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Plant Operability Margins Evaluation for Kori Unit 2

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Abstract

Korea Electric Power Research Institute is performing the relaxation of SG tube plugging(SGTP) level from 5% to 15%. The purpose of this study is to provide a discussion of the operating margin to the various Reactor Trip and Engineered Safety Features (ESF) actuation setpoints during steady-state and normal (Condition I) operating transients at the 15% SGTP conditions. Three Condition I transients, such as, 50% Step Load Rejection from 100% power, 10% Step Load Increase from 90% power and 5%/minute Ramp Load Increase from 15% to 100% power were analyzed. It is concluded that sufficient margin exists to various reactor trips and ESF actuation setpoints for the relaxed SGTP.

1. Introduction

Korea Electric Power Corporation are performing Nuclear Design Parameter Relaxation(NDPR) Program for Kori Unit 2. This NDPR includes the relaxation of SG tube plugging level from 5% to 15%. The purpose of this study is to provide a discussion of the operating margin to the various Reactor Trip and Engineered Safety Features (ESF) actuation setpoints during steady-state and normal (Condition I) operating transients at the 15% SGTP conditions. There are 14 reactor trip and 10 ESF actuation signals active during at power operation. The reactor trips, as identified in the Precautions, Limitations, and Setpoints document (Ref.1) and in Technical Specifications(Ref. 4) are:

a. Power Range, Neutron Flux, Low Setpoint
b. Power Range, Neutron Flux, High Setpoint
c. Power Range, Neutron Flux (High Positive and High Negative Rate)
d. Overtemperature DT
e. Overpower DT

f. High Pressurizer Pressure
g. High Pressurizer Water Level
h. Low Pressurizer Pressure
i. Loss of Primary Coolant Flow
j. Low-Low Steam Generator Water Level
k. Turbine Trip above P-9 permissive
l. Steam/Feedwater Flow Mismatch coincident with low steam generator level
m. Undervoltage RCP trip
n. Underfrequency RCP trip

The other reactor trips are either manually actuated or are not active during at power operation.

The ESF actuations, as identified in Ref. 1 & 4, are:

a. Low Pressurizer Pressure Safety Injection (SI)
b. Low Steam Line Pressure SI
c. Containment High Pressure SI
d. Low Steam Line Pressure coincident with SI Steam Line Isolation(SLI)
e. High-high Containment Pressure SLI
f. High Steam Flow coincident with Tavg Low-Low and SI SLI
g. High-High Steam Flow SLI
h. Hi-3 Containment pressure Containment Spray
i. High-High Steam Generator Level Turbine Trip and Feedwater Isolation
j. Low-low Steam Generator Level AFW Actuation

The current Technical Specifications reactor trip and ESF setpoints (Ref.4) are used in this margin to trip analysis because those setpoints are not changed as a result of NDPR Program.

The purpose of this margin to trip or plant operability analysis is to verify that there are adequate margins to relevant reactor trip and ESF actuation setpoints during and following the Condition I transients. These setpoints are not expected to be challenged during the condition I transient. With the 15% SGTP operating conditions, steam pressure, RCS volume, and heat transfer area are reduced. The changes may affect plant responses to Condition I transients, which requires that a margin to trip analysis be performed. The NDPR analysis may affect the best estimate nuclear kinetics parameters(i.e., MTC, Rod Worth, DTC, etc.) values, which will affect the margin to trip analysis. The limiting Condition I transients have been analyzed for the 15% SGTP operating conditions. Below is an itemization of the impact of the 15% SGTP on the operating margin of each actuation signal. The analyses are described in Section 2.2

Sections 3 and 4 provide results and conclusions of the margin to trip analysis. These analyses are performed at the current power conditions with the full load Tavg of 583°F and the average steam generator tube plugging level of 15%. The Condition I transients considered for this evaluations are initiated from full and in some cases part-power conditions.

2. Transient Description and Method of Analysis

2.1 Transient Description

The following Condition I transients (Normal Operating Transients) were analyzed to verify that sufficient operating margin exists to reactor trip and ESF setpoints with NSSS control systems in the automatic mode.

a. 50% Step Load Rejection from 100% power
b. 10% Step Load Increase from 90% power
c. 5%/minute Ramp Load Increase from 15% to 100% power

(1) 50% Load Rejection

The 50% load rejection transient is the most severe Condition I transient that the plant is expected to sustain without a reactor trip. This transient is equivalent to a 50% turbine load change. The RCS average temperature, secondary side steam temperature and pressure increase rapidly following this transient. Steam dump to the condenser is required to prevent both reactor trip and steam generator safety valve actuation.

(2) 10% Step Load Increase

The 10% step change in load demand results from disturbances in the offsite electrical network which is tied to the plant output. Following a step increase in turbine load, the secondary side steam pressure and temperature initially decrease, lagged by primary average temperature and pressure decrease. In addition to moderator temperature coefficient, the rod control system automatically withdraws the rods to increase the core power. Reactor coolant temperature and pressure are then restored to their equilibrium values.

