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Evaluation of Loss of a Main Feedwater Pump Event for YGN 3

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ABSTRACT

A loss of one main feedwater pump event and a subsequent reactor trip by the CPC variable overpower trip function occurred during the Cycle 4 of Yonggwang Unit 3. In order to investigate the transient behavior of the plant, a computer code simulation with KISPAC code was performed for this event. The turbine control system and turbine valve responses were modeled as simplified form and the CPC function was simulated by interfacing with the KISPAC code results. A comparison between the measured plant data and the computer code simulation results showed a reasonable agreement. The simulation results also showed that the reactor trip occurred when the CPC resumed its normal calculation schemes at 23 seconds after the actuation of the Reactor Power Cutback System. An understanding of the trip sequence for this event by the simulation is helpful in preventing the reactor trip under the similar situation in the future.

1. INTRODUCTION

On Loss of a Main Feedwater Pump (LOMFP) event, the Reactor Power Cutback System (RPCS) decreases the reactor power rapidly by dropping the selected control rods. Also, setback and runback functions of Turbine Control System (TCS) rapidly decrease the secondary power to the range of one main feedwater pump capacity. Therefore, a primary and secondary power balance is maintained without reactor trip after a short transient period with the automatic control actions of other control systems such as the Reactor Regulating System (RRS) and the Steam Bypass Control System (SBCS). The LOMFP event has been successfully tested as one of the Power Ascension Test (PAT) during the startup test period.[1,2]

However, a reactor trip occurred after LOMFP event during the commercial operation at the YGN Unit 3. The event occurred at the End of Cycle (EOC) of Cycle 4 operation and the reactor trip was initiated by the Core Protection Calculator (CPC) Variable Overpower Trip (VOPT) trip function. The major differences between the test performed during PAT and the event occurred during YGN 3 Cycle 4 operation are the dropped bank worth by the RPCS and the Moderator Temperature Coefficient (MTC) effect. The CEA(Control Element Assembly) groups 5 and 4 were dropped for the latter case whereas only CEA group 5 was dropped for the former case. Also, the MTC was much more negative for the latter case. The RPCS is designed to decrease reactor power rapidly to less than 75% of the rated power, and the possibility of both CEA groups 5 and 4 insertion increases as the fuel burnup increases. When both CEA groups 5 and 4 are dropped, the reactor power decreases below the secondary power controlled by the TCS and, therefore, the cold leg temperature decreases. On the other hand, when only CEA group 5 is dropped, the reactor power usually remains above the secondary power, and the cold leg temperature increases. For both cases, the reactor power rises again after the initial decrease caused by the CEA drop due to the fuel temperature and MTC effects.

The CPC is a digital protection system whose VOPT function can protect the reactor core from the rapid power increase and the overpower. The neutron flux power exceeded the VOPT setpoint in CPC channel B and C during the LOMFP event of YGN 3 Cycle 4 operation. The CPC does not execute some of its functions after RPCS actuation to prevent unnecessary reactor trips and resumes those functions after some period of time.

In this paper, the LOMFP event was simulated with KISPAC code[3] which is used for plant performance analysis. The CPC simulation was based on CPC FORTRAN code[4] with minor modification needed for interface with KISPAC code.

2. MODEL DESCRIPTION

2.1 General KISPAC Code Description

The KISPAC code is a best-estimate nuclear power plant simulation tool. The KISPAC code is designed to analyze the thermal-hydraulic responses of the NSSS and major secondary systems during non-LOCA accidents, power range transients, reactor trips, plant heatup and plant cooldown. Major systems modeled in detail include the reactor coolant system, main steam system, main and auxiliary feedwater systems, containment heat transfer and all NSSS control systems. Other systems which influence the response of the major heat transport systems are also modeled. These include the chemical and volume control system, safety injection system and a limited turbine system model. Plant monitoring, control and protection systems, including instrument lag times and instrument decalibration due to environmental effects are also modeled.

