

February 26, 2013

MEMORANDUM TO: Patrick Hiland, Director  
Division of Engineering  
Office of Nuclear Reactor Regulation

FROM: Roy K. Mathew, Acting Chief */RA/*  
Electrical Engineering Branch  
Division of Engineering  
Office of Nuclear Reactor Regulation

SUBJECT: NRC BULLETIN 2012-01, "DESIGN VULNERABILITY IN ELECTRIC  
POWER SYSTEM": SUMMARY REPORT

On July 27, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued Bulletin (BL) 2012-01, "Design Vulnerability in Electric Power System" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12074A115). This BL had the following purposes:

- (1) To notify the addressees that the NRC staff is requesting information about the facilities' electric power system designs, in light of the recent operating experience that involved the loss of one of the three phases of the offsite power circuit (single-phase open circuit condition) at Byron Station, Unit 2, to determine if further regulatory action is warranted.
- (2) To require that the addressees comprehensively verify their compliance with the regulatory requirements of General Design Criterion (GDC) 17, "Electric Power Systems," in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," or the applicable principal design criteria in the updated final safety analysis report and the design criteria for protection systems under 10 CFR 50.55a(h)(2) and 10 CFR 50.55a(h)(3).
- (3) To require that addressees respond to the NRC in writing, in accordance with 10 CFR 50.54(f).

Specifically, the NRC requested licensees to provide information by October 25, 2012, (1) regarding the protection scheme to detect and automatically respond to a single-phase open circuit condition or high impedance ground fault condition on GDC 17 power circuits, and (2) operating configuration of engineered safety features buses at power.

CONTACT: Roy K. Mathew, NRR/DE/EEEE  
301-415-8324

P. Hiland

- 2 -

The Electrical Engineering Branch staff has reviewed the information that NRC licensees provided. The enclosed summary report discusses the details of this review. Based on its review, the staff recommends additional regulatory actions. The staff's recommendation is provided in the attached final report.

Enclosure: As stated

The Electrical Engineering Branch (EEEB) staff has reviewed the information provided by the NRC's licensees. The enclosed summary report discusses the details of this review. Based on the review of the licensees' responses, the staff recommends additional regulatory actions. The staff's recommendation is provided in the attached final report.

Enclosure: As stated

DISTRIBUTION: (Public)

JAndersen	TMcGinty	CScott	NHilton	MCheck
MEvans	ELeeds	DDorman	TBergman	GTracy
WDean	VMcRee	CCasto	ECollins	

**ADAMS Accession Number: ML13052A711**

\*email concurrence

OFFICE	Tech Editor	NRR/DE/EEEB	NRR/DE/EEEB	NRR/DE/EEEB: BC (A)	NRR/DE: D
NAME	JDoughterty	GMatharu	VGoel	RMathew	PHiland
DATE	02/15/2013	02/19/2013	02/22/2013	02/22/2013	02/26/2013

**OFFICIAL RECORD COPY**

## DESIGN VULNERABILITY IN ELECTRIC POWER SYSTEM

### SUMMARY REPORT

On July 27, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued Bulletin (BL) 2012-01, "Design Vulnerability in Electric Power System," (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12074A115). This BL had the following purposes:

- (1) To notify the addressees that the NRC staff is requesting information about the facilities' electric power system designs, in light of the recent operating experience that involved the loss of one of the three phases of the offsite power circuit (single-phase open circuit condition) at Byron Station, Unit 2, to determine if further regulatory action is warranted.
- (2) To require that the addressees comprehensively verify their compliance with the regulatory requirements of General Design Criterion (GDC) 17, "Electric Power Systems," in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," or the applicable principal design criteria in the updated final safety analysis report and the design criteria for protection systems under 10 CFR 50.55a(h)(2) and 10 CFR 50.55a(h)(3).
- (3) To require that addressees respond to the NRC in writing, in accordance with 10 CFR 50.54(f).

Specifically, the NRC requested from its licensees the following information in two specific areas:

- (1) Given the requirements specified in BL 2012-01, describe how the protection scheme for engineered safety feature (ESF) buses (Class 1E for current operating plants or non-Class 1E for passive plants) is designed to detect and automatically respond to a single-phase open circuit condition or high impedance ground fault condition on a credited offsite power circuit or another power source. Also, include the following information:
  - (a) The sensitivity of protective devices to detect abnormal operating conditions and the basis for the protective device setpoint(s).
  - (b) The differences (if any) of the consequences of a loaded (i.e., ESF bus normally aligned to offsite power transformer) or unloaded (e.g., ESF buses normally aligned to unit auxiliary transformer) power source.
  - (c) If the design does not detect and automatically respond to a single-phase open circuit condition or high impedance ground fault condition on a credited offsite power circuit or another power source, describe the consequences of such an event and the plant response.
  - (d) Describe the offsite power transformer (e.g., startup, reserve, station auxiliary) winding and grounding configurations.

