APR1400 DCD CHAPTER 8, "ELECTRIC POWER," AUDIT REPORT

1.0 SUMMARY

Korea Hydro and Nuclear Power Co., Ltd, (KHNP), the applicant, submitted to the U.S. Nuclear Regulatory Commission (NRC), Design Control Document (DCD) for its Advanced Power Reactor 1400 Megawatts (APR1400) application in December 2014. The staff reviewed the DCD and responses to Requests for Additional Information (RAIs) associated with DCD Tier 2, Chapter 8, "Electric Power" and interfacing DCD Tiers 1 and 2. In addition, KHNP submitted the Technical Report titled "Onsite AC Power System Analysis Technical Report" (Reference 1) as part of its design certification application. The NRC staff concluded that additional information was needed to make a determination that the applicant meets the applicable regulatory requirements to comply with Title 10 of the *Code of Federal Regulations* (10 CFR) Parts 50 and 52.

This technical report addresses the adequacy of onsite ac power systems in the APR1400 design by evaluating whether the electrical equipment operates as designed in various plant operating modes and conditions, across the electric power distribution system. It supports the KHNP DCD, Chapter 8, "Electric Power." In reviewing DCD Tier 2, Chapter 8 and the related ac power system technical report, the NRC staff identified a need to conduct a regulatory audit of the various calculations and methodologies related to the electric power distribution system, specifically the calculations and methodologies related to the electrical transient analyzer program (ETAP).

On May 25, 2016, the NRC staff conducted an audit of KHNP's APR1400 ETAP methodologies and calculations at the 11333 Woodglen Drive, Rockville, Maryland office, as specified in the audit plan (ML16118A095). The focus of the audit was to review and evaluate the documentation provided and review applicant's methodologies and to determine whether Chapter 8 of the APR1400 DCD design meets the applicable regulations. The purpose of this audit was to: (1) to examine and evaluate technical, procedural, and process information and (2) to understand or verify information to support the basis of licensing and regulatory design certification decisions related to specific areas of Chapter 8, Sections 8.1, 8.2, 8.3.1, 8.3.2, and 8.4 of the APR1400 DCD and 3) to resolve other opens items in the DCD, Tier 2, Chapter 8 Safety Evaluation (SE).

The audit included a presentation of ETAP methods and calculations, along with a discussion of the technical basis for the methodologies and calculation results. As part of the audit, the staff reviewed various applicable documents such as load calculation sheets, logic diagrams, circuit breaker specifications, electrical single line diagrams, and applicability of results, as well as a demonstration of how various load assumptions effect minimum and maximum voltage requirements and equipment selection. Discussions were held throughout the audit regarding the technical basis for the assumptions and design descriptions, including consistency of conservative design determinations.

The applicant mentioned in the technical report (Reference 1) that the calculations of the power system analysis and characteristic data of major equipment are obtained from a reference plant, which is in operation and/or under construction. Therefore the assumptions of the design data and calculation/analyses are based on the reference plant Shin Kori Nuclear Plants, Units 3 and 4, located in Korea.

Included in this audit report is the Basis of the audit, Observations, Results, and the NRC staff's Conclusions. No RAIs were generated as a result of this audit; the NRC's observations are included in the audit conclusions.

2.0 REGULATORY BASIS

- NUREG-0800, "Standard Review Plan," Chapter 8, "Electric Power"
- Part 50 of 10 CFR, Appendix A, General Design Criterion (GDC) 17, "Inspection and Testing of Electric Power Systems"
- Part 50 of 10 CFR, Appendix A, GDC 18, "Electric Power Systems"
- Section 50.9 of 10 CFR, "Completeness and Accuracy of Information"
- Part 52 of 10 CFR, "Licenses, Certifications, and Approvals for Nuclear Power Plants"

