Evaluation of Automated Cycle Counting Algorithms for APR1400 Fatigue Monitoring System with Power Ascension Test Results of Shin-Kori Nuclear Power Plant Unit 3

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1. Introduction

The ACCS is used to count the occurrences of design basis events for calculation of accumulated usage factor of plant components. The ACCS is a part of the APR1400 FMS which has been developed by KEPCO E&C to evaluate the actual loads on the critical components and their fatigue usages over the plant lifetime.

The ACCS consists of algorithms to automatically identify the occurrences of design basis events, listed in Table 1, during plant operation. Figure 1 shows the algorithm used to identify the occurrence of “Turbine Generator Runback to Houseload” event, as an example of the ACC algorithms [1].

Table 1: List of ACC Transients

Category	Transient Name
Normal Event	Daily Load Follow Operation
	Turbine Power Ramp Changes
	Loss of MFWPs without Reactor Trip
	Turbine Load Rejection of up to 50% Power
	Turbine Generator Runback to House Load
	Reactor Trip
	Turbine Trip
	Opening or Closure of EFWCV
	Shift from Normal to Maximum CVCS flowrate
	Low-Low VCT Level and Charging Pump Diversion to BAST
	Spurious Actuation of Pressurizer Spray
	Spurious Actuation of Pressurizer Heaters
	Inadvertent Closure of One EFWCV or DFWCV
	Inadvertent Opening of One EFWCV or DFWCV
	Inadvertent Isolation of One Main Feedwater Heater
Upset Event	Startup and Coastdown of a RCP at HSB
	Startup and Shutdown of SCS at HSD
	Spurious Actuation of Pressurizer Heaters at HSB
	Decrease in Feedwater Temperature
	Increase in Feedwater Flowrate
	Increase in Steam Flowrate
	Inadvertent Opening of MSSV
	Loss of External Load
	MSIV Closure
	Loss of Normal Feedwater Flow

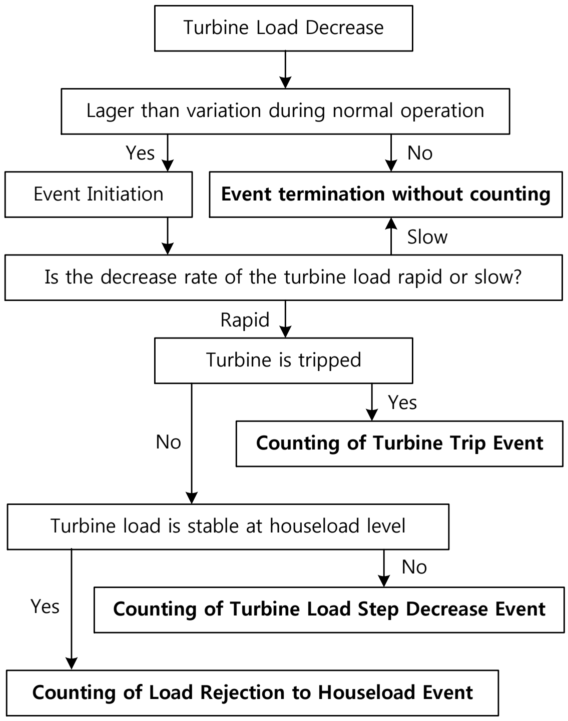

Fig. 1. ACC Algorithm for Turbine Generator Runback to Houseload Event

The ACC algorithms were originally developed with the transient data generated from the simulation since the actual plant data of APR1400 were not available at the development stage. After the successful completion of the PAT of SKN3, the performance of the ACCS has been evaluated using the operational transient data of the PAT (defined as the PAT data) of SKN3.

2. Description of the PAT

A series of the tests during the PAT has been conducted to bring the reactor from zero to full power. The major tests during the PAT are performed at plateaus of approximately 20, 50, 80, and l00% power to demonstrate that the facility operates in accordance with its design during steady-state conditions and, to the extent practicable, during anticipated transients. A list of the major tests during the PAT and their initial power level of SKN3 is provided in Table 2.