(3) 5%/Minute Ramp Load Increase

The unit loading transients are represented by continuous and uniform ramp power changes between 15% and 100% power. This load swing is the maximum possible consistent with operation under automatic reactor control. Due to turbine loading limitations, the actual loading rates are typically lower than 5%/minute.

2.2 Method of Analysis

The above Condition I transients were analyzed using the PC version of LOFTRAN code (LOFT1302). Since these normal operating transients would produce the most severe challenges to the reactor trip and the ESF systems, these transients were selected for the margin to trip analysis.

The following assumptions are relevant to all transient analyses for the margin to trip analysis.

a. Steam generator tube plugging level of 15% is assumed for the analysis.
b. All NSSS control systems (i.e., Rod Control, Steam Dump Control, Steam Generator Level Control, and Pressurizer Pressure and Level Control) are assumed operational and are in automatic mode of control.
c. The steam dump total capacity of 38.2% with 15% SGTP operating conditions.
d. The steam dump valves design stroke time of 20 seconds for modulating open and 3 seconds for trip open are used.
e. The setpoints and time constants for all other NSSS control systems are taken from of the Kori 2 Precautions, Limitations and Setpoints (PLS) document (Ref.1).
f. Since the Condition I transient analyses are best estimate analyses, best estimate kinetic parameters (Moderator Temperature Coefficient, Doppler Defect, Control Rod Worth) are assumed in the analysis. The best estimate kinetic parameters assumed in the analysis are contained in Ref.2. A conservative, Beginning of Life (BOL) core parameters are assumed for the analysis.

3. Results of Reactor Trip and ESF Setpoints Evaluations

3.1 High Flux

Setpoint: 109% of rated thermal power (1882 MWt)

Power increase transients would challenge the high flux reactor trip setpoint. The most severe of these normal operational power increase transients are: a 10% step increase in power from 90% power and a 5%/minute ramp increase from 15% power. These two transients are analyzed to verify the margin to this reactor protection setpoint.
The results of both these transient analyses show that the peak reactor power remained below 103.6% of rated thermal power. Since the actual power increase transients are generally expected to be less severe than these, it is concluded that there would be sufficient margin to the high flux reactor trip at the 15% SGTP conditions.

3.2 Overtemperature DT

OTDT Setpoint : See below.

$$OT\ \Delta T\left(\frac{1+\tau_4 s}{1+\tau_5 s}\right)\left(\frac{1}{1+\tau_3 s}\right) \le \Delta T_0$$

$$\left\{ K_1 - K_2\left(\frac{1+\tau_1 s}{1+\tau_2 s}\right) \left[T\left(\frac{1}{1+\tau_3 s}\right) - T' \right] + K_3(P-P') - f_1(\Delta I) \right\}$$

Parameter	Setpoint
K_1	1.09
K_2	0.0165/°F
K_3	0.0007/psi
τ_1	30 sec
τ_2	4 sec
τ_3	2 sec
τ_4	8 sec
τ_5	3 sec
$f_1(\Delta I)$ penalty breakpoints	function of indicated difference between top and bottom detector
ΔT_0	Indicated ΔT at rated thermal power, °F
T'	Indicated Tavg at rated thermal power, °F
P'	Nominal RCS operating pressure, 2250 psia
ΔT	Measured ΔT , °F
T	Average Temperature, °F
P	Pressurizer Pressure, psia
s	Laplace Transform Operator

3.3 Overpower DT

OPDT Setpoint : See below.

$$OP\ \Delta T\left(\frac{1+\tau_4 s}{1+\tau_5 s}\right)\left(\frac{1}{1+\tau_6 s}\right) \le \Delta T_0$$

$$\left\{ K_4 - K_5\left(\frac{\tau_3 s}{1+\tau_3 s}\right)\left(\frac{1}{1+\tau_6 s}\right)T - K_6 \left[T\left(\frac{1}{1+\tau_6 s}\right) - T'' \right] - f_2(\Delta I) \right\}$$

Parameter	Setpoint
K_4	1.09
K_5	0.02/°F
K_6	0.0012/°F
τ_3	5 sec

τ_4	8 sec
τ_5	3 sec
τ_6	2 sec
$f_2(\Delta I)$ penalty breakpoints	function of indicated difference between top and bottom detector
ΔT_0	Indicated ΔT at rated thermal power, °F
T"	Indicted Tavg at rated thermal power, °F
ΔT	Measured ΔT, °F
T	Average Temperature, °F
s	Laplace Transform Operator

The Condition I transient (normal operating transient) that would produce the most severe challenge to the OTDT and OPDT trips is the 50% load rejection from 100% power transient. This transient is analyzed with the effective steam dump capacity of 38.2% of nominal steam flow at the 15% SGTP. The key assumptions for this analysis are shown in Section 2.2. The results of this analysis show that the minimum margins to the OTDT and OPDT are approximately 2.9% and 7.1% of full power ΔT respectively, for the 15% SGTP operating conditions. The margins are considered to be adequate.

