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.:	**163-8178**
SRP Section:	**08.03.02 – DC Power Systems (Onsite)**
Application Section:	**8.3.2**
Date of RAI Issue:	**08/20/2015**

Question No. 08.03.02-1

Question 1:

DCD, Tier 2, Table 8.3.2-4 (Page 1), shows 116 cells for a 125 Vdc battery, and 116 cells for 250 Vdc battery. Typically, 125 Vdc batteries have around 60 cells. Please clarify the apparent discrepancy.

Question 2:

DCD, Tier 2, Table 8.3.2-4 (Page 1, Non- Class 1E DC and I&C, component data), shows that Division I battery and charger capacity are different than that of Division II battery and charger capacity as below. Please explain the differences, and explain whether a divisional pair of larger capacity can be replaced by the other pair of lower capacity, without any impact to operation of the DC/UPS systems. Explain if any load shedding is involved in the design.

Division I battery Chargers output current rating is 1800 Amp, whereas Division II battery chargers are 1600 Amp.

Division I battery capacity is 4,000 Amp-Hour, whereas Division II battery capacity is 3600 Amp-Hour.

Question 3:

DCD, Tier 2, Table 8.3.2-1 (4 sheets), shows that the duty cycle is 8 hours long for Train A and 16 hours for Train C (Notes 5 and 8). Similarly for Train B (8 Hours) & D (16 Hours). Please explain the reason for such difference in duty cycle. Considering the duty cycle diagram for APR1400 design for each battery train, discuss how the most critical time was determined and how the section of the duty cycle was identified that controls battery size (Momentary, random and continuous). Provide the controlling portion of the duty cycle time in minutes as per guidance in Figure 1 of IEEE Std. 485 (Diagram of a duty cycle) for random loads, representative of the two different duty cycles.

Question 4:

DCD, Tier 2, Table 8.3.2-4 (Page 1), provides electrical equipment rating. Provide the inverter efficiency factor assumed, when determining Class 1E battery loads.

Question 5:

DCD, Tier 2, Table 8.3.2-4 (Page 2), indicates that the Class 1E 125 Vdc battery capacity is 8800 AH for Trains C&D.

(a) Discuss how this capacity is determined. Provide a summary of the calculation results with assumptions, and acceptance criteria.

(b) Discuss whether large capacity battery will impact the short circuit capacity of the distribution system and connected equipment.

(c) Provide the time to recharge the battery from a fully discharged state, based on the worst-case duty cycle, to approximately 95 percent capacity during operating conditions.

(d) Confirm that the acceptance criteria for selecting the DC system equipment (batteries, battery chargers, inverters, DC switchgear, panels, and connecting cables) are such that the equipment ratings are sufficient to start and operate required loads during normal and off-normal plant conditions including DBA [Design Basis Accident].

Response

The following responses correspond to the above Question 1 through Question 5.

Response to Question 1:

The number of battery cells is determined in consideration of the discharge characteristics (i.e. minimum cell voltage) of the battery cells and also charging voltage on the battery.

For the APR1400 125 Vdc batteries, the selected number of cells is 58 based on the following:

- Minimum cell voltage is 1.81V, which corresponds to the minimum allowable voltage of the 125 Vdc system (105V).
- Maximum battery cell (equalizing) charging voltage is less than 2.40V, which corresponds to the maximum allowable voltage of the 125 Vdc system (140V).

The number of cells for each non-Class 1E 125 Vdc battery located in the auxiliary building is indicated as 116 cells since two banks are installed in parallel to meet the capacity requirements.

Response to Question 2:

Load difference and replacement: Unlike the Class 1E dc system, the non-Class 1E dc system is not made up of redundant systems and each division (division I and II) is independent of each other. The difference in the non-Class 1E battery and charger size between division I and division II is due to the different load combinations between division I and division II, as listed in DCD Tier 2, Table 8.3.2-2 (pages 1 and 2).

For instance, there are three feedwater pump turbines, each with a dc emergency lube oil pump. Two of the emergency lube oil pumps are assigned to division I and one is assigned to division II. Therefore, the loads on their respective non-Class 1E 125 Vdc switchgears are 136 A and 68 A, respectively.

Due to the different ratings between division I and II, the non-Class 1E 125 Vdc components are not interchangeable between divisions.

Load shedding: As described in DCD Tier 2, Table 8.3.2-2 (pages 1 and 2), the non-Class 1E batteries provide back-up power for the dc/UPS systems up to 8 hours considering load shedding according to the characteristics of each load (operation period, operating times, etc.).

