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Development of Automated Cycle Counting Algorithms for APR1400 Fatigue Monitoring System

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1. Introduction

Effect of light water reactor environments on fatigue behavior in the reactor coolant system structural materials has been an issue for decades among nuclear industries and safety regulators, particularly for the design of long-life nuclear power plants including APR1400.

In 2007, U.S.NRC issued Regulatory Guide 1.207 for use in the design analyses of new reactors, incorporating the fatigue life reduction of pressure boundary components due to the effects of the plant environment [1].

The environmental fatigue is considered as a safety issue, and thus the highest quality standard issue for new plant design. APR1400 Fatigue Monitoring System (FMS) is being developed to evaluate actual loads and fatigue usages in critical components over the plant lifetime.

The automated cycle counting system (ACCS) is one of the APR1400 FMS main modules used to count the occurrences of design basis events for calculation of accumulated usage factor of plant components.

The purpose of this paper is to introduce the ACCS algorithms developed by KEPCO E&C, which are effective for evaluation of the integrity of APR1400 NSSS components.

2. General Description of APR1400 FMS

The APR1400 FMS consists of three modules for the following functions (Figures 1 and 2): (1) automated cycle counting, (2) cycle-based fatigue monitoring, and (3) stress-based fatigue monitoring including environmental fatigue. The APR1400 FMS does not require new plant instruments but uses the existing instruments. Each module is briefly described below.

The Data Acquisition System (DAS) acquires the plant operation data and provides input data which are used in the APR1400 FMS.

The ACCS automatically identifies each of the design basis set of transients (cycles) based on a stream of actual plant input data acquired through the DAS. The input data stream consists of existing plant signals already processed by plant computers. The ACCS recognizes every transient and records it in the database together with the key parameters that will characterize the severity of the transient.

The cycle-based fatigue (CBF) assessment module is an add-in to the ACCS module. This module evaluates fatigue usage at plant location where high fatigue usage is expected using the accumulated event database established by the ACCS module. The Environmentally Assisted Fatigue (EAF) usage monitoring for the CBF locations, as applicable, is included in the CBF assessment module.

The stress-based fatigue (SBF) assessment module uses plant instrument data to calculate stress time histories, and then uses those stress time histories to evaluate fatigue usage. This module uses a Green's Function methodology to calculate the stress time histories based on the actual plant data. This module is used for those plant components which are experiencing relatively complicated thermal hydraulic transients, and for which the simple CBF algorithms may not provide adequately refined fatigue usage estimates. An example component would be the steam generator feedwater nozzle, where transients may be severe and thus the design basis fatigue usage is high. The EAF usage monitoring for the SBF locations, as applicable, is also included in the SBF assessment module.

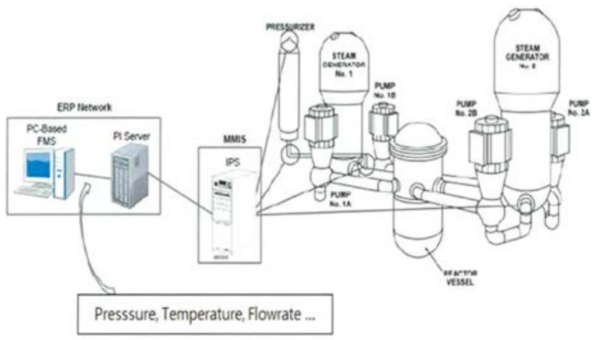

Figure 1. Concept for APR1400 FMS

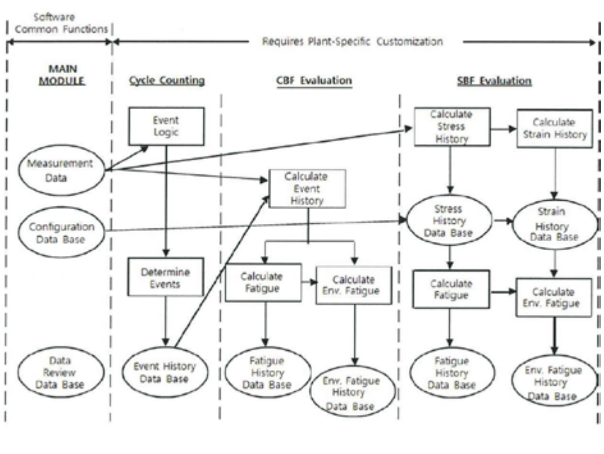

Figure 2. APR1400 FMS Flow Diagram

3. Development of ACCS Algorithms

The ACCS has algorithms to automatically count the number of occurrences for a total of 60 significant thermal-hydraulic design basis events including the major normal and upset events as summarized in Table 1.

Table 1 Major Normal and Upset events

Normal Events	Daily Load Follow Operation
	Turbine Load Step/Ramp Change
	Turbine Load Rejection
	Reactor Trip
	Turbine Trip
	Loss of Main Feedwater Pumps
Upset Event	Inadvertent Isolation Feedwater Heater
	Decrease in Feedwater Temperature
	Natural Circulation Cooldown

The algorithm for counting of occurrences of an event should be verified and validated using the existing plant operating data as well as the logic test data to screen the events which has similar responses with the event. An additional event counting could result in the fatigue usage over the design limit in certain components which experience severe transient. Thus, the development of ACC logic has focused on achieving the capability of ACCS to correctly count the intended event, avoiding additional counting of events showing similar response, through validation process using APR1400 plant operation data.

In this respect, the ACC algorithms for load rejection to houseload and decrease in feedwater temperature events are explained, for example, as follows.