3.0 OBSERVATIONS AND RESULTS

3.1 Bus Transfer

Bus transfer is a process of transferring bus loads from one power source to another. The APR1400 plant switchgear bus configuration are shown on the single line diagrams in Figure 8.1-1, Revision 0, DCD Tier 2. These drawings depict that the onsite power system is connected to the switchyard through two independent offsite circuits, and the offsite circuit is connected to the high-voltage side of the station auxiliary transformer (SAT). In case the power supply is unavailable from the unit auxiliary transformer (UAT) to the safety and non-safety loads fed from the plant switchgear, the power supply is maintained because the onsite non-safety-related and safety-related bus connections are transferred automatically from the UATs to the SATs. During bus transfer, resultant voltage and frequency decay may cause transients so that damage can occur to the motors and loads. The staff reviewed the bus transfer strategy and associated design.

During the audit, the applicant presented the bus transfer analysis and its related control logic diagram provided in the following documents: 1) Bus Transfer Analysis (Reference 12), and 2) 1-823-E158-002, Revision 1, "Control Logic Diagram Class 1E 4.16 kilovolt Switchgear Alternate Feed Power Circuit Breaker from SAT" (Reference 15).

The applicant performed the bus transfer analysis to determine whether a fast transfer is permitted for the medium voltage buses on the basis of the acceptance criteria in accordance with ANSI/NEMA C.50.41-2012, "Polyphase Induction Motors for Power Generating Station." ANSI/NEMA C.50.41-2012 defines a fast bus transfer as one which: a) occurs within a time period of 10 cycles or less, b) the maximum phase angle between the motor residual volts per hertz (V/Hz) vector and the system equivalent V/Hz vector does not exceed 90 degrees, and c) the resultant V/Hz between the motor residual V/Hz phasor and the incoming source V/Hz phasor at the instant of transfer or reclosing is completed does not exceed 1.33 per unit V/Hz on the motor rated voltage and frequency basis. ANSI/NEMA C.50.41-2012 also recommends the use of a synchronizing check device to supervise the switching operation, which the applicant confirmed.

The NRC staff discussed the bus transfer scheme with the applicant as provided in the technical report (Reference 1). The applicant clarified that the primary transfer scheme is a fast sequential transfer scheme. If the conditions before a fast bus transfer do not satisfy the above criteria, a residual voltage bus transfer is implemented. KHNP also stated that the acceptance criteria for the residual bus transfer are based on operation experiences of the reference plant.

“Bus Transfer Analysis” (Reference 12) includes the assumptions and the summary of the bus transfer analysis. During the audit, the applicant informed the staff that the assumptions included an incorrect time chart for the voltage phase difference between two offsite sources from the UAT and the SAT during the transfer. The applicant revised the analysis based on the correct time chart in which the staff verified that the fast transfer from the UAT to the SAT in the revised time chart occurs in less than 10 cycles and is within the acceptance criteria per ANSI/NEMA C.50.41-2012. The staff also verified that the results of the voltage phase angle differences and the resultant V/Hz for the fast bus transfer provided in the summary of the analysis are within the acceptance criteria per ANSI/NEMA C.50.41-2012.

Reference 15 includes the control logic diagram for the fast bus transfer with the synchronizing check relay. The NRC staff inquired whether the transfer is automatic or manual. The applicant clarified that the bus transfer is automatic, but bus transfer can be done manually.

During the onsite audit, the applicant further stated that the bus transfer analysis is under the combined license (COL) applicant’s responsibility and has been identified in the DCD Tier 2 as COL Information Item 8.3(14), as major input data that affect the analysis are assumed from the reference plant and will be refined with site specific information for COL application.

