Journal of the Korean Nuclear Society
Volume 33, Number 3, pp.339~348, June, 2001

《Technical Note》

The Performance Evaluation of NSSS Control Systems for UCN 4

Suk-Whun Sohn, In-Ho Song, Jong-Joo Sohn, Jong-Ho Choi, and Jong-Tae Seo
Korea Power Engineering Company, Inc.
150 Duckjin-Dong, Yusong-Ku, Taejon, 305-353, Korea
swson@ns.kopec.co.kr

(Received October 29, 1999)

Abstract

NSSS Control Systems automatically mitigate transient conditions and leads to a stable plant condition without operator actions when a transient occurs during normal power operation. In this paper, the function and performance of NSSS control systems were examined and evaluated by comparing the predicted results with the measured data for the selected events. Loss of a Main Feedwater Pump and Load Rejection to House Load Operation events were selected for the evaluation among the transient tests performed during the Power Ascension Test (PAT) of UCN unit 4. The overall schematic control actions of NSSS control systems can be evaluated easily through the observation of these two typical events. The selected events were analyzed by the KISPAC computer code[1] which had been used in developing the control logic and determining the control setpoints during the plant design. Additionally, the performance of FWCS during low power operation was evaluated. The result of evaluation showed that the NSSS control systems were designed properly and the performance of the NSSS control systems was excellent and also the computer code had a good prediction capability.

Key Words : KSNP, NSSS, Control Systems, Performance, LOMFP, Load Rejection

1. Introduction

The Nuclear Steam Supply System (NSSS) control systems are composed of Feedwater Control System (FWCS), Steam Bypass Control System (SBCS), Reactor Regulating System (RRS), Reactor Power Cutback System (RPCS) and Pressurizer Pressure/Level Control System (PPCS/PLCS). These systems can accomodate the plant transient condition such as 5%/min ramp load change, 10% step load change, any magnitude of load rejection, loss of a main feedwater pump and the other Performance Related Design Basis Events (PRDBE). The role of NSSS control systems is to restore the plant from the disturbed condition caused by the

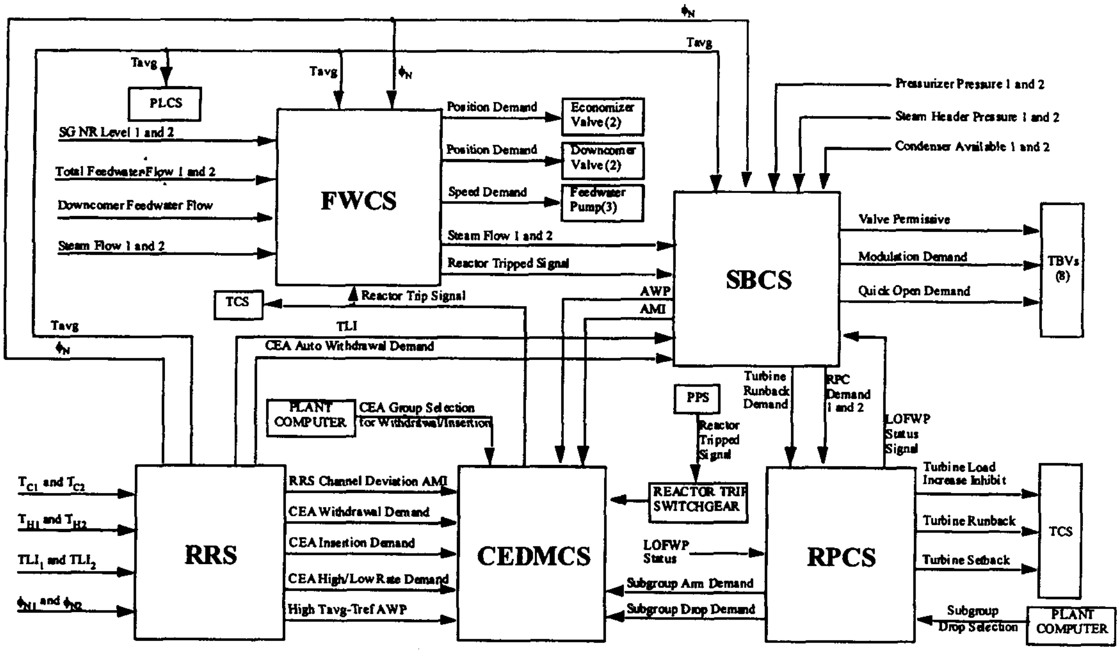

Fig. 1. Signal Interfaces of NSSS Control Systems

transient events to a stable condition automatically with satisfaction to the following acceptance criteria.

