-8.333	ft
Letdown isolation valve CH-110Z open/close setpoint	3.0/1.083	ft

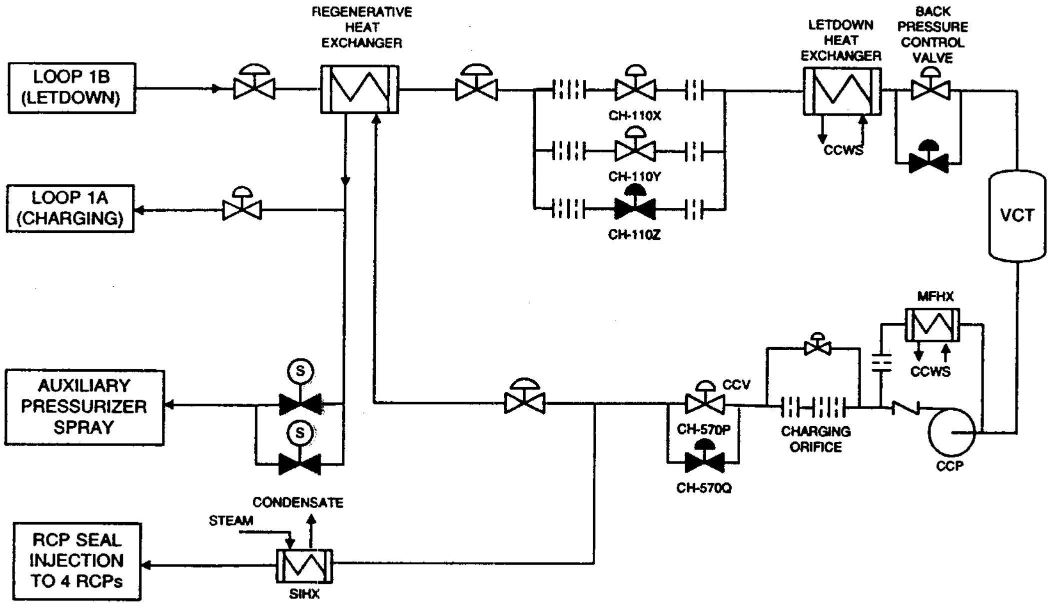
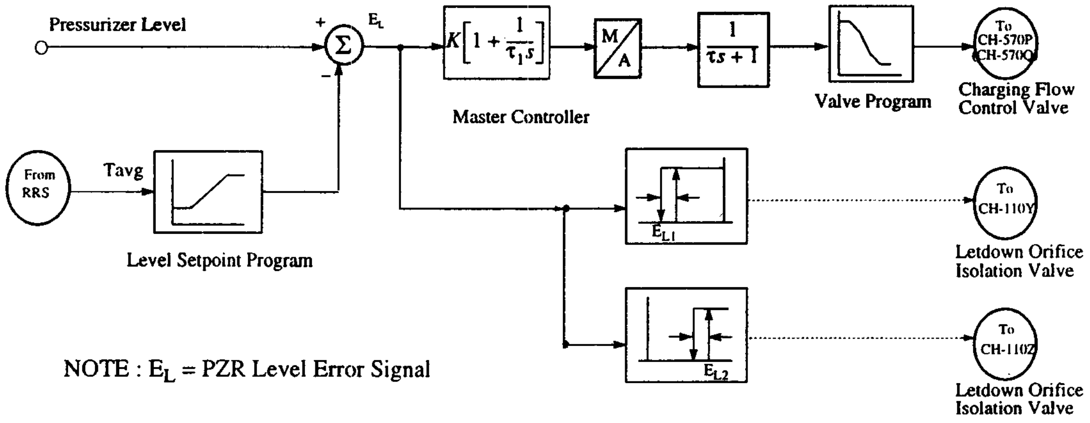


