Quantitative Analysis of Multiple Spurious Operation Scenarios for the Electrical Power System of Domestic Nuclear Power Plant

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1. Introduction

In the deterministic fire safety analysis of domestic nuclear power plants (NPPs), multiple spurious operations (MSOs) are analyzed using the MSO scenarios outlined in NEI 00-01[1]. Until now, fire probabilistic safety assessment (PSA) for operating domestic NPPs has been conducted using mainly the EPRI (Electrical Power Research Institute) method [2]. While the ASME/ANS (probabilistic risk assessment) standard [3] does not mention that fire PSA address MSOs or incorporate deterministic MSO analysis results into it, it does explicitly state that fire PSA should take into account fire-induced equipment spurious operations that lead to initiating events or affect the availability of mitigating systems.

According to the MSO definition in EGM 09-002 [4], a single equipment spurious operation can occur due to an MSO. A previous study [5] identified the relevant MSO scenarios from NEI 00-01 for domestic reference NPPs. Here, we focus on quantifying the MSO scenarios related to the electrical power system of domestic reference NPPs within the context of fire PSA, specifically examining the Class 1E 4.16KV system.

2. Methods and Results

2.1 Electrical Power System of Domestic Reference NPP

Fig. 1 shows the simplified diagram of Class 1E electrical power system for the domestic reference NPP. The electrical power system of the reference NPP consists of the main power (MP) system and the auxiliary power (AP) system. The MP system includes the main generator, generator circuit breaker, and main transformer, supplying power to the switchyard and the AP system, which distributes power to station electrical loads. The AP system comprises medium and low voltage components, with Class 1E (Safety) and Non-Class 1E (Non-safety) subsystems. AC AP subsystems are powered from the unit auxiliary transformers (UATs) either from the main generator when the unit is operating or from the switchyard via the main transformer when the plant is shutdown or during startup. When the normal power supply via UATs is unavailable, they are powered from the standby auxiliary transformers (SATs) from the switchyard. If the power supply from the UATs and SATs is not available, emergency diesel generators (EDGs) supply power to the Class 1E AC AP subsystems. When the station blackout occurs, one alternate AC diesel generator supplies power to the one division of Class 1E AC AP subsystems.

2.2 Quantification of the Electrical Power System MSO scenarios

Table I presents the MSO scenarios applicable to the electrical power system of domestic reference NPPs. While Scenario ID 48 has been addressed in previous fire PSAs, other MSO scenarios have not, and thus, Scenario ID 48 was excluded from our analysis. Table II outlines the modeling strategies for these MSO scenarios in the fire PSA context.

Scenario ID 46 can occur due to the overload of credited EDG. When there is a loss of power on a Class 1E bus, all loads connecting the Class 1E bus are shed and the EDG starts. Once the EDG has reached rated voltage and speed, it is connected to the bus, sequentially restoring power to the loads. The non-class 1E power associated with the Class 1E bus is not automatically restored. The circuit breaker of non-class 1E power associated with the Class 1E bus can close due to a fire. Then, the EDG can fail due to the overload more than its design capacity. This scenario is modeled for the mitigating system fault tree (FT) of the EDG.

Scenario ID 47 can occur due to the simultaneous loading of safety system pump motors when the EDG sequentially supplies power to the safety system pumps. The fire PSA model for this MSO scenario was constructed with the failure criterion that more than two load sequencers of safety system pumps including 480V Load centers are simultaneously powered from the EDG. This scenario is modeled for the mitigating system FT of the EDG.

Scenario ID 49 can occur due to spurious closure of the circuit breaker for EDG and undesired operation status of circuit breakers for UAT or SAT. This MSO scenario consists of two scenarios. One case is when the power supply from the UAT is a failure and that from the SAT is a success. The other case is when the power supply from the UAT is a success and that from the SAT is a failure. This scenario is modeled for the loss of 4.16KV A initiating event FT and for mitigating system FT of Class 1E 4.16KV bus.

Scenario ID 49.1 can be caused by the success of the power supply from the UAT or the SAT and the

spurious closure of the circuit breaker for SAT or UAT. This scenario is modeled for the loss of 4.16KV A initiating event FT and for mitigating system FT of Class 1E 4.16KV bus.

The risk quantification results show that all MSO scenarios but one scenario were estimated below 1.0E-8/yr. The current quantification results are judged to be conservative because the detailed circuit analysis was not conducted. Based on a review of the cutsets for quantification results of the scenarios, no accident scenarios were identified that resulted in the loss of both Class 1E 4.16KV trains A and B. Additionally, no offsite power loss accident scenarios were identified.

