Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1995

Reactor Power Cutback System Test Experience at YGN 4

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Abstract

YGN 3 and 4 are the nuclear power plants having System 80 characteristics with a rated thermal output of 2815 MWth and a nominal net electrical output of 1040 MWe. YGN 3 achieved commercial operation on March 31, 1995 and YGN 4 completed Power Ascension Test (PAT) at 20%, 50%, 80% and 100% power by September 23, 1995. YGN 3 and 4 design incorporates the Reactor Power Cutback System (RPCS) which reduces plant trips caused by Loss of Load (LOL)/Turbine Trip and Loss of One Main Feedwater Pump (LOMFWP).

The key design objective of the RPCS is to improve overall plant availability and performance, while minimizing challenges to the plant safety systems. The RPCS is designed to rapidly reduce reactor power by dropping preselected Control Element Assemblies (CEAs) while other NSSS control systems maintain process parameters within acceptable ranges.

Extensive RPCS related tests performed during the initial startup of YGN 4 demonstrated that the RPCS can maintain the reactor on-line without opening primary or secondary safety valves and without actuating the Engineered Safety Features Actuation System (ESFAS). It is expected that use of the RPCS at YGN will increase the overall availability of the units and reduce the number of challenges to plant safety systems.

I. Introduction

YGN 3 and 4 NSSS design includes a number of design features aimed at improving overall plant availability and operational flexibility. One of such improvements is the RPCS[1]. During LOL and LOMFWP, the RPCS is designed to provide a rapid reduction in reactor power, while other NSSS control systems maintain process parameters within acceptable transient values. This ability eliminates a reactor trip, initiation of ESFAS and/or opening of primary and secondary safety valves. The use of RPCS also relaxes the design requirements for the capacity of the steam bypass valves, the condenser, and the main feedwater pumps. The NSSS, with RPCS design incorporated, can accommodate a full load rejection with only 55% steam bypass capacity. The use of RPCS also reduces the main feedwater pump runout capacity to 65% of full power feedwater flowrate, from approximately 85% capacity that would be required to accommodate a LOMFWP event without RPCS[2].

Even though YGN 4 is the follow-on-unit of YGN 3, extensive RPCS related tests for YGN 4 were performed for design verification and operator training. The expected responses of the NSSS control systems (including RPCS) following LOL and LOMFWP events are summarized in Table 1. Table 2 summarizes all of the RPCS related transient tests performed at YGN 4 along with their test objectives.

During YGN 4 transient related tests, the Test Data Acquisition System (TDAS) was used to evaluate the test results[3]. The TDAS is a high speed computer based data acquisition and recording system. The TDAS consists of a real-time UNIX Operating System based on the 7250 mini-computer supplied by Concurrent Computer Corporation and signal conditioning front-end system supplied by Analog Devices. The TDAS provides capabilities of real-time data acquisition, data recording, and data reduction up to 128 input channels. The TDAS can achieve a sampling rate up to 200,000 samples per second. During the YGN 4 startup testing, 112 input channels were used for data recording at 10 scans per second to properly evaluate the NSSS responses.

II. Description of RPCS

The RPCS actuation signal for large load rejection is generated by the Steam Bypass Control System (SBCS) which monitors the steam flow to the turbine. A rapid reduction in steam flow is indicative of a load rejection. A reactor power cutback signal is generated only if the magnitude of the load rejection is sensed to be greater than the available steam bypass capacity. Also, the RPCS actuation signal is generated whenever the RPCS receives the loss of a single feedwater signal which is determined based on a pair of redundant pump speed signal from each main feedwater pump. The RPCS also generates turbine setback signal during LOMFWP if the initial power level is greater than 60% of rated power. The turbine setback signal rapidly reduces turbine power (480%/min.) to 60%.

During RPCS actuation, the core power is rapidly reduced below a target power level (75%) by dropping the pre-selected CEA groups. The target power is selected based on the design capacity of the steam bypass valves and the runout flow capacity of each main feedwater pump. The CEA groups to be dropped are selected based on the "CEA Selection Program for RPCS" algorithm in the Plant Computer System (PCS)[4]. This algorithm uses the current power level, the current core burnup, moderator temperature coefficient, fuel temperature coefficient, CEA position, RCS temperature, and a pre-selected target core power as inputs to calculate the minimum reactivity required to reduce core power from the current value to the target value. This minimum reactivity is compared to the available CEA reactivity. If the available Group 5 reactivity worth is greater than power defect, then Group 5 is automatically selected to be dropped. If the available Group 5 reactivity worth is less than power defect, then Groups 5+4 are selected. Since the CEA groups selected to be dropped provide discrete increments of reactivity addition, the core power level is usually reduced below the target power level.