3.2 Motor Starting Analysis:

The motor starting study performs voltage drop analysis of the onsite ac power during starting of large motors, and verifies: 1) whether the starting of the motors will not adversely affect the power distribution system and 2) the terminal voltages are maintained within the allowable limits during the starting conditions of the large motors. The applicant also made available to the staff a Motor Starting Analysis document (Reference 10) in its electronic reading room. This document addresses the motor starting voltages of all buses for various operating modes and loading categories provided in Section 4.3 of the technical report (Reference 1). The staff observed that the allowable voltages are within allowable limit as evident from the minimum operating voltage summary of Class 1E and non-Class 1E buses, i.e., 75 percent of motor rated voltage for Class 1E motors and 80 percent for non-Class 1E motors at the terminals. Additionally, the NRC staff discussed with the applicant, the capability of the motors to withstand the fast bus transfer and the motors parameters considered in the ETAP model for the motors. The applicant clarified that the motors are capable to withstand fast transfer per the guidance in ANSI/NEMA C.50.41-2012, "Polyphase Induction Motors for Power Generating Station." The applicant exhibited the revised portion of the technical report (Reference 1) with an additional loading category for emergency diesel generator (EDG) operation as Category 8, which is "Loss of Offsite Power (LOOP) coincident with Loss of Coolant Accident (LOCA) from EDG." The applicant confirmed that minimum operating voltage summary tables of Class 1E buses are updated in the revised technical report (Reference 1) to include the Category 8 as new condition and loading criteria.

3.3 DC System

During the audit, KHNP presented information to support the licensing and regulatory basis of the APR1400 design certification document related to DCD Tier 2, Section 8.3.2, "DC Power System."

The NRC staff examined the APR1400 design approach on the methodology and assumptions for the DC System Calculation. The DC System design configuration is depicted in the DCD Tier 2, Figures 8.3.2-1, 8.3.2-2 and 8.3.2-3.

The NRC staff discussed, with KHNP, the DC System Short Circuit Current Calculation Number 1-841-E342-020, Revision 3 (Reference 4) made available during the audit. The purpose of this calculation is to determine the short circuit current available in each DC subsystem, and that the equipment are rated to withstand the short circuit contribution. The NRC staff asked the applicant to identify the batteries listed in the table in Section 4.1 of the calculation (Reference 4). The applicant responded that the equipment include the Class 1E 125 Vdc batteries and the Non-Class 1E 125 Vdc and 250 Vdc batteries. This includes the alternate ac (AAC) Gas Turbine Generator batteries, which are Non-Class 1E 125 Vdc.

IEEE Std. 946, "Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations," provides guidance on DC System Short Circuit Calculation. The staff verified: 1) the sum of the short circuit delivered by the battery, battery charger and continuous-duty motors, 2) the assumption for the battery charger output current limit and, 3) the assumption for motors maximum short circuit currents in accordance with IEEE Std. 946. Therefore, the applicant followed the assumptions and methodology as recommended by the guidance in IEEE Std. 946.

DC Battery Sizing is covered in the applicant's RAI 8178, Question 08.03.02-1 response (ML16012A553) and in follow-up RAI 8549, Question 08.03.02-3 response (ML16134A350).

3.4 Power Quality

During the audit, KHNP presented Reference 10, "Total voltage harmonics distortions for all Buses," which provides an analysis of the total voltage harmonic distortions for all the APR1400 buses. The staff used this document along with the technical report (Reference 1), to evaluate the analysis performed by KHNP.

DCD Tier 2, Sections 8.3.1.3.6, and 8.3.2.3.5, state that the non-linear loads such as battery chargers and inverters contribute total harmonic distortion (THD) to the distribution power system. THD degrades the power quality of the system, causing heating at harmonic frequencies on electrical equipment such as motors, transformers and switchgears. The applicant designed the power distribution system so that THD does not affect the Class 1E equipment. The applicant performed the harmonic analysis to determine if the total voltage harmonic distortions, under different plant conditions, are within the recommended limits based on the acceptance criteria in accordance with IEEE Std. 519-2014, "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems." The purpose of the harmonic analysis is to calculate individual and total harmonic distortion and verify if the distortions are within acceptable limits, as established in IEEE Std. 519-2014.

The applicant discussed the harmonic analysis and methodology with the staff. Section 5.1, "Recommended harmonic voltage limits," of IEEE Std. 519-2014 provides the recommended limits for voltage harmonics. For Bus voltages between 1 kilovolt (kV) and 69 kV is recommended that the individual harmonic and the total harmonic distortion (THD) should not exceed 3 percent and 5 percent respectively. The staff verified the acceptance criteria used by KHNP in Section 6.4, "Harmonics Analysis" of the technical report (Reference 1) and the analysis results of the harmonic analysis, and found that the applicant performed the analysis as recommended in Section 5.1 of IEEE Std. 519-2014.