1) Load Rejection to Houseload

Load rejection to houseload event occurs if the switchyard breakers are opened during normal power operation [2]. This event causes a rapid decrease in the turbine load to houseload. The ACCS monitors such change in operating conditions and starts the algorithm for counting of this event. Figure 3 shows the algorithm for the load rejection to houseload event.

The ACCS calculates the rate and amount of load change using the input data acquired by the DAS. If the calculated rate and the amount of load change are definitely large, the ACCS determines that this event has been initiated. The calculation is performed for an enough time period to determine whether this event actually occurs or not because there can be signal noises causing large variation in the data input to DAS. If these changes are determined to be an input signal noise, the ACCS determines that this event has not actually occurred.

As shown in Figure 3, the turbine trip event and the turbine load decrease event, which can show similar sequences after event initiation compared with the load rejection to houseload event, are filtered out based on the verification of the rate of load change, occurrence of turbine trip and the final load level.

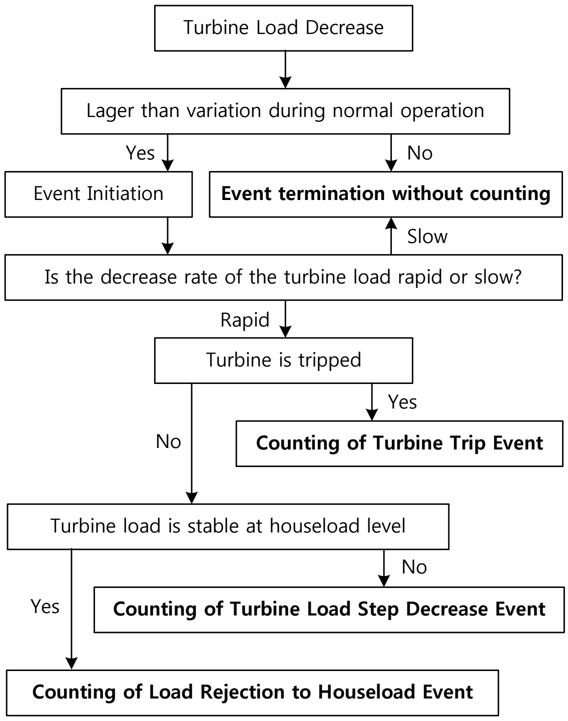

Figure 3. ACCS Algorithm for Load Rejection to Houseload Event

2) Decrease in Feedwater Temperature

Decrease in feedwater temperature event occurs if the feedwater heaters are lost due to isolation of one of two high pressure feedwater heater trains. This event causes an increase of heat transfer from primary to secondary system through steam generators, a decrease in reactor coolant temperature, an increase in reactor power due to the negative moderator temperature coefficient, and a decrease in reactor coolant system and steam generator pressures [3].

When the feedwater temperature is decreased without decrease of the turbine load, the ACCS starts the algorithm for the decrease in feedwater temperature event. Figure 4 shows the algorithm for counting of this event.

The ACCS monitors the changes in feedwater temperature, turbine load and reactor power. If the feedwater temperature is abnormally decreased but the turbine load and the reactor power are increased or not changed, the ACCS determines that this event has been initiated. When the amount of change in feedwater temperature are sufficiently larger than the normal operation condition and greater than the effect of the inadvertent isolation of one main feedwater heater event, the decrease in feedwater temperature event is counted.

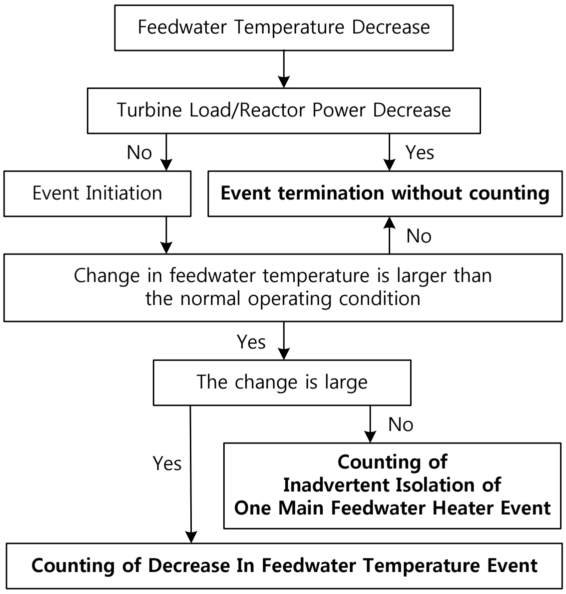

Figure 4. ACCS Algorithm for Decrease in Feedwater Temperature Event

4. Conclusions

The APR1400 FMS ACCS algorithms are being developed to effectively count the occurrence of design basis set of transients. The process of verification and validation for event counting logic using actual and virtual plant operation data will enhance the credibility of the ACCS in calculating the CBF usage of selectively monitored components of APR1400 plants.

REFERENCES

[1] Nuclear Regulatory Commission of the United States, Regulatory Guide 1.207, Guidelines for Evaluating Fatigue Analyses Incorporating The Life Reduction of Metal Components Due to The Effects of The Light-Water Reactor Environment for New Reactors, 2007.

[2] Shin-Kori Nuclear Power Plant Units 3 and 4, Final Safety Analysis Report, Revision 1, Chapter 14, Initial Test Program, 2015.

[3] Shin-Kori Nuclear Power Plant Units 3 and 4, Final Safety Analysis Report, Revision 1, Chapter 15, Accident Analyses, 2015.