Development of a Technical Specification Monitoring System Using Real-time Operating Parameters in OPR1000

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1. Introduction

Operators of all domestic nuclear power plants (NPPs) are obliged to comply with their Technical Specification (TS) in accordance with the Nuclear Safety Act. The fact that NPP in operation meets all the TS limiting conditions for operation (LCOs) means that it is within the scope of the safety analysis and consequently ensures safety. The main methods of monitoring whether the LCOs for the safe operation of NPP are violated or not are (i) monitoring the alarms related to LCOs and (ii) monitoring the site inspection results.

If single or multiple abnormal situations occur during the operation of NPP, it will adversely affect the monitoring of LCOs. In this case, operators should review whether the current condition is within the LCOs applicability and take actions to recover from the abnormal condition. These short-term tasks are big burden to operators. In addition, in order to keep the pace with the growing domestic demand for disclosure of nuclear safety information by related external agencies, operators would be psychologically pressured because they must spread the situation as quickly as possible. Recently, the penalty for operators has been strengthened for the violation of the TS, which leads to enormous stress when the operators make decisions regarding the TS.

In this study, a technical specification monitoring system (TSMS) has been developed, which continuously monitors the NPP operating status by using the plant's real-time operating parameters and alerts operators when the LCOs applicability is required. TSMS is designed to help operators to operate NPP while complying with the TS quickly and accurately. TSMS is intended for use in improved OPR1000, two-loop pressurized water reactor operated by Korea Hydro & Nuclear Power (KHNP) [1].

2. TSMS Development Environment

The PI System [2] introduced in domestic NPPs is used in order to monitor the TS LCOs by using real-time operating parameters in NPP. The PI System is real-time data management solution developed by OSISoft in the U.S and is being used by many NPPs around the world, including Exelon in the U.S. It consists of PI System Connections, PI Server and PI System Tools:

(a) PI System Connections retrieve various types of local data in the plant (temperature, pressure, machine operation status and alarm status, etc.) and transform them into a form suitable for storage in the PI Server.
(b) The PI Server stores the data from PI System Connections in the form of PI Tag and distributes it to PI System Tools by user requirements.
(c) The PI System Tools receive data from PI Server and visualize them in the format of user tastes. PI ProcessBook, an application program among them can create graphical displays and express parameter change in real-time. It also supports a programming language (Microsoft Visual Basic: VB), so users can write programs that suit user's intentions.

The TSMS has been developed by using PI ProcessBook's real-time operating parameters access and writing functions abilities.

3. Design of TSMS

TSMS is a collection of display windows developed by using PI Processbook. It monitors the TS LCOs in real-time and provides the LCO applicability results in graphical forms easy to understand to users. It consists of a general LCOs monitor window including functions to monitor all LCOs, and individual LCO monitor windows including function for monitoring each LCO's conditions satisfaction.

For reference, there is an example of providing important information to operators on one screen by using PI ProcessBook's real-time parameters access function. NPP operators can see the plant information at a glance with only this screen. [3]

3.1. System Design Principles

The NPP operates in one of the operation MODEs (MODE 1 ~ MODE 6) defined by the combination of core reactivity condition, power level, average reactor coolant system (RCS) temperature, and reactor vessel head closure bolt tensioning with fuel in the reactor vessel. TS LCOs to be satisfied in each MODE are different. Considering this, the following system design principles were established.

(a) Since NPP is operated in critical core state in operation MODE 1(Power Operation) and MODE 2(Startup), stricter LCOs are required in these MODEs. TSMS developed in this study can be used in operation MODE 1 and 2.
(b) In addition, when designing a TSMS, conservative LCOs determination concept is applied. If LCOs require the minimum/maximum

value of specific operating parameters, and they are measured in various ways in accordance with the design principle of OPR1000, then LCOs are determined using the lowest/highest parameter value. It is also designed to determine in a conservative way even for the additional NOTE specified separately in some kinds of LCOs.

(c) The LCOs relevant alarm occurrences in the Main Control Room (MCR) in NPP is deemed to be their function inoperable if LCOs require the function operable and do not specify a specific parameter for their satisfaction.

(d) General LCOs and individual LCO monitor windows will not be provided, in case real-time operating parameters are not available, LCOs entry case is dominantly low and quick LCOs check is not required.

3.2. LCOs Monitoring Windows Configuration

LCO monitoring windows consist of a general LCO monitoring window and 54 selected LCO monitoring windows in accordance with design principles. Its functional diagram is shown in Fig 1.

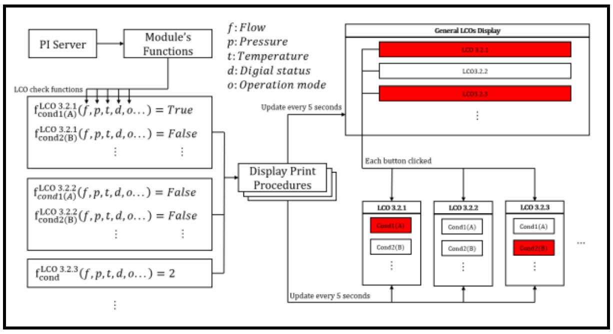


Fig. 1. LCOs monitoring windows functional diagram

Each LCO monitoring window has a display screen which is shown to users. An LCO check function and display print procedure which is invisible to users but is continuously executed are included. There is also a module, which is a set of commonly used functions, including the MODE decision function.