The staff reviewed the results of the ETAP analysis on harmonics to verify that the values of the voltage harmonics are within the limits as described in the acceptance criteria of the technical report (Reference 1). The results showed that the maximum voltage harmonic distortion is 2.75 percent. This meets the acceptance criteria of the recommended practices for harmonics voltages limits. KHNP stated that the power quality analysis for APR1400 design is performed based on a reference plant. The power quality analysis requires site-specific details and will be part of the COL applicant's calculation added in DCD Tier 2, as COL Information Item 8.3(12). In addition, to verify that the as-built distribution system THD is within acceptable limits, DCD Tier 1, Section 2.6.1, ITAAC Item 14 indicates that analysis will be performed to show that THD does not exceed five percent on the Class 1E buses.

Therefore, the staff concludes that the applicant conformed to the methodology and acceptance criteria provided in IEEE Std. 519-2014.

3.5 Equipment Sizing (Short Circuit & Load Flow)

The staff reviewed KHNP documents related to equipment sizing of the electrical equipment, which includes power system short circuit and voltage regulation analyses, motor starting analyses, and bus loading of the power distribution system. Specifically the staff reviewed the following documents on sizing of onsite ac and dc power systems: Class 1E diesel generator, AAC generator, main step-up transformer, UATs and SATs, load center transformers, medium voltage and low voltage switchgear and motor control center, and direct current (dc) system equipment. The dc power system equipment sizing which includes battery and battery charger is discussed separately in this report. The staff verified the assumptions, methodology and summary of results, to verify that the power generation and distribution equipment are adequately sized and are capable of performing its intended function.

Assumptions:

Equipment and medium and low voltage bus loading parameters for the APR1400 design are obtained from the reference plant.

Methodology:

The analyses and calculations of the power distribution system discuss the methodology followed to determine the sizing of the equipment. The applicant presented the postulated source conditions and operating modes. With the load list, initial equipment sizes and ratings were determined, with the following considerations: a) Equipment margins, b) Future load growth, c) Peak loading capacity of connected loads without applying diversity factor, and d) Brake horsepower values of the motors. The equipment sizes were then used as input data for the ETAP modeling and simulations/analysis. The onsite power system analysis for equipment sizing includes load flow and voltage regulation analysis, short circuit analysis, and motor starting analysis.

Load flow Analysis: The steady-state load flow analysis is performed to verify that the voltage regulation and continuous current ratings of the onsite power system are within the acceptable limits, which ensures that the equipment is capable of performing its intended function. The applicant performed the analysis under various plant operating conditions. The acceptance criteria for load voltage variation on continuous operation basis are +/-10 percent of the rated voltage. The summary results show that the operating voltage at the medium and low voltage (MV and LV) switchgear and motor control center (MCC) buses are within the acceptance voltage limits under all loading conditions. The staff reviewed the methodology and summary of results and found that the voltage regulation criteria is satisfied.

Short Circuit Analysis: The short circuit analysis is performed to verify that bus withstand ratings and circuit breaker interrupting ratings for all equipment are adequate for the maximum fault current. The short circuit calculation shows that the maximum short circuit currents at the MV and LV switchgear and MCCs under all operating conditions are within the closing and latching and interrupting rating of the circuit breakers. The staff reviewed the calculation and determined that the sizing of the MV and LV switchgear and MCCs is acceptable since the maximum SC currents are within the ratings of the circuit breakers.