(1) Without activating the Reactor Protection System (RPS) and Diverse Protection System (DPS)

(2) Without activating the Engineering Safety Features Actuation System (ESFAS)

(3) Without violating Technical Specification Limiting Condition for Operation (LCO)

(4) Without lifting the Pressurizer and/or Main Steam Safety Valves

In this paper, the function and performance of NSSS control systems were examined and evaluated by comparing the predicted results with the measured data for the selected events. Loss of a Main Feedwater Pump (LOMFP)[3] and Load Rejection to House Load Operation events[2,4] were selected for the evaluation among the transient tests performed during the PAT of Ulchin Nuclear Power Plant Unit 4 (UCN4) because these events well show the overall schematic control actions of NSSS control systems. These tests were successfully performed on March 5 and March 6, 1999 respectively. Without the proper actuation of NSSS control systems, the reactor would be tripped by steam generator low level or pressurizer high pressure. In the following chapters, the NSSS control systems are introduced and the selected PRDBE events test results are compared with simulation results of KISPAC (KOPEC Integrated Systems Performance Analysis Code) computer code which had been used in developing the control logic and determining the control setpoints during the UCN 3&4 plant design. Additionally, the performance of FWCS during low power operation was evaluated.

2. NSSS Control Systems

The NSSS control systems are organically operated each other. Figure 1 shows the integrated NSSS control system design and their major interfaces.

2.1. Feedwater Control System (FWCS)

The function of the FWCS is to maintain the Steam Generator (SG) water level by regulating the feedwater flow rate. Steam flow, feedwater flow and SG downcomer water level are provided as input signals to FWCS for three element control at high power level (above 20% in reactor power). The SG water level is used as an input for single element control at low power level (below 20% in reactor power). The feedwater control is achieved by positioning the feedwater control valves and regulating the feedwater pump speed. At low power level, the economizer feedwater control valve will be closed and the pump speed setpoint will be at its minimum value. Therefore, the flow control is performed by controlling the downcomer feedwater control valve. As the reactor power increases above 20%, the downcomer feedwater control valve receives bias signal which positions the valve to pass approximately 10% of full power feedwater flow. The economizer feedwater control valve position and pump speed are controlled by FWCS to provide desired feedwater flow. In UCN Unit 4, the setpoint which enables three element control was changed to 13% of full power.

2.2. Steam Bypass Control System (SBCS)

The SBCS is designed to complement the NSSS Control Systems so as to extend the load following capability of the NSSS to accommodate the load rejections of any magnitude including a turbine trip from full power without reactor trip. This is accomplished by substituting the turbine bypass valves as a load on the NSSS whenever a large power mismatch is detected through the sensing of selected NSSS parameters such as steam flow, main steam header pressure, and pressurizer pressure. Thus the SBCS controls the turbine bypass valves to limit the reactor power/turbine load mismatch by dissipating excess NSSS energy. The turbine bypass valves are modulated based on a comparison of the main steam header pressure to the setpoint. To increase the load rejection capability of the system, a quick opening of the valves, which overrides the modulation action, is performed when the load rejection is too large to be accommodated by valve modulation. Additionally, a rapid reduction in reactor power is performed through the RPCS if the magnitude of the load rejection exceeds the SBCS turbine bypass capacity. In this manner, a full load rejection can be accommodated by the turbine bypass valves and RPCS.

