VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

10CFR50.90

August 8, 2019

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555-0001

Serial No.	19-210A
NAPS/DPM	R1
Docket Nos.	50-338/339
License Nos.	NPF-4/7

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNITS 1 AND 2
PROPOSED LICENSE AMENDMENT REQUEST
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION (FOLLOW-UP)
REGARDING OPEN PHASE PROTECTION PER NRC BULLETIN 2012-01

By letter dated April 30, 2018 (Serial No. 18-072) (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18127A073), Virginia Electric and Power Company (Dominion Energy Virginia) submitted a license amendment request (LAR) to add operability requirements, required actions, and surveillance requirements (SR) to the Technical Specifications (TS) for the 4160V emergency bus negative sequence voltage (open phase) protection function.

In response to an NRC Staff request, additional information was provided on March 24, 2019 (Serial No. 19-210) (ADAMS Accession No. ML19156A207).

In a July 10, 2019 e-mail from Mr. Ed Miller (NRC) to Mr. Craig Sly (Dominion Energy Virginia), the NRC staff provided a follow-up request for additional information (RAI). Dominion's response to the follow-up RAI is provided in Attachment 1.

In addition to Dominion's response to the RAI, the following information is provided in the Attachments to this letter:

- Attachment 2 provides a copy of the marked-up Technical Requirements Manual showing how time delays are incorporated
- Attachment 3 provides copy of the UFSAR with the revised 'Insert A' (changes highlighted) and page 8.3-4, as originally submitted, for context
- Attachment 4 provides a copy of the article, "Typical Expected Values of the Fault Resistance in Power Systems"
- Attachment 5 provides a copy of the Study Cases for RAI No. 4 and Attachment 5 to Calculation EE-0894

The information provided in this letter does not affect the conclusions of the significant hazards consideration or the environmental assessment included in the April 30, 2018 LAR.

IE76
NRR

Should you have any questions or require additional information, please contact Ms. Diane E. Aitken at (804) 273-2694.

Respectfully,

Gerald T. Bischof
Sr. Vice President Nuclear Operations and Fleet Performance

COMMONWEALTH OF VIRGINIA)
)
COUNTY OF HENRICO)

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Mr. Gerald T. Bischof, who is Sr. Vice President – Nuclear Operations and Fleet Performance, of Virginia Electric and Power Company. He has affirmed before me that he is duly authorized to execute and file the foregoing document in behalf of that company, and that the statements in the document are true to the best of his knowledge and belief.

Acknowledged before me this 8th day of August, 2019.

My Commission Expires: March 31, 2022

Diane E. Aitken
Notary Public

DIANE E. AITKEN
NOTARY PUBLIC
REG. #7763114
COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES MARCH 31, 2022

Commitments contained in this letter: None

Attachments:

1. Response to NRC Request for Additional Information (Follow-up) Regarding Open Phase Protection per NRC Bulletin 2012-01 - Proposed License Amendment Request
2. Copy of the marked-up Technical Requirements Manual showing how time delays are incorporated
3. Copy of the UFSAR with the revised 'Insert A' (changes highlighted) and page 8.3-4, as originally submitted, for context
4. Copy of the article, "Typical Expected Values of the Fault Resistance in Power Systems"
5. Study Cases for RAI No. 4 and Attachment 5 to Calculation EE-0894

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NRC Senior Resident Inspector
North Anna Power Station

Attachment 1

RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION (FOLLOW-UP) REGARDING OPEN PHASE PROTECTION PER NRC BULLETIN 2012-01 - PROPOSED LICENSE AMENDMENT REQUEST

Virginia Electric and Power Company
(Dominion Energy Virginia)
North Anna Power Station Units 1 and 2

Response to NRC Request for Additional Information (Follow-up) Regarding Open Phase Protection per NRC Bulletin 2012-01 - Proposed License Amendment Request

By application dated April 30, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18127A073), Virginia Electric and Power Company (Dominion Energy Virginia), the licensee for North Anna Power Station, Units 1 and 2, proposed to revise Technical Specifications (TS) 3.3.5 for Loss of Power (LOP) Emergency Diesel Generator Start Instrumentation. The license amendment request (LAR) addresses the potential for an open phase condition (OPC) that could exist on one or two phases of a primary off-site power source and that would not currently be detected and mitigated by the existing station electrical protection scheme. In response to the NRC Staff's request, the licensee provided additional information on March 24, 2019 (ML19156A207).

The NRC staff has identified the need for additional information (follow-up) to complete the review of LAR.

Applicable Regulatory Requirements

Title 10 of the Code of Federal Regulations (10 CFR) Part 50.36(c)(2) provides the requirement for the establishment of TS limiting conditions for operation (LCO). Specifically, paragraph 50.36(c)(2)(ii) requires that a TS LCO of a nuclear reactor be established for each item meeting one or more of the criteria listed. For this LAR, Criterion 3 applies which states: "A structure, system, or component that is part of the primary success path and which functions or actuates to mitigate a DBA or transient that either assumes the failure of or presents a challenge to the integrity of a fission product barrier."

10 CFR 50.36(c)(3), Surveillance requirements, requires surveillance relating to test, calibration, or inspection to assure that the necessary quality of systems and components is maintained, that facility operation will be within safety limits, and that the limiting conditions for operation will be met.

Request for Additional Information (RAI)

RAI # 1

In the letter dated May 24, 2019 (in response to RAI-EEOB-3), the licensee stated that because BE1-47N relay operates with an inverse time characteristic, which would result in a range of time delays for various OPC events, the inclusion of the allowable values for the full range of time delays in TS is not considered practical. The North Anna Technical Requirements Manual is being revised to incorporate the setpoint for the BE1-47N relay, which will include the time dial setting.

Please provide a mark-up of North Anna Technical Requirements Manual showing how the time delays will be incorporated and explain how any future changes in time delay settings will be controlled.

Dominion Energy Response

Attachment 2 provides a copy of the marked-up North Anna Technical Requirements Manual showing how the time delays will be incorporated. Changes to the Technical Requirements Manual are controlled in accordance with station procedures that require a 50.59/72.48 Applicability Review and a detailed Technical Analysis and Safety Assessment.

RAI # 2

The staff noticed the following underlined discrepancies in statements made in the LAR and a statement made in the mark-up of UFSAR provided in response to RAI-EEOB-12:

LAR Attachment 1, Page 8: At a minimum of 4 percent negative sequence, the BE1-47N relay will energize [trip] and send a start signal [to EDG] in approximately 11 seconds.

LAR Attachment 1, Page 14: Analysis results show that for most open phase events in which the BE1-47N relays trip, the tripping time is less than 6 seconds after the open phase event occurs.

Mark-up of UFSAR (Page 8.3-4, Insert A): A time dial setting is used which results in a typical trip time delay of less than 6 seconds for any open phase condition sensed at an emergency bus.

Please address how you will resolve these discrepancies. If UFSAR changes are needed to make the UFSAR consistent with the LAR, provide any corresponding UFSAR revision markups.

Dominion Energy Response

To address the discrepancies described above, 'Insert A' for page 8.3-4 of the UFSAR change submitted in Attachment 7 to Virginia Electric and Power Company letter dated May 24, 2019, "Response to Request for Additional Information on Proposed License Amendment Request Open Phase Protection Per NRC Bulletin 2012-01," (ADAMS Accession No. ML19156A207) has been revised. Attachment 3 provides a copy of the revised 'Insert A' (changes highlighted) and page 8.3-4, as originally submitted, for context.

RAI # 3

In the LAR, Attachment 1, Page 10, the licensee stated that the following open phase conditions were considered:

- *Single open phase without a ground connections;*
- *Single open phase with a 350 ohm grounded connection; and*
- *Single open phase with a solid grounded connection.*

Regarding the 350 ohms ground connection, in the letter dated May 24, 2019 (in response to RAI-EEOB-5), the licensee stated that the total fault impedance of a high resistance fault was calculated based on an empirical model as discussed in the Surry Open Phase Condition Detection Analysis calculation and IEEE paper, "Typical Expected Values of the Fault Resistance in Power Systems." Using the most conservative method discussed in the IEEE paper, a total fault impedance of 173.4 ohms was calculated. This value was doubled to 346.8 ohms and rounded to 350 ohms for use in North Anna's calculation.

Please provide the following additional information:

(a) A brief calculation showing how the above fault impedance of 173.4 ohms was obtained.

(b) Confirmation that doubling the fault impedance is considered more conservative.

(c) How the above various types of ground connections were considered in the Table-1 provided on Page 15 of LAR, Attachment 1, and explain the significance of "Time = 8 seconds" provided in Table-1.

Dominion Energy Response

Response to RAI #3(a):

By letter dated March 14, 2018, Virginia Electric and Power Company submitted, "Clarification of Request for Additional Information Response and Associated License Amendment Request Revision" (ADAMS Accession No. ML18075A324). Pages 4 and 5 of the March 14, 2018 letter provided a summary of the OPC analysis performed for Surry Power Station which included a brief analysis showing how the fault impedance of 173.4 ohms was obtained. These analyses are applicable for North Anna.

Additionally, Attachment 4 provides a copy of the article, "Typical expected values of the fault resistance in power systems," referenced on page 4 of the March 14, 2018 letter as, "The most conservative method per the reference...is based on the empirical model proposed by A. Washington,..."

Response to RAI #3(b):

Case studies were performed that verified doubling the fault impedance was conservative.

Response to RAI #3(c):

The three types of ground connections described above were considered for Buses 1H, 1J, 2H and 2J in Table 1 on page 15 of Attachment 1 to the license amendment request (LAR) submitted by Virginia Electric and Power Company on April 30, 2019 (ADAMS Accession No. ML18127A073).

Each row of Table 1 is associated with an OPC location/alignment. The columns are associated with the minimum and maximum V_2 (Negative Sequence Voltage) values for each emergency bus. The minimum and maximum values are associated with all three ground conditions that were evaluated.

"Time = 8 seconds" provided in Table 1 is the post-transient time from the open phase event.

RAI # 4

In the letter dated May 24, 2019 (in response to RAI-EEOB-8), the licensee stated that for a voltage unbalance greater than 5%, the BE1-47N relays should isolate the motor loads from the OPC condition prior to the I2 x t value reaching 20 pu. To validate this condition was met for the BE1-47N relays, a model was created in EMTP-RV to calculate the time until the I2 x t value for each monitored motor reached 20 pu. This value was compared to the trip time of the BE1-47N relay for each event modeled.

In the LAR, Attachment 1, Page 13, the licensee also stated: "For a voltage unbalance between 1% and 5%, the NEMA MG-1 de-rating factor was applied to the motor rating. If the brake horsepower (BHP) of the motor is less than the de-rated horsepower rating, then continuous operation of the motor was determined to be acceptable. In cases where the BHP is greater than the de-rated horsepower rating, the motor must be isolated from the faulted source. The calculation quantifies the time duration for which the motor may be operated on the faulted source before the negative sequence current heating capability is exhausted. The resulting time duration was used to determine if manual action (alarm) is acceptable or if automatic action (trip) is necessary."

Because no alarm is provided in the control room if the voltage unbalance is between 1% and 5%, please provide a tabulation of all study cases in which the voltage unbalance is between 1% and 5%, and justification why all these cases are considered acceptable without any alarm or tripping function.

Dominion Energy Response

Attachment 5 provides 4 tables of the cases in which the negative sequence voltages were between 1% and 5%, one table for each emergency bus. There are three types of results; "Yes", "No", and "Yes***".

"Yes***" results are for Auxiliary Feedwater and Inside Recirculation Spray cases where the NEMA derating factor was unacceptable. The thermal margin for these cases was evaluated to be acceptable in Attachment 5 of calculation EE-0894 (provided in Attachment 5 to this response).

Results specified as "No" indicate cases where sufficient NEMA derating was not available. In these cases, motor damage could result after an extended duration of operation, degrading the expected life of the motor. Therefore, to preclude this from occurring, additional relays have been installed on Transformer 1 and Transformer 2 that provide an alarm function to the Main Control Room when these conditions exist. The alarm will alert the operators of the need to isolate the impacted emergency bus.

Attachment 2

COPY OF THE MARKED-UP TECHNICAL REQUIREMENTS MANUAL SHOWING HOW TIME DELAYS ARE INCORPORATED

Virginia Electric and Power Company
(Dominion Energy Virginia)
North Anna Power Station Units 1 and 2

Table 4.5-1 (page 5 of 5)
Engineered Safety Features Response Times

INITIATING SIGNAL AND FUNCTION	RESPONSE TIME IN SECONDS
13. Loss of Power	
a. 4.16 kv Emergency Bus Undervoltage (Loss of Voltage)	$\leq 13.3^{(e)}$
b. 4.16 kv Emergency Bus Undervoltage (Degraded Voltage)	$\leq 11.5^{(e)}$ with SI signal $\leq 74.0^{(e)}$ with no SI signal
14. Automatic Switchover to Containment Sump	
a. Automatic Actuation Logic and Actuation Relays	N.A.
b. Refueling Water Storage Tank (RWST) Level-Low Low	≥ 110 ≤ 200

(e) The response times shown are based on the time from when the signal reaches the trip setting until the diesel generator is supplying the emergency bus.

c. 4.16 kv Emergency Bus Negative Sequence Voltage — N.A.

Table 4.9-1 (page 1 of 1)
EDG Loss of Power Start Instrumentation Trip Setpoints

FUNCTION	TRIP SETPOINT
Loss of Power	
a. 4160 Volt Emergency Bus Undervoltage (Loss of Voltage)	3080 volts with a time delay of 2.0 ± 0.5 seconds
b. 4160 Volt Emergency Bus Undervoltage (Degraded Voltage)	3746 volts with a time delay of: 1. 7.5 ± 0.75 seconds with Safety Injection (SI) signal; and 2. 56 ± 6 seconds, without SI signal
c. 4160 Volt Emergency Bus Negative Sequence Voltage	4% Negative Sequence Volts with a time dial setting of 10 (a)

(a) Negative Sequence Voltage is calculated as a percentage of nominal voltage

Attachment 3

COPY OF THE UFSAR WITH THE REVISED 'INSERT A' (CHANGES HIGHLIGHTED) AND PAGE 8.3-4, AS ORIGINALLY SUBMITTED, FOR CONTEXT

Virginia Electric and Power Company
(Dominion Energy Virginia)
North Anna Power Station Units 1 and 2

No changes for this page. Page provided for reference only.

The 4160V emergency switchgear is arranged in two separate systems designated H and J. The H bus is associated with train A, while the J bus is associated with train B. The buses are physically as well as electrically, separated from each other in different missile-protected areas on the bottom floor of the service building as shown in Reference Drawing 18. The 4160V H and J buses are arranged as shown in Reference Drawing 4. The 4160V buses are rated 1200A serving emergency loads through breakers equipped to protect the loads from overcurrent. The 480V emergency switchgear is also separated and located in missile-protected areas.

The 480V emergency switchgear buses H and J are arranged as shown in Reference Drawing 5. These buses are rated at 2000A with breakers equipped with overcurrent protection for the loads. The 480V motor control centers are shown in Reference Drawings 6 through 11 and 19.

