

LabVIEW-Based Design of Reactor Coolant Temperature Protection System

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***Keywords : Reactor protection system, LabVIEW simulation, Temperature monitoring, Signal calibration**

1. Introduction

In nuclear power plants, the reactor coolant temperature protection system plays a critical role in monitoring the temperature of the reactor coolant system (RCS) and generating protection signals to prevent core damage. The protection logic typically includes average temperature (T_{avg}), temperature difference (ΔT), over-temperature ΔT (OT ΔT), and over-power ΔT (OP ΔT) calculations. With the obsolescence of analog control cards used in the Kori 3 and 4 units, there is an increasing need to implement a digital alternative for maintenance, testing, and training purposes. LabVIEW, a graphical programming environment, offers an effective platform for simulating such control systems.

2. System Overview

2.1 Configuration and Functionality

The original temperature protection system is part of the '7300' process control system used in the WEC pressurized water reactors (PWRs). The system receives RTD sensor inputs from hot and cold legs, calculates T_{avg} and ΔT , and compares these with setpoints to generate reactor trip and control rod signals. The OT ΔT and OP ΔT signals are calculated using dynamic compensators with parameters such as T_{avg} , pressurizer pressure, and ex-core flux deviation.

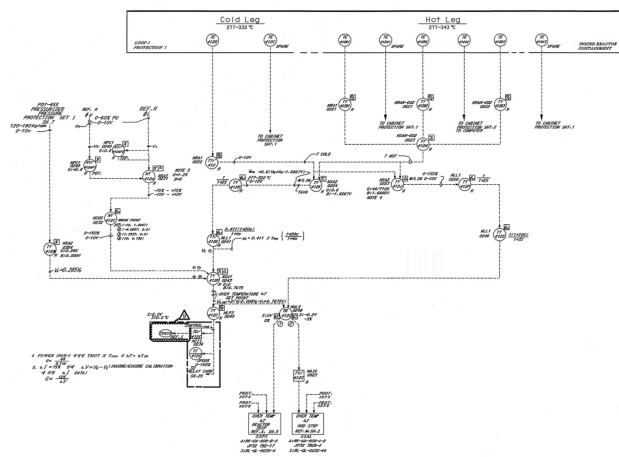


Fig. 1. Simplified Process Control Block Diagram

2.2 Challenges and Motivation for LabVIEW Implementation

With over 100 analog control cards involved, the complexity of signal flow and logic interpretation poses challenges in troubleshooting and training. Simplifying and visualizing these loops through LabVIEW can improve understanding and support the development of replacement systems.

3. Implementation Using LabVIEW

LabVIEW was used to replicate the reactor coolant temperature protection logic. Each control card function such as RTD signal conversion, summation, isolation, lag/lead-lag compensation, and setpoint calculation was implemented using formula nodes and graphical blocks.

The front panel was configured with input controls, indicators, and test switches to allow simulation of functional test conditions and fault cases.

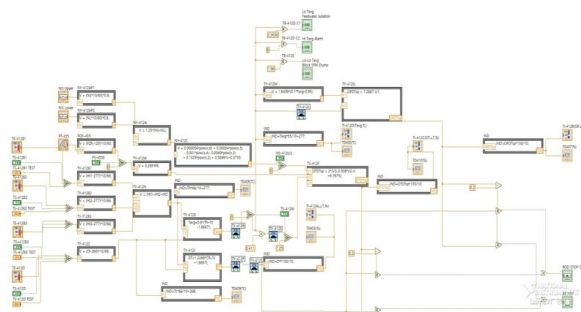


Fig. 2. Structure of the Block Diagram

4. Case Study

4.1 System Verification by Functional Testing

The LabVIEW implementation was verified under the same conditions as the periodic functional tests of Kori 4. Key variables such as T_{avg} , ΔT , OT ΔT setpoint, and OP ΔT setpoint were monitored under various scenarios: normal operation, test mode activation, pressurizer pressure signal removal, ex-core flux signal removal. Table I summarizes the test procedures used to verify the OT ΔT and OP ΔT protection logic.