2.3. Reactor Regulating System (RRS)

The NSSS has an inherent load following characteristic arising from reactivity feedback due to negative moderator coefficient and doppler effect. The RRS provides the capability of the reactor to follow turbine load changes keeping main steam pressure and reactor coolant average temperature within specified values by means of reactivity adjustments utilizing the Control Element Assemblies (CEAs) operated through the Control Element Drive Mechanism Control System (CEDMCS). To maintain main steam pressure requirements, a setpoint for reactor coolant average temperature is programmed as a function of turbine load. The RRS receives TLI (Turbine Load Index), reactor coolant hot leg and cold leg temperatures, and reactor power signals. The resulting error signal is fed to the CEA rate and direction program, where the rate and direction for CEA movement are determined before they are sent to the CEDMCS.

2.4. Reactor Power Cutback System PCS)

The RPCS provides a rapid reduction of reactor power by dropping one or two pre-selected CEA groups into the reactor core for events which result in a large mismatch between the reactor and turbine power such as a large turbine load rejection, a turbine trip or a loss of one of two operating main feedwater pumps. After RPCS actuation, the remaining mismatch between the reactor and turbine power is controlled either by the RRS when the reactor power is larger than the turbine power or by the turbine runback logic when the reactor power is smaller than the turbine power.

2.5. Pressurizer Pressure/Level Control System (PPCS and PLCS)

The pressurizer serves as a surge tank for RCS to accommodate the change in primary coolant volume due to temperature changes. When the average coolant temperature decreases (or increases), the coolant volume shrinks (or swells) and causes the pressurizer coolant level to decrease (or increase). The PLCS provides a mechanism for the automatic and manual control of the pressurizer level by controlling the charging and letdown flows. The PPCS provides a mechanism for the automatic and manual control of pressurizer pressure, and thus the RCS pressure, at the desired value by controlling the heater power and the spray flow.

3. The Performance of NSSS Control Systems at Transient

LOMFP and load rejection to house load event were selected for the evaluation of NSSS control system performance. Test results were compared with KISPAC computer code simulation results in order to understand the role of NSSS control system and to validate the prediction capability of KISPAC computer code which had been used in plant performance analysis. Additionally, the performance of FWCS during low power operation was evaluated.

3.1. Loss of a Main Feedwater Pump(LOMFP)

This event is initiated by tripping one of the two normally operating main feedwater pumps. Without the proper actuation of NSSS control systems, the reactor will be tripped by steam generator low level. In order to prevent a reactor trip and to continue power operation during LOMFP event, the RPCS is designed to actuate on main feedwater pump trip signal. The RPCS generates reactor power cutback and turbine setback signals simultaneously. The CEDMCS receives the RPC demand from RPCS, then drops a pre-selected CEA groups into the reactor core resulting in a rapid decrease of the reactor power. Figure 2 shows the reactor power transient. The Turbine Control System(TCS) receives turbine setback from RPCS, then decrease turbine power to 60% with a maximum rate (Fig. 6). The flow error and level error are increased due to reduction of feedwater flow which was caused by pump trip. The FWCS rapidly increases the main feedwater pump speed and opens economizer feedwater control valves using these error signals.

After the fast responses are completed, the RRS sends CEA insertion demand to CEDMCS in order to maintain balance between reactor power and turbine power. As reactor coolant temperature decreases due to reactor power cutback (Fig. 3), the PLCS decrease the letdown flow to maintain