The 480V emergency buses are equipped with normally open back feed breakers and an electrical connection which can be powered by a portable generator during a Beyond Design Basis Event.

The loads on the H and J buses on either the 4160V or the 480V level are typically redundant and are sized based on their required functions or the required functions of their associated components (e.g. a motor on a safety-related pump). The safety-related buses and their loads are shown in Reference Drawings 1 through 11 and 19.

There are other interconnections between buses, buses and loads, and buses and sources on the emergency 4160V system. The interconnection between bus and supply will be described for the H bus only since the J bus is identical, with the exception of the reserve station service transformer and transfer bus used and as noted in the following paragraph.

or open phase condition

undervoltage, overcurrent, or open phase condition.

The H bus is connected to the reserve station service transformer C, its preferred supply, through a feeder breaker from the transformer to transfer bus F and two breakers in series between the transfer bus and the emergency bus. The feeder breaker from the transformer trips on overcurrent; transfer bus undervoltage; both 34.5 kV breakers (powering the transformer) open; or reserve station service transformer pilot wire, differential, or overcurrent. The breaker from the transfer bus trips due to overcurrent; undervoltage on either of the transfer or emergency buses; a trip of the feeder breaker from the transformer to the transfer bus; or transformer pilot wire, differential, or overcurrent. The feeder breaker in the emergency bus will trip due to an emergency bus ~~undervoltage or overcurrent~~. The emergency diesel generator starts when a safety injection signal is received, at approximately 74% voltage on the bus for 2 seconds, ~~or~~ a 90% degraded voltage level exists for 56 seconds. Following the safety injection start signal, the emergency diesel generator will load if a 90% degraded voltage level exists for 7.5 seconds. The emergency diesel generator breaker closes on the isolated bus at 95% generator voltage if certain conditions are met. The load breakers automatically trip on overcurrent or electrical fault and lock out, which prevents the breaker from being reclosed manually or automatically. Most of the 4160V load breakers also trip on undervoltage with time controlled reclosing when voltage is

, or when an open phase condition is detected. [ADD TEXT FROM INSERT A HERE]

or phase voltage unbalance

The information contained in the electronic version of the SAR may be different from the information found in the hardcopy version of the SAR. Such differences are intentional and are the result of approved changes to the SAR that have not yet been submitted to the NRC.

Insert A

An open phase condition causes a voltage unbalance on the system which is detected via emergency bus negative sequence voltage relays. The negative sequence voltage relays include an inverse time characteristic which introduces a trip time delay based on the magnitude of the negative sequence voltage above the nominal setting of 4%. A time dial setting is used which results in a trip time delay of less than 11 seconds for open phase conditions that are detected by the emergency bus negative sequence voltage detection relays.

Attachment 4

COPY OF THE ARTICLE, "TYPICAL EXPECTED VALUES OF THE FAULT RESISTANCE IN POWER SYSTEMS"

**Virginia Electric and Power Company
(Dominion Energy Virginia)
North Anna Power Station Units 1 and 2**

Typical expected values of the fault resistance in power systems

Virgilio De Andrade, Elmer Sorrentino

***Abstract*-This article presents a range of possible values for the fault resistance in transmission power systems, considering six existing models for the arc resistance and a model for the grounding impedance of the towers. Resistance by possible additional objects in the path of the fault current was not considered. Known the short circuit level (without fault impedance), the fault resistance was calculated with the above mentioned models, for line-to-line and line-to-ground faults. This calculation was made for diverse nominal voltages and diverse short circuit levels for solid faults. The obtained range might be useful to improve the way of computing the settings for the corresponding protective devices.**

***Index Terms*- Arc resistance, grounding resistance, fault resistance, short circuit level.**

I. Introduction

SHORT circuit current may be limited by a fault impedance, which may be composed by three elements: electric arc, tower grounding, and the presence of objects in the fault path. Electric arc is a non-linear phenomenon that depends on diverse factors; however, there is a tradition considering the arc as a resistance, dependent on the arc current, in order to compute the short circuit currents in a simple way [1-13]. The effective grounding impedance of towers is mainly resistive, its inductive part is greater when there are ground wires [14-20], and its value is assumed to be not dependent on the fault current. Impedance of possible additional objects interposed in the path of the fault current is usually considered mainly resistive, and its value might be zero or very high [1]; by this reason, fault impedance may be described as an unpredictable quantity [21].

For transmission line protection, fault resistance (R_F) is assumed to be composed by the arc resistance (R_A) and the effective grounding resistance of the towers (R_G) [11-14]. A range of values for R_F was computed in this article, by using existing models for R_A and for the effective grounding impedance of the towers (Z_G), and by assuming the short circuit level without fault impedance (I_{SCL}) as known. The obtained range for R_F may be considered typical for the nominal voltages used as examples; however, it was considered necessary to emphasize that the R_F values may be out of the studied range because the factors that affect R_A and Z_G are very diverse and, additionally, there could be other objects interposed in the path of the current.

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II. Applied Models

A. Models for the arc resistance

A.1. Model 1

This model probably is the most well-known, and it was proposed by A. Warrington in 1931 [1,2]:

$$R_{A1} = \frac{28707.35 \cdot L}{I^{1.4}} \tag{1}$$

R_{Aj}: Arc resistance (Ω), according to model j ($j=1...6$).
L: Arc length (m).
I: Rms value of the fault current (A).

A.2. Model 2

This model is based on the analysis of Mason [11] about the results of Warrington [1], Strom [6] and other authors:

$$R_{A2} = \frac{1804.46 \cdot L}{I} \tag{2}$$

A.3. Model 3

This model is based on a article written by Goda et al. [3]:

$$R_{A3} = \left(\frac{950}{I} + \frac{5000}{I^2}\right) \cdot L \tag{3}$$

A.4. Models 4 and 5

These models are based on articles written by Terzija and Koglin [4-5]:

$$R_{A4} = \frac{G \cdot L}{I} \tag{4}$$

$$R_{A5} = \left(\frac{855.30}{I} + \frac{4501.58}{I^2}\right) \cdot L \tag{5}$$

G: Constant (between 1080.38 and 1350.47 V/m).

A.5. Model 6

This is in a book written by Blackburn and Domin [12]:

$$R_{A6} = \frac{1443.57 \cdot L}{I} \tag{6}$$

A.6. Some details about these models

a) Each model was developed from experiments done with a specific range of currents, but they have been used in a wider range. In this work, the value of the fault resistance was calculated of two ways: Method A, considering that each

model is valid for the whole range of currents, and Method B, considering that each model is only valid for the specific range of currents of the corresponding experimental tests (table I).

TABLE I: RANGE OF CURRENTS FOR METHOD B

Model	Range of currents (A)
1	135 - 960
2	1000 - 20000
3	5000 - 50000
4	2000 - 12000
5	2000 - 12000
6	70 - 20000

b) In this work, a maximum value and a minimum value are used for the arc length (L). Therefore, for Method A:

- b.1) Model 2 and model 4 are complementary by using model 2 with maximum length (L_{MAX}), and model 4 with minimum length (L_{MIN}) and G=1080.38 V/m.
- b.2) Model 3 and model 5 are complementary by using model 3 with L_{MAX} and model 5 with L_{MIN}.
- b.3) Model 6 is equivalent to the use of G=1443.57 V/m; therefore, its result is an intermediate value between model 2 and model 4, and its calculation is not strictly necessary.
- b.4) Model 1 must be computed with L_{MAX} and L_{MIN}; this implies the calculation of two different resistances.
- b.5) By this analysis, only the calculation of a subset of models is strictly necessary; however, the results of the 6 models are shown in this article in order to see their differences.

c) The analyzed models, with the exception of model 1, can be considered particular cases of the general model stated by Ayrton in 1901 [7], by using the adequate value of the constants A, B, C, D:

$$R_A = \frac{A + B \cdot L}{I} + \frac{C + D \cdot L}{I^2} \tag{7}$$

B. Model for the effective grounding impedance of the towers

This article only considers the case of transmission lines with ground wires. Hence, for a line-to-ground fault at a tower, a part of the fault current circulates by the individual tower grounding and other one circulates by the ground wires. This implies that the effective grounding impedance (Z_G) is different from the individual grounding resistance of the tower (R_T). Minimal value of the effective grounding impedance (Z_{GMIN}) is assumed to be for faults at a substation, and its maximum value (Z_{GMAX}) is assumed to be for faults in a line without contribution from the remote end. An analysis of the recommendations for the model of Z_G [15-17,22-24] was done specifically for this article, and by such analysis: Z_{GMIN} is assumed to be equal to r multiplied by the parallel equivalent of R_E with Z_P/N_G, and Z_{GMAX} is assumed to be the parallel equivalent of R_T with Z_P.

R_E: Grounding resistance of the substation.

Z_P: Equivalent impedance of a ladder network formed by an infinite number of individual grounding resistances of towers and grounding wires whose length is the average line span.

N_G: Number of lines arriving to the substation.

r: Quotient of the fault current that does not return through the grounding wires that arrive to the substation divided by the total current of the line-to-ground fault.

The values of Z_P and r are:

$$Z_P = 0.5 \cdot Z_W + \sqrt{(0.5 \cdot Z_W)^2 + Z_W \cdot R_T} \tag{8}$$

$$r = 1 - \frac{Z'_{WL}}{Z'_W} \tag{9}$$

Z'_W: Self impedance per unit length of the grounding wires.

Z_W: Self impedance of the grounding wires for an average line span d_T ($Z_W = d_T \cdot Z'_W$).

Z'_{WL}: Mutual impedance per unit length between the grounding wires and the phase conductors of the line.

III. RANGE OF USED VALUES

R_E was assumed to be between 0.01 and 5 Ω [20,22], but only its minimal value (0.01 Ω) is needed for this article because it only influences the value of Z_{GMIN}. R_T was assumed to be between 1 and 800 Ω [12-13,25-27]; its minimal value (1Ω) is needed to calculate Z_{GMIN} and its maximum value (800 Ω) is needed to calculate Z_{GMAX}.

Table II shows the range used for the other parameters. These values were estimated from the analysis of the constructive characteristics that were reviewed for a wide variety of transmission lines [25-34].

Arc lengths are different for line-to-line faults (L_{L-L}) and for line-to-ground faults (L_{L-G}). L_{MIN} was assumed to be the minimal distance required for a 50 % of probability of the arc occurrence at the corresponding nominal voltage (with standard atmospheric conditions) [35]. A large arc lengthening might exist by convection, wind action and/or electromagnetic attraction (the arc might evolve in the time), and this affect L_{MAX}. By this reason, a value of L_{MAX} was assumed for the instantaneous action of the protections and other one for the delayed action. L_{MAX} for the instantaneous protections was considered to be equal to the minimal distance of separation (between phases or between phase and ground, according to the case) plus 6 meters of initial lengthening, which was estimated considering a wind speed of 30m/s during 0.1s. L_{MAX} for delayed protections was assumed to be 5 times the minimal separation distance between phases, or between phase and ground, according to the case; such multiple is arbitrary and it is based on a qualitative appreciation of the available information (in the literature and in videos). The criteria enunciated for L_{MAX} have an exception for line-to-ground faults at 69kV because the value for instantaneous protections would be greater than the value for delayed protections; by this reason, there was only used the arc length calculated for the delayed protection.

The minimum values for Z'_W and the maximum values for Z'_{WL} are necessary to compute Z_{GMIN}, and they were estimated with two grounding wires (ACSR 240/40 at 20°C) and with a soil resistivity of 20 Ωm. The maximum values for Z'_W were estimated with a soil resistivity of 10000 Ωm, with a

grounding wire (extra-high-strength steel, 3/8", at 100°C) for instantaneous protections and at its admissible short circuit temperature (200 °C) for the delayed protections (except in case of 765 kV, that was estimated by two grounding wires of this type because all the lines analyzed for this case had two grounding wires). The value used for N_G is 16.

TABLE II: RANGE FOR THE VARIABLES THAT DEFINE THE VALUES OF Z_{GMIN} (UPPER ROW), AND THE VALUES OF Z_{GMAX} FOR INSTANTANEOUS PROTECTIONS (MIDDLE ROW) AND DELAYED PROTECTIONS (LOWER ROW)

V_N (kV)	L_{L-L} (m)	L_{L-G} (m)	Z'_W (Ω/km)	Z'_{WL} (Ω/km) *	d_T (m)
69	0.23	0.15	0.120 + j0.577	0.059 + j0.362	94
	7.83	5.80	6.098 + j2.502	-	246
	9.15	5.80	8.129 + j2.502		
115	0.37	0.23	0.120 + j0.573	0.059 + j0.342	101
	8.49	7.83	6.098 + j2.502	-	322
	12.5	9.15	8.129 + j2.502		
230	0.70	0.42	0.120 + j0.568	0.059 + j0.320	126
	11.0	8.77	6.098 + j2.502	-	451
	25.0	13.9	8.129 + j2.502		
400	1.23	0.70	0.120 + j0.563	0.059 + j0.290	152
	13.6	10.3	6.098 + j2.502	-	503
	38.2	21.5	8.129 + j2.502		
765	2.06	1.33	0.120 + j0.511	0.059 + j0.236	213
	18.0	13.6	3.078 + j1.489	-	512
	60.0	38.1	4.094 + j1.489		

*: Only the maximum values of Z'_{WL} are required (they are required to compute the minimum fault impedance).

For each nominal voltage (V_N), the range for the short circuit level without fault impedance (I_{SCL}) is between 0.1 and 50 kA. Such range is greater than the usually required values because the objective is to observe the behavior of the results in the range of currents as wide as possible. The range assumed for the angle of the corresponding current is shown in table III. The lower angle values were used to obtain the maximum arc resistance values and vice versa.

TABLE III: RANGE FOR THE ANGLE OF I_{SCL}

V_N (kV)	Line-to-ground	Line-to-line
69 y 115	71.6°...87.1° (X/R: 3...20)	78.7°...87.1° (X/R: 5...20)
230	71.6°...87.7° (X/R: 3...25)	78.7°...87.7° (X/R: 5...25)
400	76.0°...88.1° (X/R: 4...30)	81.9°...88.1° (X/R: 7...30)
765	78.7°...88.6° (X/R: 5...40)	84.3°...88.6° (X/R: 10...40)

IV. METHOD FOR COMPUTING THE ARC RESISTANCE

For the described models, the arc resistance is a decreasing function of the fault current:

$$R_A = g(I) \qquad (10)$$

Arc resistance allows to calculate the fault current by using the Thevenin equivalent circuit. A way for expressing this calculation is:

$$I = h(R_A) = \left| V_{TH} / (Z_{TH} + R_A + Z_G) \right| \qquad (11)$$

Thevenin voltage (V_{TH}) is the line-to-line voltage for line-to-line faults and the line-to-neutral value for line-to-ground faults. Thevenin impedance (Z_{TH}) is the sum of the impedances of positive and negative sequence for line-to-line faults, and the average of the three sequence impedances for line-to-ground faults. Z_G is zero for line-to-line faults. I_{SCL} is the value of $h(R_A)$ for $R_A = 0$ (and with $Z_G = 0$, for line-to-ground faults).