III. RPCS Related Test Results and Evaluation

The results obtained from YGN 4 for the RPCS related LOL and LOMFWP tests listed in Table 2 are summarized in Table 3. A detail description of the LOL and LOMFWP test results at 100% is provided below.

<u>Loss of Load (LOL) Test at 100%</u>

The LOL test at 100% power was successfully performed on September 20, 1995, and the key NSSS parameters recorded by TDAS are plotted Figure 1. When the plant was in steady state with approximately 100% reactor power, the load rejection was initiated by opening the 345 KV switchyard breaker. Upon the load rejection, the turbine power decreased immediately to house loads (about 40 MWe) in response to the Turbine Control System (TCS) action. The decrease in turbine power caused a dramatic decrease in the steam flow to the turbine and a sharp increase in steam generator (S/G) pressure. In response to the decrease in steam flowrate and the increase in S/G pressure and pressurizer pressure, the SBCS generated the Quick Open (Q.O.) X and Y signals and the reactor power cutback demand signal, simultaneously. The SBCS Q.O. signal opened all 8 steam bypass valves within 1.0 second, and the reactor power cutback signal dropped the pre-selected CEA group (Group 5) into the core, resulting in a rapid reactor power decrease.

The S/G water level initially decreased mainly due to the shrink caused by the S/G pressure increase and, then, recovered to the normal water level as the S/G pressure was stabilized. The decrease in S/G water level caused the Feedwater Control System (FWCS) to respond with an increased demand signal, which more increased the main feedwater pump speed and more opened the economizer feedwater control valves.

As reactor power decreased, the SBCS started to close steam bypass valves. Based on the decrease in RCS Tavg, the Pressurizer Level Control System (PLCS) controlled the letdown flow to match the pressurizer level to the programmed level, and the Pressurizer Pressure Control System (PPCS) controlled the pressurizer pressure to its nominal pressure of 158.2 kg/cm^2a by controlling the pressurizer heaters or spray.

The final power achieved following load rejection is set by the Automatic Motion Inhibit (AMI) setpoint. The function of the AMI setpoint is to limit the decrease in core power by preventing withdrawal and insertion of CEAs in response to Reactor Regulating System (RRS) demand. This allows a quick return to full rated power, once the cause of load rejection has been determined and proper corrective actions have been completed. The AMI setpoint is automatically set to the smaller value between the operator adjustable setpoint and the available capacity of steam bypass valves.

After the drop of Group 5, the RRS started to insert Group 4 at the high insertion rate (76.2 cm/min.) into the core. When reactor power decreased to 55%, the SBCS generated the AMI signal to block the automatic CEA insertion. The prompt decrease in core power was followed by a small increase in power due to temperature feedback (moderator and fuel) effect. Further reduction of the reactor power below 55% was due to the negative reactivity insertion caused by xenon buildup.

Loss of a Main Feedwater Pump (LOMFWP) Test at 100%

The LOMFWP test at 100% power was successfully performed on September 15, 1995, and the key NSSS parameters are presented in Figure 2. This test was initiated by manually tripping the Main Feedwater Pump (MFP) 02P when both MFP 01P and 02P were running. Upon receiving the loss of feedwater pump signal, the RPCS generated the reactor power cutback and turbine setback signals, simultaneously. The reactor power cutback signal dropped the pre-selected CEA group (Group 5) into the core, resulting in a rapid reactor power decrease. The TCS decreased the turbine power to 60% at a rate of 480%/min. by the setback function. Following RPC and turbine setback, a turbine runback (133%/min.) was also initiated to match the turbine power with the reactor power. This further reduction in turbine power is required to provide proper control of primary temperature and secondary pressure when reactor power falls below 60% following a RPCS actuation. In addition, a Q.O. block signal is provided to the SBCS to prevent the steam bypass valves from being quick opened when steam flow to the turbine was being decreased. An Automatic Load Increase Inhibit signal is provided to the TCS to prevent increases in turbine load during the event. An Automatic Withdrawal Prohibit (AWP) signal is provided to the Control Element Drive Mechanism Control System (CEDMCS) to prevent inadvertent withdrawal of CEAs and hence prevent increases in core power following a RPCS actuation, whenever turbine bypass demand exists.

