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TECHNICAL-EVALUATION REPORT ON THE
ADEQUACY OF STATION ELECTRIC-
DISTRIBUTION-SYSTEM VOLTAGES FOR THE
PRAIRIE ISLAND NUCLEAR GENERATING PLANT,
UNITS 1 AND 2

MASTER

(Docket Nos. 50-282, 50-306)

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September 17, 1982

Lawrence
Livermore
Laboratory

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ABSTRACT

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This report documents the technical evaluation of the adequacy of the station electric distribution system voltages for the Prairie Island Nuclear Generating Plant, Units 1 and 2. The evaluation is to determine if the onsite distribution system in conjunction with the offsite power sources has sufficient capacity to automatically start and operate all Class 1E loads within the equipment voltage ratings under certain conditions established by the Nuclear Regulatory Commission. The evaluation finds that with some minor transformer loading modifications, hardware changes and the results of equipment testing and manufacturer data, the offsite sources were demonstrated to supply adequate voltage to the Class 1E equipment under worst case conditions.

FOREWORD

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TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
2. DESIGN BASIS CRITERIA	2
3. SYSTEM DESCRIPTION	2
4. ANALYSIS	5
4.1 Analysis Conditions	5
4.2 Analysis Results	6
4.2.1 Undervoltage	6
4.2.2 Overvoltage	9
4.3 Analysis Verification	9
5. EVALUATION	10
6. CONCLUSION	11
REFERENCES	12

ILLUSTRATIONS

	<u>Page</u>
FIGURE 1 Prairie Island Nuclear Generating Plant, Units 1 and 2 Electrical One-Line Diagram	3
TABLE 1 Prairie Island Nuclear Generating Plant, Units 1 and 2 Class 1E Equipment Voltages Ratings and Analyzed Worst Case Terminal Voltages.	7

TECHNICAL EVALUATION REPORT ON THE
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FOR THE PRAIRIE ISLAND NUCLEAR GENERATING PLANT, UNITS 1 AND 2

(Docket Nos. 50-282, 50-306)

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1. INTRODUCTION

The Nuclear Regulatory Commission (NRC) by a letter dated August 8, 1979 [Ref. 1] expanded its generic review of the adequacy of the station electric distribution systems for all operating nuclear power facilities. This review is to determine if the onsite distribution system in conjunction with the offsite power sources has sufficient capacity and capability to automatically start and operate all required safety loads within the equipment voltage ratings. In addition, the NRC requested each licensee to follow suggested guidelines and to meet certain requirements in the analysis. These requirements are detailed in Section 5 of this report.

By letters dated July 17, 1981 [Ref. 2], November 20, 1981 [Ref. 3], April 13, 1982 [Ref. 4], and August 17, 1982 [Ref. 5], Northern State Power Company (NSP), the licensee, submitted their analysis and conclusion regarding the adequacy of the electrical distribution system's voltages at Prairie Island Nuclear Generating Plant, Units 1 and 2.

The purpose of this report is to evaluate the licensee's submittal with respect to the NRC criteria and present the reviewer's conclusion on the adequacy of the station electric distribution systems to maintain the voltage within the design limits of the required Class 1E equipment for the worst case starting and load conditions.

2. DESIGN BASIS CRITERIA

The design basis criteria that were applied in determining the adequacy of station electric distribution system voltages to start and operate all required safety loads within their required voltage ratings are as follows:

- (1) General Design Criterion 17 (GDC 17), "Electric Power Systems," of Appendix A, "General Design Criteria for Nuclear Power Plants," in the Code of Federal Regulations, Title 10, Part 50 (10 CFR 50) [Ref. 6].
- (2) General Design Criterion 13 (GDC 13), "Instrumentation and Control," of Appendix A, "General Design Criteria for Nuclear Power Plants," in the Code of Federal Regulations, Title 10, Part 50 (10 CFR 50) [Ref. 6].
- (3) General Design Criterion 5 (GDC 5), "Sharing of Structures, Systems and Components," of Appendix A, "General Design Criteria for Nuclear Power Plants," in the Code of Federal Regulations, Title 10, Part 50 (10 CFR 50) [Ref. 6].
- (4) ANSI C84.1-1977, "Voltage Ratings for Electric Power Systems and Equipment" [Ref. 7].
- (5) IEEE Std 308-1974, "Class 1E Power Systems for Nuclear Power Generating Stations" [Ref. 8].
- (6) "Guidelines for Voltage Drop Calculations," Enclosure 2, to NRC letter dated August 8, 1979 [Ref. 1].