Enclosure

- (2) Briefly describe the operating configuration of the ESF buses (Class 1E for current operating plants or non-Class 1E for passive plants) at power (normal operating condition). Include the following details:
- (a) Are the ESF buses powered by offsite power sources? If so, explain what major loads are connected to the buses including their ratings.
  - (b) If the ESF buses are not powered by offsite power sources, explain how the surveillance tests are performed to verify that a single-phase open circuit condition or high impedance ground fault condition on an offsite power circuit does not exist.
  - (c) Confirm that the operating configuration of the ESF buses is consistent with the current licensing basis. Describe any changes in offsite power source alignment to the ESF buses from the original plant licensing.
  - (d) Do the plant operating procedures, including off-normal operating procedures, specifically call for verification of the voltages on all three phases of the ESF buses?
  - (e) If a common or single offsite circuit is used to supply redundant ESF buses, explain why a failure, such as a single-phase open circuit or high impedance ground fault condition, would not adversely affect redundant ESF buses.

On August 21, 2012, a public meeting was held between the NRC staff and representatives of the Nuclear Energy Institute (NEI) and nuclear power plant industry at NRC headquarters in Rockville, MD. During the meeting, NEI discussed industry questions that required clarification to address information requested in BL 2012-01. The NRC staff provided its responses to the industry questions during the meeting and stated that the meeting summary would include its responses. The meeting summary was issued on September 7, 2012 (ADAMS Accession No. ML12243A426).

## **BACKGROUND**

On January 30, 2012, Byron Station, Unit 2, experienced an automatic reactor trip from full power because the reactor protection scheme detected an undervoltage condition on the 6.9-kilovolt (kV) buses that power reactor coolant pumps (RCPs) B and C (two of four RCPs trip initiate a reactor trip). A broken insulator stack of the phase C conductor for the 345-kV power circuit that supplies both station auxiliary transformers (SATs 242-1 and 242-2) caused the undervoltage condition. This insulator stack failure caused the phase C conductor to break off from the power line disconnect switch, resulting in a phase C open circuit and a high impedance ground path. Specifically, the parted phase C connection remained electrically connected on the transformer side, and the loose bus bar conductor end fell to the ground. This ground was a direct result of the broken insulator and not an independent event. The connected loose bus bar provided a path to ground for the transformer high-voltage terminal, but did not result in a detectable ground fault (i.e., neither solid nor impedance) as seen from the source. Since the switchyard (i.e., source side) relaying was electrically isolated from the fault, it did not detect a fault; therefore, it did not operate.

After the reactor trip, the two 6.9-kV buses that power RCPs A and D, which were aligned to the unit auxiliary transformers (UATs), automatically transferred to the SATs, as designed.

Because phase C was on an open circuit condition, the flow of current on phases A and B increased because of unbalanced voltage and caused all four RCPs to trip on phase overcurrent. Even though phase C was on an open circuit condition, the SATs continued to provide power to the 4.16-kV ESF buses A and B. The open circuit created an unbalanced voltage condition on the two 6.9-kV nonsafety-related RCP buses and the two 4.16-kV ESF buses. ESF loads remained energized momentarily, relying on equipment protective devices to prevent damage from an unbalanced overcurrent condition. The overload condition caused several ESF loads to trip.

With no RCPs functioning, control room operators performed a natural-circulation cooldown of the unit. Approximately 8 minutes after the reactor trip, the control room operators diagnosed the loss of phase C condition and manually tripped breakers to separate the unit buses from the offsite power source. When the operators opened the SAT feeder breakers to the two 4.16-kV ESF buses, the loss of ESF bus voltage caused the emergency diesel generators to start automatically and restore power to the ESF buses. The licensee declared a notice of unusual event based on the loss of offsite power. The next day, the licensee completed the switchyard repairs, restored offsite power, and terminated the notice of unusual event.