The MSO scenarios addressed in this study are not subject to deterministic MSO analysis. This is because the 4.16 KV A and B buses and EDGs at the reference plant are designed to be physically isolated. However, the fire PSA analyzes MSO scenarios that affect any equipment or system. In this study, consistent with the deterministic analysis results for MSO scenarios, no fire event was identified that would result in the loss of both 4.16 KV safety buses A and B.

3. Concluding Remarks

Quantitative analysis of the electrical power system MSO scenario revealed non-negligible risk for one scenario. Additionally, no scenario resulting in the loss of both 4.16KV safety bus trains A and B was identified, consistent with deterministic MSO analysis results. Detailed circuit analysis may yield more optimistic risk evaluation results for the scenarios analyzed in this study.

Acknowledgments

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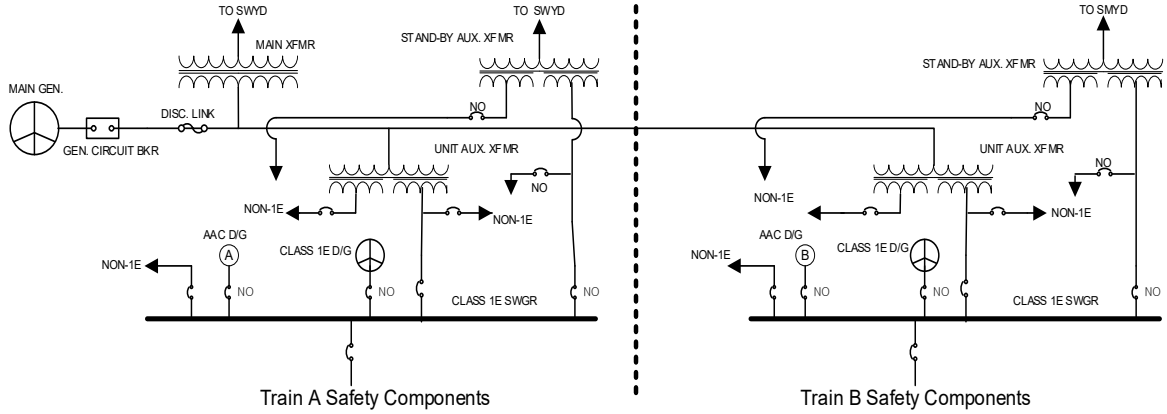

Fig. 1. Simplified diagram of Class 1E electrical power system for the domestic reference NPP.

Table I: List of MSO scenarios for the electrical power system

Scenario ID	Description	Remarks
46	Overload of credited diesel generator due to spurious operation of non-credited component breakers	
47	Overload of credited diesel generator due to simultaneous loading of credited equipment.	
48	Diesel generator spuriously starts without service water cooling	Not analyzed in this study
49	Non-synchronous paralleling of EDG with on-site and off-site sources through spurious breaker operations	
49.1	Similar to nonsynchronous paralleling-inadvertent crosstie breaker operation between opposite divisions or non-synchronous paralleling-inadvertent cross tying the offsite power sources through the on-site busses and breakers, with synchronous faults. Spurious closure on alt feeder and failure of normal to open (i.e. parallel supply) + circuit fault could result in short circuit currents above withstand /interrupt ratings.	

Table II: Modeling strategies on MSO scenarios for the electrical power system of domestic reference NPP

Scenario ID	Modeling logics	Modeling locations
46	Spurious closure of Non-class 1E circuit breaker associated with Class 1E medium SWGR bus	Mitigating system: EDG
47	Simultaneous closures of more than two breakers of safety systems connected to Class 1E medium SWGR bus	Mitigating system: EDG
49	Scenario 1: Loss of power from UAT to Class 1E medium SWGR bus* Successful operation of power from SAT to Class 1E medium SWGR bus * Spurious closure of circuit breaker for EDG Scenario 2: Successful operation of power from UAT to Class 1E medium SWGR bus * Loss of power from SAT to Class 1E medium SWGR bus * Spurious closure of circuit breaker for EDG	Initiating event LOKVA and mitigating system FTs: Class 1E medium SWGR bus A and B
49.1	Scenario 1: Successful operation of power from UAT to Class 1E medium SWGR bus * Spurious closure of circuit breaker for SAT*No Loss of Power Scenario 2: Successful operation of power from SAT to Class 1E medium SWGR bus * Spurious closure of circuit breaker for UAT*No Loss of Power	Initiating event LOKVA and mitigating system FTs: Class 1E medium SWGR bus A and B