3. SYSTEM DESCRIPTION

A one-line diagram of Prairie Island Nuclear Generating Plant, Units 1 and 2 (Prairie Island) is shown in Figure 1. This figure was adapted from one-line diagrams submitted to the NRC in letters dated July 17, 1981 [Ref. 2] and August 17, 1982 [Ref. 5]. There are four 4160-volt Class 1E buses each supplying a 480-volt Class 1E bus. The Class 1E buses for Unit 1 are designated 15 and 16 for the 4160-volt buses and 110 and 120 for the 480-volt buses. The Class 1E buses for Unit 2 are designated 25 and 26 for the 4160-volt buses and 210 and 220 for the 480-volt buses.

PRAIRIE ISLAND
 PLANT ELECTRICAL SYSTEM — ONE-LINE DIAGRAM
 FIGURE 1

The output of each unit is connected to the 345 kV switchyard through the unit's main 20/345 kV transformer. The 345 kV switchyard is supplied by four offsite transmission lines. The reserve transformer 1R is connected to a 161 kV switchyard where it can be supplied by the 161 kV Spring Creek line. The 161 kV system is also connected to the 345 kV system through a 161/345/13.8 kV autotransformer No. 10. Each of the two cooling tower transformers (CT11 and CT12) have a separate source connection. The CT11 transformer is supplied from the cooling tower transformer No. 1 (345/13.8 kV) connected to the 345 kV system. The CT12 transformer is supplied from the tertiary winding of the 161/345/13.8 kV autotransformer. Each of the cooling tower transformers normally supplies two towers of fans, two pumps, and one load group of Class 1E buses in each unit. The reserve transformer 2R is supplied from the 345 kV system. The 2R reserve transformer is currently planned for full operational capability by June 1983.

The supply to the 4160-volt Class 1E buses will be as follows:

- (1) Bus 15: The preferred offsite source is reserve transformer 1R with the bus tie to Bus 26 as the alternate offsite source. This transfer is automatic. The unit auxiliary transformer 1M can be used as another source. The transfer from 1M to 1R is automatic when 1M is the normal supply source.
- (2) Bus 16: The preferred offsite source is reserve transformer 1R with a cooling tower CT11 transformer as the alternate offsite source. A second alternate offsite source is the bus tie to Bus 25. The transfer between the preferred and first alternate is automatic and manual between first alternate and second alternate.
- (3) Bus 25: The preferred offsite source is reserve transformer 2R with the bus tie to Bus 16 as the alternate offsite source. The transfer between these two sources is automatic.
- (4) Bus 26: The preferred offsite source is reserve station transformer 2R with the cooling tower transformer CT12 as the alternate offsite source. A second alternate offsite source connection is the bus tie to Bus 15. The transfers between the preferred and first alternate is automatic and manual from first alternate to second alternate.

The plant's auxiliary systems are normally supplied by each of the unit's auxiliary transformer 1M and 2M.

Each 4160-volt Class 1E bus has 6 relays monitoring the voltage. Three relays are used to monitor the voltage on each of phases A and C. These relays are designated 27R, 27A, and 27A1 for phase A and 27S, 27B, and 27B1 for phase C. The 27R and 27S relays have a setpoint of $90\% \pm 2\%$ of 4160 volts with a time delay of 2 ± 2 seconds. The 27A and 27B relays have a setpoint of $55\% \pm 10\%$ of 4160 volts with a time delay of 2 ± 2 seconds. Finally, the 27A1 and 27B1 relays have a setpoint of $90\% \pm 2\%$ of 4160 volts with a time delay of 6 ± 2 seconds. Operation of these relays is as follows:

- (1) Should the voltage drop below $90\% \pm 2\%$ of 4160 volts for longer than 2 seconds, the 27R (27S) relay will drop out which causes an auxiliary relay 27RX (27SX) to also drop out.
- (2) Should the voltage continue to drop below $55\% \pm 10\%$ of 4160 volts (loss-of-voltage) for longer than 2 seconds, relay 27A (27B) and it's auxiliary relay 27AX (27BX) will drop out. This combination of auxiliary relay actuation (modified 2-out-of-4) will initiate the voltage restoration scheme.
- (3) Should the voltage drop below the $90\% \pm 2\%$ of 4160 volts for longer than 6 seconds. Relay 27A1 (27B1) would drop out causing auxiliary relay 27AX (27BX) to also drop out producing the required logic which will then initiate the voltage restoration scheme.

