RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**442-8550**
SRP Section:	**08.03.01 – AC Power Systems (Onsite)**
Application Section:	**8.3.1**
Date of RAI Issue:	**03/14/2016**

Question No. 08.03.01-25

This is a follow-up questionnaire to Applicant's response to RAI 8104, Question 08.03.01 – 17, on Failure Mode Effects Analysis (FMEA), for the Onsite AC Power System.

1. In the Failure Mode Effects Analysis (FMEA) table, the Unit Aux Transformer (UAT) and Standby Aux Transformer (SAT) are included but the Main Step-up Transformer (MSUT) is not listed as equipment under the "Component" column in the table. Please provide the MSU transformer failure mode and detection details, when the MSUT has internal or external fault.

2. Item No. 6 in the FMEA Table, related to UAT, indicates that the loss of one of the cooler banks does not have any immediate consequences. Can the UAT run on its self-cooled rating and still power its normal loads at full load? Would this loss of cooling cause high temperature and consequently produce any Hi-Temp alarm? What happens if one entire cooler bank of one UAT is lost?

3. Item No. 7 in the FMEA Table, related to MSUT cooling, indicates that for the "Loss of one failure of the cooler banks", the applicant indicated that there are no immediate consequences with main transformer at full load in the "Failure Effect" column. Also it is indicated in the second bullet of the "Failure Effect" that the continued transformer and unit operation is dependent upon its rated capacities with and without cooling. Please explain how the MSUT will function at its full load with its loss of cooler bank(s). Please clarify if there is a margin in the cooling system, and whether the MSUT can run at full load at its self-cooled rating.

4. Items 15 and 16 in the FMEA Table, indicates Undervoltage Alarm OR Breaker Inoperable Alarm as "Detection." Please explain what the Breaker Inoperable Alarm means.

5. The power cables from UAT and SAT to respective 4.16 kV Class 1E Switchgear are not found listed as a component for FMEA. Please provide the interconnecting cable FMEA.

6. Please include the FMEA Tables in the DCD.

Response

Below shown are answers to each of the staff's requests.

1. The failure modes and effects analysis (FMEA) for the main transformer (MT) is provided in the attached FMEA table for the offsite power system and the onsite ac power system.

2. The cooling equipment of the unit auxiliary transformer (UAT) is divided into multiple (e.g., two or three) independent cooler groups. With any one cooler group out of operation, the UAT is designed to be able to carry full load (ONAF at 55 °C base rating) which envelopes normal and abnormal loadings without exceeding 65 °C temperature rise.

   If there are no available cooler groups, the UAT has only the ONAN rating (e.g., self-cooled rating) which envelops normal operating loads without exceeding 65 °C temperature rise.

   In case of plant abnormal loading conditions, such as a unit trip coincident with LOCA, startup, etc., the entire loss of cooler groups may cause high temperature in the UAT. If the UAT temperature exceeds the predetermined setpoint for the high temperature alarm, the alarm would be generated to alert the operator to take action to determine the cause of the alarm.

   If the UAT temperature exceeds the predetermined setpoint for tripping the UAT (i.e., a high-high temperature condition), the offsite power supply to the onsite ac power system is transferred automatically from the UATs to the standby auxiliary transformers (SATs) and the power supply to the onsite ac power system is maintained.

3. The cooling equipment for the MT is divided into multiple (e.g., six or seven) independent cooler groups. With any one cooler group out of operation, the MT is designed to be able to carry full load (OFAF at 55/65 °C base rating) without exceeding the design temperature rise. If more than one cooler group loses their function, the MT's capacity would be degraded below the rated capacity. The loss of function of all the cooler groups results in the loss of function of the MT since the MT's cooling class is OFAF, requiring forced circulation.

4. The breaker inoperable alarm indicates the switchgear's circuit breakers' status; either in a trouble or disabled status.

   The trouble status includes the following representative conditions:

   - After a predetermined time following receipt of a command signal (either breaker trip or close), the breaker position is opposite to the command signal.