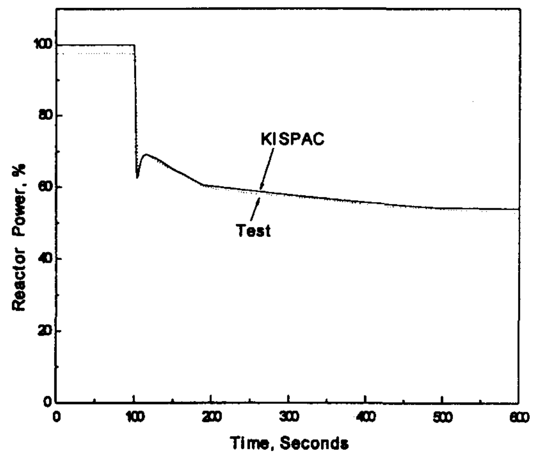

Fig. 2. Reactor Power During LOMFP

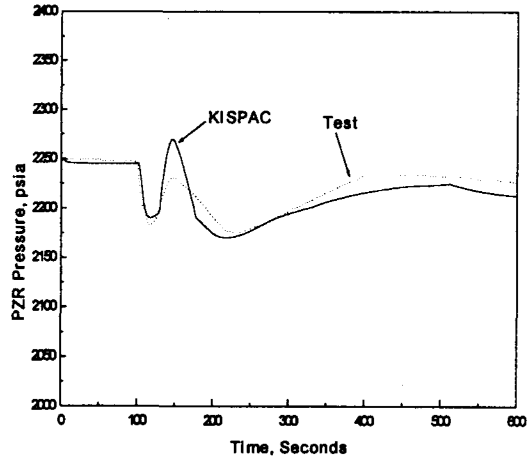

Fig. 4. PZR Pressure During LOMFP

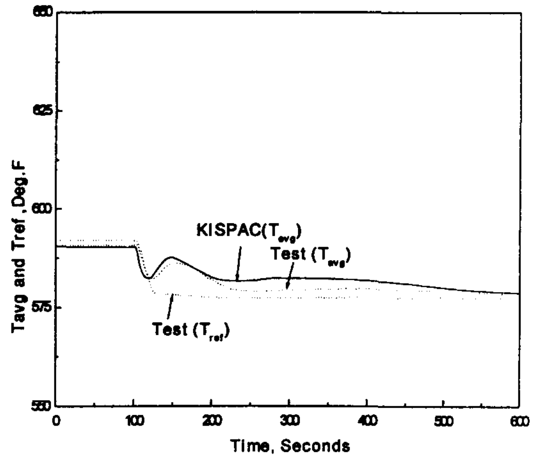

Fig. 3. Tavg During LOMFP

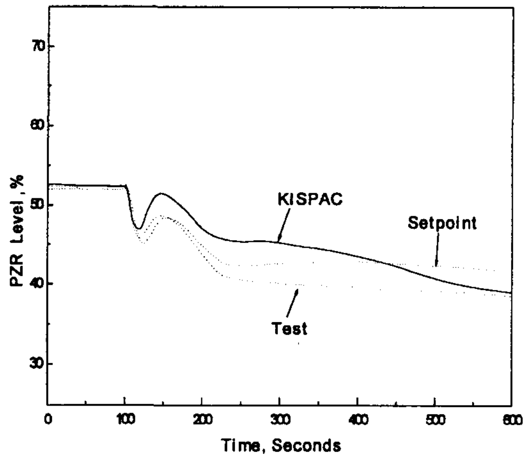

Fig. 5. PZR Level During LOMFP

the pressurizer level to its setpoint (Fig. 5). The steam generator level is stabilized at its setpoint by FWCS (Fig. 8). The PPCS maintains the pressurizer pressure around 2250 psia using pressurizer heater and spray flow (Fig. 4).

3.2. Load Rejection to House Load Peration

This event is initiated by disconnecting the plant from the grid system during normal operation. Unless the NSSS and T/G (Turbine/Generator) control systems actuate properly, the reactor will be tripped by high pressurizer pressure[5] or low steam generator water level, and turbine will be tripped by over-speed protection.

Upon initiation of load rejection, the turbine power is dramatically reduced by PLU (Power Load Unbalance) signal of turbine control system (Fig. 14). As the steam flow to the turbine