Table 2: List of the Major Tests during the PAT of SKN3

Test Name	Power
Control System Checkout Test	18% 20% 50% 80% 100%
FWCS Valve Transfer Test	18%
Shutdown from Outside Control Room Test	20%
ADV & TBV Capacity Test	20%
Load Rejection Test (with RPCS)	50% 80% 100%
Loss of a MFWP Test	60% 100%
Unit Load Transient Test	50% 100%
Loss of two out of three MFWPs Test	80%
100-50-100% Power Load Cycle Test	100%
Turbine Trip without RPCS and NCC Test	100%
LOOP Test	15%
Plant Acceptance Test (NSSS)	100%

3. Expected Results of Evaluation

Table 3 shows the summarized list of expected PAT that should be identified as the ACC transient by the algorithms.

Table 3: PAT List Identified as ACC Transient

<table>
<tr><th>PAT</th><th>ACC Transient</th></tr>
<tr><td>FWCS Valve Transfer Test</td><td>Opening or Closure of EFWCV</td></tr>
<tr><td>Shutdown from Outside Control Room Test</td><td rowspan="3">Reactor Trip</td></tr>
<tr><td>LOOP Test</td></tr>
<tr><td rowspan="2">Turbine Trip without RPCS and NCC Test</td></tr>
<tr><td>Startup and Coastdown of a RCP at HSB</td></tr>
<tr><td>Load Rejection Test (with RPCS)</td><td>Turbine Generator Runback to House Load</td></tr>
<tr><td>Loss of a MFWP Test at 60% Power</td><td rowspan="2">Loss of MFWPs without Reactor Trip</td></tr>
<tr><td>Loss of two MFWPs Test</td></tr>
<tr><td>Unit Load Transient Test</td><td>±5%/min Turbine Power Ramp Change</td></tr>
<tr><td>Power Load Cycle Test</td><td>Daily Load Follow Operation</td></tr>
</table>

3.1 FWCS Valve Transfer Test

This test is performed to verify automatic transfer between the DFWCV and the EFWCV by the FWCS. During the test, the reactor power is manually maneuvered from 18% to 21% and vice versa. When the reactor power increases above 20%, the EFWCV is opened and the DFWCV partially closes its position. When the reactor power decreases to approximately 18%, the EFWCV is fully closed and the DFWCV begins controlled to appropriately provide feedwater to steam generators. Therefore, this test should be identified as a “Opening or Closure of EFWCV” event.

3.2 Shutdown from Outside Control Room Test

This test is performed to verify the capability of manual reactor shutdown at the outside of the MCR. Since this reactor shutdown is uncomplicated, this test should be identified as a “Reactor Trip” event.

3.3 LOOP Test

This test is performed to verify the capability of manual reactor shutdown and maintaining the plant at the HSB condition following a simulated loss of turbine generator and offsite power. Since this reactor trip is uncomplicated shutdown, this test should be identified as a “Reactor Trip” event.

3.4 Turbine Trip without RPCS and NCC Test

This test consists of Turbine Trip without RPCS followed by NCC test.

Turbine Trip without the RPCS test is performed to verify the capability of automatic reactor shutdown initiated by a turbine trip with the RPCS out of service. Although there is a specific algorithm for “Turbine Trip” event in the ACCS, this test should be identified as a “Reactor Trip” event because “Turbine Trip” event does not cause the reactor trip during normal operation due to the RPC actuation.

NCC test is performed to verify the capability of maintaining the plant at the HSB condition without forced cooldown by the RCPs. Since all RCPs are turned off to establish the NCC condition, this test should be identified as a “Startup and Coastdown of a RCP at HSB” event.