The following load shedding is considered in the design:

- After 30 minutes, the IP inverter loads are shed;
- After 120 minutes, other loads except for emergency lighting (e.g., local control panels; emergency lube oil pumps for the feedwater pump turbine system; solenoids for CVCS, feedwater and main steam , and safety injection system valves) are shed;
- Emergency lighting loads are only shed after 8 hours.

Response to Question 3:

Reason for the difference in duty cycle: Both train A and train B batteries have a capacity of 2,800 AH which can provide backup power for 2 hours without load shedding and an additional 6 hours with load shedding. Train C and train D batteries have a capacity of 8,800 AH which can provide backup power for up to 16 hours without load shedding. The reason for the difference in duty cycle between train(s) A (B) and train C (D) is due to the APR1400 mitigation strategies for beyond design basis external events (BDBEEs) described in DCD Tier 2, Section 19.3 and Technical Report APR1400-E-P-NR-14005-P (Rev. 0). According to the mitigation strategies for BDBEEs, a load cycle of 16 hours is applied only to trains C and D batteries to support operation of the turbine-driven auxiliary feedwater pumps (TDAFWPs).

Discussion of the most criterial time and duty cycle: Each of the dc loads powered by the battery throughout its duty cycle is classified as continuous or noncontinuous. Continuous loads are energized throughout the duty cycle. These loads are those normally carried by the battery charger and are initiated at the inception of the duty cycle. Noncontinuous loads are energized only during a portion of the duty cycle. These loads come on at any time within the duty cycle, are on for a set length of time, and are either removed automatically, removed manually by operator action, or continue to the end of the duty cycle. Momentary loads can occur one or more times during the duty cycle, but are of short duration, (i.e., not exceeding one minute at any occurrence). Loads that occur at random are energized at the most critical time of the duty cycle in order to simulate the worst-case load on the battery.

Random loads may be noncontinuous or momentary loads. To determine the most critical time, the battery was sized without the random loads and the section of the duty cycle that controls battery size was identified. The random loads were then superimposed on the end of the controlling section of the duty cycle.

The portion of the duty cycle for momentary loads of the Class 1E dc system (trains A, B, C, and D) is identified in the first minute of the duty cycle. The most critical time for random loads for trains A, B, C, and D is identified in the last hour of the duty cycle.

The duty cycle diagrams for trains A, B, C, and D Class 1E 125 Vdc batteries are provided in Figures 1 through 4 of the attachment.

Response to Question 4:

For battery sizing, the assumed inverter efficiency (factor) is 85 percent at the full load condition.

Response to Question 5:

(a) The capacity of train C and D batteries has been determined as follows:

- According to the APR1400 mitigation strategies for BDBEEs addressed in DCD Tier 2, the duty cycle of 16 hours is applied to trains C and D of the Class 1E dc system.
- After the magnitude and time period of each component load and the overall duration are determined in accordance with the APR1400 mitigation strategies for BDBEEs, the duty cycles of trains C and D batteries are constructed as provided in Figures 3 and 4 of the attachment.
- Sizing of the Class 1E trains C and D batteries are determined in accordance with IEEE Std. 485 (Cell sizing worksheet) based on the following assumptions and acceptance criteria.
    - A minimum electrolyte temperature of 65°F is applied for derating of battery capacities.
    - A design margin of 10 percent is added to account for future dc loads.
    - A design margin of 25 percent is added to account for aging.
- The calculation results of the Class 1E trains C and D batteries are 8,527 AH and 8,561 AH, respectively, and the capacity of trains C and D batteries are selected as 8,800 AH (4,400 AH x 2 banks in parallel).

(b) To determine the maximum available short-circuit (SC) current, which is the required interrupting capacity for feeder breakers/fuses and withstand capability of the distribution buses and disconnecting devices, the total short-circuit current is the sum of that delivered by the battery, charger, and motors (as applicable).

The SC current at the dc switchgear bus is calculated by the following equation in accordance with IEEE Std. 946;

$$I_S = \frac{E_F}{R_B + R_C} + I_C + I_M$$

Where,

I_S : Total short circuit currents

E_F : Floating voltage of the battery (use 2.17 V/cell in this calculation)

R_B : Total internal resistance of battery

R_C : Total resistance of main lead cables

I_C : Battery charger contribution (rated output current x 1.25)

I_M : dc motor contributions

Using the equation above and equipment parameters derived from the reference plant (Shin-kori NPP units 3 and 4), the maximum SC current at each dc switchgear bus is calculated as shown in the following table.