The licensee reviewed the event and identified design vulnerabilities in the protection scheme for the 4.16-kV ESF buses. The loss of power instrumentation protection scheme is designed with two undervoltage relays on each of the two ESF buses. These relays are part of a two-out-of-two trip logic based on the voltages being monitored between phases A–B and B–C of ESF buses. Even though phase C was on open circuit, the voltage between phases A–B was normal; therefore, the situation did not satisfy the trip logic. Because the conditions of the two-out-of-two trip logic were not met, the protection system generated no protective trip signals to automatically separate the ESF buses from the offsite power source.

A second event also occurred at Byron Station Unit 1 on February 28, 2012. This event was also initiated by a failed inverted porcelain insulator. In this event, the 4.16-kV ESF buses did sense fault condition and separated SATs from the 4.16-kV buses. The 1A and 1B DGs started and energized the 4.16-kV ESF buses as designed.

Past operating experience has identified design vulnerabilities associated with single-phase open circuit conditions at Beaver Valley Power Station, Unit 1 (BVPS1), James A. FitzPatrick (JAF) Nuclear Power Plant, and Nine Mile Point, Unit 1 (NMP1). These events involved offsite power supply circuits that an open-circuited phase rendered inoperable. In each instance, the condition went undetected for several weeks because offsite power was not aligned during normal operation and the surveillance procedures, which recorded phase-to-phase voltage, did not identify the loss of the single phase. For more information on the events at BVPS1, JAF, and NMP1, see NRC Information Notice 2012-03, "Design Vulnerability in Electric Power System," dated March 1, 2012 (ADAMS Accession No. ML120480170).

## **DISCUSSION**

The operating experience at BVPS1, JAF, and NMP1 demonstrated the potential for loss of a single phase between the transmission network and the onsite power distribution system. The events indicate that the design of the electric power systems to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power from the transmission network were inadequate because it did not consider the possibility of the loss of a single phase between the transmission network and the onsite power distribution system.

At Byron, a failure to design the electric power system's protection scheme to sense the loss of a single phase between the transmission network and the onsite power distribution system resulted in unbalanced voltage at both ESF buses (degraded offsite power system), trip of several safety-related pieces of equipment such as essential service water pumps, centrifugal charging pumps, and component cooling water pumps and the unavailability of the onsite electric power system. This situation resulted in neither the onsite nor the offsite electric power system being able to perform its intended safety functions (i.e., to provide electric power to the ESF buses with sufficient capacity and capability to permit functioning of structures, systems, and components important to safety).

Since loss of a single phase on the offsite power source can potentially damage both trains of the emergency core cooling system, the protection scheme must automatically initiate isolation of the degraded offsite power source and transfer the safety buses to the emergency power source within the time period assumed in the accident analysis.

For the AP1000 reactors, the alternating current (ac) power system is designed such that plant auxiliaries can be powered from the grid or the standby non-Class 1E system under all modes of operation. The offsite power system provides power to the safety-related loads through the battery chargers and defense-in-depth capabilities for reactor coolant makeup and decay heat removal during normal, abnormal, and accident conditions. Since the primary means for accident and consequence mitigation in these reactors do not depend on ac power, the ac power systems are not as risk-important as they are in currently operating plants.

## **APPLICABLE REGULATORY REQUIREMENTS**

GDC 17 establishes requirements for the electric design of nuclear power plants for which a construction permit application was submitted after the Commission issued the GDC. GDC 17 states:

An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents....

Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions....

Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies...

For current operating power plants designed before GDC 17 was issued, the updated final safety analysis report sets forth criteria similar to GDC 17, which requires, among other things, that plants have an offsite and an onsite electric power system with adequate capacity and capability to permit the functioning of structures, systems, and components important to safety in the event of anticipated operational occurrences and postulated accidents.

In 10 CFR 50.55a(h)(2), the NRC requires nuclear power plants with construction permits issued after January 1, 1971, but before May 13, 1999, to have protection systems that meet the requirements stated in either Institute of Electrical and Electronics Engineers (IEEE) Standard 279, "Criteria for Protection Systems for Nuclear Power Generating Stations," or IEEE Standard 603-1991, "Criteria for Safety Systems for Nuclear Power Generating Stations," and the correction sheet dated January 30, 1995. For nuclear power plants with construction permits issued before January 1, 1971, protection systems must be consistent with their licensing basis or meet the requirements of IEEE Standard 603-1991 and the correction sheet dated January 30, 1995. In 10 CFR 50.55a(h)(3), the NRC requires that applications filed on or after May 13, 1999, for combined licenses under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," must meet the requirements for safety systems in IEEE Standard 603-1991 and the correction sheet dated January 30, 1995. These IEEE standards state that the protection systems must automatically initiate appropriate protective actions whenever a condition the system monitors reaches a preset level. Once initiated, protective actions should be completed without manual intervention to satisfy the applicable requirements of the IEEE standards.

