Study on the Development of I&C Equipment Performance Monitoring Program for Nuclear Power Plants

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Abstract. The equipment performance monitoring program is designed to provide guidance for monitoring the performance of equipment, with an aim to enable engineers to identify hidden hazards as early as possible and take corresponding corrective actions to achieve the purpose of equipment reliability management of nuclear power plant. The nuclear power plant realizes monitoring, control and protection of the whole plant through I&C equipment, by which to ensure the safe, reliable and economic operation of the nuclear power plant. In this paper, a set of performance monitoring program process special for I&C equipment of nuclear power plant is developed. And the RGL system (rod control system and rod position system) of a nuclear power plant is taken as an example to illustrate, analyze and summarize, which lays a foundation for nuclear power plant to carry out equipment reliability management.

1. Introduction

The concept of system equipment performance monitoring originates from the Equipment Reliability Process Description AP-913 issued by the USA Institute of Nuclear Power Operations (INPO), as illustrated in Figure 1. The equipment reliability process represents the integration and coordination of a broad range of equipment reliability activities into one process for plant personnel to evaluate important station equipment, develop and implement long-term equipment health plans, monitor equipment performance and condition, and make continuing adjustments to preventive maintenance tasks and frequencies based on equipment operating experience. Among them, equipment performance monitoring belongs to the performance monitoring module, which plays a crucial role in equipment reliability management. According to the latest research, the actual failure curve of equipment is not a single "bathtub curve", 89% of the equipment failures are time independent. Therefore, it is impossible to avoid the equipment failure only by regularly maintenance. Instead, the equipment and its associated parameters should be scientifically monitored, establish a database, then based on the operation status of the equipment, track and analyze its change trend to make maintenance decision.
The equipment performance monitoring program is designed to provide guidance for monitoring the equipment performance. At present, no unified development process has been established for domestic nuclear power plants using the equipment performance monitoring program. Therefore, the study on the development of a equipment performance monitoring program is of great guiding significance for the implementation of equipment performance monitoring.

2. Development of Equipment Performance Monitoring Program

2.1 Performance monitoring scope of I&C equipment.

Equipment performance monitoring refers to the tracking and evaluation of the operating status of the equipment, so as to prevent the potential function failure of the equipment and ensure the reliability of the equipment. The deterioration of equipment operating status is a process of gradual development. On the premise that the relationship between equipment operating parameters and equipment operating status is known, the potential function failure of equipment can be prevented through evaluating these parameters and their changing trend.

The nuclear power plant realizes monitoring, control and protection of the whole plant through I&C equipment, by which to ensure the safe, reliable and economic operation of the nuclear power plant. However, there is a large number of I&C equipment, and if all of them are monitored, it will consume a lot of manpower and resources, thus resulting in an increase in cost. Therefore, some of them should be selected for performance monitoring. Single Point Vulnerability (SPV) are a subset of critical equipment and should include as a minimum those equipment whose failure will directly result in a reactor or turbine trip/scram (SPV equipment refers to the equipment whose single failure can lead to shut down, trip and significant power drop). The performance monitoring of SPV equipment can help to identify the hidden hazards of equipment as early as possible, improve the reliability of equipment, and thus to ensure the safe and stable operation of the nuclear power plant.
Generally, the I&C equipment receiving performance monitoring includes: power supply, recorder, controller, transmitter, etc. When the equipment is of complex structure, it is necessary to monitor its auxiliary equipment.

2.2 Development process of equipment performance monitoring program.
Before the equipment performance monitoring, the equipment engineer responsible for the technical management of the equipment shall be appointed to prepare the equipment performance monitoring program. Based on the collected data, the equipment engineer first divides important parameters of the equipment into key parameters and non-key parameters, then conducts a comprehensive analysis of the trend of the parameters, evaluates the reliability and availability of the equipment in combination with the actual operating status of the equipment, and verifies the effectiveness and applicability of the equipment performance monitoring program at the same time.

The content of the equipment performance monitoring program should vary according to the category of systems to which the equipment belongs. For the SPV equipment of the I&C system, the performance monitoring program should cover: scope of equipment, basis/reference documents, monitored parameters and evaluation criteria of equipment status of performance monitoring. The process is shown in Figure 2.

