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.:	**413-8529**
SRP Section:	**08.03.01 – AC Power Systems (Onsite)**
Application Section:	**08.03.01**
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Question No. 08.03.01-22

By letter dated January 15, 2016, the applicant provided a response to RAI 8104, Question 08.03.01-13, regarding "Electrical Power System calculations". The RAI response attached a Technical Report (TeR) APR1400-E-E-NR-14001-P Rev 1.

The staff reviewed the TeR and requests the following information/clarifications:

1. Emergency Diesel Generator (EDG) Loading Scenario:

   In Section 4.3 of the TeR, various plant operating modes and source conditions are categorized, except that the EDG scenarios and modeling assumptions are not described here. Please discuss if any of the loading categories stated in the TeR include EDG. Discuss the scenario(s) when power is supplied from the EDG, with EDG loading based upon a loss of offsite power (LOOP) simultaneous with loss of coolant accident (LOCA). Discuss the EDG electrical transient analyzer program (ETAP) results in terms of bus voltages at the Class 1E buses.

2. Cable Sizes and Impedances:

   In Section 5.1.9, the applicant states that cable sizes and assumed lengths are based on the reference plant to facilitate model updates. Please provide a summary as how the cables (MV and LV) are modeled with design assumptions. Describe how the sizing (loading), derating, cable spacing, tolerance of lengths, ambient temperature, cable operating temperatures and other anticipated correction factors are determined in the ETAP model.

3. Motor Loading in ETAP:

   In Section 5.2.7 of the TeR, the motor loading capacities in horse power (HP) are provided for various loading scenarios. Please discuss the assumptions for service factor, rated motor slip, motor efficiency and power factors in general for large and low voltage motors (as per National Electrical Manufacturers Association (NEMA) MG 1) in the ETAP model. Also discuss the assumptions on the motor locked rotor current and locked rotor power factor, as modeled.

4. Tolerance in %Z:

   In Section 5.2.3 of the TeR, the %Z and the tolerance values for transformers are provided. The tolerance for Unit Auxiliary Transformer (UAT) and Station Auxiliary Transformer (SAT) are assumed as ± 20%. The applicant indicated that the tolerances are in accordance with the IEEE Std. C57.12.00 as the reference guidance. IEEE Std. C57.12.00 (Liquid-Immersed Distribution, Power and Regulating Transformers), Section 9.2, states that the impedance of a transformer having three or more windings shall have a tolerance of ± 10%. Please provide a clarification as how the tolerance was determined for UAT and SAT at ± 20%, which is not as per the IEEE guidance.

5. Winding Temperature Rise:

   In Section 5.2.3 of the TeR, the average winding temperature rise for UAT and SAT is provided as 55 ◦C. The guidance in IEEE Std. C57.12.00), Section 5.11, states that the average winding temperature rise above ambient temperature shall not exceed 65 ◦C, at rated kVA. Please provide a clarification as to why the temperature rise is selected at 55 ◦C at rated KVA. Please discuss further if the UAT and SAT also have a 65 ◦C rise with increased rating at rated KVA at ambient of 30 ◦C. Also provide the temperature rise value for Main Transformer (MT). Please explain the difference.

6. Main Generator and Main Transformer Rating:

   In Sections 5.2.2, and 5.2.3 of the TeR, the MG and MT ratings are indicated as 1690 MVA, and 1670 MVA respectively. Please explain the difference in these ratings and how these ratings have been determined (accounting for losses, Unit aux loads etc.) and verified.

7. Cooling Class:

   In Sections 5.2.3, and 5.2.6 of the TeR, the Cooling Class designations are provided as AA, or AA/FA for Load Center Transformers. Are these dry type or oil-filled transformers? According to C57.12.00, these designations (AA, AA/FA) are previous designations and have been updated. Please provide the present designation of the cooling scheme as per C57.12.00, Table 2, if these are oil-filled transformers. Provide the Cooling Class designation of the Main Transformer, UAT and SAT.

8. Tap Bus rating:

   In Section 5.2.6 of the TeR, the Isolated Phase Main Bus rating is provided. Please provide the Tap Bus (Main bus to UAT) continuous current rating and short-time current rating. Explain how the tap-bus rating has been determined and verified for the adequacy of the rating.