This analysis is based on the use of phasors. Therefore, the effect of non-sinusoidal waveforms is not considered. The value used for the Thevenin voltage is the nominal value.

The iterative method for computing the solution is very simple: the first value of I for computing R_A with equation (10) is I_{SCL}; with such value of R_A, then I is updated by using equation (11); and with such value of I, R_A is updated by using equation (10). This iterative process is repeated until the convergence is achieved. The error for the current must be lower than 0.1 % as convergence criterion.

In a graphic way, the solution for the equations (10) and (11) is at the intersection of the curves (Fig. 1). Generally there is only one solution; nevertheless, in case of two solutions, only the solution with lower value of R_A has been considered in this article (the computing method forces such solution).

In practice, the possibility of no intersection of the curves is negligible. If this happen for the maximum arc lengths, the recommendation of this article is to evaluate the biggest arc length that allows an intersection of the curves and to use the results of such intersection. An example of this is shown at the section V.B.3.

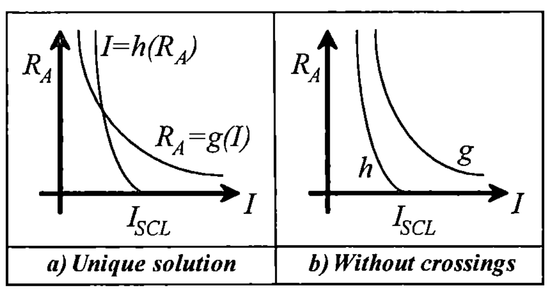

Fig. 1. Examples of the relationship between the equations 10 and 11.

V. RESULTS

A. *Effective grounding impedance of the towers*

Table IV shows the results of the effective grounding impedance of the towers (Z_G). The effective grounding resistance of the towers (R_G) is simply the real part of the impedance value.

Minimum value of Z_G is practically zero and its maximum value is near to 45Ω (+/-10Ω). This maximum value is moderate, in comparison with the average individual grounding resistance of the towers (R_T =800 Ω); this is due to the presence of the grounding wires. Angle of Z_{GMAX} is small, but the value in ohms of its reactive component is not

negligible, and it might influence the apparent reactance seen by the distance protections.

TABLE IV: EFFECTIVE GROUNDING IMPEDANCE OF THE TOWERS

V_N (kV)	Minimum value (mΩ)	Maximum values (Ω) for instantaneous protections (upper row) and delayed protections (lower row)
69	2.51 /12.40° = 2.45 + j0.54	35.2 /10.9° = 34.6 + j6.67
		39.9 /8.34° = 39.5 + j5.79
115	2.73 /13.12° = 2.66 + j0.62	40.2 /10.9° = 39.4 + j7.58
		45.5 /8.30° = 45.0 + j6.57
230	3.07 /13.09° = 2.99 + j0.70	47.3 /10.8° = 46.5 + j8.88
		53.5 /8.26° = 53.0 + j7.69
400	3.51 /13.55° = 3.41 + j0.82	49.9 /10.8° = 49.0 + j9.35
		56.4 /8.24° = 55.8 + j8.09
765	4.02 /13.44° = 3.91 + j0.93	36.6 /12.6° = 35.7 + j7.99
		41.2 /9.73° = 40.6 + j6.96

B. Arc resistance

B.1. General description of the graphs of results

Fig. 2 and Fig. 3 show the results of the arc resistance (R_A) in function of the short circuit level (I_{SCL}, without fault impedance). The minimum values of resistance are equal in both figures. The maximum values of Fig. 2 and Fig. 3 correspond to the instantaneous and delayed protections, respectively. Each graph in both figures indicates the results of the arc models for the minimal and maximum values of R_A. For example, Fig. 2 shows that for line-to-ground faults at 230kV whose I_{SCL} is 1 kA, the value of R_A is between 0.36Ω and 23Ω for Method A, with minimal values in the range between 0.36Ω and 0.76Ω, and maxima values between 9.5Ω and 23Ω (according to the considered arc model). The corresponding case in Fig. 3 indicates that the maximum value for delayed protections is 42Ω (with values between 16Ω and 42Ω, according to the considered arc model).

B.2. Comparison between Method A and Method B

Fig. 2 and Fig. 3 indicate that the minimum values of R_A in the Method A are obtained with model 5. For Method B, model 5 is assumed to be valid only for fault currents between 2 and 12 kA; by this, its minimal values are obtained with model 6 for low values of I_{SCL}, with model 5 for intermediate values of I_{SCL}, and with model 3 for highest values of I_{SCL}. The fact of obtaining the minimal values with model 3 in Method B only can be seen easily for line-to-line faults at 765kV because the R_A values are very small for these high values of I_{SCL} and such R_A values leave the graph by the minimum value used in the scale (0.1Ω). In the Method B, the assumed range for the fault current (table 1) is not equal to the range for I_{SCL} by the effect of the fault impedance; this is more evident for the maximum values of R_A for line-to-ground faults because the fault impedances are greater.

The maximum values of R_A with Method A are obtained with model 1 for the lower values of I_{SCL} and with model 2 for the higher values. In Method B, model 1 is assumed to be only valid for fault currents between 0.135 and 0.96 kA, and model 2 for values between 1 and 20 kA; by this, its maximum values are obtained with model 6 for very low values of I_{SCL}, with model 1 for the moderately low values of I_{SCL}, with model 2 for almost all the higher values of I_{SCL}, and with model 3 for line-to-line faults whose I_{SCL} is greater than 20kA approximately. The maximum values with model 6 in Method B have little practical application because they are obtained for negligible values of I_{SCL}.

Fig. 2 and Fig. 3 show that the low and high limits of the graphs tend to be very similar for Method A and Method B. Additionally, the variables that define the value of the fault impedance are unpredictable. By these two reasons, the use of the results of Method A is advisable for the sake of simplicity.

B.3. Shape of the curves

All the curves of the minimal values of R_A, and the curves of the maximum values of R_A for line-to-line faults, tend to be straight lines in the chosen logarithmic scale. This occurs because $R_A = g(I)$ is a hyperbolic function in terms of the fault current, what means a straight line in the logarithmic scale, and in these cases the fault impedance is moderate (and by this, I_{SCL} is similar to the value of the fault current).

The curves of the maximum values of R_A for line-to-ground faults tend to be inclined straight lines for low values of I_{SCL} and to become stable horizontally for high values of I_{SCL}. This occurs because the values of Z_G are very high, and for high values of I_{SCL}, such Z_G value tends to define the value of the fault current; therefore, as the fault current has little changes, the arc resistance also has little changes.

There are two cases without intersection between the curves $R_A = g(I)$ and $I = h(R_A)$. Both were obtained with model 1, for the maximum values of R_A for line-to-ground faults at 69kV, and I_{SCL} equals to 0.1kA (one case is in Fig. 2 and the other one is in Fig. 3). As it was indicated in section IV, the biggest arc length that allows intersection of the curves was computed for such cases, and the result of this intersection was applied to the graph for these values of I_{SCL}.

B.4. Comparison between different nominal voltages

Except in case of the maximum values of R_A for line-to-ground faults, for each I_{SCL} value, the estimated values of R_A tend to be greater while greater is the nominal voltage (V_N). This occurs because the simulated arc length is greater while greater is V_N.

In case of the maximum values of R_A for line-to-ground faults, the simulated values of Z_G are very big and they do not differ very much between the different V_N values. By this, at each I_{SCL} specific value, for the lower values of V_N there is a greater reduction in the fault current; such reduction in the fault current influences more in the function $R_A = g(I)$, increasing the value of R_A, than the influence by the reduction of the simulated arc length for the lower values of V_N.

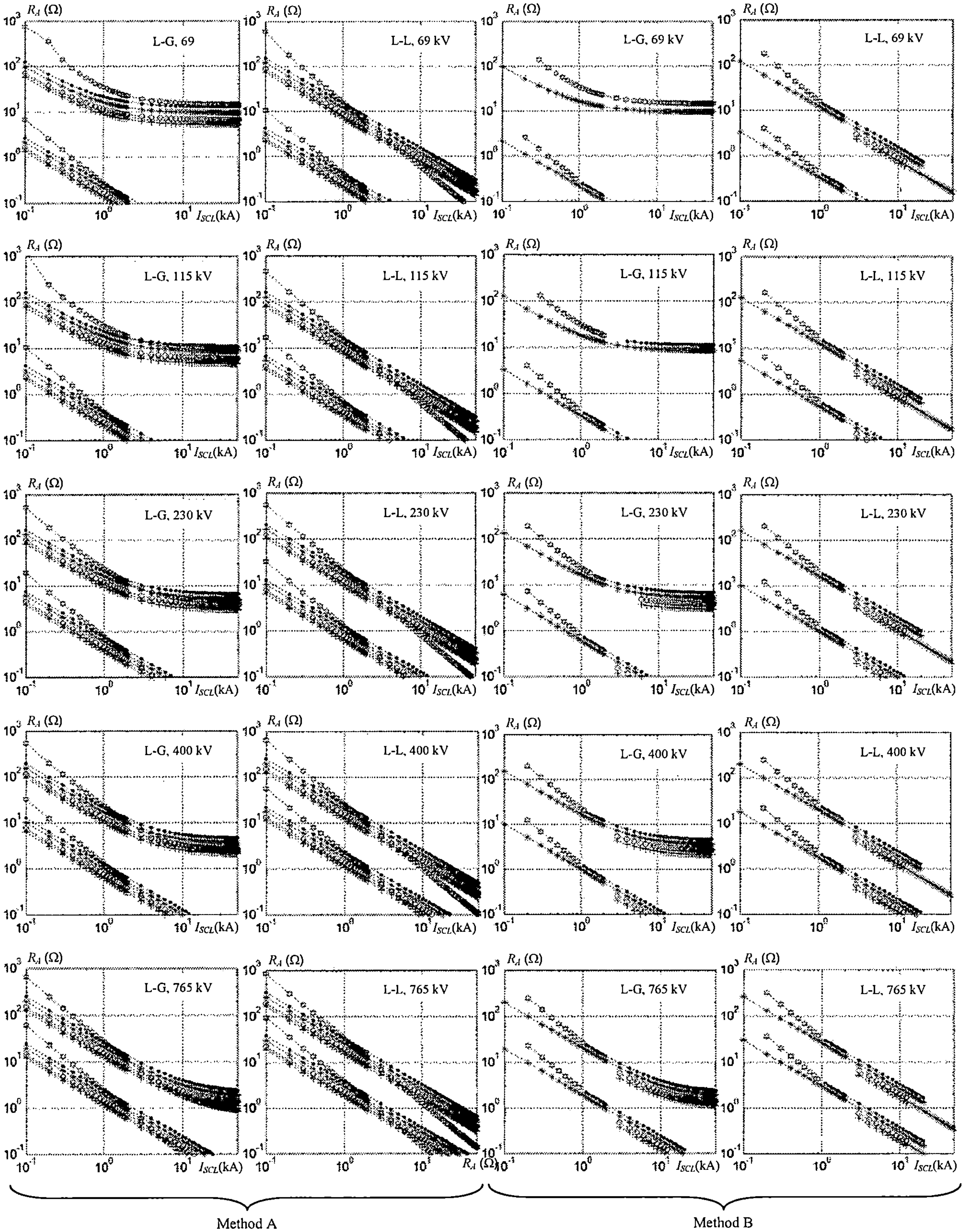

Fig. 2. Minimal and maximal arc resistances for instantaneous protections.
Legend for the arc models: ✡ Model 1, • Model 2, × Model 3, O Model 4, + Model 5, ∗ Model 6.

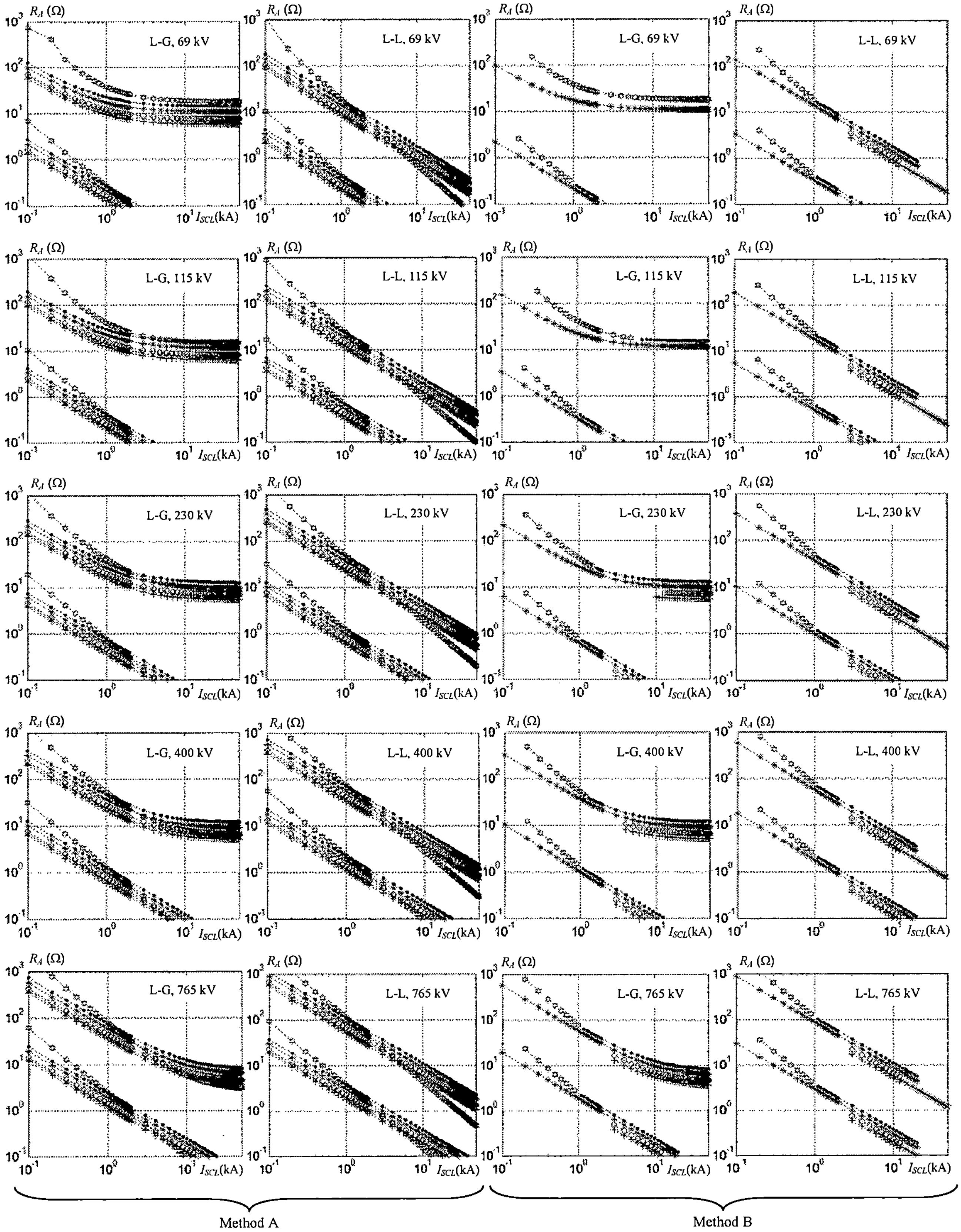

Fig. 3. Minimal and maximal arc resistances for delayed protections.
Legend for the arc models: ✡ Model 1, • Model 2, × Model 3, O Model 4, + Model 5, ∗ Model 6.

