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.:	**148-8104**
SRP Section:	**08.03.01 – AC Power Systems (Onsite)**
Application Section:	**8.3.1**
Date of RAI Issue:	**08/10/2015**

Question No. 08.03.01-15

RG 1.206, Sections C.I.8.3.1.3 and C.I.8.3.2.3 identify a list of electrical system calculations (or studies) necessary for the onsite ac and dc distribution systems. In this RAI, the summary of the calculations (i.e. load flow, short circuit, equipment sizing) were requested in a separate question with results, assumptions and acceptance criteria/conclusions.

Please provide a similar summary of calculations or studies and assumptions used to demonstrate adequacy for insulation coordination (surge and lightning protection) (item 5 of C.I.8.3.1.3) and power quality limits (harmonic distortion-item 6) as cited in the above RG 1.206.

DCD Section 8.3.3, COL items, includes insulation coordination of surge and lightning protection. Additionally, DCD Tier 2, Section 8.3.1.3.6 indicates that an analysis will be performed so that total harmonic distortion (THD) is less than or equal to 5% according to IEEE Std. 519. Please indicate if the power quality analyses will be performed in accordance with RG 1.206 and be included as a COL item.

Response

Requirements for the insulation coordination study for surge and lightning protection are described in DCD Tier 2, Subsections 8.3.1.3.5. Insulation coordination for surge and lightning protection is performed in accordance with IEEE Std. C62.82.1 and IEEE Std. 1313.2. Since the insulation coordination for surge and lightning protection is to be provided by the COL applicant as described in COL item 8.3(5), a summary of calculations or studies and assumptions used to demonstrate adequacy for insulation coordination is also to be provided by the COL applicant.

A preliminary study of the power quality limits has been performed based on the equipment characteristic data obtained from a reference plant (Shin-Kori nuclear power plants units 3 and 4). The results of the study shows that the individual and total voltage harmonic distortion at each Class 1E bus meets the respective acceptance criteria (3 percent individual voltage distortion, 5 percent total voltage distortion). The preliminary study is included in Technical Report, APR1400-E-E-NR-14001-P (Rev.0), which will be submitted as an attachment to the response to Question 08.03.01-13 of this RAI. The COL applicant is to perform a detailed study of the power quality limits (i.e., harmonic distortion) based on the site-specific technical data. Accordingly, KHNP will add COL item 8.3(12) to clarify the responsibility of the COL applicant.

Impact on DCD

DCD Tier 2, Table 1.8-2 and Subsections 8.3.1.3.5, 8.3.1.3.6, and 8.3.3 will be revised 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.

COL 8.3(12) The COL applicant is to provide the analysis and underlying assumptions used to demonstrate adequacy for power quality limits (harmonic distortion).

add

the analysis and underlying assumptions used to demonstrate adequacy for

Table 1.8-2 (11 of 29)

Item No.	Description
COL 8.3(1)	The COL applicant is to provide and to design a mobile generator and its support equipment.
COL 8.3(2)	The COL applicant is to describe and provide detailed ground grid and lightning protection.
COL 8.3(3)	The COL applicant is to provide testing, inspection, and monitoring programs for detecting insulation degradation of underground and inaccessible power cables within the scope of 10 CFR 50.65.
COL 8.3(4)	The COL applicant is to provide protective device coordination.
COL 8.3(5)	The COL applicant is to provide insulation coordination of surge and lightning protection.
COL 8.3(6)	The COL applicant is to develop the maintenance program to optimize the life and performance of the batteries.
COL 8.3(7)	The COL applicant is to provide short circuit analysis of onsite dc power system with actual data.
COL 8.3(8)	The COL applicant is to describe any special features of the design that would permit online replacement of an individual cell, group of cells, or entire battery.
COL 8.4(1)	The COL applicant is to identify local power sources and transmission paths that could be made available to resupply power to the plant following the loss of a grid or the SBO.
COL 8.4(2)	The COL applicant is to develop detailed procedures for manually aligning the alternate AC power supply when two (Trains A and B) of the four diesel generators are unavailable during a loss of offsite power event.
COL 9.1(1)	The COL applicant is to provide operational procedures and maintenance program as related to leak detection and contamination control.
COL 9.1(2)	The COL applicant is to maintain complete documentation of system design, construction, design modifications, field changes, and operations.
COL 9.1(3)	The COL applicant is to address the load-handling procedures. Load-handling procedures are established for component handling procedures and plant operating procedures in accordance with ASME B30.2. ASME B30.2 requires establishing component handling procedures that include (1) a safe load path for lifting heavy loads to perform special handling component inspections, (2) acceptance criteria prior to lift, and (3) use of steps and proper sequence in handling the load. ASME B30.2 requires plant operating procedure guidelines that include appropriate crane operator training and crane inspections. ASME B30.2 also requires that the load-handling procedures include preparing operating procedures for preoperational load testing and checkouts of interlocks, brakes, hoisting cables, control circuitry, and lubrication of OHLHS equipment.