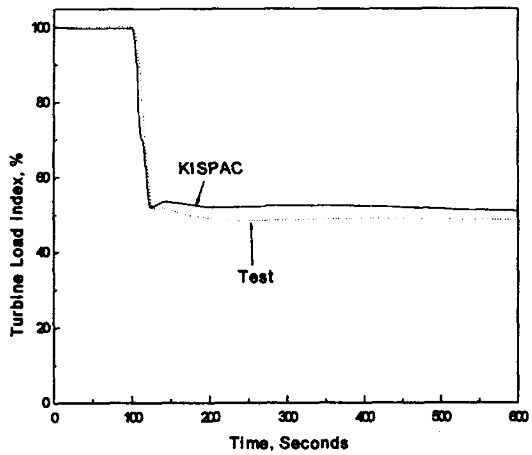

Fig. 6. TLI During LOMFP

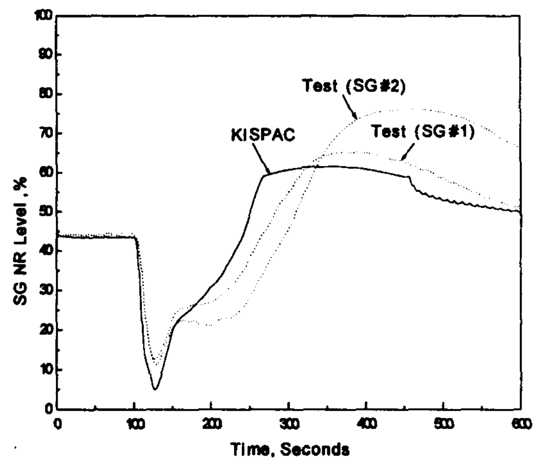

Fig. 8 SG Level During LOMFP

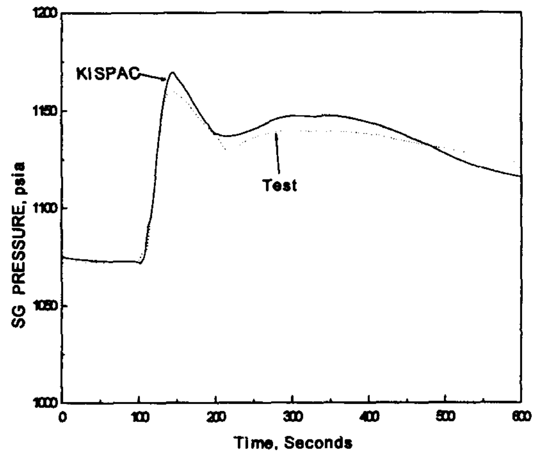

Fig. 7. Steam Header Pressure During LOMFP

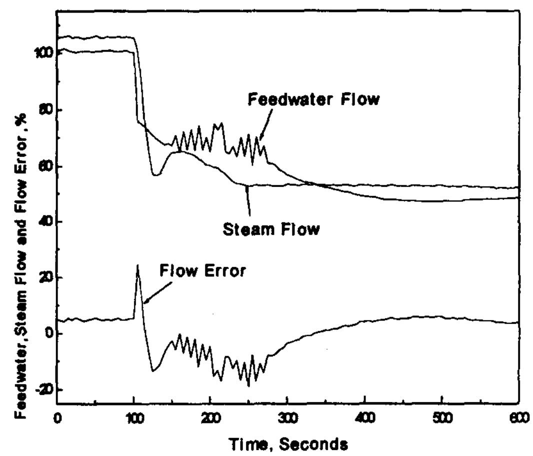

Fig. 9. Flow Error Siganl During LOMFP

decreases sharply, the steam generator pressure is rapidly increased (Fig. 15). The SBCS detects the reduction of steam flow (Fig. 17) and generates quick open demand signal which fully opens turbine bypass valves within 1 second for alleviation of steam generator pressure rise (Fig. 15). If the magnitude of load rejection above the SBCS capacity is occurred, the SBCS sends reactor power cutback demand signal to RPCS. Then, the RPCS is actuated to rapidly reduce the reactor power by dropping pre-selected CEA groups into the core (Fig. 10). At the same time, the flow error between feedwater flow and steam flow is increased due to reduction of steam flow (Fig. 17). The SG level error is increased due to reduction of steam generator level because steam generator pressure rise shrinks the water level (Fig. 16). The FWCS controls the main feedwater pump speed and economizer feedwater control valve positions using these error signals. As