Criterion XVI, "Corrective Action," of 10 CFR Part 50, Appendix B, requires, in part, that conditions adverse to quality be promptly identified and corrected. In the case of significant conditions adverse to quality, the measures shall assure that the cause of the condition is determined and corrective actions taken to preclude repetition.

### **Summary of Bulletin Requested Information**

The staff reviewed responses from 65 nuclear power plant sites (104 operating reactor units/plants), and two new nuclear power plant sites (four new reactor units/plants) with combined operating licenses.

### **Summary and Analysis of Responses to Question 1**

Licensees for the current operating plants stated that Class 1E buses are not designed to detect and automatically respond to a single-phase open circuit condition or high impedance ground fault condition on a credited offsite power circuit or other power sources. Specifically, the licensees stated that, consistent with the current licensing basis, existing protective circuitry will separate the ESF buses from a connected failed offsite source due to a complete loss of voltage or a sustained, balanced degraded grid voltage concurrent with certain design-basis accidents. The existing relay schemes at the plant buses were neither specifically designed nor sensitive to detect a single-phase open circuit condition in a three-phase system. The licensees stated that detection of a single-phase open circuit condition is beyond the approved design and licensing basis of the plant. Most licensees responded that a high impedance fault by itself (independent of the open-phase circuit condition) is not a concern, not credible, or the existing protection is adequate. Although the Byron initiating event (single-phase open circuit at the high-voltage connection to the SAT with high impedance ground fault condition) can occur at all operating plants, one licensee stated that this is not a credible event at its facility because of the unique



design of the switchyard (each circuit is routed in metal-enclosed, Sulphur Hexafluoride (SF6) gas-insulated bus).

In addition, the majority of the licensees stated that without formalized engineering calculations or engineering evaluations, the electrical consequences of such an open-phase event, including plant response can only be evaluated against the generic overview that the Electric Power Research Institute (EPRI) and Basler (a relay manufacturer) published. The licensees stated that the preliminary evaluations based on the industry guidance are generic assessments and cannot be formally credited as a basis for an accurate response. The licensees also stated that detailed plant-specific models need to be developed (e.g., transformer magnetic circuit models, electric distribution models, motor models; including positive, negative, and zero sequence impedances, voltage, and currents). Further, the models need to be compiled, validated, and analyzed for the plant-specific Class 1E electric distribution system. Some licensees have performed qualitative analyses to assess the impact of high impedance ground faults with the loss (i.e., open) of the same phase and without open phase. The results showed that protection schemes may not detect and isolate the high impedance ground fault on either the low or the high side of the SAT for an open phase on the HV side of the transformer; and for all the three phases intact on the HV side, the existing protection scheme is adequate.

The staff's review of the licensees' responses concluded that most of the licensees did not perform detailed analysis to validate the plant-specific capability to detect and automatically respond to a single-phase open circuit condition with and without high impedance ground fault condition on the required offsite power circuits.

The staff's detailed review of the responses indicated the following major differences in the design of electrical system for current operating power plants:

The offsite power transformer (e.g., startup, reserve, station auxiliary) winding configuration.

The staff noted that there are 43 plants with the same offsite power transformer winding configuration (Wye-Wye-Wye with solidly grounded primary and resistance grounded secondary) as the Byron Station. The remaining units have a wide variety of offsite power transformer winding configurations, such as Delta-Wye-Wye, Wye-Delta-Delta, Wye-Wye-Buried Tertiary Delta, Delta-Wye, Wye- Delta, Wye- Wye- Delta, and Wye- Wye with Delta stabilizing winding.

The staff noted that although the Wye-connected primary winding configuration is most susceptible to the voltage unbalance, other winding configurations, such as the delta connected primary winding configurations, also may be vulnerable based on the transformer loading conditions during a design-basis event. Therefore, a detailed plant-specific electrical system analysis for various design-basis loading conditions should be performed to validate the performance of the electrical power system including transformers to support the design-basis requirements.