2.2 TCS and Turbine Control Valve Response Modeling

The TCS[5] is very complicated system and most of its functions are not required for simulation of this event except the turbine setback and runback functions. The turbine control valve positions are controlled with three-coil servo valve actuators in normal control and fast acting solenoid valve in protection control. The setback and runback functions belong to normal control and the control valve responses are delayed from the valve position demand signals. This delay is modeled by second order response function. Figure 1 shows the functional block diagram for the TCS modeling in this study.

The runback signal is generated if the Turbine Load Index (TLI) is above 60% power level when the setback signal is turned on. The TLI is a function of the turbine first stage pressure which represents the turbine power. But, KISPAC code does not have a model to calculate the turbine first stage pressure and the TLI is given by the turbine power demand. This modeling shorten the runback duration than that of the real plant and the plant behaves differently. For this reason, the runback duration is given by user input based on the previous plant experience.

2.3 CPC Simulation Interface with KISPAC Results

The CPC Fortran Code has capability to simulate the online CPC. It requires the pump speeds, cold leg and hot leg temperatures, pressurizer pressure, excore detector signals, and the CEA positions as the inputs. These information are obtained directly from KISPAC results or with some processes.

The three level detector responses are calculated from the three level core power distribution and the core power level. The core power distribution is assumed because the KISPAC code has point kinetics model for the core power. The temperature shadowing effects, shape annealing effects, and rod shadowing effects are considered as follows:

$$\mathbf{D} = \mathrm{TSF} \cdot \mathbf{M} \cdot \mathbf{R} \cdot \mathbf{C}$$

where,

$$\mathbf{D} = \begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix}, \quad \mathbf{M} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}, \quad \mathbf{R} = \begin{bmatrix} R_1 & - & - \\ - & R_2 & - \\ - & - & R_3 \end{bmatrix}, \quad \mathbf{C} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix}$$

The vector **D** is excore detector signal, **C** is core average power distribution, **R** is rod shadowing factor, **M** is inverse Shape Annealing Matrix (SAM) matrix, and TSF is temperature shadowing factor. This algorithm is basically the same with the CPC algorithm except the CPC calculates the core power distribution with detector responses. The rod shadowing factor is calculated based on 20 nodes with CEA inserted positions and the temperature shadowing factor is calculated as follows:

TSF = 1 + TSFC*(TCREF-Tcold)

TSFC is the coefficient for temperature shadowing factor, TCREF is the reference cold leg temperature, and Tcold is the cold leg temperature from KISPAC code.

The temperature and pressure data are calculated from KISPAC results with first order lag function as follows:

$$q_o = \frac{1}{\tau s + 1} q_i$$

where , τ is the sensor response time.

3. INPUT DATA FOR SIMULATION

The general KISPAC code inputs were prepared during design period of YGN Unit 3&4. The control system parameters installed during startup of the plants were also updated. The physics parameters which are dependent on fuel burnup were prepared based on the Nuclear Design Report (NDR)[6] for YGN 3 Cycle 4. The TCS related inputs were prepared based on the plant setpoints. The turbine runback duration after setback and the turbine control valve response time are prepared based on plant behaviors during many cases of LOMFP events. The turbine runback duration and the turbine control valve response time are 23 seconds and 3 seconds, respectively.

The CPC simulation requires CPC database and simulated CPC sensor input. The CPC Reload Data Block (RDB) and the addressable constants for YGN 3 Cycle 4 were used for CPC database. The CPC channel C data were used for channel dependent addressable constants. The simulated CPC sensor inputs were prepared from KISPAC code results. Because the point kinetics model is used in KISPAC code, the power distribution was assumed to generate three levels of excore detector signals. The coefficient for temperature shadowing factor used for the simulated input was 0.006, and the rod shadowing factor for both CEA groups 5 and 4 insertion was 1.0. The inverse SAM matrix of CPC channel C was also used. It was found that the response time for the CPC temperature sensors was one of the major influencing parameters to CPC VOPT. Three cases of 3, 5, and 8 seconds for the response time were simulated.