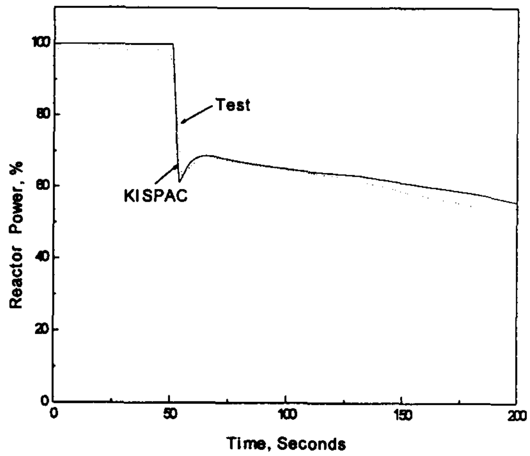

Fig. 10. Reactor Power During Load Rejection

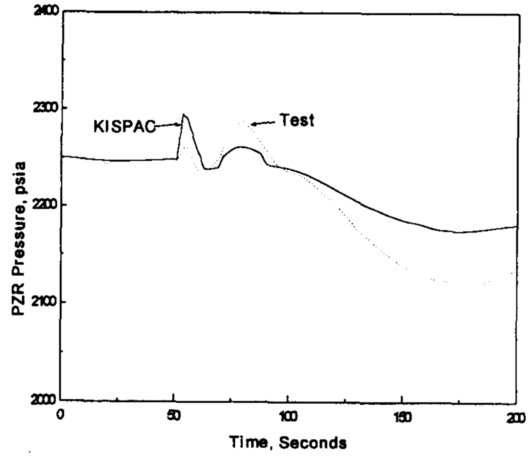

Fig. 12. PZR Pressure During Load Rejection

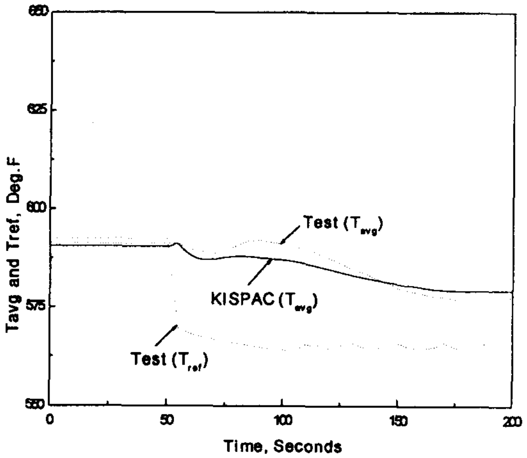

Fig. 11. Tavg During Load Rejection

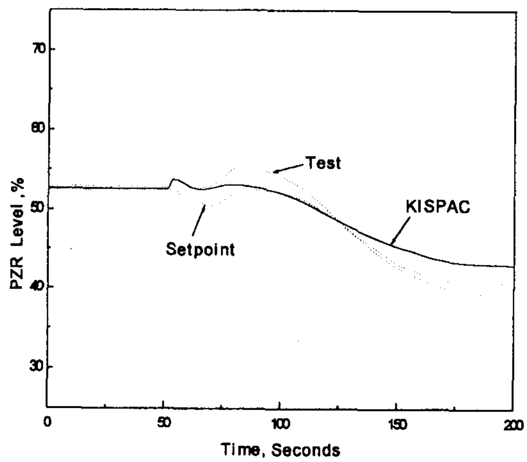

Fig.13. PZR Level During Load Rejection

pressurizer pressure increases, PPCS opens spray control valve and de-energizes proportional heater. Therefore, pressurizer pressure rise is limited (Fig. 12).

After the fast responses are completed, the RRS sends CEA insertion demand to CEDMCS in order to maintain balance between reactor power and turbine power. The SBCS opens the turbine bypass valve with modulation mode to control steam generator pressure after TBV quick opening. The steam generator level is stabilized at its setpoint by FWCS. As reactor coolant temperature decreases due to reactor power cutback (Fig. 11), the PLCS decreases the letdown flow for maintaining the pressurizer level to its setpoint (Fig. 13). The PPCS maintains the pressurizer pressure around 2250 psia using pressurizer heater and spray flow (Fig. 12).