Class 1E Diesel Generators

During the audit, KHNP provided Document 1-820-E342-120, Revision 4, “Class 1E Diesel Generator Sizing” (Reference 2). The document provides the design criteria and methodology used for the sizing of the Class 1E diesels generators. Regulatory Guide 1.9, “Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants,” endorses IEEE Std. 387-1995, “IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations.” Section 2 of Reference 2 provides the design criteria used for the sizing of the Class 1E diesels, which includes: 1) the diesel generator continuous load rating plus 10 to 15 percent of the margin, the margin resulting from the diesel operating at maximum frequency, and 2) the motor ratings. Section 3 of Reference 2 provides the methodology used for calculating the size of the Class 1E diesels using the design criteria specified in Section 2 and Section 4 provides the calculations performed for the sizing of the Class 1E diesel generators.

The staff reviewed the methodologies and results of the calculations to verify that KHNP follows the guidance as specified in RG 1.9. Specifically, the staff verified that the loading of the diesel was in accordance with the guidance in RG 1.9, and that the applicant included the 10 percent margin of the continuous load. The staff determined that adequate information on the Class 1E diesel generators is provided and that the calculations performed where in accordance with RG 1.9.

AAC Generator sizing

KHNP provided Document 1-820-E342-140, Revision 5, "AAC Generator Size" (Reference 3). The document provides the design criteria and methodology used for the sizing of the of the AAC generator. The applicant used the same methodology for sizing the AAC generator as that of Class 1E diesel generators. The non-Class 1E AAC generator is provided for operation of all systems necessary for coping with an SBO and to help mitigate the effects of station blackout (SBO) conditions.

The AAC generator is also used to power permanent non-safety (PNS) loads during a LOOP. In the event of a SBO, the AAC generator provides power to the safety shut-down loads. KHNP performed a calculation, including the 10 percent margin, of the PNS total loads and the safety shut-down loads to compare them to select the greater load for the sizing of the AAC generator. Based on the calculations performed, KHNP concluded that the greater load was the safety shut-down loads.

The staff reviewed the results of the calculations to verify that KHNP followed the guidance as specified in RG 1.9. Specifically, the staff verified that the loading of the AAC generators was in accordance with the guidance, and that the applicant included the 10 percent of the continuous load. The staff determined that adequate information on the generator is provided and that the calculations performed where in accordance with RG 1.9.

Transformers Sizing

KHNP provided "Selection of Load Center Transformer Capacities (revised)," (Reference 5) which provides the methodology for determining the size of the transformers. KHNP followed IEEE C57.12.01-2015, "IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers." KHNP stated that the transformer forced cooled rating should not be less than the maximum expected loading of the load center. The applicant verified this by a load flow analysis using ETAP. The results of the load flow analysis were provided in the applicant's calculation (Reference 5).

The staff verified that the capacity of the transformers were determined based on the requirements established in IEEE C57.12.01-2015. Section 5.2, "Rated Power," of IEEE C57.12.01-2015, provides guidance of the selection of the rated power of the transformer. The staff reviewed the results of the load flow analysis and verified that the transformer loading is less than the rating provided in Tables 8.2-1 of the DCD Tier 2. The staff determined that the load analysis demonstrates that the transformer loads are less than the transformers rating and the sizing is adequate.

3.6 Generator Circuit Breaker

During the audit, the applicant provided Calculation Number 1-811-E342-020, Revision 1, "Isolated Phase Bus Steady State and Short Circuit Current Ratings" (Reference 14). The purpose of the calculation is to select the steady-state and short circuit current ratings of the isolated phase bus and generator circuit breaker (GCB) interrupting rating. The NRC staff examined the APR1400 design approach on the methodology and assumptions for the isolated phase bus (IPB) and generator circuit breaker.

The purpose of the GCB is to connect main generator (MG) to the low-voltage winding of the MT and the high-voltage winding of the UATs. Under normal operations, the MG supplies power through an IPB and GCB to the MT and UAT.

SRP 8.2, Appendix A, "Guidelines for Generator Circuit Breakers/Load Break Switches," and IEEE Std. C37-013-1997, "Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis," provide information related to the generator circuit breaker's capability of interrupting the system maximum available fault current. SRP 8.2, Appendix A, Section 2.B.iii, "Short Circuit Current Rating" states that "the circuit breaker should have, as a minimum, the capability of interrupting the maximum asymmetrical and symmetrical fault current available at the instant of primary arcing contact separation. This current should be calculated by assuming a bolted three phase fault at a point on the system which causes the maximum amount of fault current flowing through the generator circuit breaker."