Response

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

1. Emergency Diesel Generator (EDG) Loading Scenario

No loading category in Section 4.3 of the onsite ac power system analysis technical report APR1400-E-E-NR-14001-P, Rev.1 (hereinafter "TeR") included EDG operation. A loading category is being added to address the loading case when the Class 1E EDGs supply the worst case electrical loads for safe shutdown during a LOCA concurrent with a LOOP. In this case, each EDG is deemed to supply the maximum expected load, as listed in Table 8.3.1-2 of DCD Tier 2, irrespective of the operating status of redundant loads in the other trains.

An ETAP-based load flow analysis was performed to check the bus voltages at the Class 1E buses of each train. The minimum operating voltages at the Class 1E buses during a LOCA concurrent with a LOOP, are summarized in Table 1 and the result of the load flow analysis shows that the operating voltages at the medium voltage (MV) switchgear, load center (LC), and motor control center (MCC) buses of each train are within the acceptable voltage limit provided in Subsection 6.1.1 of the TeR.

Table 1. Minimum Operating Voltage Summary (Unit: %) TS

2. Cable Sizes and Impedances

In the ETAP model, the branch cables are modeled on the basis of the cable data from the reference plant (Shin-Kori Nuclear Power Plant Units 3 & 4). The cable sizing work performed for the reference plant did not rely on the ETAP cable sizing function, but was done by using cable ampacity tables. The ampacity tables provide the allowable continuous current value for each cable size of different voltage levels and considered the cable grouping, specific cable spacing and derating effects due to ambient temperature, fire wrap or stop, and other conditions that have impact on current carrying capability of cables.

Further details on the base cable ampacities and derating factors applied are discussed in the response provided to RAI 210-8239, Question 08.03.01-20 (Reference KHNP submittal MKD/NW-15-0308L, dated December 3, 2015; ML15338A033).

The adequacy of branch cable sizes in terms of voltage drop, has been reviewed in the APR1400 ETAP model through the load flow analysis discussed in Section 6.1 of the TeR. For instance, if the length of a cable is very long such that a significant voltage drop occurs across the cable causing low voltage at the bus(es) fed by the cable, the size of the cable is re-adjusted to maintain the bus voltage within the proper level.

Tolerance of cable lengths is not specifically considered in the ETAP analysis since the cable design lengths used are based on final cable routing design of the reference plant.

3. Motor Loading in ETAP

The motor characteristic models and parameters such as locked rotor current, locked rotor power factor, power factor, efficiency, rated motor slip used in the ETAP model were derived from the motor characteristics data for the reference plant provided by the manufacturers. In instances where there is a design change from the reference data (e.g., new load or rating change), similar parameters to the existing ones were considered.

In ETAP models, service factor (SF) is used with a study option for voltage drop calculations of the machine feeder cable. A default SF of "1" is reflected in the APR1400 ETAP model since the APR1400 ETAP model did not include the machine feeder cables. The ETAP study option that considers SF in the voltage drop calculation of machine feeder cable will not be used for the APR1400 since the machine loads of the APR1400 are designed to operate at design load, which does not consider the SF.

4. Tolerance in %Z

The UATs and SATs adopt on load tap changers (OLTCs) that change the position of the primary winding between minus 15 percent and plus 5 percent with reference to the nominal tap position. The turn ratio between the primary and secondary windings varies according to the tap positon. In order to compensate for the impedance variation due to the turn ratio change, ±10 percent tolerance is assumed and applied in addition to the ±10 percent manufacturing tolerance, which renders the overall transformer tolerance to be ±20 percent.

The COL applicant may want to obtain actual impedance variation data according to the turn ratio from the selected transformer manufacturer and perform an ETAP analysis based on the actual data.

5. Winding Temperature Rise

The UAT and SAT have dual MVA ratings both at 55 °C and 65 °C average winding temperature rise above an ambient temperature of 40 °C. The 55 °C base rating is for the balanced condition which means large motor loads are assigned to be as unbiased as possible to neither Division I nor Division II. The 65 °C base rating is for the unbalanced condition which means large motor loads are assigned to be biased to either Division I or Division II. The 65 °C base MVA rating is 112 percent of the 55 °C base MVA rating in accordance with IEEE Std. C57.12.40.