B.5. Summary of typical values for I_{SCL} greater than 1kA

For each I_{SCL} and V_N, Fig. 2 and Fig. 3 indicate exactly the minimal and maximum estimated values of R_A. Nevertheless, it is also possible to indicate some approximate relations:

a) Except for 69kV and 115kV, the minimal values of R_A are approximately 1Ω at 1kA, 0.1Ω at 10kA, and tend to be lower than 0.1Ω for I_{SCL} greater than 10kA. For 69kV and 115kV, the minimal values of R_A tend to be even lower.

b) For line-to-line faults, the maximum values of R_A for instantaneous protections are approximately 20Ω at 1kA and 2Ω at 10kA if V_N is 69kV, 115kV or 230kV, and they are approximately 40Ω at 1kA and 4Ω at 10kA if V_N is 400kV or 765kV. The corresponding values for delayed protections are approximately 30Ω at 1kA and 3Ω at 10kA if V_N is 69kV or 115kV, they are approximately 60Ω at 1kA and 6Ω at 10kA if V_N is 230kV, and they are approximately 100Ω at 1kA and 10Ω at 10kA if V_N is 400kV or 765kV.

c) For line-to-ground faults, the maximum values of R_A for instantaneous protections are approximately 60Ω at 1kA and tend to become stable to 25Ω at 3kA if V_N is 69kV, they are approximately 30Ω at 1kA and tend to become stable at 10Ω at 3kA if V_N is 115kV or 230kV, and they are approximately 30Ω at 1kA and 6Ω at 10kA if V_N is 400kV or 765kV. The corresponding values for delayed protections are similar if V_N is 69kV, they are approximately 60Ω at 1kA and tend to become stable to 15Ω at 3kA if V_N is 115kV, 230kV or 400kV, and they are approximately 100Ω at 1kA and 15Ω at 10kA if V_N is 765kV.

Another way for doing a summary of these results is making use of the fact that the sloping part of the curves tend to a straight line in the logarithmic scale, whose expression is:

$$R_A I_{SCL} = K \qquad (12)$$

K: Constant.

The curve of maximum values of R_A for line-to-ground faults can be approximated as the intersection of an inclined straight line with a horizontal one. The horizontal straight line is described by the values of stabilization ($I_{SCL,ST}$ and $R_{A,ST}$); therefore:

$$R_A I_{SCL} = K, \quad \text{if } I_{SCL} < I_{SCL,ST} \qquad (13)$$

$$R_A = R_{A,ST}, \quad \text{if } I_{SCL} \geq I_{SCL,ST} \qquad (14)$$

This summary of the results is different to the described one in the previous items (a, b, c) and it has a greater accuracy and simplicity (Tables V and VI).

TABLE V: APPROXIMATE RESULTS OF R_A FOR LINE-TO-LINE FAULTS, AND I_{SCL} > 1 KA (EQUATION 12).

V_N (kV)	Minimum	Maximum (instantaneous protection)	Maximum (delayed protection)
	K (kV)	K (kV)	K (kV)
69	0.20	15	18
115	0.32	16	24
230	0.60	20	49
400	1.1	25	72
765	1.6	33	112

TABLE VI: APPROXIMATE RESULTS OF R_A FOR LINE-TO-GROUND FAULTS, AND I_{SCL} > 1 KA (EQUATIONS 13 AND 14).

V_N (kV)	Min.	Maximum (instantaneous protection)			Maximum (delayed protection)		
	K (kV)	K (kV)	$I_{SCL,ST}$ (kA)	$R_{A,ST}$ (Ω)	K (kV)	$I_{SCL,ST}$ (kA)	$R_{A,ST}$ (Ω)
69	0.13	54	3	18	66	3	22
115	0.20	52	4	13	72	4	18
230	0.36	49	6	8.2	75	5	15
400	0.60	47	8	5.9	91	7	13
765	1.1	46	16	2.9	130	13	10

VI. CONCLUSION

A range of typical expected values for the fault resistance in electrical transmission systems was computed, by using six existing models for the arc resistance and a model for the effective grounding impedance of the towers. The minimal and maximum expected values for the fault resistance are dependent of the short circuit level and the nominal voltage of the system. The component of the fault resistance associated with the effective grounding resistance of the towers is shown in tables because it is not dependent of the short circuit level, while the component associated with the arc resistance is shown in graphs in function of the maximum short circuit level (without fault impedance). The achieved information can be useful to have a fast estimation of the required range of fault resistances.

The maximum values of the arc resistances were computed considering two different assumptions about the arc lengthening. The considered arc length for the instantaneous protections is lower than for the delayed protections.

For line-to-ground faults, the fault impedance has an inductive part. The angle of the fault impedance is small, but the modules of the possible maximum values are so high that the inductive part of the impedance is not insignificant, and it might affect the behavior of some distance protections.

VII. REFERENCES

[1] A. Warrington, "Reactance relays negligibly affected by arc impedance", *Electrical World*, Sept. 1931, pp. 502-505.

[2] A. Warrington, *Protective Relays. Their theory and practice. Volume one*, Chapman & Hall Ltd., London, 1976.

[3] Y. Goda, M. Iwata, K. Ikeda, S. Tanaka, "Arc voltage characteristics of high current fault arcs in long gaps", *IEEE Transactions on Power Delivery*, Vol. 15, N° 2, April 2000, pp. 791–795.

[4] V. Terzija, H. Koglin, "On the modeling of long arc in still air and arc resistance calculation", *IEEE Transactions on Power Delivery*, Vol. 19, N° 3, July 2004, pp. 1012-1017.

[5] V. Terzija, H. Koglin, "New dynamic model, laboratory testing and features of long arc in free air", *Electrical Engineering*, Springer-Verlag, Vol. 83, N° 4, Aug. 2001, pp. 193-201.

[6] A. P. Strom, "Long 60-Cycle arcs in air", *American Institute of Electrical Engineers*, Vol. 65, N° 3, March 1946, pp. 113-118.

[7] H. Ayrton, "The mechanism of the electric arc", in *Proceedings of the Royal Society of London*, Vol. 68, 1901, pp. 410-414.

[8] V. Terzija, D. Dobrijevic, "Short circuit studies in transmission networks using improved fault model", in *IEEE Power Tech*, Lausanne, July 2007, pp. 1752-1757.

[9] V. Terzija, R. Ciric, H. Nouri, "A new iterative method for fault currents calculation which models arc resistance at the fault location", *Electrical Engineering*, Springer-Verlag, Vol. 89, Feb. 2006, pp. 157-165.

[10] D. Jeerings, J. Linders, "Ground resistance - revisited", *IEEE Transactions on Power Delivery*, Vol. 4, N° 2, April 1989, pp. 949-956.
[11] R. Mason, *The art and science of protective relaying*, John Wiley & Sons Inc., 1956.
[12] J. Blackburn, T. Domin, *Protective relaying. Principles and applications*, third edition, Taylor & Francis Group, LLC, Boca Raton, 2007.
[13] *IEEE guide for protective relay applications to transmission lines*, IEEE Standard C37.113-1999(R2004), Dec. 2004.
[14] G. Ziegler, *Numerical distance protection. Principles and applications*, second edition, Siemens, Erlangen, 2006.
[15] J. Endrenyi, "Analysis of transmission tower potentials during ground faults", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-86, N° 10, Oct. 1967, pp. 1274-1283.
[16] *Short-circuit currents in three-phase a.c. systems – Part 3: Currents during two separate simultaneous line-to-earth short circuits and partial short-circuit currents flowing through earth*, IEC Standard 60909-3, Sept. 2003.
[17] A. Meliopoulos, *Power system grounding and transients*, Marcel Dekker, Inc., New York, 1988.
[18] C. Ramírez, *Subestaciones de alta y extra alta tensión*, second edition, Mejía Villegas S.A., Medellín, 2003.
[19] J. Martín, *Diseño de subestaciones eléctricas*, second edition, McGraw-Hill, Mexico D. F., 1987.
[20] H. Langrehr, *Valores básicos de cálculo para sistemas de alta tensión*, second edition, AEG-Telefunken, Berlin, 1970.
[21] J. Barnard, A. Pahwa, "Determination of the impacts of high impedance faults on protection of power distribution systems using a probabilistic model", *Electric Power Systems Research*, N° 28, 1993, pp. 11-18.
[22] *IEEE guide for safety in AC substation grounding*, IEEE Standard 80-2000, Aug. 2000.
[23] M. Vintan, "Fault current distribution computation on overhead transmission lines", in *Proceedings of the Fifth International World Energy System Conference*, Vol. II, Oradea, Rumania, 2004, pp. 273-279.
[24] S. Sebo, "Zero-sequence current distribution along transmission lines", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-88, N° 6, June 1969, pp. 910-919.
[25] T. White, R. Adler, S. Daniel, C. Helsing, M. Lauby, R. Ludorf, W. Ruff, "An IEEE survey of transmission line population and design characteristics", *IEEE Transactions on Power Delivery*, Vol. 6, N° 4, Oct. 1991, pp. 1934-1945.
[26] ABB Electric Systems Technology Institute, *Electrical transmission and distribution reference book*, fifth edition, Raleigh, 1997.
[27] Electric Power Research Institute, *Transmission line reference book, 345 kV and above*, second edition, Palo Alto, 1982.
[28] *Electrical equipment – Data for short-circuit current calculations in accordance with IEC 909 (1988)*, IEC Standard 909-2, Aug. 1992.
[29] F. Kiessling, P. Nefzger, J.E Nolasco, U. Kaintzyk, *Overhead power lines – Planning, design, construction*, Springer, Berlin, 2003.
[30] Areva T&D, *Network protection & automation guide*, first edition, Paris, 2005.
[31] A. Hileman, *Insulation Coordination for Power Systems*, Taylor & Francis Group, LLC, Boca Raton, 1999.
[32] K. Girkmann, E. Königshofer, *Die hochspannungs-freileitungen*, second edition, Springer-Verlag, Vienna, 1952.
[33] Ch. Lavanchy, *Étude et construction des lignes électriques aériennes*, second edition, J.-B. Baillière, Paris, 1952.
[34] W. Lewis, *The protection of transmission systems against lightning*, Dover Publications, Inc., New York, 1965.
[35] *Insulation co-ordination – Part 2: Application guide*, IEC Standard 71-2, third edition, Dec. 1996.

Attachment 5

STUDY CASES FOR RAI NO. 4
AND
ATTACHMENT 5 TO CALCULATION EE-0894

Virginia Electric and Power Company
(Dominion Energy Virginia)
North Anna Power Station Units 1 and 2

1H Emergency Bus Cases

BE1-47N Relay Case Results (EE-0894 Attachment 1)

Case #	Unit 1 Power %	Unit 2 Power %	Bus Loading	Open Phase Location	Open Phase Ground	LOCA	Negative Sequence, V2 t = 8s (L-N rms, at 4200:120 PT secondaries) SWGR 1H	SWGR 1J	SWGR 2H	SWGR 2J	% V2 SWGR 1H	% Deratin SWGR 1H	Derating Acceptable (SWGR 1H Equipment) AFW	SW	CH	LHSI	OSRS	QS	ISRS	CC
1	0	0	Norm	TX1	No	No	2.821	0.305	0.309	2.829	4.07	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
2	0	0	Norm	TX1	No	No	2.815	0.307	0.311	2.823	4.06	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
3	0	0	Norm	TX1	No	No	2.842	0.305	0.309	2.850	4.10	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
14	0	0	Norm	TX1	No	Yes	2.844	0.301	0.306	2.853	4.11	0.81	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
19	0	0	Norm	TX1	No	No	2.843	0.305	0.308	2.851	4.10	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
22	0	0	Min	TX1	No	No	2.897	0.317	0.304	2.898	4.18	0.80	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
29	0	0	Min	TX1	No	Yes	2.881	0.297	0.300	2.891	4.16	0.80	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
32	0	0	Min	TX1	No	No	2.920	0.318	0.303	2.922	4.21	0.80	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
35	100	100	Norm	TX1	No	No	1.965	0.330	0.323	1.969	2.84	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
38	100	100	Norm	TX1	No	Yes	1.980	0.347	0.323	1.985	2.86	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
41	100	100	Norm	TX1	No	No	1.935	0.323	0.323	1.968	2.79	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
44	100	100	Min	TX1	No	No	1.891	0.299	0.343	1.891	2.73	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
47	100	100	Min	TX1	No	Yes	2.002	0.325	0.338	2.009	2.89	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
50	100	100	Min	TX1	No	No	1.871	0.301	0.309	1.872	2.70	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
233	0	0	Norm	GSU 1	No	No	0.937	0.323	0.322	0.306	1.35	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
236	0	0	Norm	GSU 1	No	Yes	0.985	0.342	0.323	0.340	1.42	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
239	0	0	Norm	GSU 1	No	No	0.938	0.316	0.325	0.360	1.35	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
242	0	0	Min	GSU 1	No	No	0.983	0.300	0.322	0.307	1.42	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
245	0	0	Min	GSU 1	No	Yes	0.976	0.302	0.321	0.307	1.41	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
248	0	0	Min	GSU 1	No	No	0.983	0.317	0.325	0.360	1.42	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
252	0	0	Norm	GSU 1	350 Ohm	No	0.693	0.734	0.700	7.496	1.00	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
253	0	0	Norm	GSU 1	GND	No	1.023	1.144	1.079	14.571	1.48	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
255	0	0	Norm	GSU 1	350 Ohm	Yes	0.694	0.723	0.680	7.462	1.00	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
256	0	0	Norm	GSU 1	GND	Yes	1.021	1.123	1.020	14.479	1.47	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
258	0	0	Norm	GSU 1	350 Ohm	No	0.695	0.735	0.700	7.480	1.00	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
259	0	0	Norm	GSU 1	GND	No	1.024	1.147	1.081	14.544	1.48	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
261	0	0	Min	GSU 1	350 Ohm	No	0.695	0.736	0.694	7.894	1.00	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
262	0	0	Min	GSU 1	GND	No	1.025	1.148	1.037	15.370	1.48	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
264	0	0	Min	GSU 1	350 Ohm	Yes	0.694	0.724	0.688	7.460	1.00	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
265	0	0	Min	GSU 1	GND	Yes	1.021	1.124	1.020	14.477	1.47	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
267	0	0	Min	GSU 1	350 Ohm	No	0.697	0.737	0.395	7.859	1.01	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
268	0	0	Min	GSU 1	GND	No	1.027	1.151	1.039	15.299	1.48	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
270	0	0	Norm	GSU 2	350 Ohm	No	0.899	6.329	0.970	0.899	1.30	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
271	0	0	Norm	GSU 2	GND	No	1.685	14.177	1.591	1.685	2.43	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
273	0	0	Norm	GSU 2	350 Ohm	Yes	0.804	6.290	0.857	0.804	1.16	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
274	0	0	Norm	GSU 2	GND	Yes	1.450	13.959	1.583	1.452	2.09	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
276	0	0	Norm	GSU 2	350 Ohm	No	0.898	6.331	0.853	0.899	1.30	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
277	0	0	Norm	GSU 2	GND	No	1.684	14.175	1.580	1.685	2.43	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
279	0	0	Min	GSU 2	350 Ohm	No	0.887	11.215	0.863	0.887	1.28	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
280	0	0	Min	GSU 2	GND	No	1.642	25.691	1.615	1.645	2.37	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
282	0	0	Min	GSU 2	350 Ohm	Yes	0.884	6.288	0.859	0.885	1.28	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
283	0	0	Min	GSU 2	GND	Yes	1.564	14.062	1.582	1.571	2.26	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
285	0	0	Min	GSU 2	350 Ohm	No	0.901	6.637	0.857	0.901	1.30	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
286	0	0	Min	GSU 2	GND	No	1.617	14.940	1.585	1.623	2.33	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
288	0	0	Norm	GSU 2	350 Ohm	No	0.877	0.792	6.424	0.709	1.27	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
289	0	0	Norm	GSU 2	GND	No	1.639	1.507	14.270	1.189	2.37	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
291	0	0	Norm	GSU 2	350 Ohm	Yes	0.867	0.792	6.401	0.696	1.25	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
292	0	0	Norm	GSU 2	GND	Yes	1.612	1.506	14.188	1.130	2.33	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
294	0	0	Norm	GSU 2	350 Ohm	No	0.852	0.849	6.281	0.657	1.23	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
295	0	0	Norm	GSU 2	GND	No	1.642	1.510	14.240	1.191	2.37	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
297	0	0	Min	GSU 2	350 Ohm	No	0.879	0.795	6.752	0.691	1.27	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
298	0	0	Min	GSU 2	GND	No	1.644	1.511	15.030	1.153	2.37	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
300	0	0	Min	GSU 2	350 Ohm	Yes	0.867	0.792	6.401	0.692	1.25	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
301	0	0	Min	GSU 2	GND	Yes	1.612	1.506	14.188	1.148	2.33	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
303	0	0	Min	GSU 2	350 Ohm	No	0.854	0.851	6.602	0.615	1.23	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
304	0	0	Min	GSU 2	GND	No	1.647	1.514	14.974	1.155	2.38	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