4. COMPARISON BETWEEN PLANT DATA AND SIMULATED RESULTS

At 04:17:25 on May 9, 1999, the LOMFP event initiated due to a loss of booster pump signal at YGN Unit 3. The CEA groups 5 and 4 were dropped by the RPCS and turbine setback and runback functioned by the TCS. But, at about 23 seconds after the event initiation, a reactor trip occurred by the Plant Protection System (PPS) due to CPC VOPT.

The various plant data are logged continuously every 5 seconds by Plant Monitoring Systems (PMS) except for the data related to CPC which are updated every 10 minutes. The CPC trip buffer report, which contains the CPC data when its channel trip occurs, is an important information for comparison with simulated results.

The plant data and the KISPAC code results for major plant parameters are plotted in Figures 2 to 9. Because the transient CPC data are not available, only CPC simulated results related to CPC VOPT are plotted in Figure 10. In KISPAC Code simulation, the LOMFP event was initiated at 27 second and reactor trip due to CPC VOPT was not modeled to estimate the plant behaviors without reactor trip.

The reactor power dropped sharply due to dropping of the control rods and rised again about 20% due to fuel and moderator temperature effects as shown in Figure 2. The steam flow rate decreased due to turbine setback and runback functions. The turbine first stage pressure and the turbine electrical power decrease slowly compared to the steam flow rate in plant data. The KISPAC results show some differences for these data because the KISPAC has no model for the turbine first stage pressure and the turbine electrical power.

The most important parameter in this event is the cold leg temperature because it reflects the power mismatch between the primary and secondary side and the MTC effect is dependent on it. Moreover, CPC temperature shadowing effect, which adjust the CPC neutron flux power, is a function of the cold leg temperature. When comparing plant data with KISPAC results, the response time of the temperature sensor should be considered.

The CPC VOPT related parameters are plotted in Figure 10. The PHICAL, which is CPC neutron flux power, jumps at 23 seconds after the RPCS actuation and reaches the VOPT setpoint at this time. The CPC skips some of its normal power distribution calculations during 23 seconds when the RPCS is actuated. When it resumes its normal calculations, the RSF for both CEA groups 5 and 4 insertion is applied. The database value for the RSF is 0.84 for that case, and it means that when the CEA groups 5 and 4 are inserted, the excore detector response is only 84% of the core power. So, the core power is calculated with excore detector signal divided by the RSF in CPC and the neutron flux power jumps about 19% of the previous power level before it resumes the normal calculation scheme. CPC Trip Buffer parameters are compared in Table 1. It can be concluded that the CPC simulation is reasonable because all of the major trip buffer parameters are similar with the simulation results.

Figures 11 through 13 show that the response time in CPC temperature sensor has significant effect on CPC VOPT setpoint. The response times are to be less than 8 seconds in design requirement and it is used for many cases for the conservatism. But, the actual response times are much less than 8 seconds. Shorter the response time, the BDT, which is the CPC thermal power, responses faster, and the VOPT setpoint decreases faster. Figure 11 shows that the VOPT trip does not occur when the response time is 8 seconds. It is difficult to conclude by direct comparison between the temperatures of plant data and the simulation results because the plant data has some other delays in data acquisition and PMS data logging. But, the response time less than 8 seconds is more reasonable in these cases.

5. CONCLUSIONS

The KISPAC simulation of YGN Unit 3 Cycle 4 LOMFP event was successfully done including CPC simulation. The simulation results are compared to the plant data and most plant parameters including CPC trip parameters are in reasonable agreement. But, KISPAC code has a limitation on calculation of turbine first stage pressure, which is used in turbine runback and RRS reference temperature.

The CPC simulation shows that the trip occurred when the CPC resumed its normal calculation scheme at 23 seconds after the RPCS actuation. The response time of the CPC temperature sensor has significant effect on CPC VOPT setpoint.