3.5 Load Rejection Test

This test is performed three times at 50%, 80% and 100% power to verify that loss of load by manual opening of the switchyard PCB does not cause reactor shutdown and opening of safety valves, and the plant can be normally operated at houseload by operation of the NSSS control systems. When the switchyard PCB is manually opened, the turbine load rapidly decreases to houseload and the plant is controlled for houseload operation. Therefore, this test should be identified as a "Turbine Generator Runback to House Load" event.

3.6 Loss of a MFWP Test

This test is performed twice at 60% and 100% power to verify that trip of a MFWP during normal operation does not cause reactor shutdown and opening of safety valves, and the plant can be stabilized by operation of the NSSS control systems.

In SKN3 design, there are three MFWPs, each with a 55% of rated capacity. Normally, three MFWPs are in operation above 70% reactor power and two MFWPs above 35% reactor power to provide feedwater to steam generators.

Therefore, if one of three operating MFWPs is tripped, it does not cause any transient because two MFWPs can provide 100% of feedwater flow. However, if one MFWP is tripped when two MFWPs are operating above 55% reactor power, it causes a rapid decrease of the turbine load and can be considered as the transient condition. Therefore, this test at 60% power should be identified as a "Loss of MFWPs without Reactor Trip" event, but not the test at 100% power.

3.7 Loss of two MFWPs Test

This test is performed to verify that trip of two MFWPs when all MFWPs are in operation does not cause reactor shutdown and opening of safety valves, and the plant can be stabilized by operation of the NSSS control systems. This test causes actuation of the RPCS and should be considered as the transient condition. Therefore, this test should be identified as a "Loss of MFWPs without Reactor Trip" event.

3.8 Unit Load Transient Test

This test is performed twice at 50% and 100% power. This test consists of Turbine Load Step Change, and Turbine Load Ramp Change.

Turbine Load Step Change is performed to verify that the reactor power can be regulated by the RRS when the turbine load is rapidly changed by 10% and the plant can be stabilized by operation of the NSSS control systems. Since such a postulated load maneuver is not expected to occur during normal operation, this test is not identified by the ACCS. If it is necessary to identify this test as a transient, it can be manually counted on the FMS.

Turbine Load Ramp Change is performed to verify that the reactor power can be regulated by the RRS when the turbine load is linearly changed by 15% with rate of 5% per minute, and the plant can be stabilized by operation of the NSSS control systems. Therefore, this test should be identified as a "±5%/min Turbine Power Ramp Change" event.

3.9 Power Load Cycle Test

This test is performed to verify that the plant can be stabilized by operation of the NSSS control systems while the load follow operation. For the test, the reactor power is changed from 100% to 50% in a two-hour period, and vice versa. Therefore, this test should be identified as a "Daily Load Follow Operation" event.

3.10 Other Tests

Other tests not listed in Table 3 are not expected to cause any considerable transient. Therefore, these tests are not identified by the ACCS. If it is necessary to identify these tests as a transient, these can be manually counted in the FMS.

4. Result of Evaluation

The additional evaluation of the performance of the ACC algorithms using the actual plant data has been performed when the PAT of SKN3 was successfully finished.

However, in the preliminary evaluation, there was unexpected over-counting of the ACC transients. For example, "Reactor Trip" event was counted 22 times during the PAT. This number is much more than the expected number of occurrence, i.e. 3 times. These over-counting of the ACC transients can act as a factor giving effects on the accumulated usage factor of plant components.

It has been found from the root cause evaluation that the major cause of the over-counting was caused by unexpected operating conditions, such as maintenance and operation tests performed for individual instruments and components, which lead to abnormal behavior of the key operating parameters during the temporary overhaul period. Therefore, the ACC algorithms were modified to prevent over-counting and incorporate every operational data even during overhaul period.

As a result of upgrade, the ACCS has been able to appropriately identify the occurrence of transients as much as expected, and the reliability of the ACC algorithms has been significantly enhanced. The final results of additional evaluation using the PAT data of SKN3 by the ACCS are shown in Table 4.