- After a breaker trip, the cause of the trip remains present.

The disabled status means that a breaker cannot be controlled in the normal manner to support the nuclear plant system equipment for several reasons such as a loss of power to the breaker control system.

As indicated in the response to RAI 148-8104, Question No. 08.03.01-17, the breaker inoperable alarm in FMEA Item No. 15 indicates that a circuit breaker between the Class 1E switchgear and an associated large motor or load center (LC) is in the trouble status or disabled status. The breaker inoperable alarm in FMEA Item No. 16 indicates that a circuit breaker between an EDG and the Class 1E switchgear is in the trouble status or disabled status.

5. The FMEA for the power cables from the UAT and SAT to respective 4.16 kV Class 1E switchgear is provided in the attached FMEA table.

6. The FMEA table for the offsite power system and the onsite ac power system will be provided as Table 8.3.1-7 in the DCD Tier 2.

Impact on DCD

DCD Tier 2, Chapter 8, list of tables and Subsection 8.3.1.1.2.2 will be revised and Table 8.3.1-7 will be added as shown in the Attachment.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.

8.3.1.1.2.1 System Redundancy

The onsite ac power system has the required redundancy of safety-related components and systems assuming a single failure. The Class 1E onsite ac power system consists of two redundant load groups (division I and division II), with four independent trains (A, B, C, and D), as shown in Figure 8.3.1-1. One of the two divisions (trains A and C or trains B and D), including associated Class 1E EDGs and electrical distribution systems, is required to supply the loads for safe shutdown during a LOCA concurrent with a LOOP.

Safety-related loads within a division are distributed between its two safety trains. Power for instrumentation and control (I&C) devices for Class 1E loads is supplied from the same safety train that supplies power to their loads, and 120 V power for Class 1E I&C devices is supplied through the inverter of the same safety train as described in Subsection 8.3.2.1.2.2. The configuration of the onsite ac power distribution system, including busing arrangements, loads supplied from each medium-voltage bus, safety-related equipment identification, and power connections to the I&C devices of the power systems is shown in a simplified electric power system single-line diagram in Figure 8.1-1. Switchgear locations are shown in Figure 8.2-1.

8.3.1.1.2.2 Single Failure Criteria

The Class 1E power system has sufficient capability to perform its safety function assuming a single failure. The independent trains of the Class 1E power system are provided with the required electrical and physical separation between trains to meet the single failure criterion. If one-out-of-two divisions is not available assuming a single failure, the other division (trains A and C or trains B and D) is capable of performing a safe shutdown of the plant.

Add

Each independent electrical train distribution system consisting of Class 1E 4.16 kV switchgear, 480V load center, and MCC are physically separated and located in separate rooms within the seismic Category I auxiliary building. The structures of the auxiliary building are designed to withstand the effects of natural phenomena such as hurricanes, floods, tornadoes, tsunami, and earthquakes without a failure to perform their safety functions.

The capability to perform the safety function assuming postulated accidents (including a single failure) is verified as a failure modes and effects analysis (FMEA) for the onsite ac power system. The FMEA is presented in Table 8.3.1-7.

Table 8.3.1-7 (1 of 8)