The computer simulation in this study shows the reactor trip sequence occurred during YGN Unit 3 Cycle 4 operation. An understanding of this event by the simulation is helpful in preventing the reactor trip under the similar situation in the future.

REFERENCES

1) "JSD Startup Evaluation Report for YGN 3," 10487-SE-SER01, KOPEC, June 21, 1995.

2) "JSD Startup Evaluation Report for YGN 4," 10487-SE-SER02-00, KOPEC, January 15, 1996.

3) "Technical Manual for KISPAC," KOPEC, 1999.

4) "Users' Manual for the CPC/CEAC FORTRAN Simulation Code," Rev. 01, 00000-ICE-3812, ABB-CE

5) "Description of SPEEDTRONIC Mark V Control System – Large Steam," GEK 104007, GE, December 1993.

6) "Nuclear Design Report for YGN 3 Cycle 4," KNFC

Table 1. Comparison of the CPC Trip Buffer Information and the Simulated Results

CPC Parameters	Plant Data Channel B	Plant Data Channel C	Simulation Results
Loop 1 Cold Leg Temp.	559.00 °F	559.29 °F	558.37 °F
Loop 2 Cold Leg Temp.	559.45 °F	558.61 °F	558.64 °F
Loop 1 Hot Leg Temp.	590.97 °F	591.08 °F	590.97 °F
Loop 2 Hot Leg Temp.	590.63 °F	552.18 °F	591.44 °F
Pressurizer Pressure	2111.74 psia	2120 psia	2112.25 psia
Calibrated Neutron Flux Power	70.06 %	69.609 %	70.61 %
Static Thermal Power	59.06 %	59.03 %	59.37 %
FOLLOW	59. 06 %	59.04 %	59.39 %
VOPT Setpoint	69. 06 %	69.04 %	69.37 %
Temperature Shadowing Factor	1.082	1.074	1.080
Updated Value of DNBR	1.824	1.940	1.947
Compensated Local Power Density	11.379 kw/ft	10.787 kw/ft	10.773 kw/ft