add

add: the analysis and underlying assumptions used to demonstrate adequacy for

transformer, and switchyard facilities. Insulation coordination is performed in accordance with IEEE Std. C62.82.1 (Reference 49) and IEEE Std. 1313.2 (Reference 50). The COL applicant is to provide the insulation coordination of surge and lightning (COL 8.3(5)).

8.3.1.3.6 Power Quality Limits

Nonlinear loads such as battery chargers and inverters contribute total harmonic distortion (THD) to the distribution power system. THD degrades electric power quality, causing increased heating due to copper and iron losses at harmonic frequencies on electrical equipment such as motors, transformers, and switchgears. Therefore, the electrical distribution system is designed so that THD does not affect Class 1E equipment. THD is maintained within the acceptance criteria in accordance with IEEE Std. 519 (Reference 51). ~~An analysis is performed so that THD is~~ less than or equal to 5 percent. Reasonable assurance of the protective device application within the power quality that is needed for the device to operate, is provided.

add: The COL applicant is to provide the analysis and underlying assumptions used to demonstrate adequacy for power quality limits (harmonic distortion) (COL 8.3.(12)).

8.3.1.3.7 Monitoring and Testing

Monitoring of the distribution power system is provided with information such as the quantitative value of equipment, circuit breaker status, and the protective device alarm by ESF-CCS and QIAS-P for Class 1E and the P-CCS and IPS for non-Class 1E equipment in the main control room and remote shutdown console. The operator can use the information that is necessary for efficient operation of the unit. All control room I&C is designed in accordance with the human factors engineering design criteria and implementation methods as described in Chapter 18.

Testing of the onsite ac power system is described in Subsection 8.3.1.1.6.

Load sequence testing for LOOP or combined LOOP and LOCA is performed during the plant shutdown condition. EDG testing capability is described in Subsection 8.3.1.1.3.7.

revise: The power quality analyses are performed in accordance with RG 1.206 and allowable THD is limited to

COL 8.3(12) The COL applicant is to provide the analysis and underlying assumptions used to demonstrate adequacy for power quality limits (harmonic distortion)

The ground detector has an alarm in the MCR to monitor constant grounding and recording. The ground detector has high sensitivity.

8.3.3 Combined License Information

COL 8.3(1) The COL applicant is to provide and to design a mobile generator and its support equipment.

COL 8.3(2) The COL applicant is to describe and provide detailed ground grid and lightning protection.

the analysis and underlying assumptions used to demonstrate adequacy for

COL 8.3(3) The COL applicant is to provide testing, inspection, and monitoring programs for detecting insulation degradation of underground and inaccessible power cables within the scope of 10 CFR 50.65.

COL 8.3(4) The COL applicant is to provide protective device coordination.

add

COL 8.3(5) The COL applicant is to provide insulation coordination of surge and lightning protection.

COL 8.3(6) The COL applicant is to develop the maintenance program to optimize the life and performance of the batteries.

COL 8.3(7) The COL applicant is to provide a short-circuit analysis of the onsite dc power system with actual data.