The voltage restoration scheme will automatically start the diesel generator associated with the voltage degraded bus, check for availability of the alternate offsite source and if the alternate source bus voltage is acceptable, supply the bus from the alternate offsite source. If the alternate offsite source is unacceptable, the loads are shed and the bus is energized by the emergency diesel generator. The loads are then sequenced back onto the bus. Block loading of the Class 1E loads on the alternate offsite source can occur if, following the completion of the load sequencing, the preferred source becomes degraded. Thus, resulting in source transfer. For the postulated worst case conditions, one Class 1E bus with safeguard loads from Unit 1 and one Class 1E bus with normal shutdown loads for Unit 2 would be block transferred to the alternate source.

4. ANALYSIS

4.1 ANALYSIS CONDITIONS

Northern States Power Company analyzed each offsite source to the onsite distribution system under minimum and maximum expected offsite grid voltages in conjunction with minimum and maximum load demand conditions to determine the terminal voltage at the Class 1E equipment. The normal off-site grid ranges are $351 \text{ kV} \pm 3 \text{ kV}$ and $168 \pm 2 \text{ kV}$ for the 345 kV and 161 kV systems, respectively, with the units on-line. The offsite grid voltages used in the analyses were 345 kV and 164.2 kV (units off-line). The maximum load condition used in the analyses was a unit trip and an SI in Unit 1 with a simultaneous turbine and reactor trip in Unit 2.

In addition to the above conditions, numerous other assumptions were modeled in the computer load flows. These assumptions covered such areas as equipment design ratings (nameplate), power factors, maximum KW and KVAR, locked rotor values, speed and torque curve values, motor acceleration times, time limits of overload protection devices, etc. [Ref. 2]. Using these assumptions and conditions, the licensee submitted an analysis for steady state, block transfer, and sequential loading. The steady state analysis assumed all loads running with minimum grid voltages and maximum load conditions. The block

transfer analysis assumed the same conditions as the steady state with the exception of all Class 1E loads in locked rotor to demonstrate transient voltages with motors starting. The sequence loading analysis calculated the voltages on the 4160-volt and 480-volt Class 1E buses as each sequenced load is added to the bus. Its purpose was to demonstrate adequate voltage and time for starting each sequenced load.

The licensee also submitted analyses showing the effect of starting a large non-Class 1E load while all the Class 1E equipment is running.

4.2 ANALYSIS RESULTS

The results of the licensee's analyses using the assumptions and plant conditions outlined above are as follows and are shown in Table 1:

4.2.1 Undervoltage

Steady State Analysis

The steady state analysis was to demonstrate that for the worst case conditions, the voltage on the Class 1E distribution system would be maintained above the upper setpoint tolerance (90% + 2.0% of 4160 volts) of the degraded voltage protection scheme. Also, for the lower setpoint tolerance of 88% of 4160 volts (90% - 2.0%), the Class 1E equipment is still operating properly.

The analysis results demonstrated that for the offsite sources through transformers 1R, 2R and CT12, the voltage on the 4160-volt buses would be maintained above the upper setpoint. The steady state results for these three sources (with no load limitations) were 93.3%, 95.5% and 92.8%, respectively, with CT12 being the worst case source. For the offsite sources through transformers CT11 and 1R (with the 161 kV Spring Creek line as the source), adequate voltage would be supplied provided load limitations existed on the sources. In the case of CT11, the analysis showed that if the cooling tower loads were reduced, acceptable voltages could be maintained. For the 161 kV Spring Creek line to be an acceptable source, several conditions had to be assumed. These conditions were with the Red Wing station on-line, the grid at 102%, and Unit 2 in a hot shutdown mode rather than simultaneously tripping with Unit 1, which represents a more realistic condition. For these load limitations, CT11 is the most limiting source of all the offsite sources with a steady state result of 91.9% of 4160 volts.