The main transformer (MT) also has dual MVA ratings that have the same ratio relationship between 55 °C and 65 °C base ratings like the UATs and SATs. The required MVA rating of the MT depends on the main generator (MG) operating power modes such as whether it is lagging or leading. The 55 °C base rating is for the lagging operation mode and the 65 °C base rating is for the leading operation mode.

Each 65 °C base rating of the aforementioned transformers, which is larger than each 55 °C base rating, is enough to supply the required loadings in all analyzed conditions. However, the 55 °C base rating is sized sufficiently for the normal load condition and the 65 °C base rating is sized sufficiently for the adverse heavy operating condition. Each transformer's dual rating shall satisfy both conditions. By using this conservative methodology to determine the dual ratings of 55 / 65 °C, the transformers' life expectancies are considered to be longer than transformers of single 65 °C base rating.

The MVA ratings of the UAT, SAT, and MT are provided in Table 2.

Table 2 MVA ratings and Cooling Class of Power Transformers (Unit: MVA)

Average Winding Temperature Rise above Ambient Temperature	MT	UAT	SAT
55 °C	1670	H = 71.0/94.7 X = 48.0/64.0 Y = 23.0/30.7	H = 67.0/89.4 X = 44.0/58.7 Y = 23.0/30.7
65 °C	1870	H = 79.6/106.0 X = 53.8/71.7 Y = 25.8/34.3	H = 75.1/100.0 X = 49.3/65.7 Y = 25.8/34.3
Cooling Class[1)]	OFAF or ODAF	ONAN/ONAF	

Notes

1) Oil direct air forced (ODAF) cooling of transformer can be considered as the improved version of OFAF. Forced circulation of oil is directed to flow through predetermined paths in transformer winding. The cool oil, entering the transformer tank from cooler or radiator, is passed through the winding where gaps for oil flow between insulated conductors are provided for ensuring faster rate of heat transfer. The meanings of the other cooling designations are described in IEEE Std. C57.12.00

6. Main Generator and Main Transformer Rating

The MG rating of 1,690 MVA at a 0.9 lagging power factor is based on the finalized technical data of the MG of the reference power plant.

The MT rating is derived from the following equation, subtracting the UAT loading and the MT loss from the MG output.

$$R_T = P_T + jQ_T = P_G + jQ_G - \{(p_t + jq_t) + (P_a + jQ_a)\}$$

where,
- R_T : MT output MVA
- P_T : MT output MW
- Q_T : MT output MVAR
- P_G : MG output MW

- Q_G : MG output MVAR
- p_t : MT loss MW
- q_t : MT loss MVAR
- P_a : UAT loading MW
- Q_a : UAT loading MVAR

As a result of the calculation, the MT's demanded output MVA value is 1519.2 / 1701.5 MVA at OFAF 55 / 65 °C.

Taking into account a design margin of 10 percent being added to the above values to account for overload operation and reliability, the MT is sized as 1,670 / 1,870 MVA at OFAF 55 / 65 °C.

7. Cooling Class

The LC transformers, which have ventilated cast resin encapsulated windings, are dry type transformers and meet the design and test requirements stipulated in IEEE Std. C57.12.01-2005. The cooling classes provided in Table 5-5 of the TeR are the applicable ones in accordance with the cooling classes identified in IEEE Std. C57.12.01.

The cooling class designations of the MT, UAT, and SAT are provided in Table 2 of this response.

8. Tap Bus rating

The UAT tap bus's continuous current rating is 2,700 A and the short-time current rating is 690 kA, asymmetrical rms.

The continuous current rating is determined by considering the UAT's maximum MVA rating

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and the MG's minimum output voltage as provided in the following fomula.

According to the above calculation, the UAT tap bus's continuous current rating is sized as 2,700 A.