![Figure 2. Development Flow Chart of Equipment Performance Monitoring Program.](image)

2.2.1 Determination of equipment performance monitoring parameters.
The existing equipment monitoring parameters are determined through looking up the historical data of equipment. The historical data of equipment include system manual, alarm procedures, setting value manual, maintenance procedures, test procedures, system engineer inspection, PI system data trend, operator inspection and other performance data sources.

2.2.2 Determination of types of performance monitoring parameters.
The equipment performance monitoring parameters are classified into quantitative parameters and qualitative parameters.

(1) Quantitative parameter
Quantitative parameters refer to those that have been monitored and recorded with numerical physical and chemical quantities by the nuclear power plant, such as temperature, pressure and flow, which can be filled in as direct parameters. If a performance parameter belongs to direct parameter, it needs to determine the data source, the normal value and the alarm value of it, and judge whether it belongs to key parameter. According to the parameter source, direct parameters are classified into
online monitoring parameters, standby monitoring points, in situ measurement parameters, offline monitoring parameters, other system-related parameters and equipment status judgment parameters, which should be filled in different forms of the program. The filling template of quantitative parameters is shown in Table 1 below. It is generally applicable to key equipment with multiple quantitative parameters with single equipment as the monitoring object. In case of unknown information, it can be indicated with "NA".

Table 1. Template for Quantitative Parameter Table.

| S/N | Parameter Name | Source (AI NO., etc.) | PI System ID No. | Normal Value | Setting Value Manual or Master Control | Alarm Value | Key Parameters | Corresponding Monitoring Equipment Code |
|-----|----------------|----------------------|------------------|--------------|----------------------------------------|-------------|----------------|-----------------------------------------|

Source (AI No., etc.) includes address number of PI system, name and address number of other systems, or indicates manual entry.

The alarm value can be set directly according to the alarm value stipulated in the master control room of the nuclear power plant or in the setting value manual, or it can be set to alarm earlier. And secondary alarm should be set, such as low alarm (L), low-low alarm (LL), high alarm (H) and high-high alarm (HH).

The early warning value should be set based on the trend chart of PI system monitoring parameters and the engineering experience, and it is determined in accordance with the early warning value in equipment reliability management software. The early warning value may need to be revised several times before it can be determined, and it may also change with the change or rectification of the equipment status. The early warning value should be set earlier than the alarm value.

(2) Qualitative parameter

Qualitative parameters refer to those that are not numerically recorded by the nuclear power plant, such as equipment fault, test failure and repetitive defects, which can be filled in as indirect parameters. And qualitative parameters are mainly applicable to the equipment with large quantity and few quantitative parameters, with type of equipment as the monitoring object. If the performance parameter is indirect parameter, it only needs to fill in the criteria for evaluating the eligibility of parameters.

2.2.3 Effectiveness of equipment performance monitoring program.

After the completion of the equipment performance monitoring program, special equipment engineers shall be organized to review it, and it will take effect after it is confirmed to be qualified.

3. Development Case of I&C System Equipment Performance Monitoring Program

3.1 Introduction to RGL system equipment.

The RGL system (rod control system and rod position system) of nuclear power plant is an important system for controlling the reactor. It is designed to ensure the normal power regulation or shutdown of nuclear power plant through the holding, inserting and lifting actions of control rods, and monitor the position of each control rod cluster. The fault of equipment in the RGL system is likely to cause the actual position of the control rod deviates from the setting position, thus affecting the distribution of the reactor core power, which is extremely harmful to the safe operation of the reactor. In the RGL system, the rod position detector and the control rod drive mechanism (CRDM)
belong to SPV equipment. CRDM is used to drive the operation of the control rod cluster, and the rod position detector is used to monitor the position of the control rod.

3.2 RGL system equipment performance monitoring program.

3.2.1 Scope of equipment of performance monitoring.
The scope of performance monitoring of RGL system equipment in a pressurized water reactor power plant includes 61 rod position detectors and 61 CRDMs.