The display screen of each LCO monitoring window shows the contents of LCO and change the color of set texts (e.g. [CONDITON 1], [CONDITION 2] …) by receiving the result of LCO check function. The LCO check function is written separately because each LCO is different. If each CONDITION can occur at the same time in some LCO, there are functions to check their CONDITION respectively, and the output is True (Violation) or False (Satisfied). If each CONDITION cannot occur at the same time, the output of its check function is either 0 (Satisfied) or violated CONDITION number (1, 2, 3…).

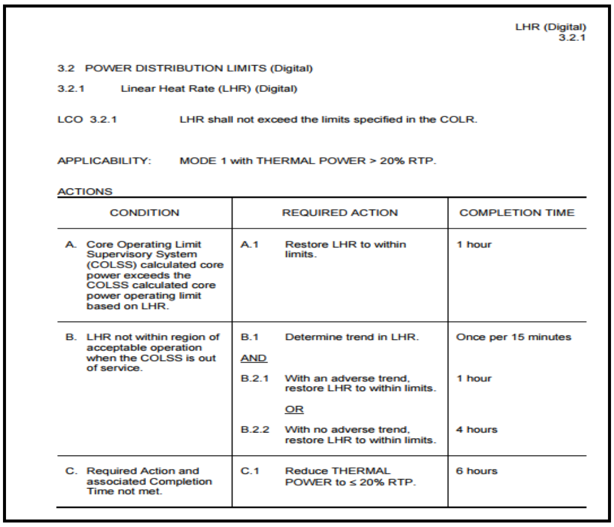
The display print procedure uses the Display_DateUpdate event built in PI ProcessBook to execute LCO check functions and to change the color of set texts (CONDITION status) in the display according to the result of them every 5 seconds.

The module includes functions for converting a PI Tag assigned to each real-time operating parameter into a variable type suitable for VB programming, function for calculating the maximum, minimum and average value of operating parameters, and time calculation and reset functions. TSMS refers to PI SDK 1.3 Library provided by OSISoft for writing above functions. The MODE decision function distinguishes MODE 1, 2, 3, 4 and 5 by returning a number from 0.5 to 5 using NPP representative power and RCS temperatures. It returns value 0.5+0.001*PP in MODE 1 to assign each value into specific power level.

On the display screen of the general LCOs monitoring window, there are command buttons to enter each LCO monitoring window. It also includes a display print procedure that changes the color around each button from blue to red if LCO is violated to alert users. All LCO can be monitored through it because it includes all LCO check functions and module.

4. Implementation of TSMS

In this paper, improved OPR1000 TS is not disclosed so TSMS implementation methods are described by using Combustion Engineering (CE) Plants TS [4] which is reference models of improved OPR1000. (Fig. 2)



LHR (Digital)
3.2.1

3.2 POWER DISTRIBUTION LIMITS (Digital)

3.2.1 Linear Heat Rate (LHR) (Digital)

LCO 3.2.1 LHR shall not exceed the limits specified in the COLR.

APPLICABILITY: MODE 1 with THERMAL POWER > 20% RTP.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Core Operating Limit Supervisory System (COLSS) calculated core power exceeds the COLSS calculated core power operating limit based on LHR.	A.1 Restore LHR to within limits.	1 hour
B. LHR not within region of acceptable operation when the COLSS is out of service.	B.1 Determine trend in LHR. AND B.2.1 With an adverse trend, restore LHR to within limits. OR B.2.2 With no adverse trend, restore LHR to within limits.	Once per 15 minutes 1 hour 4 hours
C. Required Action and associated Completion Time not met.	C.1 Reduce THERMAL POWER to ≤ 20% RTP.	6 hours

Fig. 2. Combustion Engineering TS, LCO 3.2.1 Linear Heat Rate (LHR) (Digital)

4.1. Selection of Operating Parameters related to LCOs

LCO consists of single or multiple CONDITION [1(A), 2(B), 3(C)…] in OPR1000 and CE plants respectively. CE plants way is used in this paper. Operating parameters that used in each CONDITION are provided in two forms: digital values and real values.

The parameters necessary to Linear Heat Rate (LHR) LCO shown in Fig 2. are current LHR value, Core Operating Limits Report (COLR) value designated in the TS, MODE, thermal power, core power calculated in Core Operating Limit Supervisory System (COLSS), core power operating limit based on LHR, availability of COLSS and the time when each CONDITION occurs.