Failure Modes and Effects Analysis for the Onsite AC Power System

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
1. The isolated phase bus (IPB) from the main transformer (MT) to the generator circuit breaker (GCB) or to the unit auxiliary transformer (UAT) or the UAT	Power supply to the onsite ac power system	Loss of power	• Open circuit • Short circuit • UATs fault	• The faulted equipment is isolated by protective relaying and protective equipment. • The main generator (MG) and turbine automatically trip and the GCB opens. • The other independent preferred offsite circuit remains unaffected. • The switchgears are transferred automatically from the UATs to the standby auxiliary transformers (SATs).	Annunciation by protective relays
2. Standby auxiliary transformer (SAT)	In case of a loss of power from the UAT, power supply to the onsite ac power system	Loss of power	• Open circuit • Short circuit • SATs fault	• The faulted equipment is isolated by protective relaying and protective equipment. • The other independent preferred offsite circuit remains unaffected. • No effect on unit power generation or essential safety buses since not normally connected to onsite system.	Annunciation by protective relays
3. IPB connecting the GCB and the MG or MG	Power supply to transmission network and the onsite ac power system	Loss of power	• Open circuit • Short circuit • MG fault	• The GCB opens. • The turbine and the MG are tripped automatically. • All unit and Class 1E auxiliaries continue to receive uninterrupted offsite power from the UATs.	Annunciation by protective relays
4. GCB	Supplying and breaking of the MG output power	• Breaker open by breaker malfunction • Interrupting failure at fault	• Breaker fault, failure, or pole disagreement	• The other two poles of the breaker trip. • The faulted equipment is isolated by protective relaying and protective equipment. • The other independent preferred offsite circuit remains unaffected. • Automatic reactor and turbine trips occur. • The switchgears are transferred automatically from the UATs to the SATs.	Breaker fail alarm

Table 8.3.1-7 (2 of 8)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
5. IPB cooling system	Cooling of IPB	Loss of cooling of IPB	• Mechanical or electrical fault	• No immediate consequence. • The unit and Class 1E auxiliaries continue to receive an uninterrupted flow of power through the UATs. • The continued unit operation is dependent upon bus design capacities without forced cooling.	Cooling system fault alarm
6. UATs cooling system	Cooling of UATs	Loss of one of the cooler banks	• Mechanical or electrical fault	• No immediate consequence. • The unit and the Class 1E auxiliaries continue to receive an uninterrupted flow of power from this source. • The continued transformer and unit operation is dependent upon its rated design capacities without cooling.	Cooling system fault alarm
7. MT	Transferring of power to the transmission network and the onsite ac power system	Loss of power	• Open circuit • Short circuit • Main transformer fault	• The faulted equipment is isolated by protective relaying and protective equipment. • The MG automatically trips and the GCB opens. • The other independent preferred offsite circuit remains unaffected. • The switchgears are transferred automatically from the UATs to the SATs.	Annunciation by protective relays
8. MT cooling system	Cooling of MT	Loss of one of the cooler banks	• Mechanical or electrical fault	• No immediate consequence with the MT at full load. • The continued transformer and unit operation is dependent upon its rated design capacities without cooling.	Cooling system fault alarm
9. Power cables from the UAT (or SAT) to 4.16 kV Class 1E switchgear	Transferring of power from the UAT (or SAT) to the 4.16 kV Class 1E switchgear	Loss of switchgear power	• Cable fault (grounded, shorted)	• The associated switchgear feeder breaker trips and isolates the fault from the system. • The associated Class 1E 4.16 kV switchgear bus is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for safe shutdown of the reactor.	Annunciation by protective relays

Table 8.3.1-7 (3 of 8)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
10.13.8 kV non-Class 1E switchgear normal incoming feeder breaker	Power supply to 13.8 kV non-Class 1E switchgear	Interrupting failure at fault	• Operating device fault • Malfunction of the protective relay	• The faulted switchgear is isolated from power source by protective relaying and protective equipment (GCB and Switchyard breaker). • Automatic turbine and generator trips occur. • All switchgears except for faulted switchgear are transferred automatically from the UATs to the SATs.	Undervoltage alarm or breaker inoperable alarm
		Breaker open by malfunction	Relay setting error	• The switchgear normal incoming breaker trips. • The associated switchgear bus is de-energized. • Required unit power reduction to the capacity supported by remaining non-Class 1E auxiliaries or may cause unit to trip. • If reactor coolant pump (RCP) switchgear bus is unavailable, the plant will experience a reactor trip due to the loss of RCPs. Turbine and generator also trip.	Undervoltage alarm or breaker trip alarm
11.13.8 kV non-Class 1E Switchgear Bus or Feeder Breaker	Power supply for 13.8 kV Loads	Bus unavailable	• Bus insulation fail (Grounded, Shorted) • Feeder breaker interrupting fail on fault	• The switchgear normal incoming breaker trips. • The associated switchgear bus is de-energized. • Required unit power reduction to the capacity supported by remaining non-Class 1E auxiliaries or may cause unit to trip. • If RCP switchgear bus is unavailable, the plant will experience a reactor trip due to the loss of RCPs. Turbine and generator also trip.	Undervoltage alarm or breaker inoperable alarm
		Breaker open by malfunction	Relay setting error	• Switchgear Feeder Breaker trips. • The associated switchgear load is de-energized. • If RCP feeder breaker trips, the plant will experience a reactor trip due to the loss of RCPs. Turbine and generator also trip.	Undervoltage alarm or breaker inoperable alarm