Table 2. Scope of Equipment of Performance Monitoring.

| S/N | Equipment Code | Equipment Name                  | Remarks                  |
|-----|----------------|---------------------------------|--------------------------|
| 1   | RGL001XX       | Rod position detector 01        |                          |
| 2   | RGL002XX       | Control rod drive mechanism (CRDM) 01 |                          |

3.2.2 Reporting cycle of equipment performance monitoring.
The equipment performance monitoring is reported at the interval of every cycle. The equipment performance monitoring report includes status of direct parameters of the equipment, important internal and external experience feedback, engineer's analysis & evaluation, and corrective action plan within one monitoring cycle.

3.2.3 Direct parameters and criteria.

Table 3. Online Monitoring Parameters - From PI System.

| S/N | Parameter Name | Source (AI NO., etc.) | PI System ID No. | Normal Value | Setting Value Manual or Master Control Alarm | Early Warning Value | Alarm Value | Key Parameters | Corresponding Monitoring Equipment Code |
|-----|----------------|-----------------------|------------------|--------------|---------------------------------------------|---------------------|-------------|----------------|-----------------------------------------|
| 1   | Steps of control rod N | RGL001XX |               | 0-232 step | NA                                         | NA                  | NA          | N              | RGL001XX                                |

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Table 4. Online Monitoring Parameters - From KIC System.

| S/N | Parameter Name | Source (AI NO., etc.) | Tag No. | Normal Value | Setting Value Manual or Master Control Alarm | Early Warning Value | Alarm Value | Key Parameters | Corresponding Monitoring Equipment Code |
|-----|----------------|-----------------------|---------|--------------|---------------------------------------------|---------------------|-------------|----------------|-----------------------------------------|
| 1   | PWE            | NA                    | RPN0    | 0            | NA                                         | NA                  | NA          | 1              | RGL001XX                                |
operating fault
One rod cluster is not at the bottom after reactor shutdown

|   | Parameter Name | Source (AI NO., etc.) | Normal Value | Setting Value Manual or Master Control | Early Warning Value | Alarm Value | Key Parameter | Corresponding Monitoring Equipment Code |
|---|----------------|-----------------------|--------------|-----------------------------------------|--------------------|-------------|---------------|------------------------------------------|
| 1 | Insulation value of rod position detector coil | NA | >100MΩ | NA | ≤100MΩ | Y | RGL001XX |
| 2 | Coil resistance increased by CRDM yoke coil | NA | 1.36±0.08 Ω | NA | >1.44Ω or <1.28Ω | Y | RGL002XX |

Table 5. Offline Monitoring Parameters.

3.2.4 Evaluation criteria.
1. When the key parameters exceed the alarm value, the health color is evaluated as red;
2. When more than 3 non-key parameters exceed the alarm value, the health color is evaluated as yellow;
3. When more than 1 non-key parameter exceeds the alarm value, the health color is evaluated as white;

After comprehensive judgment, the engineer can give an appropriate health color.

4. Conclusion
In this paper, a set of performance monitoring program process for I&C equipment of nuclear power plant is developed. By making full use of the performance monitoring and monitoring standards in AP-913, it plays a guiding role in the development of other equipment performance monitoring programs for the nuclear power plant, and lays a foundation for the nuclear power plant to use the equipment performance monitoring data to optimize the preventive maintenance project of the system equipment later and to carry out equipment reliability management.
Reference

[1] USA INPO AP913 Equipment Reliability Process Description. Revision 6. B USA: 2018.10.
[2] Yingrui G, Chengbin R, Jindong Y and Deleng Z 2018 Based on the performance monitoring method of nuclear power plant equipment application system J. China Academic Journal Electronic Publishing House. C 68–71
[3] 1992 Methodology for the Management of Nuclear Power Plant Equipment Important to Safety IAEA Technical Reports Series No. 338
[4] Ligang G, Zhongjun W and Zhonghua D 2006 Daya Bay Nuclear Power Station equipment reliability management system innovation J. Chinese Journal of Nuclear Science and Engineering 26(2) 156–64
[5] Xiaojing S 2011 Thermal System Equipment Performance Monitoring of Power Plant and Application Research D
[6] Wen Z, Yu-hui Y 2003 Design of Rod Control and Rod Position System in Qinshan Phase II NPP Project. J. Nuclear Power Engineering. 24(2) 146–9
[7] Wenyue L, Xiaoming L, Qinghao H 2005 Exploration & Practice of Reliability Management System for Nuclear Power Station Equipment. J. Nuclear Power Engineering 26(6)