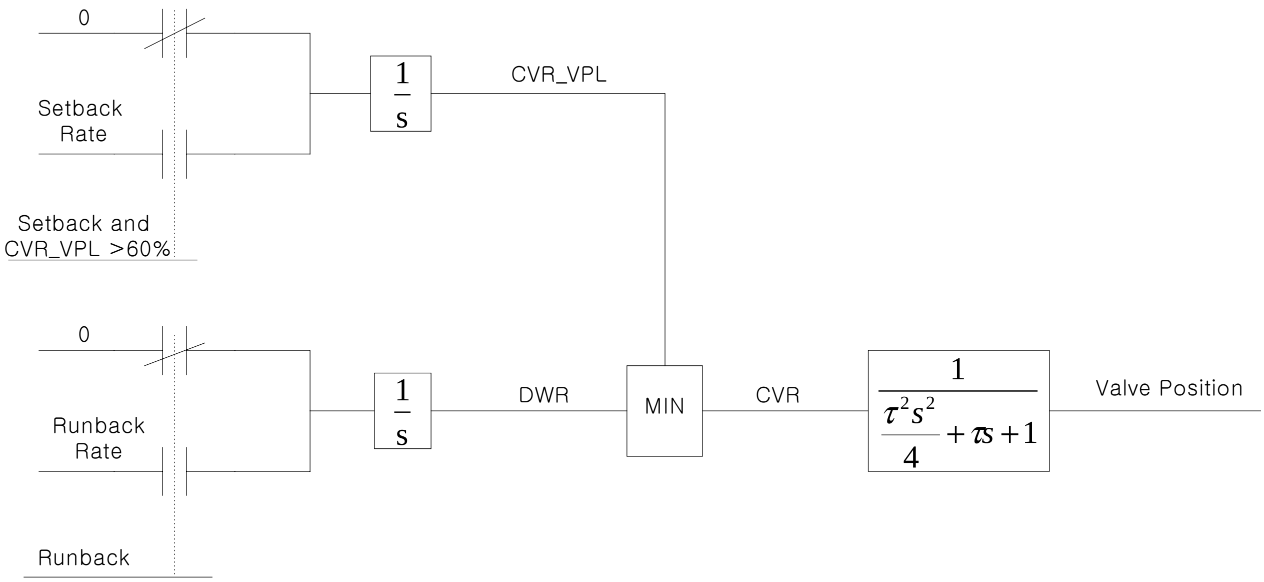

Figure 1. TCS Setback/Runback and Valve Response Modeling for KISPAC Simulation

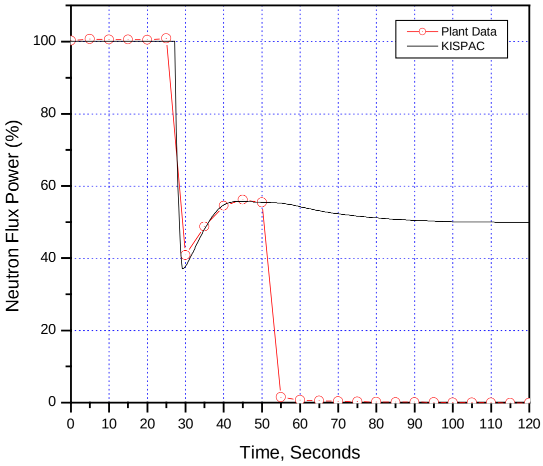

Figure 2. Comparison for Reactor Power

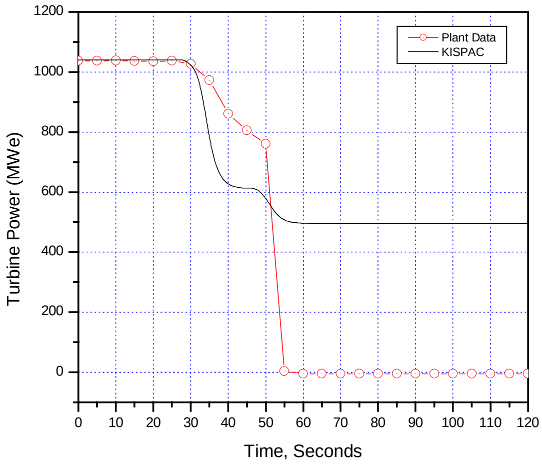

Figure 3. Comparison for Turbine Power

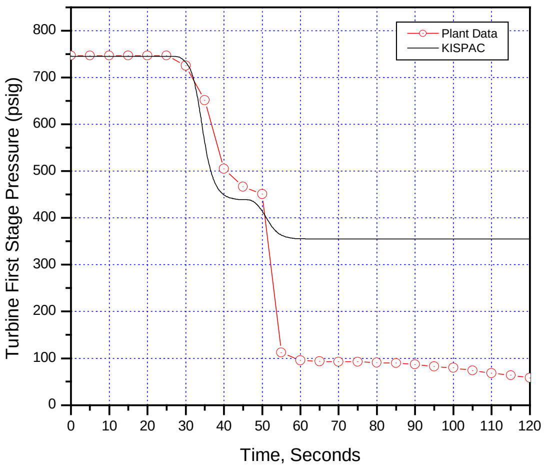

Figure 4. Comparison for Turbine First Stage Presure

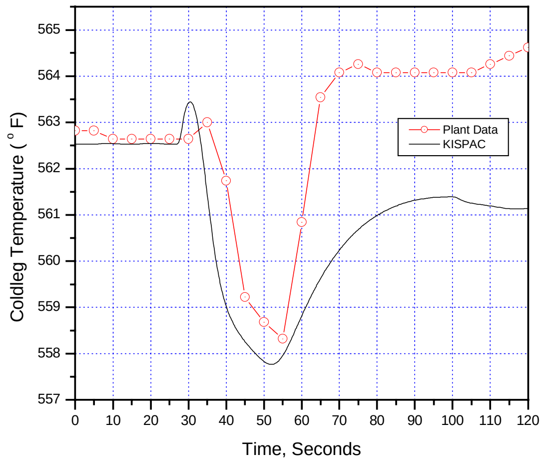