Table 8.3.1-7 (4 of 8)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
12. 4.16 kV non-Class 1E switchgear normal incoming breaker	Power supply to the switchgear bus	Interrupting failure at fault	• Operating device fault • Malfunction of the protective relay	• The faulted switchgear is isolated from power source by protective relaying and protective equipment (GCB and switchyard breaker). • Automatic turbine and generator trips occur. • All switchgears except for faulted switchgear are transferred automatically from the UATs to the SATs.	Undervoltage alarm or breaker inoperable alarm
		Breaker open by malfunction	Relay setting error	• The switchgear normal incoming breaker trips. • The associated switchgear is de-energized. • Required unit power reduction to the capacity supported by remaining non-Class 1E auxiliaries or may cause unit to trip.	Undervoltage alarm or breaker trip alarm
13. 4.16 kV non-Class 1E switchgear bus or the feeder breaker	Power supply to 4.16 kV non-Class 1E loads	Bus unavailable	• Bus insulation fail (grounded, shorted) • Feeder breaker interrupting fail	• The switchgear normal incoming breaker trips. • The associated switchgear is de-energized. • Required unit power reduction to the capacity supported by remaining non-Class 1E auxiliaries or may cause unit to trip.	Undervoltage alarm or breaker inoperable alarm
		Breaker open by malfunction	Relay setting error	• The switchgear feeder breaker trips. • The associated switchgear load is de-energized.	Breaker trip alarm

Table 8.3.1-7 (5 of 8)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
14. The feeder cable of 13.8 kV / 480 V or 4,16 kV / 480 V non-Class 1E load center transformer or load center incoming breaker	Power supply to 480 V load center	Load center power supply feeder unavailable	• Cable fault (grounded, shorted) • Transformer fault • Incoming breaker interrupting fail at fault	• The associated 13.8 kV or 4.16 kV feeder breaker trips and isolates the fault from the system. • The associated 480 V load center bus is de-energized.	Switchgear breaker trip alarm or load center undervoltage alarm
		Breaker open by malfunction	Relay setting error	• The load center incoming breaker trips. • The associated load center bus is de-energized.	Breaker trip alarm or undervoltage alarm
15. 480 V non-Class 1E load center bus or 480 V non-Class 1E load center feeder breaker	Power supply to 480 V load center loads	Bus unavailable	• Bus insulation fail (grounded, shorted) • Feeder breaker interrupting fail on fault	• The load center incoming breaker trips. • The associated 480 V load center bus is de-energized.	Load center fault alarm
		Breaker open by malfunction	Relay setting error	• The load center feeder breaker trips. • The associated 480 V load is de-energized.	Breaker trip alarm