For the conditions of maximum load and minimum grid voltage, the worst case 480-volt bus voltage condition resulted in a 460 volt motor terminal voltage of 89.1% and a 480-volt motor control center (MCC) voltage for the starters of 86.0%. These analysis values were based on the 4160-volt bus at 92% (upper setpoint tolerance) voltage for all sources. For proper motor starter operation, MCC voltage had to be at least 82.3%.

TABLE 1

PRAIRIE ISLAND NUCLEAR GENERATING PLANT, UNITS 1 AND 2
CLASS 1E EQUIPMENT VOLTAGE RATINGS AND ANALYZED
WORST CASE TERMINAL VOLTAGES
(in % of Equipment Nominal Voltage Rating)

Equipment	Nominal Voltage Rating (100 %)	Maximum		Minimum	
		Rated	(a) Analyzed	Rated	Analyzed
			Steady State		Steady State Transient
Motors	4000				
Start				80	79.3
Operate		110	109.6	90	95.6
Motors	460				
Start				80	73(b)
Operate		110	110.2	90	89.1(c)
Starters	480				
Pickup				(d)	86.0(d)
Dropout		71			70(b)
Operate		110	105.6	85	86.0(d)
Other(e) Equipment					

(a) Voltage percentage is at the bus level and for no-load conditions.

(b) These voltages are based on 80% of 4160 volts at T = 0 seconds on the 4 kV buses and 88% voltage at T = 4.0 seconds. Tests, manufacturer data, and computer analyses demonstrated that the worst case motors would start and accelerate to rated speed at this reduced voltage without causing overload devices to trip.

(c) Operating at 85% voltage at full load for 30 minutes will reduce the motor life by 15 minutes out of a 40 year design life. The motors have a service factor rating of 1.15 and Class B insulation. Motor overload devices are sized to permit operation at this voltage level.

(d) Pickup voltage for size 1, 2, 3 and 4 starters are 390, 375, 395, and 395 volts, respectively. Size 3 and 4 starters are generally provided with interposing relays. Tests on the two worst case size 1 starters demonstrated pickup voltage at 340 and 380 volts.

(e) Instrument and control loads supplied from inverters.

Block Transfer Analysis

The block transfer analysis was to demonstrate that in the auto-transfer from the preferred source to the alternate source following completion of load sequencing, acceptable starting voltages would be supplied. The analysis used bus voltage dead times of 2 and 4 seconds to determine the effect on the starting motors.

The analysis results demonstrated that the offsite sources through transformers 1R, 2R and CT12 would supply adequate starting voltages to all the Class 1E motors with CT12 being the worst case source. Employing the load limitations of reduced cooling tower loads and only one safeguard train, CT11 was shown to be an acceptable source. The 161 kV Spring Creek line was shown to be an acceptable source for the limitations of an SI in Unit 1 and Unit 2 in a hot shutdown mode, Red Wing station on-line and the grid at 102% at the 161 kV substation. Comparing these sources, CT11 is the worst case source. Under the worst case conditions of maximum load and minimum grid voltage, all motors started without tripping on any overload and accelerated in sufficient time to prevent a spurious actuation of the degraded voltage relays. Also the starting transient times were such that no motor starter fuses would blow.

Sequence Loading Analysis

The sequential loading analysis was to demonstrate that adequate voltage would be supplied for normal load sequencing under the worst case conditions.

The analysis results showed that adequate starting voltages were supplied to the 4160-volt Class 1E equipment through transformers 1R, 2R and CT12 with CT12 as the worst case source. By reducing the cooling tower loads and only one safeguard bus, CT11 was shown to provide adequate starting voltages to the Class 1E equipment. The 161 kV Spring Creek line supplied adequate starting voltages with the limitations of an SI in Unit 1 and a hot shutdown in Unit 2, Red Wing station on-line and the 161 kV substation at 102% voltage. Again, CT11 was shown to be the weakest offsite source.