The staff verified the methodology for determining the isolated phase bus rating (continuous current and momentary duty) as well as the generator circuit breaker interrupting current rating. Specifically, the staff verified that for this calculation: 1) a prefault voltage of 1.05 per unit (pu) was applied for isolated phase bus maximum short circuit current and 2) fault locations chosen produced fault currents from the grid source, generator, UATs, and combinations thereof to ensure that the equipment can accommodate maximum amount of fault current flowing through the isolated phase bus and generator circuit breaker. The staff verified that the calculation concludes that the generator circuit breaker has the capability of interrupting the maximum asymmetrical and symmetrical fault current. The staff concludes that the applicant conformed to the methodology provided in SRP 8.2 and IEEE C37-013-1997.

3.7 The Staff's Review of the RAI Responses

The NRC staff requested additional information and clarification of the applicant's approach on the analyses, design calculations, methodology, and assumptions discussed in various RAIs and in the technical report (Reference 1). The information provided by KHNP were assessed to augment the staff's understanding and verification in this audit. This information received in the RAI responses and staff's review are in the Staff's Safety Evaluation Report (SER) on the methodology and assumptions of the calculations and analyses, regarding how the electrical systems conform to the applicable regulations.

4.0 CONCLUSION

The NRC staff began and ended their audit in one day, May 25, 2016. The audit confirmed the NRC's knowledge of the validity of KHNP's ETAP design, analyses, and results. All NRC staff questions were satisfactorily answered and the need for follow-on RAIs is not anticipated. The NRC staff: (1) examined and evaluate technical, procedural, and process information and (2) verified information to support the basis of licensing and regulatory design certification decisions related to specific areas of Chapter 8, Sections 8.1, 8.2, 8.3.1, 8.3.2, and 8.4 of the APR1400 DCD Tier 2. As discussed in Section 3 of this report, the staff reviewed applicant's methodologies and finds that the specific documentation reviewed meets the applicable regulations.

LIST OF ATTENDEES

May 25 – 26, 2016

Name	**Affiliation**
Jorge A. Cintron-Rivera	NRC
Adakou Foli	NRC
Ngola Otto	NRC
Sheila Ray	NRC
Fanta Sacko	NRC
Swagata Som	NRC
James Steckel	NRC
Che-Wung Ha	KHNP
Seokhwan Hur	KEPCO E&C
Sung Jo Jo	KEPCO E&C
Kyung Woong Kang	KEPCO E&C
Seung Min Lee	KEPCO E&C
Steven Mannon	AECOM
Rob Sisk	Westinghouse

Enclosure 1

LIST OF DOCUMENTS MADE AVAILABLE TO THE NRC STAFF

APR1400 DCD CHAPTER 8 ETAP AUDIT

1. APR1400-E-E-NR-14001-P, Revision 2 (Draft), Onsite AC Power System Analysis Technical Report.

2. 1-820-E342-120, Revision 4, "Class 1E Diesel Generator Size."

3. 1-820-E342-140, Revision 5, "AAC Generator Size."

4. 1-841-E342-020, Revision 3, "DC System Short Circuit Current."

5. ETAP Input Data (including load list).

6. Selection of Load Center Transformer Capacities.

7. Bus Loading.

8. Load Flow Analysis.

9. Short Circuit Analysis.

10. Motor Starting Analysis.

11. Harmonic Analysis.

12. Bus Transfer Analysis.

13. ETAP Single Line Diagrams.

14. 1-811-E342-020, Revision 1, "Isolated Phase Bus Steady State and Short Circuit Current Ratings."

15. 1-823-E158-002, Revision 1, "Control Logic Diagram Class 1E 4.16 kilovolt Switchgear Alternate Feed Power Circuit Breaker from SAT."

Enclosure 3