Upon tripping of one MFP, the total feedwater flow to the S/Gs decreased rapidly. The S/G water level decreased mainly due to the decrease in feedwater flow and shrink caused by the S/G pressure increase. This decrease in the S/G water level caused the FWCS to respond with an increased demand signal, which more increased the operating MFP speed and more opened the economizer feedwater control valves.

The FWCS increased the feedwater pump speed such that the unaffected pump would deliver the required feedwater flow up to about 65% of total feedwater flow and restore the S/G levels to their normal water level setpoint (44% of narrow range). As reactor power decreased, the SBCS started to close the steam bypass valves, if opened. Based on the decrease in the RCS Tavg, the PLCS controlled the letdown flow to match the pressurizer level to the programmed level, and PPCS controlled the pressurizer pressure to its nominal pressure of 158.2 kg/cm^2 by controlling the pressurizer heaters or spray.

After the drop of Group 5, Group 4 was inserted to match the reactor power to the turbine power. The Group 4 insertion resulted in a corresponding reactor power decrease and RCS Tavg decrease. The generator power initially decreased to about 60% by the turbine setback and followed by a further decrease to the final steady state value of 54% due to the subsequent turbine runback signal.

IV. Conclusions

The RPCS related transient tests were successfully performed at YGN 4 demonstrating as-built RPCS capability. In addition, a total of 3 unplanned LOL and LOMFWP events during the initial startup of YGN 3 and 4 occurred and the RPCS successfully maintained the reactor on-line without opening safety valves and without ESFAS actuation. Therefore, it is expected that RPCS will increase the plant availability and enhance overall plant safety.

References

(1) K. I. Han, "Advanced Design Features of YGN-3,4 Nuclear Power Plant", Presented at the 10th KAIF/KNS Annual Conference, Seoul, Korea, April 1995.

(2) D. R. Chari et. al.,"Experience with Reactor Power Cutback System at Palo Verde Nuclear Generating Station", Presented at the Topical Meeting on Anticipated and Abnormal Transients at NPP, April, 1987.

(3) ABB-CE, "Operator's Manual for Test Data Acquisition System for YGN 3 and 4", Z-005-DM-001-02, 1994.

(4) ABB/CE, "Design Requirements for the CEA Applications, CEA Selection and Xenon and Reactivity Balance Programs for YGN 3 and 4", Z-630-DR-002-04, 1994.

Table 1. Expected NSSS Responses During LOL and LOMFWP Events

Power Level	Loss of Load	Loss of One Main Feedwater Pump
0 to 60%	- SBCS quick opens steam bypass valve to release excess energy. - RRS inserts CEAs to match reactor power with available capacity of steam bypass valve. - SBCS modulates steam bypass valves to maintain secondary pressure to programmed setpoint.	- Normally, only one feedwater pump is in service.
60% to 75%	- Same as above	- RRS inserts CEAs to reduce reactor power. - TCS initiates turbine setback to 60% power. - TCS initiates turbine runback to match turbine power with reactor power. - FWCS increases output signal to the operating feedwater pump. - Operating feedwater pump increases speed and thus output to both S/Gs. - SBCS modulates steam bypass valves to maintain secondary pressure at programmed setpoint.
75% to 100%	- RPCS drops preselected CEA groups to rapidly reduce power. - Remainder same as 0 to 60%.	- RPCS drops preselected CEA groups to rapidly reduce power. - Remainder same as 60 to 75%.

Table 2. RPCS Related Tests and Objectives

RPCS Test	Test Objectives
50% LOL	- To verify steam bypass capacity sufficient to accommodate 50% power load rejection. - To verify TCS ability to accommodate house load.
70% LOMFWP	- To verify the following 1) RPCS does not drop any CEAs. 2) Turbine setback to 60% power is initiated at a minimum rate of 480%/min. 3) RPCS generates a Q.O. block signal to SBCS. 4) Automatic Load Increase Inhibit Signal is generated. 5) RRS and TCS stabilize the reactor and turbine power at approximately 55% power. 7) Operating feedwater pump increases output to maintain S/G level.
80% LOL*	- To verify the following 1) RPCS drops only preselected CEA group. 2) RRS inserts CEAs to reduce core power to AMI setpoint. 3) SBCS quick opens the steam bypass valves and modulates them to control the sec. pressure
100% LOMFWP	- To verify that the NSSS can accommodate a LOMFWP from full rated power.
100% LOL	- To verify that the NSSS can accommodate a full load rejection.

* LOL test at 80% was not performed for YGN 4.