Switchyard Unbalance Cases (EE-0894 Attachment 2)

2	0	0	Norm	TX1	B	No	2.193	1.835	1.674	2.198	3.16	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
3	0	0	Norm	TX1	C	No	2.867	1.827	1.667	2.875	4.14	0.80	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
9	100	100	Norm	TX1	A	No	3.094	1.873	1.081	3.102	4.47	0.77	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
10	100	100	Norm	TX1	A	Yes	3.067	1.799	1.801	3.088	4.43	0.78	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
11	100	100	Norm	TX1	A	No	3.071	1.837	1.800	3.079	4.43	0.78	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
12	100	100	Min	TX1	A	No	3.238	1.711	1.689	3.240	4.67	0.75	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
14	100	100	Min	TX1	A	No	3.215	1.690	1.691	3.216	4.64	0.76	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
15	0	0	Norm	TX2	A	No	1.631	1.714	4.143	1.632	2.35	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
16	0	0	Norm	TX2	A	Yes	1.505	1.714	4.157	1.505	2.17	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
17	0	0	Norm	TX2	A	No	1.629	1.714	4.167	1.629	2.35	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
18	0	0	Min	TX2	A	No	1.560	1.716	4.270	1.560	2.25	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
19	0	0	Min	TX2	A	Yes	1.551	1.715	4.130	1.552	2.24	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
20	0	0	Min	TX2	A	No	1.562	1.716	4.293	1.562	2.26	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
21	100	100	Norm	TX2	A	No	1.815	1.686	3.577	1.816	2.62	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
22	100	100	Norm	TX2	A	Yes	1.654	1.689	3.598	1.655	2.39	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
23	100	100	Norm	TX2	A	No	1.882	1.709	3.612	1.816	2.72	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
24	100	100	Min	TX2	A	No	1.727	1.686	3.666	1.726	2.49	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
25	100	100	Min	TX2	A	Yes	1.683	1.708	3.578	1.683	2.43	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
26	100	100	Min	TX2	A	No	1.704	1.696	3.664	1.703	2.46	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
27	0	0	Norm	GSU 1	A	No	2.046	1.789	1.662	1.573	2.95	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
28	0	0	Norm	GSU 1	A	Yes	1.988	1.666	1.636	1.572	2.87	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
29	0	0	Norm	GSU 1	A	No	2.045	1.592	1.730	1.740	2.95	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
30	0	0	Min	GSU 1	A	No	2.090	1.655	1.662	1.579	3.02	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
31	0	0	Min	GSU 1	A	Yes	2.020	1.662	1.636	1.573	2.92	0.89	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
32	0	0	Min	GSU 1	A	No	2.045	1.592	1.730	1.741	2.95	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
33	0	0	Norm	GSU 1	A	No	1.574	1.737	1.636	1.966	2.27	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
34	0	0	Norm	GSU 1	A	Yes	1.539	1.758	1.569	2.006	2.22	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
35	0	0	Norm	GSU 1	A	No	1.539	1.789	1.662	1.974	2.22	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
36	0	0	Min	GSU 1	A	No	1.538	1.789	1.531	2.060	2.22	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
37	0	0	Min	GSU 1	A	Yes	1.539	1.758	1.524	1.973	2.22	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
38	0	0	Min	GSU 1	A	No	1.539	1.790	1.531	2.041	2.22	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
39	0	0	Norm	GSU 2	A	No	2.171	1.774	2.058	2.172	3.13	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
40	0	0	Norm	GSU 2	A	Yes	1.931	1.883	2.109	1.935	2.79	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
41	0	0	Norm	GSU 2	A	No	2.171	1.782	1.999	2.171	3.13	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
42	0	0	Min	GSU 2	A	No	2.014	2.323	1.998	2.023	2.91	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
43	0	0	Min	GSU 2	A	Yes	2.004	1.339	2.013	2.009	2.89	0.89	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
44	0	0	Min	GSU 2	A	No	2.098	1.850	2.004	2.102	3.03	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
45	0	0	Norm	GSU 2	A	No	2.161	1.971	1.875	1.515	3.12	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
46	0	0	Norm	GSU 2	A	Yes	2.126	1.971	1.814	1.510	3.07	0.88	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
47	0	0	Norm	GSU 2	A	No	2.161	1.971	1.859	1.516	3.12	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
48	0	0	Min	GSU 2	A	No	2.161	1.970	1.874	1.481	3.12	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
49	0	0	Min	GSU 2	A	Yes	2.125	1.973	1.813	1.477	3.07	0.88	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
50	0	0	Min	GSU 2	A	No	2.161	1.971	1.859	1.483	3.12	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

*** Values have been evaluated as acceptable in EE-0894 Attachment 5

1J Emergency Bus Cases

BE1-47N Relay Case Results (EE-0894 Attachment 1)																						
Case #	Unit 1 Power	Unit 2 Power	Bus Loading	Open Phase		LOCA	Negative Sequence, V2 t = 8s (L-N rms, at 4200:120 PT secondaries)				% V2	% Derating	Derating Acceptable (SWGR 1J Equipment)							
	%	%		Location	Ground		SWGR 1H	SWGR 1J	SWGR 2H	SWGR 2J	SWGR 1J	SWGR 1J	AFW	SW	CH	LHSI	OSRS	QS	ISRS	CC
234	0	0	Norm	GSU 1	GND-R	No	7.528	0.716	0.676	0.642	1.03	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
235	0	0	Norm	GSU 1	GND	No	14.756	1.143	1.070	1.009	1.65	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
238	0	0	Norm	GSU 1	GND	Yes	14.563	1.064	1.053	1.005	1.54	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
241	0	0	Norm	GSU 1	GND	No	14.746	1.028	1.106	1.100	1.48	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
244	0	0	Min	GSU 1	GND	No	15.560	1.072	1.074	1.013	1.55	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
247	0	0	Min	GSU 1	GND	Yes	14.563	1.065	1.053	1.005	1.54	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
250	0	0	Min	GSU 1	GND	No	14.746	1.028	1.106	1.100	1.48	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
252	0	0	Norm	GSU 1	GND-R	No	0.693	0.734	0.700	7.496	1.06	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
253	0	0	Norm	GSU 1	GND	No	1.023	1.144	1.079	14.571	1.65	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
255	0	0	Norm	GSU 1	GND-R	Yes	0.694	0.723	0.680	7.462	1.04	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
256	0	0	Norm	GSU 1	GND	Yes	1.021	1.123	1.020	14.479	1.62	0.97	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
258	0	0	Norm	GSU 1	GND-R	No	0.695	0.735	0.700	7.480	1.06	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
259	0	0	Norm	GSU 1	GND	No	1.024	1.147	1.081	14.544	1.66	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
261	0	0	Min	GSU 1	GND-R	No	0.695	0.736	0.694	7.894	1.06	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
262	0	0	Min	GSU 1	GND	No	1.025	1.148	1.037	15.370	1.66	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
264	0	0	Min	GSU 1	GND-R	Yes	0.694	0.724	0.688	7.460	1.04	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
265	0	0	Min	GSU 1	GND	Yes	1.021	1.124	1.020	14.477	1.62	0.97	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
267	0	0	Min	GSU 1	GND-R	No	0.697	0.737	0.395	7.859	1.06	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
268	0	0	Min	GSU 1	GND	No	1.027	1.151	1.039	15.299	1.66	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
272	0	0	Norm	GSU 2	No	Yes	0.328	0.768	0.326	0.330	1.11	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
275	0	0	Norm	GSU 2	No	No	0.329	0.705	0.348	0.329	1.02	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
278	0	0	Min	GSU 2	No	No	0.362	0.906	0.344	0.363	1.31	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
284	0	0	Min	GSU 2	No	No	0.352	0.695	0.346	0.353	1.00	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
288	0	0	Norm	GSU 2	GND-R	No	0.877	0.792	6.424	0.709	1.14	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
289	0	0	Norm	GSU 2	GND	No	1.639	1.507	14.270	1.189	2.18	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
291	0	0	Norm	GSU 2	GND-R	Yes	0.867	0.792	6.401	0.696	1.14	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
292	0	0	Norm	GSU 2	GND	Yes	1.612	1.506	14.188	1.130	2.17	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
294	0	0	Norm	GSU 2	GND-R	No	0.852	0.849	6.281	0.657	1.23	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
295	0	0	Norm	GSU 2	GND	No	1.642	1.510	14.240	1.191	2.18	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
297	0	0	Min	GSU 2	GND-R	No	0.879	0.795	6.752	0.691	1.15	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
298	0	0	Min	GSU 2	GND	No	1.644	1.511	15.030	1.153	2.18	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
300	0	0	Min	GSU 2	GND-R	Yes	0.867	0.792	6.401	0.692	1.14	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
301	0	0	Min	GSU 2	GND	Yes	1.612	1.506	14.188	1.148	2.17	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
303	0	0	Min	GSU 2	GND-R	No	0.854	0.851	6.602	0.615	1.23	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
304	0	0	Min	GSU 2	GND	No	1.647	1.514	14.974	1.155	2.19	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

Switchyard Unbalance Cases (EE-0894 Attachment 2)																				
1	0	0	Norm	TX1	A	No	3.730	1.807	1.649	3.740	2.61	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
2	0	0	Norm	TX1	B	No	2.193	1.835	1.674	2.198	2.65	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
3	0	0	Norm	TX1	C	No	2.867	1.827	1.667	2.875	2.64	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
4	0	0	Norm	TX1	A	Yes	3.747	1.463	1.623	3.758	2.11	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
5	0	0	Norm	TX1	A	No	3.750	1.814	1.649	3.761	2.62	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
6	0	0	Min	TX1	A	No	3.928	1.648	1.602	3.930	2.38	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
7	0	0	Min	TX1	A	Yes	3.840	1.624	1.601	3.854	2.34	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
8	0	0	Min	TX1	A	No	3.952	1.649	1.602	3.953	2.38	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
9	100	100	Norm	TX1	A	No	3.094	1.873	1.081	3.102	2.70	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
10	100	100	Norm	TX1	A	Yes	3.067	1.799	1.801	3.088	2.60	0.91	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
11	100	100	Norm	TX1	A	No	3.071	1.837	1.800	3.079	2.65	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
12	100	100	Min	TX1	A	No	3.238	1.711	1.689	3.240	2.47	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
13	100	100	Min	TX1	A	Yes	3.825	1.384	1.307	3.827	2.00	0.95	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
14	100	100	Min	TX1	A	No	3.215	1.690	1.691	3.216	2.44	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
15	0	0	Norm	TX2	A	No	1.631	1.714	4.143	1.632	2.47	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
16	0	0	Norm	TX2	A	Yes	1.505	1.714	4.157	1.505	2.47	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
17	0	0	Norm	TX2	A	No	1.629	1.714	4.167	1.629	2.47	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
18	0	0	Min	TX2	A	No	1.560	1.716	4.270	1.560	2.48	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
19	0	0	Min	TX2	A	Yes	1.551	1.715	4.130	1.552	2.47	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
20	0	0	Min	TX2	A	No	1.562	1.716	4.293	1.562	2.48	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
21	100	100	Norm	TX2	A	No	1.815	1.686	3.577	1.816	2.43	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
22	100	100	Norm	TX2	A	Yes	1.654	1.689	3.598	1.655	2.44	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
23	100	100	Norm	TX2	A	No	1.882	1.709	3.612	1.816	2.47	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
24	100	100	Min	TX2	A	No	1.727	1.686	3.666	1.726	2.43	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
25	100	100	Min	TX2	A	Yes	1.683	1.708	3.578	1.683	2.47	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
26	100	100	Min	TX2	A	No	1.704	1.696	3.664	1.703	2.45	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
27	0	0	Norm	GSU 1	A	No	2.046	1.789	1.662	1.573	2.58	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
28	0	0	Norm	GSU 1	A	Yes	1.988	1.666	1.636	1.572	2.40	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
29	0	0	Norm	GSU 1	A	No	2.045	1.592	1.730	1.740	2.30	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
30	0	0	Min	GSU 1	A	No	2.090	1.655	1.662	1.579	2.39	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
31	0	0	Min	GSU 1	A	Yes	2.020	1.662	1.636	1.573	2.40	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
32	0	0	Min	GSU 1	A	No	2.045	1.592	1.730	1.741	2.30	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
33	0	0	Norm	GSU 1	A	No	1.574	1.737	1.636	1.966	2.51	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
34	0	0	Norm	GSU 1	A	Yes	1.539	1.758	1.569	2.006	2.54	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
35	0	0	Norm	GSU 1	A	No	1.539	1.789	1.662	1.974	2.58	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
36	0	0	Min	GSU 1	A	No	1.538	1.789	1.531	2.060	2.58	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
37	0	0	Min	GSU 1	A	Yes	1.539	1.758	1.524	1.973	2.54	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
38	0	0	Min	GSU 1	A	No	1.539	1.790	1.531	2.041	2.58	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
39	0	0	Norm	GSU 2	A	No	2.171	1.774	2.058	2.172	2.56	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
40	0	0	Norm	GSU 2	A	Yes	1.931	1.883	2.109	1.935	2.72	0.91	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
41	0	0	Norm	GSU 2	A	No	2.171	1.782	1.999	2.171	2.57	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
42	0	0	Min	GSU 2	A	No	2.014	2.323	1.998	2.023	3.35	0.86	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
43	0	0	Min	GSU 2	A	Yes	2.004	1.339	2.013	2.009	1.93	0.95	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
44	0	0	Min	GSU 2	A	No	2.098	1.850	2.004	2.102	2.67	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
45	0	0	Norm	GSU 2	A	No	2.161	1.971	1.875	1.515	2.84	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
46	0	0	Norm	GSU 2	A	Yes	2.126	1.971	1.814	1.510	2.84	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
47	0	0	Norm	GSU 2	A	No	2.161	1.971	1.859	1.516	2.85	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
48	0	0	Min	GSU 2	A	No	2.161	1.970	1.874	1.481	2.84	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
49	0	0	Min	GSU 2	A	Yes	2.125	1.973	1.813	1.477	2.85	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
50	0	0	Min	GSU 2	A	No	2.161	1.971	1.859	1.483	2.84	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