COL 8.3 (8) The COL applicant is to describe any special features of the design that would permit online replacement of an individual cell, group of cells, or entire battery.

add

8.3.4 References

1. IEEE Std. 141-1993, “IEEE Recommended Practice for Electric Power Distribution for Industrial Plants,” Institute of Electrical and Electronics Engineers, 1993.

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.:	**148-8104**
SRP Section:	**08.03.01 – AC Power Systems (Onsite)**
Application Section:	**8.3.1**
Date of RAI Issue:	**08/10/2015**

Question No. 08.03.01-16

DCD Tier 2, Section 8.3.1.1.3.1, “Starting Initiating Circuits”, item (a) indicates Figure 7.3-4 for Automatic through load Sequencer Logic. However, in Section 7 of the DCD Tier 2, this figure is found as 7.3-21.

Please confirm the correct Figure and revise the DCD.

Response

KHNP confirms that the control logic diagram for the EDG load sequencer is not Figure 7.3-4 but rather Figure 7.3-21.

KHNP will correct the figure number from 7.3-4 to 7.3-21.

Impact on DCD

DCD Tier 2, Section 8.3.1.1.3.1 will be revised 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.

The characteristics of the generator exciter and voltage regulator provide satisfactory starting and acceleration of sequenced loads and provide reasonable assurance of rapid voltage recovery when starting large motors. The ratings of the switchgear, load center, and MCC shown in Table 8.3.1-6 indicate sufficient capacity to supply power to the safety equipment during all operating modes.

8.3.1.1.3 Class 1E Emergency Diesel Generators

Each EDG train and its associated auxiliaries are installed in a separate room within physically separate seismic Category I structures that provide protection against tornadoes, hurricanes, external missiles, and seismic phenomena and are electrically isolated from the circuits of other EDGs trains and non-Class 1E circuits. Each EDG room is a separate fire area with 3-hour fire-rated walls, floors, and ceilings. Each EDG room is provided with its own independent ventilation system that automatically maintains the design room temperature for proper equipment operation and personnel access. The EDG room HVAC system and other EDG support auxiliaries are powered from the same electrical train as the EDG.

The EDG controls and monitoring instrumentation, with exception of the sensors and other equipment that are necessarily mounted on the EDG or its associated piping, are installed in free-standing, floor-mounted panels. These panels are designed for their normal vibration environment and are qualified to seismic Category I requirements.

The EDG units have the minimum target reliability factor of 0.95 in accordance with NRC RG 1.9 (Reference 10) and NRC RG 1.155 (Reference 11).

The EDG system provides the requirements with respect to the bypassed and inoperable status indication as described in Subsection 7.5.1.3.

8.3.1.1.3.1 Starting Initiating Circuits

The EDGs are started in the event of the following occurrences:

a. Automatic (through load sequencer logic shown in Figure 7.3-~~4~~ 21)

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.:	**148-8104**
SRP Section:	**08.03.01 – AC Power Systems (Onsite)**
Application Section:	**8.3.1**
Date of RAI Issue:	**08/10/2015**

Question No. 08.03.01-17

GDC 17 requires that each plant onsite electrical distribution system is supplied by at least two physically independent circuits designed and located to minimize, to the extent practical, the likelihood of their simultaneous failure during operating and postulated accident and environmental conditions. SRP 8.3.1, Part III (Review Procedures), Section 4.(A) provides criteria for review to verify the requirements of GDC 17 have been made. It describes requirements to minimize diesel generator failure and to start on demand and to ensure that diesel generator reliability and operation will not be degraded.

In DCD, Tier 2, Section 8.3.1 and 8.3.2, the applicant described that the onsite power complies with GDC 17, but did not provide any Failure Mode Effects Analysis (FMEA) for the onsite ac and dc/ups power system based on the design configuration. The staff requests additional information regarding the conformance to GDC 17 to specifically show that no single event will simultaneously fail the redundant power circuits. In the additional information, the applicant should include component identification, their functions, failure modes (loss of cooling, bus failure, loss of voltage, breaker failure, transformer failure etc.), failure mechanism (including fault location), effect/impact on any safety-related function, detection (alarm/trip), and actions to mitigate the failed status of the system/equipment.