Table 3. RPCS Test Results

NSSS Parameters	LOL				LOMFWP			
	50%		100%		70%		100%	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Reactor Power (%)	32	50	50	99	55	69	54	99
PZR Pressure (kg/cm^2a)	152	162	152	163	155	162	153	157
PZR Level (%)	36	46	40	54	43	49	38	50
S/G 1 Level (%) (Narrow Range)	22	61	15	65	18	54	13	65
S/G 2 Level (%) (Narrow Range)	22	65	14	60	20	54	12	63
Steam Header Pressure (kg/cm^2g)	79	85	73.5	86.5	76.5	81	74.8	80.7

Reactor Trip Setpoint on Low PZR Pressure (kg/cm^2a)	123.883
Reactor Trip Setpoint on High PZR Pressure (kg/cm^2a)	167.55
PZR Heater Cutoff Level (%)	25
Reactor Trip Setpoint on Low S/G Level (Wide Range) (%)	42.9
Reactor Trip Setpoint on High S/G Level (Narrow Range) (%)	93.0
Reactor Trip Setpoint on S/G Pressure (kg/cm^2a)	62.257

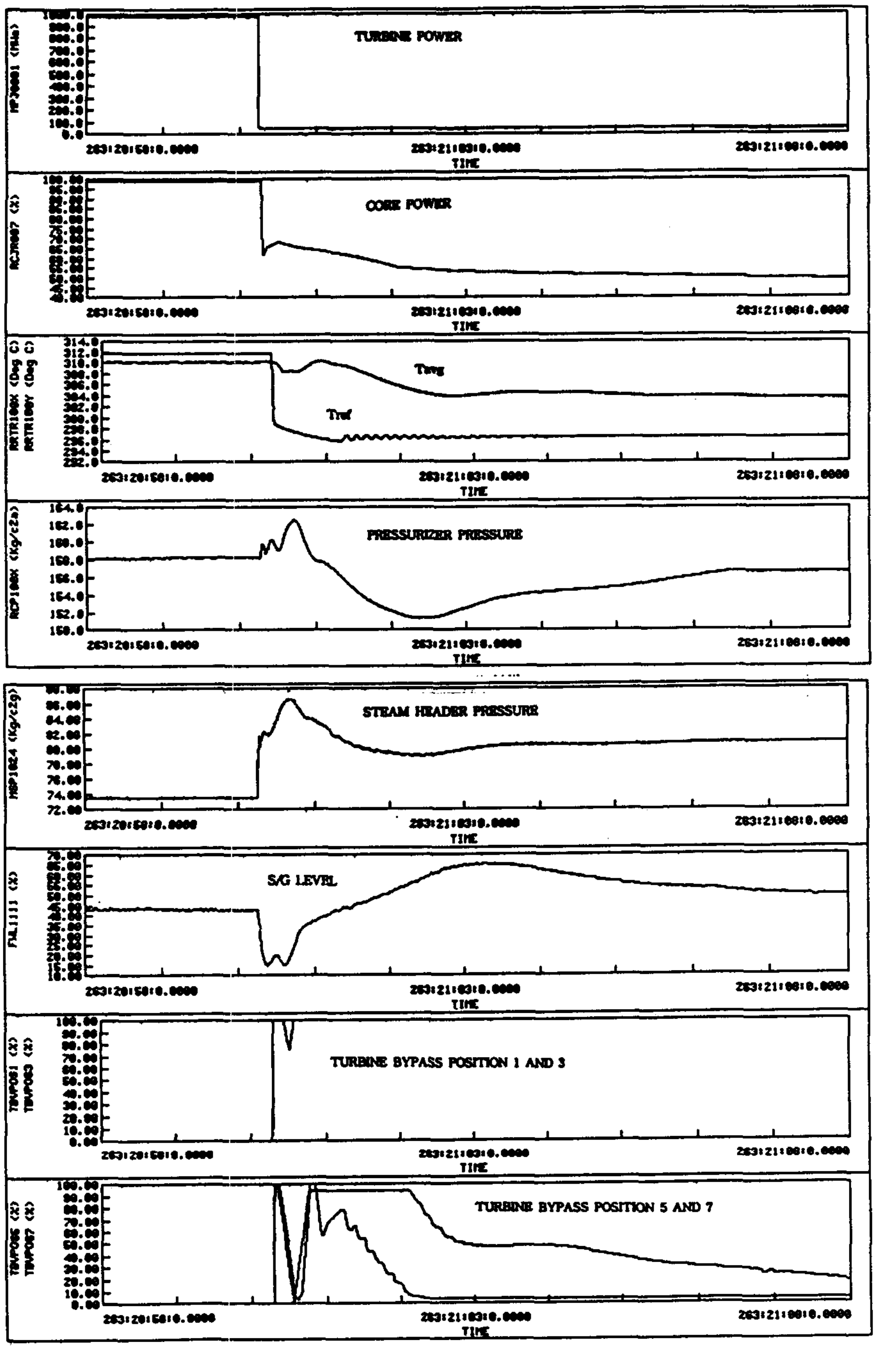

Figure 1. 100% LOL Test Results at YGN 4

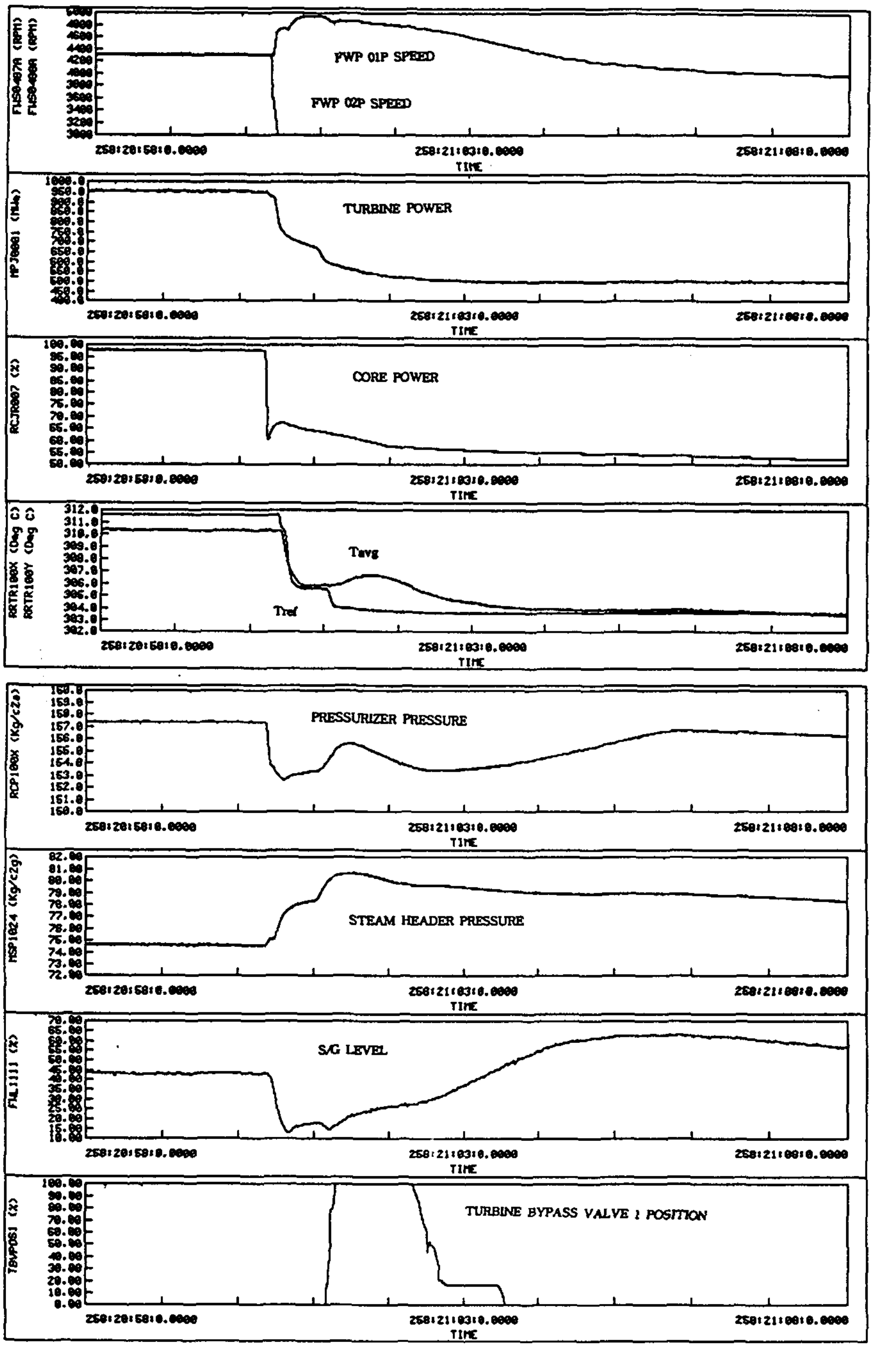

Figure 2. 100% LOMFWP Test Results at YGN 4