Under the worst case conditions of maximum load and minimum grid voltage the analysis results showed a worst case starting voltage of 73% of 460 volts for the 460-volt Class 1E motors. This value was based on 80% voltage at the 4160-volt Class 1E buses at the time of receiving the start signal ($T = 0+$). Within 4 seconds, the voltage would reach 88% of 4160 volts (degraded voltage set-point's lower tolerance) and 80.7% of 460 volts at the 4 kV and 480 volt bus level, respectively.

Summary

Based on the above analyses under worst case conditions, the licensee proposed corrective actions and provided additional information which ensured that adequate voltage was supplied to the Class 1E equipment and are as follows:

- (a) Disable the auto-transfer of CT12 loads to CT11 should CT12 fail. This will allow CT11 to only carry its dedicated loads of two towers of fans, two pumps and one load group of Class 1E buses in each unit.
- (b) Current Technical Specifications will ensure that an analysis be conducted on the adequacy of the 161 kV Spring Creek line before it can be used as an acceptable offsite source.
- (c) Worst case analysis results at the 480-volt level showed two contactors having voltage below the normal range of operability with the 4 kV buses at 88% voltage. Tests were performed to verify contactor operation at the analyzed voltages. An interposing relay was added to the start circuit of the auxiliary building special vent exhaust fan to ensure proper voltage for contactor operation.
- (d) Worst case analysis results showed several motors having starting voltages below that required assuming 80% voltage on the 4 kV buses at $T = 0$ seconds. Manufacturer's data (speed and torque curves), design specifications, temperature test data, and a computer dynamic load analysis demonstrated that these motors would start and accelerate to rated speed in sufficient time without causing protective device actuation at the reduced voltages.

4.2.2 Overvoltage

Maximum Voltage Condition

This analysis was to demonstrate that at maximum grid voltage and no-load conditions, the voltage at the terminal of the Class 1E equipment would not exceed the + 10% design voltage rating.

The worst case overvoltages occur on the 4160-volt Class 1E buses when transformer 1R (fed from the 161 kV substation) is the supplying source and on the 480-volt Class 1E buses when CT12 (fed from the 345 kV substation) is the supplying source. Both overvoltages occur for no-load conditions on the Class 1E buses.

4.3 ANALYSIS VERIFICATION

The licensee performed several tests to verify the computer model used. The tests for steady state conditions varied the loading by 400 Hp and 2500 Hp on the 4160-volt buses. Verifications were made with 1R, CT11, and CT12 as sources. Also, a transient test was performed on the safety injection (SI) pump using CT11 as the source. The voltages were measured from the switchyard down to the 4160-volt bus level. The test results showed a maximum error difference of + 0.2% in voltage drops at steady state. The SI pump voltage transient test resulted in a percentage error difference of - 1.9% in the voltage drop. A minus percentage error indicates the measured values were lower than the calculated.

5. EVALUATION

The NRC generic letter [Ref. 1] stated several requirements that the plant must meet in the voltage analysis. These requirements and an evaluation of the licensee's submittals are as follows:

- (1) With the minimum expected grid voltage and maximum load condition, each offsite source and distribution system connection must be capable of starting and continuously operating all Class 1E equipment within the equipment's voltage ratings.

The voltage analysis demonstrated that for most of the offsite sources, the voltage on the 4160-volt Class 1E buses would be maintained above the upper tolerance value (92%) of the degraded grid protection setpoint of $90\% + 2\%$ of 4160 volts. This ensures that the voltage at the 480-volt level is above the 90% lower design limit of the equipment. Should the voltage degrade to the lower setpoint tolerance value of 88% ($90\% - 2\%$ of 4160 volts), the offsite sources in some cases would provide voltages outside the design limits of some Class 1E equipment at the 480-volt level. However, in these cases either Technical Specifications (limiting the 161 kV Spring Creek line), loading modifications to CT11, addition of interposing relays or analysis documentation (i.e. equipment testing, manufacturer data, etc.) was provided which ensured that this equipment would operate and perform its safety function. Load reduction of nonessential loads at either unit following initial accident mitigation would ensure voltage recovery to near the design ratings with no appreciable effect on the operation or loss of life of the equipment.

