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Rod Control System Failure Diagnosis using Failure Analysis Methods

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1. Introduction

If a systematic analysis method is not properly applied to the failure diagnosis process, it may take a long time to resolve the failure cause depending on the maintenance worker's level of experience. While the failure analysis method used in the existing industry can be useful and be utilized effectively for diagnosing the cause of such system failures. Recently, a failure occurred in the rod control system during normal power operation at a domestic nuclear power plant. The existing failure analysis method, failure mode and effects analysis, has been applied to determine the cause, and has resolved the problem in a timely manner. After observing the failure situation at the time, the area of interest based on the measured values of the linkage of the failure condition was determined, and the failure analysis was performed on a component basis in this area of interest.

2. Review of Current Methods

Failure modes and effects analysis (FMEA) is a bottom-up approach that determines how the failure mechanisms and failure modes assumed for devices at the level of interest affect the function of higher system levels. However, FMEA is not suitable for performing analysis considering common cause failures, and cannot easily analyze comprehensive operation linked to the system, operators, and other system devices. It is difficult to analyze considering abnormal operation situations of the system and power plant that occur in non-failure situations. An additional limitation of FMEA is that it cannot analyze software problems because it assumes hardware failure [1, 4].

Fault tree analysis (FTA) is a method suitable for analyzing the effects of failures in large-scale comprehensive plants such as nuclear power plants. It uses a top-down approach that finds the cause of any result that occurs in a power plant or system [2, 4]. This analysis is a convenient method for finding factors that can cause a system failure mode because it starts from the end of the failure and approaches it to find the cause although it has limitations similar to FMEA.

HAZOP (Hazard and operability analysis) is a review method that uses guide words to identify factors that may cause problems in systems, devices, or processes. It considers a wide range of problems, including failures as well as abnormal system behavior [3]. HAZOP analysis considers all situations that deviate from design intent in a comprehensive operating situation linked to the system, operators, and other system devices and analyzes the impact from those situations. For example, even under non-fault conditions, this method also allows qualitative assessment of the system impact of the software because it allows considering certain assumed abnormal effects.

Korea Hydro and Nuclear Power Company (KHNP) is attempting to use these failure analysis methods so that make a comprehensive decision and then narrow it into actual failure causes with different ways according to the failure modes, a system level, and operating conditions of the system. In this paper, recent failure experience is included to explain diagnosing hardware failures in the control rod control system through failure mode and effects analysis.

3. Failure Diagnosis

Recently, the failure of the rod control system occurred in the control rod direct current (DC) hold switch. After the control rod partial operation test, the indicator lamp (UG lamp in Fig. 1) could not be turned off according to the normal recovery procedure after the test. The maintenance staff notified the manufacturer and the engineering support in Central Research Institute (CRI) of the malfunction, and received their review results to proceed with further inspection and repair.

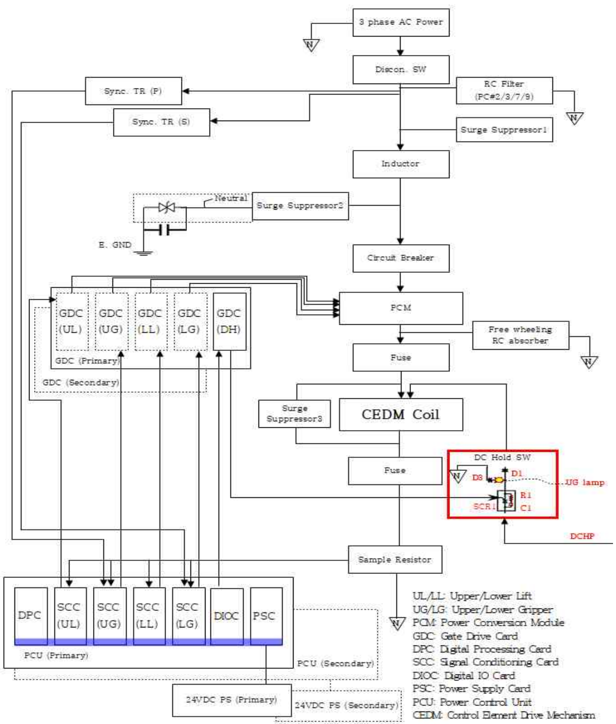

Fig. 1. Concept diagram of control rod power supply [5]