*** Values have been evaluated as acceptable in EE-0894 Attachment 5

2H Emergency Bus Cases

BE1-47N Relay Case Results (EE-0894 Attachment 1)

Case #	Unit 1 Power	Unit 2 Power	Bus Loading	Open Phase		LOCA	Negative Sequence, V2 t = 8s (L-N rms, at 4200:120 PT secondaries)				% V2	% Derating	Derating Acceptable							
	%	%		Location	Ground		SWGR 1H	SWGR 1J	SWGR 2H	SWGR 2J	SWGR 2H	SWGR 2H	AFW	SW	CH	LHSI	OSRS	QS	ISRS	CC
52	100	100	Min	TX1	GND	No	19.008	0.422	0.848	19.014	1.22	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
53	0	0	Norm	TX2	No	No	0.313	0.349	3.156	0.313	4.55	0.77	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
56	0	0	Norm	TX2	No	Yes	0.323	0.323	3.176	0.323	4.58	0.76	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
59	0	0	Norm	TX2	No	No	0.311	0.322	3.180	0.311	4.59	0.76	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
62	0	0	Min	TX2	No	No	0.309	0.329	3.203	0.309	4.62	0.76	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
65	0	0	Min	TX2	No	Yes	0.297	0.330	3.148	0.297	4.54	0.77	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
68	0	0	Min	TX2	No	No	0.308	0.330	3.227	0.308	4.66	0.75	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
71	100	100	Norm	TX2	No	No	0.326	0.361	2.445	0.326	3.53	0.85	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
74	100	100	Norm	TX2	No	Yes	0.335	0.363	2.457	0.336	3.55	0.85	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
77	100	100	Norm	TX2	No	No	0.325	0.299	2.398	0.325	3.46	0.86	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
80	100	100	Min	TX2	No	No	0.356	0.361	2.418	0.356	3.49	0.85	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
83	100	100	Min	TX2	No	Yes	0.337	0.361	2.415	0.336	3.49	0.85	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
86	100	100	Min	TX2	No	No	0.319	0.344	2.417	0.319	3.49	0.85	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
235	0	0	Norm	GSU 1	GND	No	14.756	1.143	1.070	1.009	1.54	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
238	0	0	Norm	GSU 1	GND	Yes	14.563	1.064	1.053	1.005	1.52	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
240	0	0	Norm	GSU 1	GND-R	No	7.521	0.656	0.697	0.727	1.01	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
241	0	0	Norm	GSU 1	GND	No	14.746	1.028	1.106	1.100	1.60	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
244	0	0	Min	GSU 1	GND	No	15.560	1.072	1.074	1.013	1.55	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
247	0	0	Min	GSU 1	GND	Yes	14.563	1.065	1.053	1.005	1.52	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
249	0	0	Min	GSU 1	GND-R	No	7.521	0.656	0.697	0.737	1.01	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
250	0	0	Min	GSU 1	GND	No	14.746	1.028	1.106	1.100	1.60	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
252	0	0	Norm	GSU 1	GND-R	No	0.693	0.734	0.700	7.496	1.01	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
253	0	0	Norm	GSU 1	GND	No	1.023	1.144	1.079	14.571	1.56	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
256	0	0	Norm	GSU 1	GND	Yes	1.021	1.123	1.020	14.479	1.47	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
258	0	0	Norm	GSU 1	GND-R	No	0.695	0.735	0.700	7.480	1.01	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
259	0	0	Norm	GSU 1	GND	No	1.024	1.147	1.081	14.544	1.56	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
261	0	0	Min	GSU 1	GND-R	No	0.695	0.736	0.694	7.894	1.00	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
262	0	0	Min	GSU 1	GND	No	1.025	1.148	1.037	15.370	1.50	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
265	0	0	Min	GSU 1	GND	Yes	1.021	1.124	1.020	14.477	1.47	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
268	0	0	Min	GSU 1	GND	No	1.027	1.151	1.039	15.299	1.50	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
270	0	0	Norm	GSU 2	GND-R	No	0.899	6.329	0.970	0.899	1.40	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
271	0	0	Norm	GSU 2	GND	No	1.685	14.177	1.591	1.685	2.30	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
273	0	0	Norm	GSU 2	GND-R	Yes	0.804	6.290	0.857	0.804	1.24	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
274	0	0	Norm	GSU 2	GND	Yes	1.450	13.959	1.583	1.452	2.28	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
276	0	0	Norm	GSU 2	GND-R	No	0.898	6.331	0.853	0.899	1.23	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
277	0	0	Norm	GSU 2	GND	No	1.684	14.175	1.580	1.685	2.28	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
279	0	0	Min	GSU 2	GND-R	No	0.887	11.215	0.863	0.887	1.25	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
280	0	0	Min	GSU 2	GND	No	1.642	25.691	1.615	1.645	2.33	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
282	0	0	Min	GSU 2	GND-R	Yes	0.884	6.288	0.859	0.885	1.24	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
283	0	0	Min	GSU 2	GND	Yes	1.564	14.062	1.582	1.571	2.28	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
285	0	0	Min	GSU 2	GND-R	No	0.901	6.637	0.857	0.901	1.24	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
286	0	0	Min	GSU 2	GND	No	1.617	14.940	1.585	1.623	2.29	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
287	0	0	Norm	GSU 2	No	No	0.327	0.351	0.711	0.325	1.03	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
290	0	0	Norm	GSU 2	No	Yes	0.326	0.357	0.699	0.338	1.01	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
293	0	0	Norm	GSU 2	No	No	0.327	0.355	0.707	0.327	1.02	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
296	0	0	Min	GSU 2	No	No	0.327	0.356	0.706	0.322	1.02	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
299	0	0	Min	GSU 2	No	Yes	0.326	0.358	0.719	0.324	1.04	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
302	0	0	Min	GSU 2	No	No	0.327	0.356	0.693	0.323	1.00	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

Switchyard Unbalance Cases (EE-0894 Attachment 2)

1	0	0	Norm	TX1	No	No	3.730	1.807	1.649	3.740	2.38	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
2	0	0	Norm	TX1	No	No	2.193	1.835	1.674	2.198	2.42	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
3	0	0	Norm	TX1	No	No	2.867	1.827	1.667	2.875	2.41	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
4	0	0	Norm	TX1	No	Yes	3.747	1.463	1.623	3.758	2.34	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
5	0	0	Norm	TX1	No	No	3.750	1.814	1.649	3.761	2.38	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
6	0	0	Min	TX1	No	No	3.928	1.648	1.602	3.930	2.31	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
7	0	0	Min	TX1	No	Yes	3.840	1.624	1.601	3.854	2.31	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
8	0	0	Min	TX1	No	No	3.952	1.649	1.602	3.953	2.31	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
9	100	100	Norm	TX1	No	No	3.094	1.873	1.081	3.102	1.56	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
10	100	100	Norm	TX1	No	Yes	3.067	1.799	1.801	3.088	2.60	0.91	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
11	100	100	Norm	TX1	No	No	3.071	1.837	1.800	3.079	2.60	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
12	100	100	Min	TX1	No	No	3.238	1.711	1.689	3.240	2.44	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
13	100	100	Min	TX1	No	Yes	3.825	1.384	1.307	3.827	1.89	0.95	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
14	100	100	Min	TX1	No	No	3.215	1.690	1.691	3.216	2.44	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
27	0	0	Norm	GSU 1	No	No	2.046	1.789	1.662	1.573	2.40	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
28	0	0	Norm	GSU 1	No	Yes	1.988	1.666	1.636	1.572	2.36	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
29	0	0	Norm	GSU 1	No	No	2.045	1.592	1.730	1.740	2.50	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
30	0	0	Min	GSU 1	No	No	2.090	1.655	1.662	1.579	2.40	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
31	0	0	Min	GSU 1	No	Yes	2.020	1.662	1.636	1.573	2.36	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
32	0	0	Min	GSU 1	No	No	2.045	1.592	1.730	1.741	2.50	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
33	0	0	Norm	GSU 1	No	No	1.574	1.737	1.636	1.966	2.36	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
34	0	0	Norm	GSU 1	No	Yes	1.539	1.758	1.569	2.006	2.26	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
35	0	0	Norm	GSU 1	No	No	1.539	1.789	1.662	1.974	2.40	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
36	0	0	Min	GSU 1	No	No	1.538	1.789	1.531	2.060	2.21	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
37	0	0	Min	GSU 1	No	Yes	1.539	1.758	1.524	1.973	2.20	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
38	0	0	Min	GSU 1	No	No	1.539	1.790	1.531	2.041	2.21	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
39	0	0	Norm	GSU 2	No	No	2.171	1.774	2.058	2.172	2.97	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
40	0	0	Norm	GSU 2	No	Yes	1.931	1.883	2.109	1.935	3.04	0.88	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
41	0	0	Norm	GSU 2	No	No	2.171	1.782	1.999	2.171	2.88	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
42	0	0	Min	GSU 2	No	No	2.014	2.323	1.998	2.023	2.88	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
43	0	0	Min	GSU 2	No	Yes	2.004	1.339	2.013	2.009	2.91	0.89	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
44	0	0	Min	GSU 2	No	No	2.098	1.850	2.004	2.102	2.89	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
45	0	0	Norm	GSU 2	No	No	2.161	1.971	1.875	1.515	2.71	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
46	0	0	Norm	GSU 2	No	Yes	2.126	1.971	1.814	1.510	2.62	0.91	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
47	0	0	Norm	GSU 2	No	No	2.161	1.971	1.859	1.516	2.68	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
48	0	0	Min	GSU 2	No	No	2.161	1.970	1.874	1.481	2.71	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
49	0	0	Min	GSU 2	No	Yes	2.125	1.973	1.813	1.477	2.62	0.91	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
50	0	0	Min	GSU 2	No	No	2.161	1.971	1.859	1.483	2.68	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

*** Values have been evaluated as acceptable in EE-0894 Attachment 5

2J Emergency Bus Cases

BE1-47N Relay Case Results (EE-0894 Attachment 1)

Case #	Unit 1 Power %	Unit 2 Power %	Bus Loading	Open Phase Location	Open Phase Ground	LOCA	Negative Sequence, V2 t = 8s (L-N rms, at 4200:120 PT secondaries) SWGR 1H	SWGR 1J	SWGR 2H	SWGR 2J	% V2 SWGR 1J	% Derating SWGR 1J	Derating Acceptable (SWGR 1J Equipment) AFW	SW	CH	LHSI	OSRS	QS	ISRS	CC
1	0	0	Norm	TX1	No	No	2.821	0.305	0.309	2.829	4.08	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
2	0	0	Norm	TX1	No	No	2.815	0.307	0.311	2.823	4.07	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
3	0	0	Norm	TX1	No	No	2.842	0.305	0.309	2.850	4.11	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
14	0	0	Norm	TX1	No	Yes	2.844	0.301	0.306	2.853	4.12	0.80	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
19	0	0	Norm	TX1	No	No	2.843	0.305	0.308	2.851	4.11	0.81	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
22	0	0	Min	TX1	No	No	2.897	0.317	0.304	2.898	4.18	0.80	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
29	0	0	Min	TX1	No	Yes	2.881	0.297	0.300	2.891	4.17	0.80	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
32	0	0	Min	TX1	No	No	2.920	0.318	0.303	2.922	4.22	0.80	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
35	100	100	Norm	TX1	No	No	1.965	0.330	0.323	1.969	2.84	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
38	100	100	Norm	TX1	No	Yes	1.980	0.347	0.323	1.985	2.86	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
41	100	100	Norm	TX1	No	No	1.935	0.323	0.323	1.968	2.84	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
44	100	100	Min	TX1	No	No	1.891	0.299	0.343	1.891	2.73	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
47	100	100	Min	TX1	No	Yes	2.002	0.325	0.338	2.009	2.90	0.89	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
50	100	100	Min	TX1	No	No	1.871	0.301	0.309	1.872	2.70	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
235	0	0	Norm	GSU 1	GND	No	14.756	1.143	1.070	1.009	1.46	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
238	0	0	Norm	GSU 1	GND	Yes	14.563	1.064	1.053	1.005	1.45	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
240	0	0	Norm	GSU 1	GND-R	No	7.521	0.656	0.697	0.727	1.05	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
241	0	0	Norm	GSU 1	GND	No	14.746	1.028	1.106	1.100	1.59	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
244	0	0	Min	GSU 1	GND	No	15.560	1.072	1.074	1.013	1.46	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
247	0	0	Min	GSU 1	GND	Yes	14.563	1.065	1.053	1.005	1.45	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
249	0	0	Min	GSU 1	GND-R	No	7.521	0.656	0.697	0.737	1.06	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
250	0	0	Min	GSU 1	GND	No	14.746	1.028	1.106	1.100	1.59	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
251	0	0	Norm	GSU 1	No	No	0.343	0.322	0.322	0.966	1.39	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
254	0	0	Norm	GSU 1	No	Yes	0.343	0.322	0.338	0.981	1.42	0.97	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
257	0	0	Norm	GSU 1	No	No	0.344	0.322	0.322	0.969	1.40	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
260	0	0	Min	GSU 1	No	No	0.344	0.323	0.342	1.002	1.45	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
263	0	0	Min	GSU 1	No	Yes	0.346	0.322	0.340	0.972	1.40	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
266	0	0	Min	GSU 1	No	No	0.344	0.323	0.342	0.986	1.42	0.97	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
270	0	0	Norm	GSU 2	GND-R	No	0.899	6.329	0.970	0.899	1.30	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
271	0	0	Norm	GSU 2	GND	No	1.685	14.177	1.591	1.685	2.43	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
273	0	0	Norm	GSU 2	GND-R	Yes	0.804	6.290	0.857	0.804	1.16	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
274	0	0	Norm	GSU 2	GND	Yes	1.450	13.959	1.583	1.452	2.10	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
276	0	0	Norm	GSU 2	GND-R	No	0.898	6.331	0.853	0.899	1.30	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
277	0	0	Norm	GSU 2	GND	No	1.684	14.175	1.580	1.685	2.43	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
279	0	0	Min	GSU 2	GND-R	No	0.887	11.215	0.863	0.887	1.28	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
280	0	0	Min	GSU 2	GND	No	1.642	25.691	1.615	1.645	2.37	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
282	0	0	Min	GSU 2	GND-R	Yes	0.884	6.288	0.859	0.885	1.28	0.98	Yes	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
283	0	0	Min	GSU 2	GND	Yes	1.564	14.062	1.582	1.571	2.27	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
285	0	0	Min	GSU 2	GND-R	No	0.901	6.637	0.857	0.901	1.30	0.98	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
286	0	0	Min	GSU 2	GND	No	1.617	14.940	1.585	1.623	2.34	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
288	0	0	Norm	GSU 2	GND-R	No	0.877	0.792	6.424	0.709	1.02	0.99	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
289	0	0	Norm	GSU 2	GND	No	1.639	1.507	14.270	1.189	1.72	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
291	0	0	Norm	GSU 2	GND-R	Yes	0.867	0.792	6.401	0.696	1.00	0.99	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A
292	0	0	Norm	GSU 2	GND	Yes	1.612	1.506	14.188	1.130	1.63	0.97	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
295	0	0	Norm	GSU 2	GND	No	1.642	1.510	14.240	1.191	1.72	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
298	0	0	Min	GSU 2	GND	No	1.644	1.511	15.030	1.153	1.66	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
301	0	0	Min	GSU 2	GND	Yes	1.612	1.506	14.188	1.148	1.66	0.96	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
304	0	0	Min	GSU 2	GND	No	1.647	1.514	14.974	1.155	1.67	0.96	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

