Brief Discussion on Evaluation & Demonstration of Operating Reliability of Safety-level I&C System Equipment in Nuclear Power Plant

Guixia Zhu, Yugang Qian, Jian Lan, Diliang Li, Tianmi Zhou and Yuying Hu
Research Institute of Nuclear Power Operation, Wuhan, Hubei, China
E-mail: zhugx@cnnp.com.cn

Abstract. Safety-level system equipment is essential for the nuclear power plant either to complete the reactor emergency shutdown, containment isolation, reactor core cooling and heat emission from containment and reactor, either to prevent large amounts of radioactive substances from being released into the environment, and is also the focus of system equipment reliability management. As the safety-level system equipment has seismic requirements, in this paper, the operating reliability of safety-level I&C system equipment is evaluated and demonstrated, and the general process of reliability evaluation & demonstration is worked out.

1. Introduction
In order to ensure the subsequent long-term and stable operation and supervision requirements of the safety-level I&C system equipment in nuclear power plant, it is necessary to evaluate and demonstrate the reliability of long-term and stable operation of such system equipment that has reached its identified service life. According to the latest standards, there is no clear requirement for the service life appraisal of safety-level I&C system. In this paper, the safety-level I&C system equipment is studied, in which, based on the nuclear power related regulations and standards and by virtue of the nuclear system equipment reliability evaluation & demonstration technology, the theoretical basis for the continuous stable operation of the I&C system equipment is obtained.

2. Process of Reliability Evaluation & Demonstration
According to the requirements of equipment reliability management of nuclear power plant and the existing work experience, the technical solution to reliability evaluation and demonstration of the safety-level I&C system is given by studying relevant regulations of safety-level I&C system of nuclear power plant, as illustrated in Figure 1.
Figure 1 Technical Solution to Continuous Operation of Safety-level I&C System Equipment.

2.1 Match with design basis.
For the evaluation of system life, in case of any discrepancy between the design basis and the latest version of standard, the latter shall prevail.

In accordance with IEEE323-2016, no service life appraisal is required to be made for equipment installed in a mild environment without a significant aging mechanism. When the seismic qualification of equipment installed in a mild environment is carried out by test methods, pre-aging before seismic test is required only when there is a significant aging mechanism.

2.2 Search for margin.
Searching for margin may be carried out from two aspects, namely, reference value of activation energy $e$ and temperature margin.

- Activation energy $e$
  
  Search the source of activation energy $e$ value of the appraisal procedure where it is quoted, query whether there is any update and search for a margin through making a comparison with the recommended activation energy $e$ value in the industry in recent years.

- Temperature margin
  
  If the cumulative average ambient temperature of the evaluated object is less than the set temperature in the appraisal report, a margin can be obtained.
2.3 Evaluate the reliability through modeling.

Based on the existing system information, fault and maintenance data, analyze the reliability of the system equipment, predict the fault situation of the system equipment in the next three to five years, and identify the preventive maintenance strategies for the equipment. For the whole system, the equipment is replaceable, which means that the modeling strategy of repairable system can be adopted. Repairable system refers to the system that can be restored to normal operating status through maintenance or replacement after system failure. The repairable system may fail multiple times, for its failure can be corrected through maintenance activities, and then be restored to the normal operating status.

2.4 Conduct seismic qualification.

If the safety-level I&C system equipment cannot meet the criteria of "mild environment, no significant aging mechanism, and operation within the limit value" at the same time through full verification, it is necessary to conduct seismic analysis and appraisal.

In accordance with IEEE323-2016, when the seismic qualification of equipment installed in a mild environment is carried out by test methods, pre-aging before seismic test is required only when there is a significant aging mechanism. If it has been clarified that the equipment has no obvious aging mechanism, no pre-aging is required before seismic qualification. Since a seismic qualification has been done through experiment, the finite element simulation analysis can be favorable to the first seismic qualification. According to the investigation, the finite element simulation analysis method can only verify the structural integrity of the equipment during an earthquake, but cannot verify its functional integrity. As indicated in GB-13625-1992, finite element model can be employed to complete the seismic qualification, so it can be deemed as acceptable.