Bus Name	Train/Division /Location	Calculated Maximum SC Current	Equipment SC Rating
125 V dc Class 1E Switchgear	Train A	15,957 A	30 kA
	Train B	17,063 A	30 kA
	Train C	24,760 A	30 kA
	Train D	25,030 A	30 kA
125 V dc Non-Class 1E Switchgear	Division I	18,196 A	30 kA
	Division II	15,305 A	30 kA
250 V dc Non-Class 1E Switchgear	Turbine Building	24,646 A	30 kA

The calculation result demonstrates that the impact of the large capacity Class 1E batteries (trains C and D, 8,800 AH) can be accommodated by the selected SC ratings of the connected equipment (e.g., breaker, bus, etc.).

(c) Based on the worst-case duty cycle, 8 h to 24 h is recommended as the recharge time according to IEEE Std. 946. Twelve hours was selected as the recharge time of the Class 1E train C and train D batteries. The selected battery recharging time (12 h) has been considered in the sizing of the battery chargers.

(d) Summing up all the analysis results described above, KHNP confirms that the acceptance criteria for the selection of the dc system equipment ratings are such that the equipment ratings are sufficient to start and operate required loads during normal and off-normal plant conditions including DBA and also BDBEEs.

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.

Figure 1 - Diagrams of duty cycle for Train A (8 hours) for APR1400 design

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Figure 2 - Diagrams of duty cycle for Train B (8 hours) for APR1400 design

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Figure 3 - Diagrams of duty cycle for Train C (16 hours) for APR1400 design

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Figure 4 - Diagrams of duty cycle for Train D (16 hours) for APR1400 design

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Question No. 08.03.02-2

Question 1:

DCD, Tier 2, Section 8.3.2.3.5, states that “The power quality limits are analyzed by methods that are similar to onsite ac power system”.

Discuss the important considerations that affect the design life of batteries and chargers in DC/UPS system, and how power quality will be maintained.

Question 2:

DCD, Tier 2, Section 8.3.2.2, Analysis, Regulatory Guide 1.53, states that “If one safety-related power division is inoperable because of a single failure, the other division can accomplish the intended safety function”. Please explain how the transfer of divisional loads from the inoperable division to the redundant/standby division is achieved, both manually and automatically.

Demonstrate the online DC/UPS power distribution system capability to maintain safety function in the event of a single failure by providing a failure mode and effects analysis (FMEA).

Question 3:

DCD Tier 2, Section 8.3.2 provides design aspects of DC Onsite Power System. The staff has the following questions:

- In Section 8.3.2.1.2.2, Class 1E 120 Vac Instrumentation and Control Power System, it is stated that “The Class 1E 120 Vac I&C power system, located in a seismic Category I structure”. Where are the 4 trains of this system and it’s various panel boards located? Are these locations all Seismic Category I?

- In Section 8.3.2.1.2.2, Class 1E 120 Vac Instrumentation and Control Power System, it is stated that “The four trains are separated…....independence is provided between safety trains and non-safety equipment”. Please explain how independence between safety trains and non-safety equipment is achieved.
- Section 8.3.2.1.2.1 discusses Class 1E 125 Vdc Power System. Does this Class 1E system provides power to any non-safety equipment? If yes, how the independence between safety trains and non-safety equipment is achieved.
- Section 8.3.1.1.4, Electrical Equipment Layout, states that “Piping containing fluids is excluded from the Class 1E electrical distribution equipment rooms”. Is this design aspect followed for DC/UPS system equipment? Are these DC/UPS equipment separated from the high energy lines?

Question 4:

DCD, Tier 2, Section 8.3.2, Regulatory Guide 1.129, states that “The onsite dc power system of the APR 1400 is designed to meet the requirements of GDC’s 1, 17, 18, and Criterion III of Appendix B of 10CFR Part 50.”

> RG 1.129, in addition to the above applicable regulations, also included Criterion XI, “Test Control,” in Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50. Provide a discussion regarding conformance to this regulation for Test Program and Test Procedures for installation, preoperational tests, and operational tests.

Response

The following responses correspond to the above Question 1 through Question 4.