The short-time current rating of the UAT tap bus has been determined through the following process:

- Per-unit (PU) impedance values of electrical equipment (MG, MT, and UATs) and the grid (765 kV source), which affect insulated phase bus (IPB) current ratings, are calculated at 100 MVA base.
- An impedance diagram that shows the IPB connections of the above objects and their fault currents is drawn in Figure 1.

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Figure 1. Impedance Diagram for Fault Current

- In the above impedance diagram, a fault location subject to fault currents from the 765 kV source, MG, MT, and one UAT is established and the equivalent admittance, Y_{EQ}, is calculated so that the UAT tab bus rating can be derived.

- I_{BASE} is calculated at 100 MVA base and 24 kV.

- Asymmetrical rms fault current of the UAT tap bus ($I_{S,FUT}$) is calculated by the following formula:

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No specific verification is necessary since the above assumptions and calculations are based on a conservative approach.

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

Technical Report APR1400-E-E-NR-14001-NP, Rev. 1, Sections 4.3, 6.1, and Table 6-3 will be revised and Figure 4-6 will be added as shown in the Attachment.

4.3. Source Condition and Operating Mode

This section presents the source conditions based on operating modes of the APR1400 nuclear steam supply system (NSSS) response to postulated disturbances in process variables and to postulated malfunctions or failures of equipment. Such incidents (or events) are postulated and their consequences are analyzed despite the many precautions that are taken in the design, construction, quality assurance, and plant operation to prevent their occurrence. The effects of these incidents are examined to determine their consequences and to evaluate the capability built into the plant to control or accommodate such failures and situations.

To evaluate the adequacy of auxiliary power system design and load assignments, the various plant operating modes and the source conditions are considered. As part of the evaluation, the loading are categorized into the following ~~seven~~ eight levels according to plant conditions:

Loading Categories

- Category 1: Normal operation from UAT
- Category 2: Startup from UAT
- Category 3: Unit trip coincident with LOCA from UAT
- Category 4: Hot standby from UAT
- Category 5: Unit trip coincident with LOCA from SAT
- Category 6: Hot standby from SAT
- Category 7: SBO from AAC GTG
- Category 8: LOOP coincident with LOCA from EDG

The four sources of power feeding the auxiliary system loads are shown in Figures 4-2 through 4-~~5~~6. These sources are as follows, and the valid load conditions for the respective sources are denoted in parentheses.

- Source 1: MG connected to 765 kV offsite power system. This source is valid for loading category 1 (Normal).
- Source 2: UATs connected to 765 kV offsite power system through the MT when the GCB opens (back-feeding). This source is valid for loading categories 2, 3, and 4 (startup, unit trip with LOCA, and hot standby).
- Source 3: SATs connected to 154 kV offsite power system. This source is valid for loading categories 5 and 6 (unit trip with LOCA, hot standby).
- Source 4: AAC GTG. This source is valid for loading category 7 (SBO).
- Source 5: EDGs. This source is valid for loading category 8 (LOOP with LOCA).

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6. ANALYSIS

LOOP with LOCA,

6.1. Steady-State Load Flow Analysis

Steady-state load flow analysis determines the voltage, voltage angle, active power, and reactive power in the power plant.

The load flow analysis is to check the undervoltage and overvoltage of all buses during startup, normal operation, unit trip with LOCA, hot standby, SBO, and no load condition (as an extreme case of light load). The analysis also provides the necessary information to determine or verify the following:

- The operating voltage at the MV switchgears, LC buses, and MCC buses
- Setpoint of undervoltage relay of 13.8 kV and 4.16 kV switchgears
- Percent impedance (%Z) and tap rating of transformer
- Other data for power system analysis

6.1.1 Acceptance Criteria

The acceptance criteria for load voltage variation on continuous operation basis are +/-10 percent of the rated voltage at the equipment terminals.

Considering voltage drops across the cables between the buses and load terminals, different voltage ratings of motor loads, and transformer voltage restriction, the acceptance criteria for bus voltage variations are calculated as Table 6-1.

Table 6-1. Acceptance Criteria for Bus Voltage Variation at the Steady-state

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Table 6-2. Minimum operating Voltage Summary of Non-Class 1E Buses (Unit: %) TS

Table 6-3. Minimum operating Voltage Summary of Class 1E Buses (Unit: %) TS