Qingxian Fang from Beijing Nuclear Safety Center pointed out in his article "Evaluation of Seismic Qualification of Equipment in Nuclear Power Plant" published on Nuclear Power Engineering that there are four methods for seismic qualification of equipment, namely, analysis method, test method, method combining analysis & test and experience feedback method.

Analysis method: for passive equipment, the analysis method is generally adopted. For active equipment, the analysis method can also be adopted if it can be simplified with the help of mathematical model.

Test method: this method is adopted for the first seismic qualification of active equipment and 1E electrical equipment (whose most electronic devices are active components).

Method combining analysis & test: this method must be used for some large equipment or some nonlinear problems.

Experience feedback method: from experience feedback, the seismic performance of the equipment is judged, that is, reasoning is made based on the existing seismic qualification result.

In "IAEA Safety Glossary - 2007", passive equipment is defined as: equipment that does not rely on external inputs such as triggering, mechanical operation or power sources to perform functions. Therefore, the equipment for seismic capability analysis required this time is judged to be an active one.

The equipment for seismic capability analysis has completed the first seismic qualification test when the equipment is put into operation. According to the above, the analysis method can be used for the seismic qualification after the first time. For active equipment, mathematical model can be adopted. Considering the existing information of seismic qualification equipment and the requirements for modeling and simulation test, a solution is developed, as illustrated in Figure 2.
Figure 2 Seismic Qualification Solution.

a) Identify a specific analysis object

Since three safety-related systems are composed of several devices, the analysis method is employed to appraise them as stipulated in GB-13625-1992, which does not require analysis of all equipment in the safety system. Considering workload and cost, it is recommended that a typical minimum system, namely, input, processing and output, should be selected for each system.

b) Decipher equipment schematic and identify component information

The output of this part is the input information of the simulation part of the model. The degree of deciphering relies on the complexity of the equipment. The higher level of the deciphering will lead to better simulation. Some modules hard to decipher can be processed as black boxes, which will have a certain negative impact on the subsequent model simulation part, yet they will be controllable. In the process of deciphering, it may have a destructive impact on the object.

c) Conduct modeling and simulation analysis

By using the large-scale commercial finite element analysis software (such as Ansys/Msc/Abaqus) which has widely applied in the world and has been recognized in the field of nuclear power, the transient dynamic response of the equipment under vibration and impact can be analyzed to evaluate whether the function of the equipment fails. When calculating the seismic response of the equipment, the floor response spectrum is first obtained according to the standard, and then the response spectrum is used as a condition for transient dynamic analysis based on the floor where the equipment is mounted and the cabinet.

2.5 Carry out accelerated aging test.

The significance of service life appraisal lies in that the equipment has gone through life appraisal before being put into operation and has proved to be normal in the past years. In order to prove that the equipment can run normally in the coming years, the equipment should go through service life appraisal again, which is also in line with the reliability management requirements of the equipment.

2.6 Analyze the aging sensitivity of independent components of the cabinet.

The cabinet contains clamp and other components. While considering their service life, the independent components of the cabinet should also be taken into comprehensive consideration, the types of independent components of the cabinet should be sorted out, and the aging sensitivity should be analyzed, which should be deemed as part of the continuous reliability evaluation & demonstration of the system equipment.
2.7 Optimize spare parts supply and maintenance strategy.
Organize aging, maintenance, failure and other records, evaluate the current reliability status of the system equipment, and provide suggestions on maintenance strategy.

3. Conclusion
In this paper, the process of reliability evaluation & demonstration for the safety-level I&C system which has reached its appraisal life is given. Taking the requirements of regulations and nuclear power plant equipment reliability into comprehensive consideration, this process has been successfully applied.