To determine the cause of the failure, a failure mode and effects analysis was performed on the internal components of the DC hold power switch assembly (see the red box in Fig. 1) where the UG lamp was remained lit at the time. The first possible cause of the UG lamp not being turned off is a short circuit in the thyristor SCR1 inside the control rod DC hold power switch assembly. Figure 1 demonstrates that the UG lamp is installed between the rear end of SCR1 and diode D3, so the lamp is lit only when SCR1 turns on. This means that low current is detected in the upper gripper (CEDM Coil in Fig. 1), the system determines its normal power loss and supplies the DC hold power (DCHP). However, with SCR1 short-circuited, it is impossible to disconnect DCHP even after normal power is recovered. In addition, during the control rod operation test, a resultant trouble alarm occurs because the DCHP is continuously supplied to the upper gripper coil regardless of its disengagement sequence for rod movement, making it impossible to conduct the test (refer to SCR1 in Table 1). This supposed failure mode was a burden for the power plant staff because the DC hold power switch assembly had to be replaced for fixing the failure during normal operation.

Table 1. Failure mode and effects analysis of DCHP

Comp.	Function	Failure Modes	How to identify failure	System Effects
SCR1	Supplying DCHP to UG during 'ON'	Open	Functional test	UG lamp is off. DCHP can't be provided.
		Short	UG Lamp, Functional test	UG lamp is lit. Rods can't be operated.
UG Lamp	Indicating DCHP in-serviced	Open	Functional test	No effects
		Short	Functional test	Possible current leakage during DCHP inservice
R1	Preventing SCR damage	Open /Short	Inspection	No effects
C1	Preventing SCR damage	Open /Short /Leak	Inspection	No effects
D1	Preventing reverse power	Open	Inspection, Functional test	Although UG lamp is lit, DCHP can't be inserviced.
		Short	Inspection	UG lamp is lit.
D3	Preventing reverse power	Open	Inspection	UG lamp is off. No effects for operation
		Short	Inspection	No effects

The second possible cause of the lamp not being turned off is a short-circuit failure of diode D1 inside the DC hold power switch assembly. FMEA of Table 1 shows that the lamp turns on and does not turn off when diode D1 is short-circuited. Figure 1 explains that the 3-phase AC power is rectified through the power conversion module (PCM) and supplied to the control rod gripper (CEDM coil) as normal power. This normal power flows back through the short-circuited D1 and is supplied to the UG lamp, allowing the lamp to light continuously. Differently from the previous case of SCR1 failure, although the UG lamp is turned on due to a short circuit in D1, control rod operability can be tested without any trouble alarm because SCR1 is open according to the disengagement sequence during the test.

Through failure mode and effects analysis, SCR1 and D1, which were presumed to be the cause of the failure, were recognized as possible causes, and the system inspection methods for the failure mode of the corresponding parts were presented to the plant staff.

After understanding review results from engineering supports of CRI, the plant staff confirmed that D1 was short-circuited at the connecting termination of the DC hold power switch assembly and the UG lamp according to the recommended inspection method. As a result, the cause of the failure was finally determined as D1 among SCR1 and D1, which were strong candidates for the cause of the failure, and the DC hold power switch assembly was replaced during planned outage.

4. Conclusions

If consistent analysis method is not applied to the fault diagnosis process, there may be large differences in inspector's identifying failure causes according to his or her level of system knowledge. When plant staff does not perform a failure analysis using this systematic method, they may not be able to consider important check points for failure diagnosis, and have difficulty in identifying failure causes because of the lack of complete understanding functional relationship among system modules and signals. For preventing this, efforts are needed to analyze the possibility of failure of each system component one by one by referring to design document or vendor drawing to the extent of the subcomponent level. In the case of rod control system failure included in this paper, according to the FMEA method, system design data and technical guidelines were used to create a system concept diagram and failure mode and effects analysis table that were applied to failure diagnosis. This failure diagnosis successfully helped plant staff to identify the cause of the system abnormal condition. In this way, several analysis methods for the existing industry can be effectively used to diagnose the causes of system failure or anomaly that occur in nuclear power plants. These methods may be utilized as one method fit for failure characteristics or a hybrid way including several methods for complex abnormal cases. KHNP hopes that this systematic approach to the failure analysis can be of great help in securing the operating capability of nuclear power plants.

References

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