This analysis was performed under more conservative conditions than the realistic situation of Unit 2 being in an orderly shutdown rather than tripping simultaneously with Unit 1. The current Technical Specifications will limit the use of the 161 kV Spring Creek line until it is analyzed for adequacy before connection. The disabling of the auto-transfer (modification completed) of CT12 loads to CT11 will ensure CT11 as an adequate source. The installation of the 2R transformer (fully operational by June 1983) ensured the adequacy of the other offsite sources.

- (2) With the maximum expected offsite grid voltage and minimum load condition, each offsite source and distribution system connection must be capable of continuously operating the required Class 1E equipment without exceeding the equipment's voltage ratings.

The analysis submitted by NSP demonstrated that the Class 1E equipment voltage design rating would not be exceeded for maximum grid voltage and no-load conditions.

- (3) The analysis must show that there will be no spurious separation from the offsite power source to the Class 1E buses by the

voltage protection relays when the grid is within the normal expected limits and the loading conditions established by the NRC are being met.

The analysis showed that there will be no spurious separations from the offsite sources for the worst case conditions and the starting of large non-Class 1E loads.

- (4) Test results are required to verify the voltage analyses calculations submitted.

The licensee verified their computer model calculations by tests. These tests resulted in steady state voltage drops and transient voltage drops percentage error, difference of + 0.2% and - 1.9%, respectively. These error percentages are judged acceptable.

- (5) Review the plant's electrical power systems to determine if any events or conditions could result in the simultaneous loss of both offsite circuits to the onsite distribution system (compliance with GDC-17).

The licensee has analyzed that no potential exists for violation of GDC-17 with respect to the simultaneous or consequential loss of both required circuits to the offsite network.

- (6) As required by GDC 5, each offsite source shared between units in a multi-unit station must be capable of supplying adequate starting and operating voltage to all required Class 1E loads with an accident in one unit and a safe shutdown in the remaining unit(s).

The licensee demonstrated that the shared offsite sources (1R, 2R, CT12 and with transfer load modifications to CT11) have the capacity and capability to provide adequate voltage to the Class 1E equipment of both units with an accident in one unit and a simultaneous trip of the other unit. This analysis is more conservative than with an orderly shutdown of the second unit. Technical Specifications requiring an analysis to be conducted on the offsite sources will ensure the use of the 161 kV Spring Creek line as an adequate source.

6. CONCLUSIONS

Based on the information submitted by Northern States Power Company for the Prairie Island Nuclear Generating Plant, Units 1 and 2, it is concluded that:

- (1) The completion of the proposed design modifications and existing Technical Specification requirements will ensure

that the offsite sources in conjunction with the onsite distribution system has the capacity and capability to supply adequate voltage to ensure the operation of the Class 1E equipment to perform its safety function under worst case conditions.

- (2) Spurious tripping from the offsite sources will not occur under the worst case conditions.
- (3) The Class 1E equipment's maximum voltage design limit will not be exceeded under maximum grid voltage/no-load conditions.
- (4) Acceptable test verifications were made to verify the analytical data submitted.
- (5) No event or condition will result in the simultaneous or consequential loss of both required circuits to the onsite distribution system.

Accordingly, I recommend that the NRC accept the voltage analyses submitted which demonstrates the adequacy of voltage to the Class 1E equipment for starting and continuous operation under worst case conditions.

REFERENCES

1. NRC letter (W. Gammill) to all power reactor licensees, dated August 8, 1979
2. Northern States Power Company letter (L. O. Mayer) to the NRC (Director of Nuclear Reactor Regulation) dated July 17, 1981.
3. Northern States Power Company letter (L. O. Mayer) to the NRC (Director of Nuclear Reactor Regulation), dated November 20, 1981.
4. Northern States Power Company letter (L. O. Mayer) to the NRC (Director of Nuclear Reactor Regulation), dated April 13, 1982.
5. Northern States Power Company letter (D. Musolf) to the NRC, dated August 17, 1982.
6. Code of Federal Regulations, Title 10, Part 50 (10 CFR 50), General Design Criterion 5, 13 and 17 of Appendix A for Nuclear Power Plants.
7. ANSI C84.1-1977, "Voltage Ratings for Electric Power Systems and Equipment"
8. IEEE Standard 308-1974, "Class 1E Power Systems for Nuclear Power Generating Stations"

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