Response

The content of APR1400 DCD Tier 2, Chapter 8, was established on the basis of the guidance in NRC Regulatory Guide (RG) 1.206, which requires a FMEA only of the switchyard components to assess the possibility of simultaneous failure of both offsite circuits. FMEAs for the onsite ac and dc/ups system were not included in DCD Tier 2, Chapter 8. However, as a result of this request for additional information, KHNP is attaching the result of the FMEAs for the onsite ac and dc/ups systems which show that no single event will simultaneously fail the redundant power circuits.

Impact on DCD

There is no impact on the DCD.

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.

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 1 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
1. Isolated phase bus from main transformer to the generator breaker or to the unit auxiliary transformer, or Unit auxiliary transformer	Power supply to unit auxiliary power system	Loss of power	• Open circuit • Short circuit • Unit auxiliary transformers fault	• The faulted equipment is isolated by protective relaying and protective equipment. • The main generator automatically trips and its breaker opens. • Automatic turbine and main generator trips occur. • The other independent preferred offsite circuit remains unaffected. • The switchgear supplied from the faulted circuit are connected in an automatic bus transfer to the standby auxiliary transformers.	Annunciation by protective relays
2. Standby auxiliary transformer	In case of unit auxiliary transformer fault, power supply to unit auxiliary power system	Loss of power	• Open circuit • Short circuit • Standby auxiliary transformers 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. Isolated phase bus connecting the generator circuit breaker and the unit generator or main generator	Power supply to transmission grid and unit auxiliary power system	Loss of power	• Open circuit • Short circuit • Main generator fault	• Generator circuit breaker opens. • The turbine and main generator are tripped automatically. • All unit and Class 1E auxiliaries continue to receive uninterrupted offsite power from the unit auxiliary transformers.	Annunciation by protective relays

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 2 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
4. Generator circuit breaker	Supplying and breaking of generator 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 trip occur. • All switchgear supplied from the faulted circuit are connected in an automatic bus transfer to the standby auxiliary transformers.	Breaker fail alarm
5. Isolated phase bus cooling system	Cooling of isolated phase bus	Loss of cooling of isolated phase bus	• Mechanical or electrical fault	• No immediate consequence. • The unit and Class 1E auxiliaries continue to receive an uninterrupted flow of power through the unit auxiliary transformers. However, continued unit operation is dependent upon bus design capacities without forced cooling.	Cooling system fault alarm
6. Unit auxiliary transformers cooling system	Cooling of unit auxiliary transformers	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. However, continued transformer and unit operation is dependent upon its rated design capacities with and without cooling.	Cooling system fault alarm

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 3 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
7. Main transformer cooling system	Cooling of main transformer	Loss of one failure of the cooler banks	• Mechanical or electrical fault	• No immediate consequence with main transformer at full load. • The continued transformer and unit operation is dependent upon its rated design capacities with and without cooling.	Cooling system fault alarm
8. 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 trip occur. • All switchgear except for faulted switchgear are connected in an automatic bus transfer to the standby auxiliary transformers.	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 RCP switchgear bus is unavailable, the plant will experience a reactor trip due to the loss of reactor coolant pumps. Turbine and generator also trip.	Undervoltage alarm or breaker trip alarm

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 4 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
9. 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 reactor coolant pumps. Turbine and generator also trip.	Undervoltage alarm or breaker inoperable alarm
		Breaker open by a 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 reactor coolant pumps. Turbine and generator also trip.	Undervoltage alarm or breaker inoperable alarm

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 5 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
10. 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 trip occur. • All switchgear except for faulted switchgear are connected in an automatic bus transfer to the standby auxiliary transformer.	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
11. 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

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 6 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
12. The feeder cable of 13.8 kV 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 • age relay reaker 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. • In case of cable or transformer fault, common non-Class 1E 480 V load center is transferred to the standby transformer	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. • Common non-Class 1E 480 V load center is transferred to the standby transformer	Breaker trip alarm or undervoltage alarm
13. 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