Switchyard Unbalance Cases (EE-0894 Attachment 2)

Case #	Unit 1 Power %	Unit 2 Power %	Bus Loading	Open Phase Location	Open Phase Ground	LOCA	SWGR 1H	SWGR 1J	SWGR 2H	SWGR 2J	% V2 SWGR 1J	% Derating SWGR 1J	AFW	SW	CH	LHSI	OSRS	QS	ISRS	CC
2	0	0	Norm	TX1	No	No	2.193	1.835	1.674	2.198	3.173	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
3	0	0	Norm	TX1	No	No	2.867	1.827	1.667	2.875	4.149	0.80	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
9	100	100	Norm	TX1	No	No	3.094	1.873	1.081	3.102	4.477	0.77	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
10	100	100	Norm	TX1	No	Yes	3.067	1.799	1.801	3.088	4.457	0.77	Yes***	No	Yes	No	Yes	Yes	Yes***	N/A
11	100	100	Norm	TX1	No	No	3.071	1.837	1.800	3.079	4.444	0.78	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
12	100	100	Min	TX1	No	No	3.238	1.711	1.689	3.240	4.676	0.75	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
14	100	100	Min	TX1	No	No	3.215	1.690	1.691	3.216	4.643	0.76	Yes	No	Yes	N/A	N/A	N/A	N/A	Yes
15	0	0	Norm	TX2	No	No	1.631	1.714	4.143	1.632	2.355	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
16	0	0	Norm	TX2	No	Yes	1.505	1.714	4.157	1.505	2.172	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
17	0	0	Norm	TX2	No	No	1.629	1.714	4.167	1.629	2.352	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
18	0	0	Min	TX2	No	No	1.560	1.716	4.270	1.560	2.251	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
19	0	0	Min	TX2	No	Yes	1.551	1.715	4.130	1.552	2.241	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
20	0	0	Min	TX2	No	No	1.562	1.716	4.293	1.562	2.255	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
21	100	100	Norm	TX2	No	No	1.815	1.686	3.577	1.816	2.621	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
22	100	100	Norm	TX2	No	Yes	1.654	1.689	3.598	1.655	2.388	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
23	100	100	Norm	TX2	No	No	1.882	1.709	3.612	1.816	2.621	0.91	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
24	100	100	Min	TX2	No	No	1.727	1.686	3.666	1.726	2.492	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
25	100	100	Min	TX2	No	Yes	1.683	1.708	3.578	1.683	2.430	0.92	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
26	100	100	Min	TX2	No	No	1.704	1.696	3.664	1.703	2.459	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
27	0	0	Norm	GSU 1	No	No	2.046	1.789	1.662	1.573	2.271	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
28	0	0	Norm	GSU 1	No	Yes	1.988	1.666	1.636	1.572	2.269	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
29	0	0	Norm	GSU 1	No	No	2.045	1.592	1.730	1.740	2.512	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
30	0	0	Min	GSU 1	No	No	2.090	1.655	1.662	1.579	2.279	0.93	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
31	0	0	Min	GSU 1	No	Yes	2.020	1.662	1.636	1.573	2.270	0.93	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
32	0	0	Min	GSU 1	No	No	2.045	1.592	1.730	1.741	2.512	0.92	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
33	0	0	Norm	GSU 1	No	No	1.574	1.737	1.636	1.966	2.837	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
34	0	0	Norm	GSU 1	No	Yes	1.539	1.758	1.569	2.006	2.896	0.89	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
35	0	0	Norm	GSU 1	No	No	1.539	1.789	1.662	1.974	2.849	0.90	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
36	0	0	Min	GSU 1	No	No	1.538	1.789	1.531	2.060	2.974	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
37	0	0	Min	GSU 1	No	Yes	1.539	1.758	1.524	1.973	2.848	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
38	0	0	Min	GSU 1	No	No	1.539	1.790	1.531	2.041	2.947	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
39	0	0	Norm	GSU 2	No	No	2.171	1.774	2.058	2.172	3.135	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
40	0	0	Norm	GSU 2	No	Yes	1.931	1.883	2.109	1.935	2.793	0.90	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
41	0	0	Norm	GSU 2	No	No	2.171	1.782	1.999	2.171	3.134	0.88	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
42	0	0	Min	GSU 2	No	No	2.014	2.323	1.998	2.023	2.919	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
43	0	0	Min	GSU 2	No	Yes	2.004	1.339	2.013	2.009	2.900	0.89	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
44	0	0	Min	GSU 2	No	No	2.098	1.850	2.004	2.102	3.034	0.89	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
45	0	0	Norm	GSU 2	No	No	2.161	1.971	1.875	1.515	2.187	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
46	0	0	Norm	GSU 2	No	Yes	2.126	1.971	1.814	1.510	2.179	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
47	0	0	Norm	GSU 2	No	No	2.161	1.971	1.859	1.516	2.188	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
48	0	0	Min	GSU 2	No	No	2.161	1.970	1.874	1.481	2.138	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes
49	0	0	Min	GSU 2	No	Yes	2.125	1.973	1.813	1.477	2.131	0.94	Yes***	Yes	Yes	Yes	Yes	Yes	Yes***	N/A
50	0	0	Min	GSU 2	No	No	2.161	1.971	1.859	1.483	2.141	0.94	Yes	Yes	Yes	N/A	N/A	N/A	N/A	Yes

***Values have been evaluated as acceptable in EE-0894 Attachment 3

MPR

May 24, 2017
1114-0058-LTR-001, Rev. 0

Mr. Joseph DeMarco
Dominion Innsbrook Technical Center
5000 Dominion Boulevard
Glen Allen, Virginia 23060

Subject: Calculation for AFW and ISRS Motor's Thermal Performance during an Unbalanced Condition

Dear Mr. DeMarco:

Attached, is the final Nuclear QA Calculation for the North Anna Power Station's AFW and ISRS motor's thermal performance during an unbalanced voltage condition. We incorporated the two references provided by Dominion.

The AFW pump motor insulation has reasonable assurance of operating for greater than 30 days during a design basis accident requiring 111% loading, at end of life, with a concurrent negative sequence voltage of 3.176V (4.6% unbalance) at the secondary of the 4200:120V potential transformer. Under the same voltage unbalance condition, the ISRS motors will have a service life of greater than 30 days during a design basis event occurring at the 60 year operating point.

Should you have any questions, or require any additional information, please contact us.

Sincerely,

John Festa

Enclosure(s): Calculation for AFW and ISRS Pump Motors

cc: Mike Morris

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Thermal Evaluation of AFW and ISRS Pump Motors During an Open Phase Condition

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1.0 Summary of Purpose and Results

1.1. Purpose

The purpose of this calculation is to evaluate the thermal performance of the North Anna Power Station Auxiliary Feedwater (AFW) and Inside Recirculation Spray (ISRS) motors during an unbalanced voltage condition concurrent with a design basis accident.

1.2. Results

The AFW pump motor insulation has reasonable assurance of operating for greater than 30 days during a design basis accident requiring 111% loading, at end of life, with a concurrent negative sequence voltage of 3.176V (4.6% unbalance) at the secondary of the 4200:120V potential transformer. Under the same voltage unbalance condition, the ISRS motors will have a service life of greater than 30 days during a design basis event occurring at the 60 year operating point.

2.0 Background

A bus with unbalanced voltages, such as those in an open phase condition, can induce higher than normal currents in operating polyphase motors. Since motor heating occurs as the square of motor current, elevated currents will cause the temperature of the motor components to rise. With the rotor being more thermally robust, the stator winding insulation is the limiting component to motor life under high thermal stresses (Reference 5). If the insulation degrades to the point that it no longer provides a sufficient barrier between the windings and the stator's iron core, a short to ground, turn to turn short, or an open circuit could occur. Depending on the extent of damage, some or all of these faults will cause motor failure.

The National Electric Manufacturers Association (NEMA) establishes insulation temperature limits to prevent excessive degradation of insulation. Maintaining temperatures below these limits does not stop the chemical degradation of insulation, but ensures that the insulation degradation is slow enough that the motor has a normal life expectancy. Table 2-1 shows the rated temperatures for each insulation class (Reference 10).

Table 2-1. NEMA Insulation Class Temperature Ratings for Motors

Class	Temperature Rating
A	105° C
B	130° C
F	155° C
H	180° C

North Anna Power Station (NAPS) plans to install relays that sense negative sequence voltage and trip to protect safety related motors during open phase conditions. Due to bus loading, transformer arrangement, and relay setpoint, the negative sequence relays will not trip on every open phase condition. This calculation verifies that the AFW pump and ISRS pump motors will meet design life requirements with an unbalanced voltage condition of 3.176V negative sequence voltage at the secondary of the 4200:120V potential transformer.

2.1. Scope

This calculation evaluates that:

- The AFW pump motors can operate at rated capacity for a minimum of 180 days during a design basis event.
- ISRS pump motors meet the minimum service life of 30 days during a design basis event that occurs at the end of the motor operating life.

The evaluation examines thermal effects at this negative sequence voltage. Other effects that can occur due to high negative sequence voltage, such as torque reduction, over-current device tripping, and speed changes are not part of this evaluation.

3.0 Methodology

The following sections outline the method used to determine estimated motor life while operating under unbalanced voltage conditions.

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3.1. NEMA Derating Factor

NEMA MG-1 (Reference 10) recommends using a derating factor for operation of polyphase squirrel-cage induction motors and large synchronous machines under voltage unbalance conditions. This derating factor accounts for the added heating, particularly of the rotor bars and stator iron, and the reduction in torque caused by the voltage unbalance.

NAPS specified that the AFW and ISRS pump motors are required to operate with a negative sequence voltage of 3.176V at the secondary of the 4200V:120V, open delta configuration, potential transformer (Reference 0). Transformer primary side line to line voltage is taken to be 100% and is set to 4160V (Reference 1).

4160V (line to line) on the primary of the potential transformer is taken to be 100% voltage. However, sequence voltages use a line to neutral base (Reference 2, Section 2.5). Therefore, 100% sequence voltage on the secondary side corresponds to:

$$\frac{4160V}{\sqrt{3}} * \frac{120V}{4200V} = 68.62V$$

The negative sequence voltage as a percentage is:

$$\frac{3.176V}{68.62V} = 4.6\%$$

The NEMA voltage unbalance percentage can be approximated by the ratio of negative to positive sequence voltage, provided the ratio is <5% (Reference 5, page 51) Since positive sequence voltage is 100%, the ratio of negative to positive sequence voltage is 4.6%. Thus, the 3.176V negative sequence voltage results in approximately 4.6% NEMA voltage unbalance.

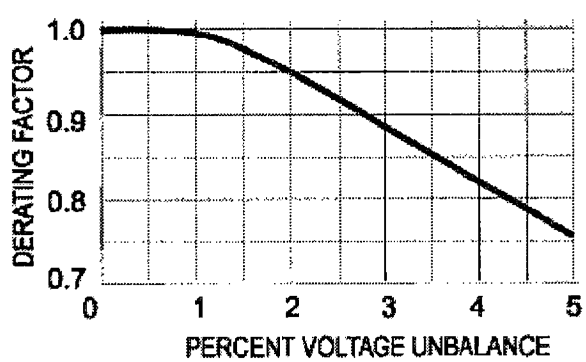

Figure 3-1. NEMA Derating Factor

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When an induction motor is operated with 4.6% unbalance, NEMA MG-1-2009 recommends multiplying the rated horsepower by a derating factor of ≈0.78, see Figure 3-1, to reduce the possibility of damage. Equivalently, the NEMA derating curve means that at 4.6% unbalance, the motor's output power should be multiplied by $\frac{1}{0.78} = 1.28$ to obtain an equivalent motor loading. The motor can then be evaluated at this equivalent motor loading.

3.2. Temperature Rise at Service Factor

The expected temperature rise while operating at service factor can be calculated using either data from a service test or the rated temperature rise for the insulation. To calculate the expected temperature rise, a ratio can be created using conservation of energy. When the motor is at thermal equilibrium the heat loss is equal to the heat input.

$$\dot{Q}_{loss} = \dot{Q}_{input}$$

Heat loss equals the heat transfer coefficient times the temperature rise above ambient. Heat input is equal to the I^2R heat generation (to a first order). For thermal equilibrium:

$$U\Delta T = I^2R$$

Where U = heat transfer coefficient.

At different motor loadings:

$$U\Delta T_{X\%} = I_{X\%}^2 R$$

$$U\Delta T_{Y\%} = I_{Y\%}^2 R$$

Taking U and R to be constant across motor loading, the two equations can be set equal to each other.

$$\frac{\Delta T_{X\%}}{I_{X\%}^2} = \frac{\Delta T_{Y\%}}{I_{Y\%}^2}$$

This ratio is then used to determine the temperature rise while operating at the motor service factor.

3.3. Determining Equivalent Motor Life

A motor's rated insulation life can be determined by using environmental qualification information or calculated manually. Safety grade motors located in an environment with an elevated temperature typically operate under an environmental qualification program which documents the procurement specification requirements, operating conditions, and service life.

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The NEMA insulation class limit is normally based on a 20,000 hour (2.3 year) operating period (Reference 4). That is, the insulation is expected to operate continuously at its maximum temperature for 2.3 years without failing. A motor operating below the insulation temperature limits will have a life expectancy much greater than 2.3 years.