Table 4: Result of Evaluation using the SKN3 PAT data

ACC Transient	Number of Occurrence
Opening or Closure of EFWCV	1
Reactor Trip	3
Startup and Coastdown of a	1 for each RCP

RCP at HSB	
Turbine Generator Runback to House Load	3
Loss of MFWPs without Reactor Trip	2
±5%/min Turbine Power Ramp Change	2 for Ramp Down 2 for Ramp Up
Daily Load Follow Operation	1 for Ramp Down 1 for Ramp Up

As shown in Table 4, “Opening or Closure of EFWCV” event was counted once. This event was identified from “FWCS Valve Transfer Test”.

“Reactor Trip” event was counted three times. This event was identified from “Shutdown from Outside Control Room Test”, “LOOP Test” and “Turbine Trip without RPCS Test”.

“Startup and Coastdown of a RCP at HSB” event was counted once for each of 4 RCPs. This event was identified from “NCC Test”.

“Turbine Generator Runback to House Load” was counted three times. This event was identified from “Load Rejection Test” at each power plateau.

“Loss of MFWPs without Reactor Trip” event was counted twice. This event was identified from “Loss of a MFWP Test” at 60% power and “Loss of two MFWPs Test”.

“±5%/min Turbine Power Ramp Change” event was counted twice for each power changing direction. This event was identified from “Unit Load Transient Test” at each power plateau.

“Daily Load Follow Operation” event was counted once for each power changing direction. This event was identified from “Power Load Cycle Test”.

5. Conclusions

The ACC algorithms for the APR1400 FMS have been developed to have capability to adequately count the occurrence of design basis transients for monitoring the integrity of the plant components during the plant life time. The evaluation of the ability of the ACC algorithms has been performed using the PAT data of SKN3.

In the preliminary evaluation, the ACC transients were over-counted due to unexpected operation condition. The ACC algorithms were modified to prevent these over-counting. Finally, the ACCS has been able to appropriately identify the occurrence of transients during the PAT of SKN3, and the reliability of the ACC algorithms has been significantly enhanced.

In conclusion, the ACC algorithms for APR1400 FMS is verified to have a sufficient capability to evaluate the actual loads on the critical components and their fatigue usages over the plant lifetime.

ACRONYMS

ACC	Automated Cycle Counting
ACCS	ACC system
ADV	Atmospheric Dump Valve
APR1400	Advanced Power Reactor 1400
BAST	Boric Acid Storage Tank
CVCS	Chemical and Volume Control System
DFWCV	Downcomer Feedwater Control Valve
EFWCV	Economizer Feedwater Control Valve
FMS	Fatigue Monitoring System
FWCS	Feedwater Control System
HSB	Hot Standby Condition
HSD	Hot Shutdown Condition
KEPCO E&C	Korea Electric Power Corporation Engineering and Construction Company, Inc.
LOOP	Loss of Offsite Power
MCR	Main Control Room
MFWP	Main Feedwater Pump
MSIV	Main Steam Isolation Valve
MSSV	Main Steam Safety Valve
NCC	Natural Circulation Cooldown
NSSS	Nuclear Steam Supply System
PAT	Power Ascension Test
PCB	Power Circuit Breaker
RCP	Reactor Coolant Pump
RPCS	Reactor Power Cutback
RPCS	RPC System
RRS	Reactor Regulating System
SCS	Shutdown Cooling System
SKN3	Shin-Kori Nuclear Power Plant Unit 3
TBV	Turbine Bypass Valve
VCT	Volume Control Tank

REFERENCES

[1] Min, Jihong, Lee, Juhan, Song, Inho, Lee, Gyucheon, Development of Automated Cycle Counting Algorithms for APR1400 Fatigue Monitoring System, Transactions of the Korean Nuclear Society Autumn Meeting, 2017.