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 7 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
14. 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 trip occur. • All switchgear except for faulted switchgear are connected in an automatic bus transfer to the standby auxiliary transformers. • 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

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 8 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
15. 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
16. 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 4.16kV 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

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 9 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
17. 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 off-site power fail, 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
18. The feeder cable of 4.16 kV/480 volt 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

Failure Modes and Effects Analysis for the Onsite AC Power Systems (Sh. 10 of 10)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
19. 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 load center load 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
20. 480 V Class 1E load center feeder cable for motor control center or 480 V Class 1E motor control center feeder breaker	Power supply to 480 V Class 1E motor control center 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 operation of the reactor.	Load center breaker trip alarm and motor control center undervoltage alarm
		Breaker open by malfunction	Relay setting error	• The motor control center 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 operation of the reactor.	MCC fault alarm

Failure Modes and Effects Analysis for the 125 V DC and Class 1E Vital Power System (Sh. 1 of 2)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
1. 480 V AC supply to chargers	Power supply to charger	Loss of AC input power	• Loss of 480 V load center power • Power supply feeder fault	• Power supply fail to DC MCC from charger • Power from battery is available to supply power without interruption.	Annunciation by charger undervoltage relay
2. Battery chargers	Power supply to 125 V DC load and charge of battery	• Loss of output power • Opening of output breaker • Undervoltage of output power • Overvoltage of output power	Component fail	• Power supply fail to DC MCC from charger • Severe internal faults may cause high short circuit currents to flow with the resulting voltage reduction on the 125 V DC bus until the fault is cleared by the isolating circuit breakers. • The 125 V DC bus receives power from its respective battery without interruption. • If the battery circuit breakers open, the complete loss of voltage on one 125 V DC bus may result but other redundant system can make a function as alternative.	• Annunciation by charger trouble detection • Annunciation by charger undervoltage / overvoltage relay
3. 125 V DC batteries	Back-up power supply to DC MCC	Battery circuit breaker open	Battery fail	• Back-up power loss • In case of charger available, even though the battery fails to supply to DC MCC, the battery charger allows to continue supplying power to DC MCC. • In case of both battery and charger unavailable, other redundant system can make a function as alternative.	Annunciation by breaker trip

Failure Modes and Effects Analysis for the 125 V DC and Class 1E Vital Power System (Sh. 2 of 2)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
4. 125 V DC control centers	Power supply to DC loads	Ground fault	Grounding of a single bus	• The 125 V DC system is an ungrounded electrical system and therefore, ground detector is under surveillance and causes alarms. • A single ground does not cause any malfunction or prevent operation of any safety feature.	Annunciation by DC MCC ground detector
		Undervoltage	Charger fail and battery discharge	• The 125 V bus is monitored to detect the voltage decay on the bus and initiate an alarm at a voltage setting where the battery can still deliver power for safe and orderly shutdown of the unit. • Upon detection, power can be restored either by correcting the deficiency, by switching to a redundant source.	Annunciation by DC MCC undervoltage relay
5. 125 V DC distribution panel	Power supply to DC loads	Main circuit breaker open	Bus shorted	• Voltage on the shorted 125 V DC bus system of the affected unit decays until isolated by the isolating circuit breakers. • Remaining redundant channels are available for the safe operation of the unit.	Annunciation by breaker trip [(Local Only)]

Failure Modes and Effects Analysis for the 120 V AC Class 1E Vital Instrumentation and Control Power System

Component	Function	Failure Mode	Failure Cause	Failure Effect and Counter Measure	Detection
1. Inverter	Power supply to vital bus panelboards	• Loss of output power • Loss of Input power • Inverter fail	Component fail	• Input power loss of 120 V vital bus distribution panel • Regulating transformer supply back-up power • Redundant system is available for the function	Annunciation by inverter undervoltage relay
2. AC instrument and control power distribution panel	Power supply to vital instrument loads	Undervoltage	Bus shorted	• Power supply loss of 120 V vital instrument loads • Sufficient redundant system provides adequate protection.	Annunciation by power loss