Table 8.3.1-7 (6 of 8)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
16. 4. 16 kV Class 1E switchgear normal incoming breaker	Power supply to the 4.16 kV Class 1E bus	Interrupting failure at fault	• Operating device fault • Malfunction of protective relay	• The faulted switchgear is isolated from power source by protective relaying and protective equipment (GCB and switchyard breaker). • Automatic turbine and generator trips occur. • All switchgears except for faulted switchgear are transferred automatically from the UATs to the SATs. • Affected 4.16 kV Class 1E switchgear is de-energized. Associated 480 V buses are also de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for safe shutdown of the reactor.	Undervoltage alarm or breaker inoperable alarm
		Breaker open by malfunction	Relay setting error	• The switchgear normal incoming breaker trips. • Affected 4.16 kV Class 1E switchgear is de-energized. Associated 480 V buses are also de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for safe shutdown of the reactor.	Undervoltage alarm or breaker trip alarm
17. 4.16 kV Class 1E switchgear bus or feeder breakers	Power supply to Class 1E large motors and load centers	Bus unavailable	• Bus insulation fail (grounded, shorted) • Feeder breaker interrupting fail	• Incoming breakers trip and the affected 4.16 kV Class 1E switchgear is de-energized. • The associated 480 V buses are also de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E auxiliary power system for the safe shutdown of the reactor.	Undervoltage alarm or breaker inoperable alarm
		Breaker open by malfunction	Relay setting error	• The switchgear feeder breaker trips. • The associated switchgear load is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E auxiliary power system for the safe shutdown of the reactor.	Breaker trip alarm

Table 8.3.1-7 (7 of 8)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
18. 4.16 kV Class 1E emergency diesel generator breaker	Power supply to the 4.16 kV Class 1E bus	Feeder breaker closing fail	Malfunction of operating device	• In case of a LOOP and a failure of EDG breaker closing, the associated 4.16 kV Class 1E switchgear is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system division.	Undervoltage alarm or breaker inoperable alarm
19. 4.16 kV Class 1E emergency diesel generator	Power supply to the Class 1E bus	• EDG start failure • Fault after starting • Undervoltage • Underfrequency	Electrical and mechanical fault	• If the EDG source is supplying power under offsite power failure, the affected safety division is de-energized until the fault is cleared. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system division.	Undervoltage alarm or EDG fault alarm
20. The feeder cable of 4.16 kV/480 V Class 1E load center transformer or 480 V Class 1E load center incoming breaker	Power supply to the Class 1E load center bus	Load center power supply feeder unavailable	• Cable fault (grounded, shorted) • Transformer fault • Incoming breaker interrupting fail	• The associated switchgear feeder breaker trips and isolates the fault from the system. • The associated 480 V load center bus is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for safe shutdown of the reactor.	Switchgear feeder breaker trip alarm or load center undervoltage alarm
		Breaker open by malfunction	Relay setting error	• The load center incoming breaker trips. • The associated 480 V load center bus is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for safe shutdown of the reactor.	Breaker trip alarm or undervoltage alarm

Table 8.3.1-7 (8 of 8)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
21. 480 V Class 1E load center bus or 480 V Class 1E load center feeder breaker	Power supply to 480 V Class 1E loads	Bus unavailable	• Bus insulation fail (grounded, shorted) • Feeder breaker interrupting fail at fault	• The load center incoming breaker trips. • The associated 480V load center bus is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for the safe shutdown of the reactor.	Load center breaker trip alarm or fault alarm
		Breaker open by malfunction	Relay setting error	• The load center feeder breaker trips. • The associated 480 V load center bus is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for the safe shutdown of the reactor.	Breaker trip alarm
22. 480 V Class 1E load center feeder cable for motor control center (MCC) or 480 V Class 1E MCC feeder breaker	Power supply to 480 V Class 1E MCC loads	MCC bus unavailable	• Feeder cable fault (grounded, shorted) • Feeder breaker interrupting fail at fault	• The associated load center feeder breaker trips. • The associated MCC bus is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for the safe shutdown of the reactor.	Load center breaker trip alarm and MCC undervoltage alarm
		Breaker open by malfunction	Relay setting error	• The MCC feeder breaker trips. • The associated MCC load is de-energized. • Sufficient redundant auxiliaries remain operable from the redundant Class 1E power system for the safe shutdown of the reactor.	MCC fault alarm