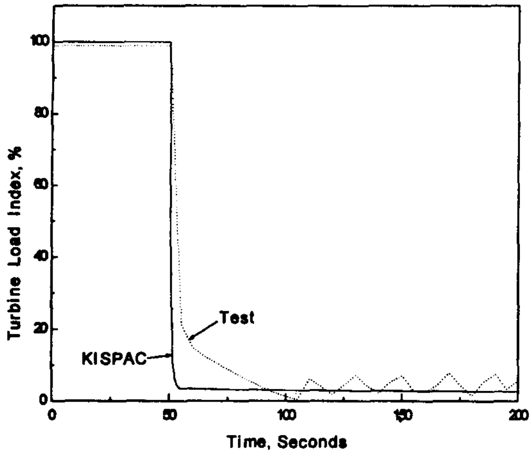

Fig. 14. TLI During Load Rejection

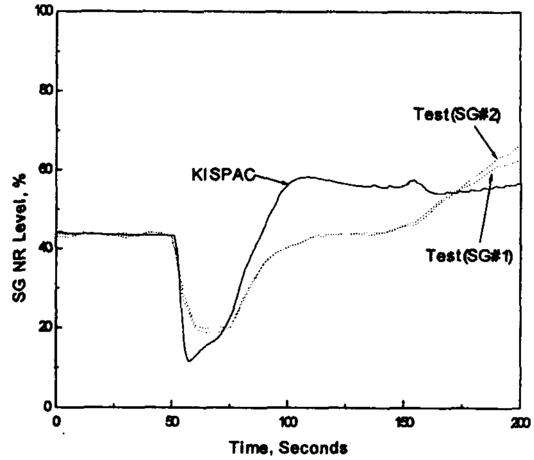

Fig. 16. SG Level During Load Rejection

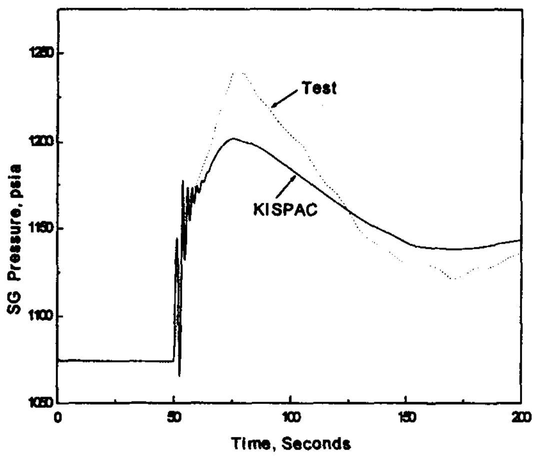

Fig. 15. Steam Header Pressure During Load Rejection

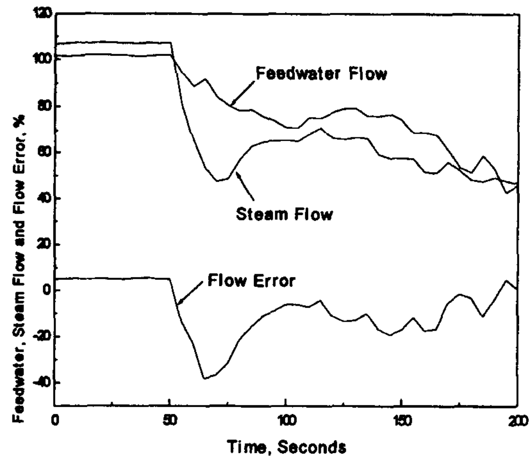

Fig. 17. Flow Error Signal During Load Rejection

3.3. SG Level Control at Low Power Operation

At low power, the steam generator level control is not easy because low feedwater temperature causes SG level shrink and swelling phenomena. Actually, many reactor trip cases due to the unstable steam generator level control have been reported at low power operation in spite of operator and designer' s continued efforts. The FWCS setpoints for low power operation are optimized during UCN 3&4, which is the first plant of Korea Standard Nuclear Power Plant (KSNP), design period and field tuning is performed during UCN 4 start-up period. Especially, the start point for 3-element