Response to Question 1:

The useful life of batteries is affected by many factors, such as specific gravity or pH of the electrolyte, depth of discharge, rate of discharge, ripple current, float voltage, temperature differential between cells, non-operating storage temperature, number of discharge cycles, rate of charge, temperature of the battery, and overcharge. Among the above factors, the output ripple of the battery chargers is an important consideration that affects the design life of the batteries.

The design life of the battery chargers is affected by the change in behavior of materials and components (e.g., resistors, capacitors, wires, connectors, semiconductors, tubes, switches, and electromechanical devices) through time under actual service, environmental, and maintenance conditions.

To guarantee the design life of the batteries and battery chargers, a quality assurance program that applies to design, qualification, production, quality control, installation, maintenance, and periodic testing will be implemented.

With regard to power quality in the dc/UPS system, the output ripple of the battery chargers is maintained within the battery manufacturer's acceptable limits by adding output filters. By adding filters, the ripple voltage at the dc input side of the inverter is reduced to prevent it from adversely affecting the inverter operation.

Response to Question 2:

Transfer of divisional loads: As described in DCD Tier 2, Subsection 8.3.2.1.2, the Class 1E dc power system is composed of four independent subsystems (trains A, B, C, and D), each of which serves the load group corresponding to the train that can accomplish the intended safety function. Like the Class 1E onsite ac power system, trains A and C of the Class 1E dc system constitute division I and trains B and D constitute division II. Divisions I and II provide the required redundancy of the safety related components and systems assuming a single failure.

If one safety related power division is inoperable because of a single failure, the other division accomplishes the intended safety function without transfer of divisional loads since during normal operating conditions, the independent subsystem trains, (i.e., trains A and C (division I) and trains B and D (division II)) are continuously energized and capable of meeting the system operating requirements.

FMEA for dc/UPS system: The content of the APR1400 DCD Tier 2, Chapter 8 was established on the basis of the guidance in NRC Regulatory Guide (RG) 1.206, which requires an FMEA only of the switchyard components to assess the possibility of simultaneous failure of both offsite circuits and thus, FMEAs for the onsite ac and dc/UPS system were not included.

However, KHNP has performed an FMEA for the onsite dc/UPS systems and is providing the results in Attachment 1 which shows that no single event will simultaneously fail the redundant divisions.

Response to Question 3:

Location of Class 1E 120 Vac instrumentation and control (I&C) power system equipment: The Class 1E 120 Vac I&C power system is divided into four trains and the equipment for each train is located in a dedicated dc and IP equipment room in the seismic Category I auxiliary building that corresponds to each train, (e.g., room numbers 078-A56A, 078-A56B, 078-A05C and 078-A05D). Additional information on the locations of the four separate dc and IP equipment rooms is provided in Attachment 2.

Independence of the Class 1E dc and 120 Vac I&C power systems: Independence of the Class 1E dc and 120 Vac I&C power system is achieved by physical separation and electrical isolation from non-safety-related equipment in accordance with RG 1.75 and IEEE Std. 384.

Physical separation of the Class 1E equipment from non-safety-related equipment is ensured in the design since the Class 1E dc and 120 Vac I&C power system equipment is located in the dc and IP rooms of the auxiliary building. There is no non-safety equipment in the dc and IP rooms.

In the current design, there is only one case where a Class 1E 120 Vac I&C power supplies a non-safety-related load. In this case, an isolation device, qualified in accordance with RG 1.75 and IEEE Std. 384, is placed between the Class 1E power source and the non-safety-related load so that the Class 1E power source will not be adversely impacted by a fault current arising from the non-Class 1E circuit.

Design concept of the dc/UPS system equipment layout: The requirements in Subsection 8.3.1.1.4 apply to all of the Class 1E electrical equipment including the Class 1E dc and 120 Vac I&C power system equipment.

Response to Question 4:

As described in DCD Tier 2, Section 17.5, KHNP applies a dedicated QA program for the APR1400 design certification, which is described in Topical Report “KHNP Quality Assurance Program Description (QAPD)”. The QAPD applies 10 CFR Part 50, Appendix B for the SSCs important to safety, and the Class 1E onsite dc power system of the APR 1400 is part of the SSCs important to safety. Therefore, Criterion XI (test control) of 10CFR Part 50, Appendix B is applied to the Class 1E onsite dc power system.

As a general rule, Criterion XI requirements will be applied to the test program and procedures for equipment proof tests, preoperational tests, and operational tests for the SSCs important to safety.

Refer to DCD Tier 2, Sections 14.1 and 14.2.1 with regard to conformance of the initial testing programs (ITPs) of major SSCs with 10 CFR Part 50, Appendix B, Criterion XI.