3.4 Low Pressurizer Pressure

Current setpoints: 1870 psig with a 12/2 lead/lag compensation (Reactor Trip)
1870 psig (SI actuation)

The limiting Condition I transient that would challenge the low pressurizer pressure reactor trip is the 50% load reduction transient as described above. The results of this transient show the compensated pressurizer pressure (lead/lag of 12/2) remained above 2174 psia during the transient. Thus, there is sufficient margin to the low pressurizer pressure reactor trip.
The minimum, uncompensated pressurizer pressure reached during the 50% load reduction transient is 2166 psig. Thus, there is sufficient margin to the low pressurizer pressure SI actuation setpoint.

Although, a reactor trip transient(an upset condition transient) is not a condition I transient, a reactor trip transient from full power is also analyzed to verify margin to SI setpoint. With the current steam dump plant trip setpoints, there is adequate margin to the low pressurizer pressure SI actuation setpoint. The minimum pressurizer pressure is 1992 psig. A reactor trip transient is also the most limiting transient with respect to the pressurizer heater uncovery. The minimum pressurizer water volume is 401 ft^3 during this transient. For comparison purposes, the pressurizer water volume of 203 ft^3 (which includes the pressurizer surge volume) corresponds to 10.8% of span (pressurizer heater uncover volume). The pressurizer water volume of 264 ft^3 (which includes the pressurizer surge volume) corresponds to 18% of span (pressurizer low level heater cutout and letdown isolation volume). Thus, pressurizer heaters are not expected to be uncovered and letdown isolation is not expected to occur during the reactor trip transient.

3.5 High Pressurizer Water Level Reactor Trip

Current Setpoint: High Level of 92% of Span

Again, the limiting Condition I transient that would challenge the high pressurizer water level reactor trip is the 50% load rejection from 100% power as described above. The results show a peak pressurizer water volume of 654 ft^3. For comparison purposes, the pressurizer water volume of 886 ft^3 (which includes the pressurizer surge volume) corresponds to 92% of span. Thus, sufficient margin to the high pressurizer water level reactor trip setpoint exists.

3.6 Low Steam Line Pressure SI and MSIV Actuation

Current Setpoint: Low Steam Pressure 570 psig with a 12/2 lead/lag compensation.

The margin to this ESF system actuation is evaluated by analyzing the load increase transients which challenge the low steam pressure setpoint. The load increase transients evaluated are the unit loading at 5%/minute and 10% step load increase transients. The key assumptions for this analysis are shown in Section 2.2. The minimum compensated (12/2) steam pressure is 820 psig for the 10% step load increase from 90% power transient. The full power steam pressure is 862 psig. Based on an evaluation of these results, sufficient margin to the low steam pressure SI setpoint exists. For 5%/minute loading, the minimum compensated steam pressure was 812 psig.

3.7 Others

The remaining reactor trips and ESF actuations (listed below) are not challenged by the normal operating transients (Condition I transients).

Source Range Neutron Flux
Intermediate Range Neutron Flux
Power Range Neutron Flux, Low Setpoint
Power Range, High Range, High Level
Power Range, Neutron Flux (Positive and Negative Rate)
High Pressurizer Pressure
Loss of Primary Coolant Flow (Low Flow, Low Frequency, Underfrequency, Low Voltage, and Undervoltage Time Delay for Reactor Trip)
Low Pressurizer Pressure Safety Injection (SI)
Containment High Pressure (SI)

High-high Containment Pressure (Steam Line Isolation)
High Negative Steamline Pressure Rate (Steam Line Isolation)
Hi-3 Containment Pressure Containment Spray

Depending on the feedwater system arrangement, the SG low-low level and high-high level setpoints may be challenged during an unanticipated loss of one main feedwater pump event. A loss of one main feedwater pump is not a condition I transient. This transient is not evaluated here.

4. Conclusions

Based on the discussions above, it is concluded that sufficient margin exists to various reactor trips and ESF actuation setpoints for the NDPR program. Because of very small K_1 value of OTDT setpoint, the margin to OTDT is very small. This small margin can be improved by revising the steam dump hi-2 setpoint and/or increasing the K_1 value. No other control system setpoints revision are required from this analysis.

References

1. Kori 2 PLS Rev.3
2. KNFC Letter on Reactivity Design Parameters for NDPR Program.
3. WCAP-7878, "LOFTRAN Code Description and User's Manual," November 1989.
4. Kori 2 Technical Specification.