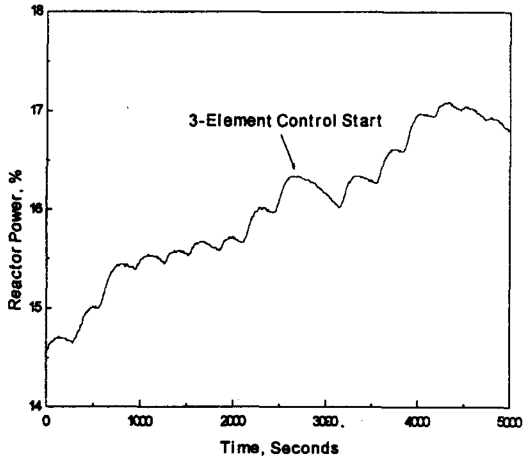

Fig. 18. Reactor Power during UCN 4 Low Power

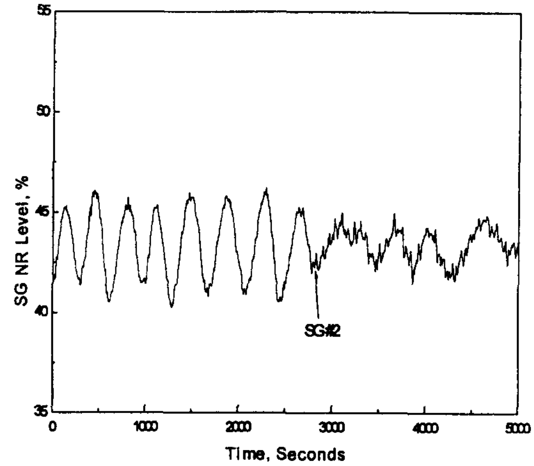

Fig. 19. SG Level During UCN 4 Low Power

is finally moved from 20% to 13% reactor power through several field tuning, enlarging the operation range with 3-element control. If the feedwater flow or steam flow is below 10% of total flow, constant value of 10% is used for FWCS input to avoid FWCS mis-operation due to large uncertainty in steam and feedwater flowrate measurements. Figure 19 shows the steam generator level behavior during power increase after the 3-element control start point is changed to 17% reactor power (Fig. 18). Of several low power operation cases, this case shows the effect of 3-element control better than another low power operation cases. As shown in Figures 18 and 19, the steam generator level is controlled within ±2% from its setpoint which is well below the control target of ±5% in the low power.

4. Conclusions

The NSSS control systems of KSNP has shown excellent control performance at the transients such as LOMFP and load rejection to house load. In UCN 4, all PAT tests were successfully performed without any reactor trip. This results were accomplished by appropriate action of NSSS control systems and related components.

The plant is expected to be stabilized without reactor trip for PRDBE based on the verified performance of NSSS control systems. Futhermore, the steam generator level control at low power was improved by determining appropriate FWCS setpoints and by tuning it in the field. This could alleviate operator' s burden at low power operation.

The reasonable agreement was observed between KISPAC code predictions and the UCN4 actual test data. This shows that the NSSS control systems respond as designed and the prediction capability of KISPAC computer code is excellent.

References

1. KOPEC, "Technical Manual for KISPAC", Rev. 0 (1999).

2. S. W. Sohn, et al., "Evaluation of Load Rejection to House Load Test at 100% Power for UCN 3", Proc. *of the KNS Fall Meeting*, Seoul, Korea, October (1998).
3. S. W. Sohn, et al., "Evaluation of Loss of a Main Feedwater Pump Test for UCN 3", Proc. *of the KNS Fall Meeting*, Seoul, Korea, October (1998).
4. J. J. Sohn, et al., "Evaluation of Load Rejection to House Load Test at 100% Power for YGN 4" Proc. *of the KNS Autumn Meeting*, Seoul, Korea, October (1995).
5. S. W. Sohn, et al. "Sensitivity Study on High Pressurizer Pressure Trip Margin of UCN 3&4", Proc. *of the KNS Spring Meeting*, Cheju, Korea, May (1996).