DCD Tier 2, Subsection 8.3.2.2.2 will be revised to reflect the applicability of RG 1.129 to the Class 1E onsite dc power system as discussed above.

Impact on DCD

DCD Tier 2, Subsection 8.3.2.2.2 will be revised as shown in Attachment 3.

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 125 V dc and Class 1E Vital Power System (Sh. 1 of 2)

Component	Function	Failure Mode	Failure Cause	Failure Effect and Countermeasure	Detection
1. 480 Vac supply to chargers	Power supply to charger	Loss of ac input power	• Loss of 480V load center power • Power supply feeder fault	• Power supply failure 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 Vdc load and charge of battery	• Loss of output power • Opening of output breaker • Undervoltage of output power • Overvoltage of output power	Component failure	• Power supply failure to dc MCC from charger • Severe internal faults may cause high short-circuit currents to flow with resulting voltage reduction on the 125 Vdc bus until the fault is cleared by the isolating circuit breakers. • The 125 Vdc bus receives power from its respective battery without interruption. • If the battery circuit breakers open, the complete loss of voltage on one 125 Vdc bus may result but other redundant system can function as alternative.	• Annunciation by charger trouble detection • Annunciation by charger undervoltage / overvoltage relay
3. 125 Vdc batteries	Back-up power supply to dc MCC	Battery circuit breaker open	Battery failure	• Back-up power loss • In case a charger is available, even though the battery fails to supply to dc MCC, the battery charger allows continued supply of power to dc MCC. • In case both battery and charger are unavailable, other redundant system can 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 Countermeasure	Detection
4. 125V dc control centers	Power supply to dc loads	Ground fault	Grounding of a single bus	• The 125V 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 failure and battery discharge	• The 125V 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 or by switching to a redundant source.	Annunciation by dc MCC undervoltage relay
5. 125V dc distribution panel	Power supply to dc loads	Main circuit breaker open	Bus shorted	• Voltage on the shorted 125V 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 Vac Class 1E Vital Instrumentation and Control Power System

Component	Function	Failure Mode	Failure Cause	Failure Effect and Countermeasure	Detection
1. Inverter	Power supply to vital bus panelboards	• Loss of output power • Loss of input power • Inverter failure	Component failure	• Input power loss of 120V 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 120V vital instrument loads • Sufficient redundant system provides adequate protection.	Annunciation by power loss

Locations of the four dc & IP equipment rooms

Security-Related Information – Withhold Under 10 CFR 2.390

of periodic testing as part of the surveillance program of nuclear power plant safety systems. Class 1E dc power systems are designed to conform with the GDC 18 and NRC RG 1.118.

NRC Regulatory Guide 1.128

NRC RG 1.128 is related to the installation design and installation of vented lead-acid storage batteries in nuclear power plants. IEEE Std. 484 (Reference 55), endorsed by NRC RG 1.128, provides the recommended design practice and procedures for storage, location, mounting, ventilation, instrumentation, pre-assembly, assembly, and charging of vented lead-acid batteries.

The Class 1E batteries of the APR1400 are installed in a separate seismic Category I room for each train. The battery cells are arranged on the racks to provide for the inspection of cell plates. Class 1E batteries, racks, and anchors are installed to withstand a safe shutdown earthquake to allow continuous battery service during and following the event in accordance with IEEE Std. 344, as endorsed by NRC RG 1.100 (Reference 56). The battery installation area is clean, dry, and well ventilated and provides adequate space and illumination for inspection, maintenance, testing, and battery cell replacement.

Each ventilation system of the Class 1E battery rooms limits hydrogen accumulation to less than 1 percent of the total volume of the battery area. An automatic fire detection system is installed in each battery room with provision for local alarm and annunciation in the MCR.

The APR1400 is designed to meet the requirements of NRC RG 1.128.

NRC Regulatory Guide 1.129

NRC RG 1.129 is related to the maintenance, testing, and replacement of vented lead-acid storage batteries for nuclear power plants. IEEE Std. 450 (Reference 57), endorsed by the NRC RG 1.129, provides recommended practices for maintenance, testing, and replacement of vented lead-acid batteries for stationary applications.

~~The onsite~~ dc power system of the APR1400 is designed to meet the requirements of GDCs 1 (Reference 58), 17, 18, and Criterion III of Appendix B to 10 CFR Part 50 (Reference 59).

The Class 1E onsite