Figure 1. Simplified Flow Diagram of the CVCS for YGN 5&6



NOTE : E_L = PZR Level Error Signal

Figure 2. Simplified PLCS Functional Block Diagram

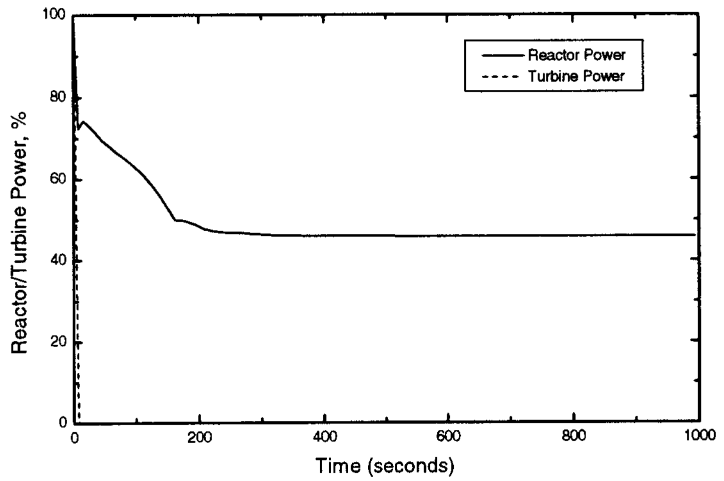


Figure 3. Reactor and Turbine Power for Loss of Load at 100% Power

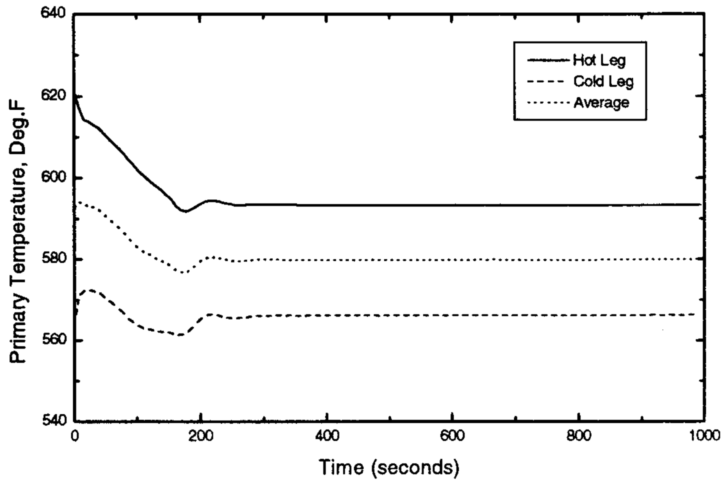


Figure 4. RCS Temperatures for Loss of Load at 100% Power

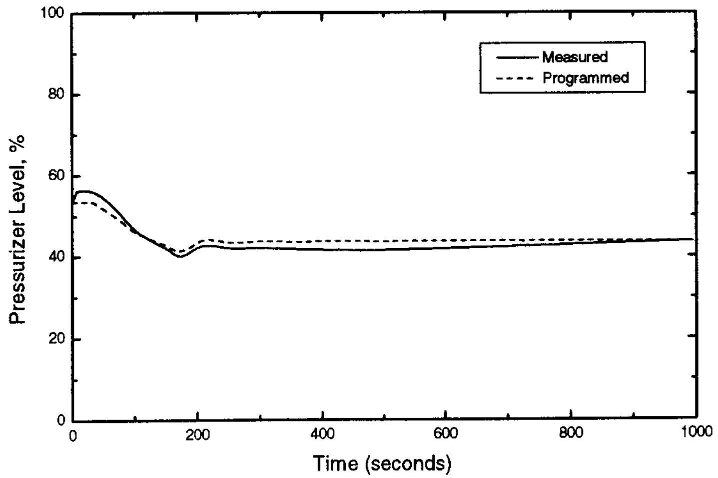


Figure 5. Pressurizer Levels for Loss of Load at 100% Power

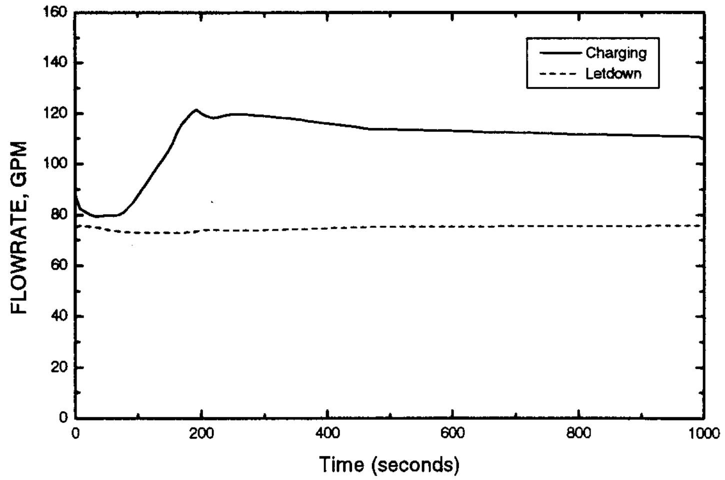