Figure 5. Comparison for Coldleg Temperature

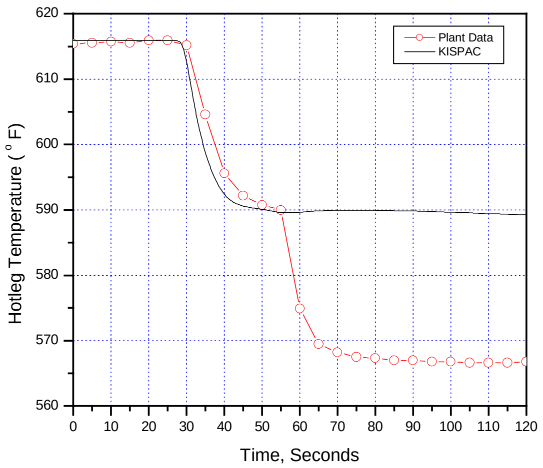

Figure 6. Comparison for Hotleg Temperature

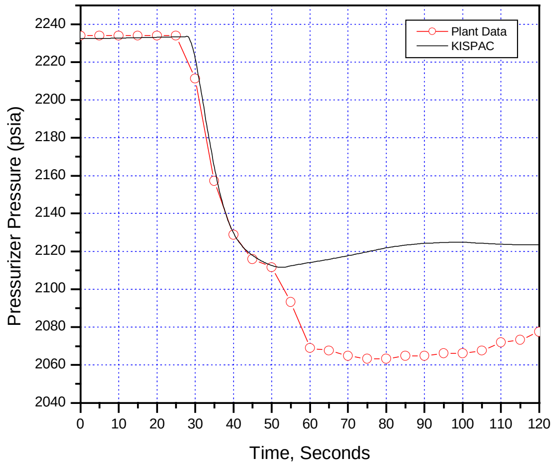

Figure 7. Comparison for Pressurizer Pressure

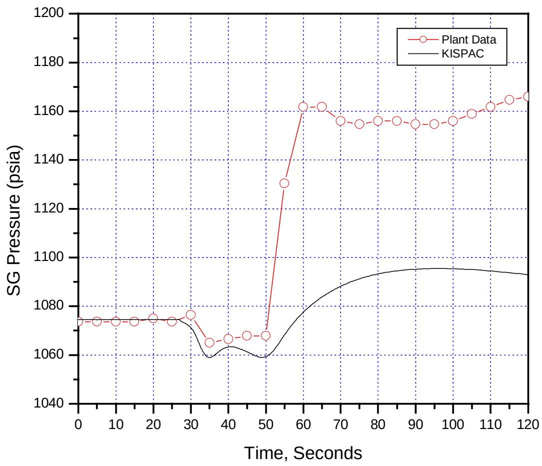

Figure 8. Comparison for SG Pressure

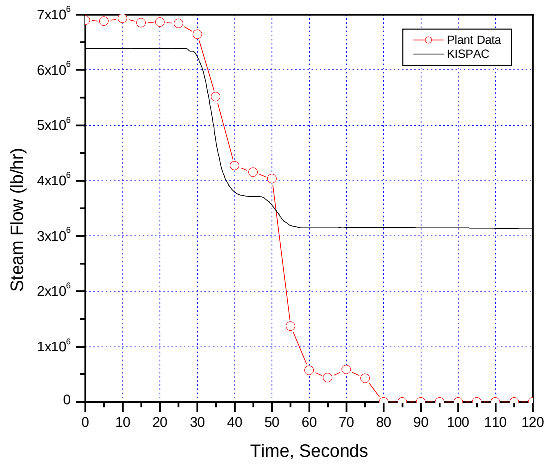

Figure 9. Comparison for Steam Flow Rate