If a motor violates a NEMA temperature limit because of unbalanced voltages or other reasons, it is possible to calculate the amount of service life remaining. An environmental qualification report will typically contain the qualified life and activation energy of the stator winding insulation. With this information, the motor's temperature and time history can be used to estimate how much the insulation has degraded using the Arrhenius methodology. The Arrhenius equation is as follows:

$$H = t\, e^{\left(\frac{1}{T_2}-\frac{1}{T_1}\right)\left(\frac{\varphi}{K}\right)}$$

Where:

H= Equivalent life hours at rated insulation temperature.

t = time at T_1

T_1 = motor temperature in Kelvin

T_2 = Reference temperature for equivalent life in Kelvin

φ = activation energy

K = Boltzmann's constant (8.617E-5 eV/°K, Reference 9)

If the activation energy, φ, for the insulation is unknown, an approximation of the Arrhenius equation can be used to estimate service life. Using a rule of thumb that for every 10° rise above motor insulation rating can reduce motor life by one-half (Reference 5) The Arrhenius equation approximation is as follows:

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$$H = t * 2^{\frac{T - T_{rated}}{10}}$$

Where:

H = equivalent life hours

T_{rated} = insulation rated temperature (130°C for Class B insulation, Reference 10)

T = operating temperature

t = operating time

The Arrhenius equation or Arrhenius approximation are used to calculate the equivalent life hours remaining at the end of the motor service life. For the worst case thermal aging analysis, a design basis accident is assumed to occur at the end of the motor service life. The motors are assumed to operate with a temperature rise at service factor loading, unless specified otherwise in the EQ report, and a negative sequence voltage of 3.176V (4.6% unbalance). The pump motor satisfies design requirements if there are equivalent life hours remaining upon completion of the design basis accident duty cycle.

4.0 Auxiliary Feed Water Pump Motor

4.1. Verified Assumptions

4.1.1. AFW Pump Insulation Degradation Estimate

To model insulation life degradation, an approximation of the Arrhenius equation is used. An industry accepted rule of thumb states that each 10° rise above the NEMA motor insulation rating will reduce motor life by one half (Reference 5).

4.1.2. Motor Testing Duration

The time required to perform the quarterly AFW pump service testing is assumed to be 4 hours, which sums to a total of 16 maintenance run hours per year. Reference 11 shows AFW pump run time during the service test of less than one hour. Four hours of AFW run time per quarter is used for conservatism.

4.1.3. Unit Trip per Calendar Year

Condition II events are defined as events of moderate frequency that at worst case result in reactor shutdown without fuel damage or reactor vessel overpressurization (Reference 15, page 67). Per reference 15, a plant trip resulting from a class II event is predicted to occur $\geq 10^{-1}$

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times per calendar year. For this calculation, a condition II event is assumed to occur once per calendar year. During this event, the AFW pumps are assumed to run for a duration of 12 hours.

4.1.4. Ambient Temperature

During testing, 20°C is assumed for the ambient temperature. Reference 7 documents that the suction piping temperature was 67°F (19.4°C) during testing, therefore 20°C is a reasonable assumption for the ambient temperature.

4.2. Unverified Assumptions

There are no unverified assumptions in this calculation.

4.3. Design Inputs

4.3.1. Motor Characteristics

AFW pump ratings obtained from NAPS calculation EE-0025 Rev 3, Attachment 14.3, Page 1 (Reference 6) and shown in Table 4-1 below.

Table 4-1. Motor Parameters for AFW Pumps

Parameter	Value
Rated Voltage	4000 V
Horsepower	450 hp
Service Factor	1.15
Full Load Amps	57.3
Rated Ambient Temperature	40°C
Insulation Class	B
Temperature Rise at Service Factor Loading	90°C

4.3.2. Voltage Unbalance

Per Reference 1, the AFW pump motors are required to operate with a negative sequence voltage of 3.176V at the 4200:120V potential transformer secondary. This design input is used as the worst-case unbalance voltage condition under which the AFW pump will operate.

4.4. Acceptance Criteria

Per Reference 1, the AFW pump motor must be able to run continuously for 30 days during a design basis accident occurring at the end of the motor's 60 year service life.

4.5. Calculation

Per reference 1 and 11, during the last AFW pump motor performance test, stator temperature stabilized at approximately 57.2° C (135° F) with a line current of 47 A (Reference 7, page 41, Reference 13, plot of AFW pump temperature). As stated in section 4.1.3 ambient temperature during testing assumed to be 20° C. Thus the temperature rise during testing periods is ΔT=37.2°C.

Using these parameters and the relationship between temperature rise and line current, we can estimate the temperature rise of the motor at different motor loadings. Using the relationship between temperature rise and stator current developed in Section 3.3, the temperature rise for the AFW motor operated at the service factor of 115% and Full Load Amps of 57.3A is calculated below.

$$\frac{37.2°C}{(47A)^2} = \frac{\Delta T_{115\%}}{(57.3A * 1.15)^2}$$

$$\Delta T_{115\%} = 73.1°C$$

The AFW pumps are located in a mild environment and thus do not have an environmental qualification (EQ) report. Since the activation energy of the AFW pump motor insulation is not available, the Arrhenius equation approximation from section 3.3 is used to calculate insulation equivalent life at a given temperature. Additionally, a nominal motor equivalent life of 20,000 hours will be used.

Based on the system operating conditions described in Section 2.2 of Reference 8, the AFW pumps operate infrequently. An AFW pump is not normally running while the plant is in Mode 1 or during normal shutdown conditions. As described, the AFW pumps only operate for maintenance or because of an infrequent fault, such as a loss of offsite power.

The evaluation analyzes the AFW motor thermal degradation for 60 year plant life. The AFW motor is not continuously run and will be operated infrequently for tests and in the event of a unit trip. At the end of plant life, a design basis accident is assumed to occur concurrent with a negative sequence voltage of 3.176V (4.6% unbalance) at the secondary of the 4200:120V potential transformer. The evaluation will determine how long the motor can operate before qualified insulation life is exhausted.

During plant life, the AFW pumps are assumed to operate for a duration of 4 hours once per quarter as part of regular service testing – a total of 16 hours per year. Additionally, a condition II event which causes a plant trip is assumed to occur once per calendar year. This plant trip will cause the AFW pump to run for a duration of 12 hours. Thus, the AFW pumps will run for a total of 28 hours per year for normal plant operation. During this time, the pump's temperature rise is

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assumed to be 73.1°C. That is, the pump is operated at its service factor (115%). This is a conservative assumption since maintenance only requires 82% loading (Reference 7). Additionally, during maintenance, or other infrequent operations, the ambient temperature is assumed to be 20°C, for an insulation temperature of 20°+73.1°= 93.1°C.

The total equivalent life of the AFW pump due to testing and plant trips is calculated below:

$$H_1 = 28\frac{hours}{year} * 60years * 2^{\frac{93.1^\circ - 130^\circ}{10}}$$

$$H_1 = 130\ hours$$

When the motor is not operating (plant life minus 28 hours per year), it will be assumed to be in a standby condition, in a 20°C room.

$$H_2 = 60years * \left(365.25\frac{days}{year} * 24\frac{hours}{day} - 28\ hours\right) * 2^{\frac{20^\circ - 130^\circ}{10}}$$

$$H_2 = 256\ hours$$

At the end of life, the evaluation postulates a design basis accident occurs with a concurrent open phase condition of 3.176V negative sequence voltage (4.6% voltage unbalance). The AFW pump motor is required to run at 111% loading (References 1 and 6). Running the motor at 111% loading while using the NEMA derating factor to account for 3.176V negative sequence voltage will have an equivalent heating effect as running the motor at 111% * 1.28 = 142% loading.

Using the temperature estimation formula:

$$\frac{37.2°C}{(47A)^2} = \frac{\Delta T_{142\%}}{(57.3A * 1.42)^2}$$

$$\Delta T_{142\%} = 111.5°C$$

For this condition, the motor is considered to be in a 40°C room. The insulation temperature will be 40°+111.5° = 151.5°C. This is about 20°C above the NEMA B rated 130°C for Class B insulation, but will not result in immediate failure since it is not near a temperature that will damage bearings or the motor casing, etc. With these values, the time before insulation rated life is exhausted can be calculated:

$$20{,}000\ hours - H_1 - H_2 = t * 2^{\frac{151.5^\circ - 130^\circ}{10}}$$

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$$t = 4420\ hours\ \approx 184\ days$$

In conclusion the AFW pumps insulation has reasonable assurance of operating for greater than 180 days during a design basis accident requiring 111% loading, at end of life, with a concurrent negative sequence voltage of 3.176V (4.6% unbalance).

5.0 Inside Recirculation Spray Pump Motors

5.1. Verified Assumptions

5.1.1. Positive Sequence Voltage

For the calculation of voltage unbalance with a negative sequence voltage of 3.176V (Reference 1), the positive sequence voltage is assumed to be 100%.

5.2. Unverified Assumptions

There are no unverified assumptions in this calculation.

5.3. Design Inputs

5.3.1. Motor Characteristics

ISRS ratings in Table 5-1 were obtained from NAPS Calculation EE-0025 Rev 3, Attachment 14.3, Page 26 (Reference 6) and the EQ report (Reference 9).

Table 5-1. Motor Parameters for ISRS Pumps

Parameter	Value
Rated Voltage	460 V
Horsepower	300 hp
Service Factor	1.00
Full Load Amps	338
Insulation Class	H
Temperature Rise	80°C

5.3.2. Motor Qualified Life

The EQ report calculates the ISRS motors have a qualified life of 2268.54 years at 132°F (55.56°C). However, the EQ specification calculates the motors use 68.73 years of equivalent

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life (at 132°F) in 60 years of plant life. At the end of plant life, the ISRS motors have $(2268.54 - 68.73) \approx 2200$ years of equivalent life (at 132°F) remaining.

5.3.3. Voltage Unbalance

Per Reference 1, the ISRS pump motors are required to operate with a negative sequence voltage of 3.176 V at the 4200:120V potential transformer secondary. This design input is used as the worst-case unbalance voltage condition under which the ISRS motors will operate.

5.4. Acceptance Criteria

Per Reference 1, the required service life of the ISRS pump motors is 30 days under conditions and duty cycle occurring during a design basis accident.

5.5. Calculation

This evaluation examines a design basis accident at end of a 60 year plant life, with a concurrent open phase condition causing a negative sequence voltage of 3.176V (4.6% unbalance).

Reference 6 lists the loading of the ISRS at 98.33% of full load. For calculation simplicity and conservatism, the ISRS will be considered to be at 100% load. As calculated previously, with a negative sequence voltage of 3.176V (4.6% unbalance), the NEMA derating factor multiplier is 1.28. Therefore, during unbalanced conditions the motor has an equivalent loading of 100% * 1.28 = 128%.

Using Full load amps and rated temperature rise from Table 5-1

$$\frac{80°\text{C}}{(338A)^2} = \frac{\Delta T_{128\%}}{(338A * 1.28)^2}$$

$$\Delta T_{128\%} = 131°C.$$

The EQ report (Reference 9) analyzes the worst case ambient temperature profile consisting of the worst case MSLB and LOCA profiles. Per the EQ report, during the first 2000 seconds of an accident, a MSLB causes a bounding temperature of 261°F = 127.2°C on the surface of the motor. After the first 2000 seconds, the LOCA temperature profile is bounding. The EQ report calculates an equivalent time and temperature for the LOCA temperature profile. The report calculates the LOCA profile is equivalent to 674,478 seconds (=187.4 hours) at 150°F (65.6°C). This temperature profile covers the entire 30 day mission time of the ISRS motor (Reference 9).

To calculate the insulation degradation during the design basis accident, two Arrhenius calculations are necessary: 2000 seconds at 127.2°C + 131°C = 258.2°C or 531°K and 187.4 hours at 65.6°C + 131°C = 196.6°C or 470°K. The combined equivalent life expended by these

two conditions must be less than 2200 years of remaining equivalent life of the motor. The ISRS pump motors use NEMA class H insulation with a thermal limit of 180°C.

The EQ report provides enough information for this motor to use the full Arrhenius equation described in section 3.3.

Per reference 9, the following parameters are used.

$T_2 = 55.56°C$ or $328.71°K$

$\varphi = 1.077eV$

$K = 8.617E\text{-}5\ eV/°K$

Using the full Arrhenius equation:

$$H_1 = 2000\ seconds\ e^{\left(\frac{1}{328.71°K}-\frac{1}{531°K}\right)\left(\frac{1.077eV}{8.617*10^{-5}\frac{eV}{°K}}\right)}$$

$$H_1 \approx 124\ years$$

And

$$H_2 = 187.4\ hours\ e^{\left(\frac{1}{328.71°K}-\frac{1}{470°K}\right)\left(\frac{1.077eV}{8.617*10^{-5}\frac{eV}{°K}}\right)}$$

$$H_2 \approx 1969\ years$$

Combining H_1 and H_2 results in 2093 years of equivalent life used during a design basis accident with a negative sequence voltage of 3.176V (4.6% unbalance). This result is below the 2200 years of equivalent life that remains at the end of 60 years of plant life. Therefore, the ISRS motor is thermally rated for the entire mission time of a design basis accident, with a concurrent open phase causing 3.165V negative sequence voltage (4.6% unbalance) at the end of the 60 year plant life.

6.0 References

1. Email from Joseph Demarco to John Festa on 4/17/2017 at 11:05AM, Subject, Fwd.: [External] NAPS Motor Analysis- Document Request (Relevant portion of email is in red text. Red text contains response to questions posed by John Cunningham in a previous email on 4/14/17)

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2. Blackburn, J. Lewis, Symmetrical Components for Power Systems Engineering, Boca Raton, FL: CRC, 2011

3. Pillay, P. and Manyage, M., Definitions of Voltage Unbalance, IEEE Power Engineering Review, May 2001

4. ASTM D 2307: Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire

5. Pillay, P. and Manyage, M., Loss of Life in Induction Machines Operating with Unbalanced Supplies, IEEE Transactions on Energy Conversion, 21(3), December 2006.

6. NAPS Calculation EE-0025, Revision 3

7. NAPS Procedure No 2-PT-71.2Q, Rev 40, Unit 2, 2-FW-O-3A, A Motor-Driven AFW Pump and Valve Test, Completed 1/4/17.

8. System Design Basis Document for Auxiliary Feedwater Systems, North Anna Power Station, SDBD-NAPS-AFW, Rev 15.

9. Qualification Documentation, QDR-N-4.4/QDR-S-4.4, ISRS Pumps, Rev 11.

10. NEMA MG-1: Motors and Generators, 2009.

11. Plot of AFW pump Test Data form Procedure No 2-PT-71.2Q, Rev 40, Unit 2, 2-FW-O-3A completed January 4, 2017.

12. NAPS Document ETE-NA-2016-0088, Design Basis for AFW Pump mission time, November, 2016.

13. Email from Joseph Demarco to John Festa on May 18, 2017, Subject: FW: [External] Calculation for the AFW & ISRS Motor Evaluation. Includes attached plot of ASW pump service test.

14. NAPS Updated Final Safety Analysis Report Chapter 15, Rev 51.06.

15. Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants. American Nuclear Society 51.1, 1983.