Figure 6. Charging and Letdown Flowrate for Loss of Load at 100% Power

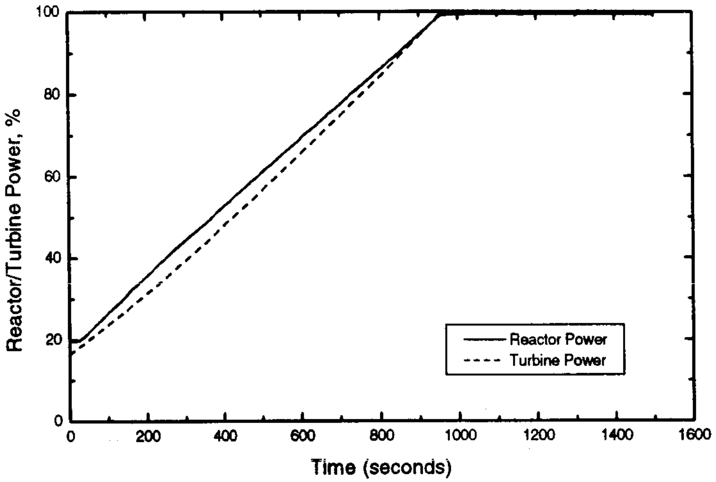


Figure 7. Reactor and Turbine Power for Load Change from 20% to 100% Power

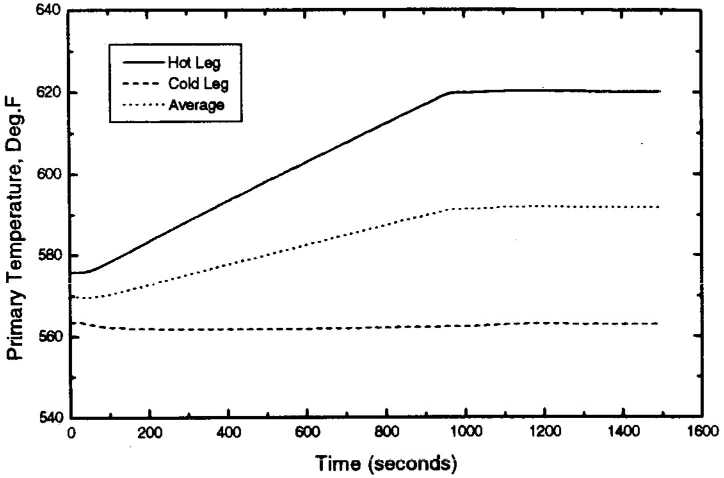


Figure 8. RCS Temperatures for Load Change form 20% to 100% Power

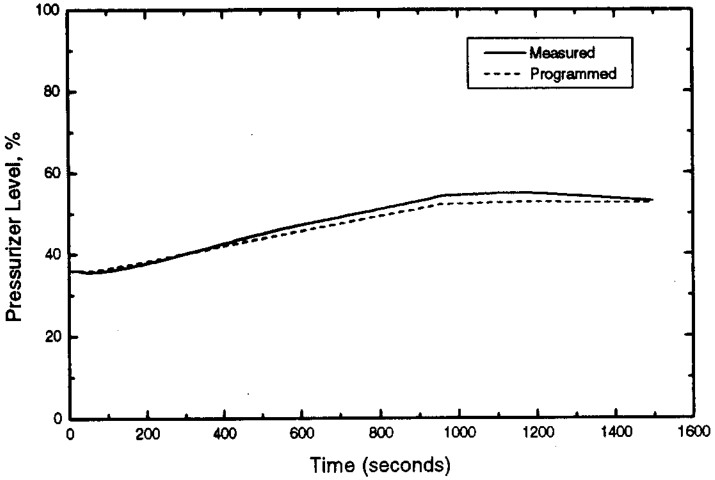


Figure 9. Pressurizer Levels for Load Change from 20% to 100% Power

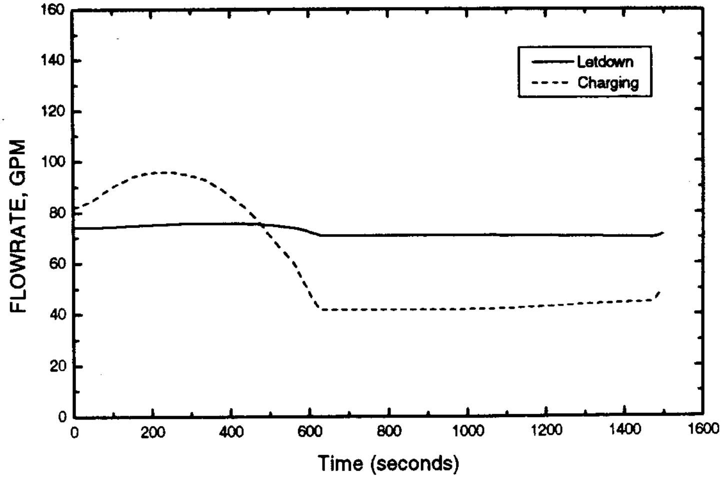


Figure 10. Charging and Letdown Flowrate for Load Change from 20% to 100% Power