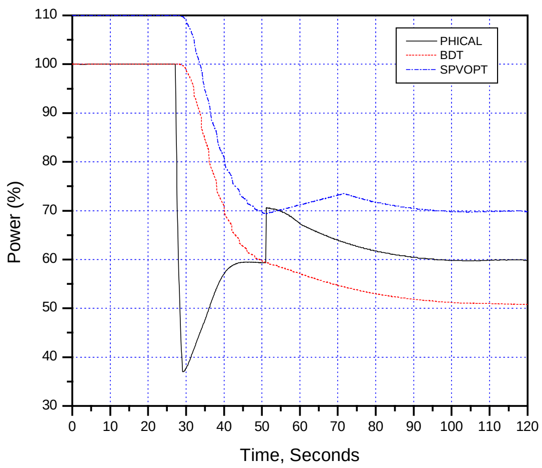

Figure 10. CPC VOPT Related Parameters

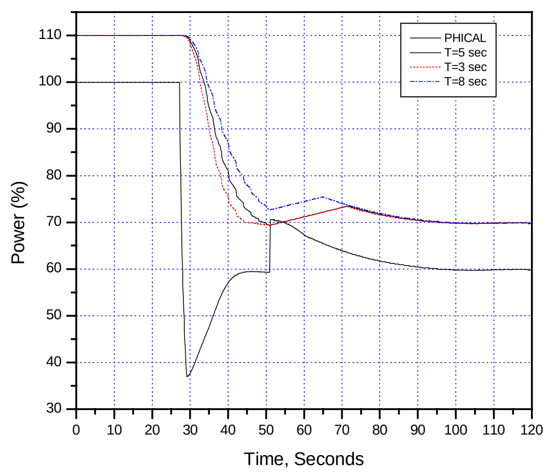

Figure 11. VOPT Setpoints depending on Temperature Response Time

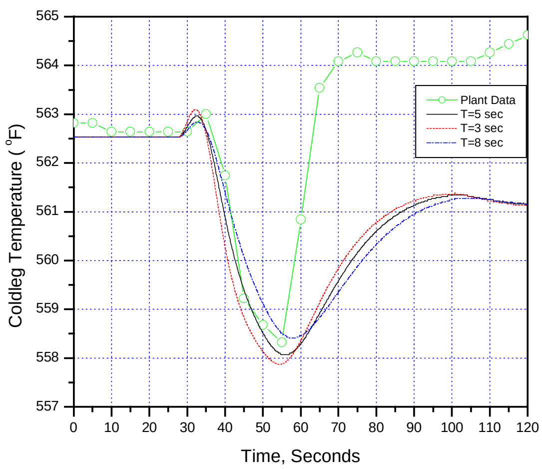

Figure12. Coldleg Temperatures depending on Temperature Response Time

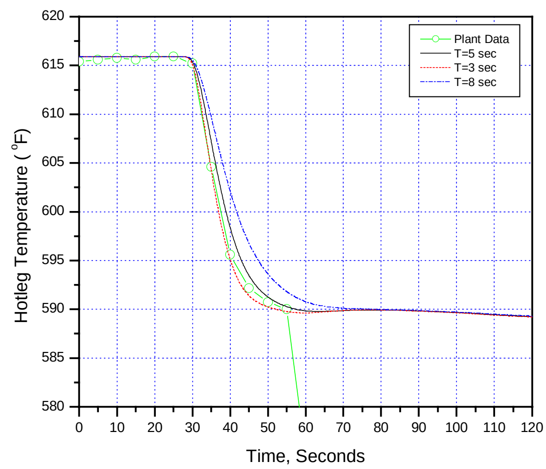

Figure 13. Hotleg Temperatures depending on Temperature Response Time