First, NPP enters CONDITION A if the core power calculated in COLSS exceeds the core power operating limit based on LHR in MODE 1 where the thermal power is over 20%. It is provided in the form of digital value whether the core power calculated in COLSS exceeds the core power operating limit based on LHR. Eventually, CONDITION A can be checked by MODE decision function return value and the provided digital data.

Second, NPP enters CONDITION B if the COLSS is not operable and current LHR exceeds the COLR value in MODE 1 where thermal power is over 20%. The availability of COLSS is determined by its related alarm status in the MCR and LHR value is conservatively selected among the multiple LHR values. CONDITION B can be checked by MODE decision function return value, the two values above and COLR value.

Finally, CONDITION C can be checked by MODE decision function return value, CONDITION A or B occurrence time and COMPLETION TIME designated in TS.

4.2. LCOs Check Algorithms and Code Writing

CONDITION A check algorithm is defined following ways. If MODE decision function returns over 0.52 and less then 1 where thermal power is over 20% in MODE 1, the following measures are taken. It returns True value and saves the occurrence time if the digital value of core power is in CONDITION A or false value otherwise.

CONDITION B check algorithm is defined following ways. If MODE decision function returns the same value in case of CONDITION A, following measures are taken. It returns True value and saves the occurrence time if the maximum value of multiple LHRs exceeds COLR value or False value otherwise.

CONDITION C check algorithm is defined following ways. If MODE decision return value is met, following measures are taken. It returns True value when current time minus each occurrence time of CONDITION A or B exceeds COMPLETION TIME, or False value otherwise.

When the above algorithms are configured, the display screen for printing results is created in PI ProcessBook. LCO check functions and display print procedure are also written using the VB language in the Visual Basic Editor included in PI ProcessBook.

When all LCO check functions are written completely, general LCOs monitoring window (Fig 3.) is designed to make it easy for users to know whether the NPP is in LCOs or not.

In the general LCO monitoring window, user can check each LCO through the color around each LCO command button. (Blue: Satisfied / Red: Violated). When users click each button, more detailed LCO information (CONDITION A, B, C…) are shown.

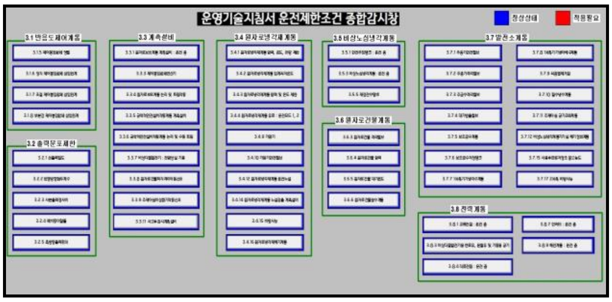


Fig. 3. General LCOs monitoring window

5. TSMS Validation and Limitations

In order to verify whether the TSMS was implemented in accordance with the design principles, the operation of the TSMS was verified by simulating each LCO. In addition, it was checked by 20 LCO histories with its operating parameters, which is recently occurred in OPR1000. [5] TSMS showed the same or conservative result as actual cases except for the cases where the LCO applications are performed manually by operator and in requirements described in TS.

TSMS checks all LCOs every 5 seconds. It can check all TS LCOs on its list successfully based on current operating parameters even when operators are busy dealing with abnormal conditions. TSMS helps operators not only make decisions related to TS but also recognize LCOs that occur between the periodic test cycle.

TSMS should be used for reference in case of emergency because it does not deal with some LCOs requiring operating parameters that are not managed through PI Server. However, it reduces the operator's TS decision time, which leads improvements operation ability in abnormal conditions if TSMS LCO check functions gain regulator's trust and its results lead directly to the LCO applications.

6. Conclusions

NPP operators are in harsh environment where they have a lot of work and have to meet the goal of improving NPP reliability. One of the most stressful tasks for them is decision related to TS. Especially in the event of abnormal conditions, heavy duty is given in a short time, so the operator's decision on TS may not be accurate and its time may be relative slow. This study proposed a method of continuously reviewing TS in real-time using a computer program, PI ProcessBook in PI System.

All domestic NPPs adopted OSISoft PI System to observe changes in operating parameters, analyze events, and discover improvements. This study developed TSMS to determine the LCOs and to inform users by using the real-time operating parameter access function and the program writing function suitable for the user's intention, provided by the PI System. TSMS includes display screens showing LCOs check results graphically, functions for checking each LCO, display print procedures and a module which is set of functions for real-time operating parameters utilization. It also contains general LCO monitoring window to inform users All LCOs status.

TSMS was verified by simulating with virtual values and by 20 LCO histories with its operating parameters in OPR1000. It showed same or conservative results except additional LCO made by operator's decision. However, TSMS should be used for reference because it cannot collect all operating parameters related to LCO through PI System. In addition, the LCO histories for TSMS verification are concentrated in some LCOs, so it is necessary to continuously update TSMS by utilizing latest operation experience. As it is a program for the operators, it is recommended to reflect the needs of operators in the future. If more advanced computer programming skill is added, improved system stability is obtained by simplification of codes and increased available computer resources.

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