Table I: Summary of Test Procedures

NO.	Action Description	Remark
1	Apply 312°C simulated signal to TE-412B1	Hot leg #1
2	Apply 329°C simulated signal to TE-412B	Hot leg #2
3	Apply 329°C simulated signal to TE-412B3	Hot leg #3
4	Apply 287°C simulated signal to TE-412D	
5	Apply 1.25V signal to OT Δ T setpoint V_2 input	Apply an arbitrary Tavg signal
6	Switch TS-412D, TS-412B1 to "TEST"	
7	Switch TS-412M, PS-455E to "Defeat"	Remove pressurizer pressure signal
8	Switch NS-412U, NS-412L to "TEST"	Remove neutron flux signal
9	Confirm OT Δ T setpoint	
10	Apply 321°C simulated signal to TE-412B2/B3	
11	Confirm OP Δ T setpoint	
12	Apply 307°C simulated signal to TE-412B2/B3	
13	Return TS-412M to "Normal"	
14	Confirm Lo Tavg tracking setpoint	
15	Apply 260°C simulated signal to TE-412B2/B3	
16	Confirm Lo-Lo Tavg tracking setpoint	
17	Restore all "TEST" and "Defeat" switches	End of test

Fig. 3. shows the trend and variable response during each test procedure. LabVIEW outputs closely matched historical plant data, confirming the accuracy of the simulated logic and calibration. Table II presents a comparison between actual and simulated values for key parameters such as Tavg, Δ T, and setpoints.

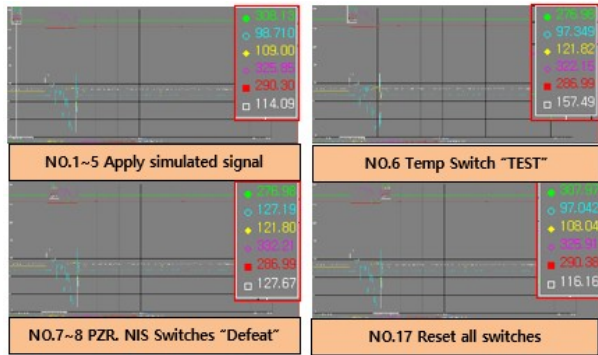


Fig. 3. Trend and Variable Check by Test Step

Table II: Comparison of Actual and Simulated Values (Functional Test)

NO.	Type	Variable					
		Tavg(°C)	Δ T(°C)	OP Δ Tsp(%)	Thot(°C)	Tcold(°C)	OT Δ Tsp(%)
1~5	Actual	308.13	98.710	109.00	325.85	290.30	114.09
	Simulated	308.075	99.1205	109.177	325.85	290.3	114.659
6	Actual	276.98	97.349	121.82	322.15	286.99	157.49
	Simulated	277	97.587	123.083	322	287	180.45
7	Actual	276.98	121.19	121.80	322.21	286.99	127.67
	Simulated	277	125.469	123.083	332	287	127.725
17	Actual	307.97	97.042	108.04	325.91	290.38	116.16
	Simulated	308.075	99.1205	109.177	325.85	290.3	114.659

4.2 Fault Case-Based System Validation

A known fault scenario from December 2015 in Kori 3 was applied to the LabVIEW system: a pressurizer pressure signal failure caused an OT Δ T spike over 150%, triggering a reactor trip. The simulation reproduced the same abnormal behavior, and by

adjusting the signal path to emulate the faulty card, the model helped identify the root cause (gain drift in TY-422W card).

Table III: Comparison of Actual and Simulated Values (Fault Scenario)

System Status	Type	Variable	
		Tavg(°C)	OT Δ Tsp(%)
Normal	Actual	307.700	114.09
	Simulated	308.075	114.659
Fault	Actual	307.700	150.1
	Simulated	308.075	227.494

When comparing the actual values obtained from the test performed on Kori Unit 4 with the simulated values from the LabVIEW system, the results, as shown in Table II, were mostly consistent within the allowable $\pm 0.5\%$ error range for the electronic cards. However, in Step No. 6, the OT Δ T setpoint showed a deviation of approximately 30%. This difference is due to the actual system's trend signal being limited to a maximum display value of 157.49%. By recalculating the actual value using the variables: $V_3 = 1.7575$, $V_2 = 1.25$, and $V_1 = 0$, and converting the voltage to OT Δ Tsp in percentage, the value matches the simulated result. A similar discrepancy is observed in Table III under fault conditions, where identical Tavg inputs result in significantly different OT Δ Tsp values (Real: >150%, LabVIEW: 227.494%), again due to the trend display cap. Nonetheless, the LabVIEW simulation accurately reflects the full expected response beyond this limit.

5. Conclusions

The LabVIEW-based implementation of the reactor coolant temperature protection system effectively reproduces the logic and behavior of analog control systems in Westinghouse-type reactors. It supports training, testing, and development of replacement digital systems. Future research will focus on extending this modeling approach to additional protection logics, such as pressurizer level/pressure control and turbine trip systems, ultimately supporting the qualification of digital systems and facilitating regulatory evaluations.

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