Consequences of failure to detect and automatically respond to a single-phase open circuit condition or high impedance ground fault condition. The licensees' responses indicated that single-phase open circuit consequences cannot be evaluated without formalized engineering calculations and electrical system modeling. Most licensees reviewed their plant design using the generic guidance from published literature. This review did not provide conclusive evidence that the plant protection features are capable of detecting and automatically responding to a single-phase open circuit condition or a high impedance ground fault condition. Some licensees have performed preliminary analysis using commercially available software, such as Electro

Magnetic Transient Program (EMTP) or Power System Computer Aided Design (PSCAD), which indicated that a voltage imbalance on the ESF buses will not be detected and automatically isolated in all design-basis loading conditions by the existing protective relay schemes.

## **Summary and Analysis of Responses to Question 2**

Offsite power sources alignment to the ESF buses. The licensees for the operating power plants stated that operating configuration of the ESF buses of all plants is consistent with the current licensing basis. The staff noted that there are 19 plants with the same system configuration as the Byron Station (i.e., single connection to offsite power source (switchyard) feeding both ESF buses through one or two offsite power transformers (SATs) during at normal power operating condition). Auxiliary transformers that supply offsite power have different designations in various plants, such as startup transformer or reserve station service transformer (RSST) or common station service transformer, system service station transformer (SSST), reserve auxiliary transformer (RAT), backup auxiliary transformer, etc. Such plants are vulnerable to degraded offsite power conditions on redundant safety buses as experienced at Byron Station and described in the background section.

There are 27 plants with ESF buses normally aligned to the UAT during power operation. Upon unit trip, the ESF buses are transferred (using a bus transfer scheme) to the offsite power transformers that are normally energized but may be on standby mode (no load condition) or partially loaded with some nonsafety-related loads. Most licensees with plants using this type of configuration stated that ESF buses, when initially fed from the main generator through UAT, would see balanced voltages under normal conditions. Although the staff did not ask licensees to respond, the licensees stated that in case of an open phase between the switchyard and main transformer (MT), the main generator would trip on negative sequence current protection. Therefore, the main concern is the open phase between switchyard and the offsite power transformer such as the SAT (after the fast transfer). Under normal operating conditions, SATs are lightly loaded; therefore, the ESF buses may not see any significant voltage unbalance between the phases. However, under accident conditions, when loaded, the ESF buses will experience significant voltage unbalance between phases. Therefore, appropriate corrective actions may be required to address this design vulnerability.

Variations of fast transfer schemes are used at different plants. In cases where the fast transfer occurs to different SATs with separate connections to switchyard, only one train of ESF buses may be potentially vulnerable to open-phase condition between the switchyard and a SAT, as it is unlikely that redundant trains will be impaired simultaneously. However, the events at Byron Units 1 and 2 revealed that multiple open-phase conditions can occur within a short period because of a common cause failure of nonsafety-related components in the offsite power system. There are 40 plants with redundant offsite power sources feeding the redundant ESF buses during normal plant operation. Therefore, appropriate corrective actions may be required to address this design vulnerability.

Nine plants have a generator output breaker. This design uses the generator step up transformer and the unit auxiliary transformers as the immediate access power source from the grid after the turbine or generator trip. In such plants, ESF buses do not automatically transfer to redundant offsite circuits. Licensees using this type of plant configuration stated that under normal conditions, the ESF buses when fed from the main generator through UAT will experience balanced voltage conditions. In case of open phase between the switchyard and MT, the main generator will trip on negative sequence current protection. After the unit trip, the

ESF buses will be subjected to voltage unbalance because of the open-phase condition between the switchyard and MT. The staff noted that in most cases, the generator power source will be tripped, but open phase will not be detected and automatic actions to separate the degraded power source to the ESF buses may not take place with the existing protection scheme. Therefore, corrective actions are required to automatically separate the degraded offsite power source such that the ESF buses can be transferred to an alternate offsite source or the onsite power system.

Nine plants operate with the normal feeds to ESF buses split between UATs and SATs. In seven out of nine plants, after the unit trip, the ESF bus fed from UAT will also be automatically transferred to a common SAT. If open phase occurs between the switchyard and the SAT, both trains of ESF buses will experience unbalance voltage conditions on redundant trains after a unit trip. Only one train of ESF buses will experience unbalance voltage conditions in the remaining units. Therefore, corrective action may be required to address this design vulnerability.

Plant operating procedures to monitor voltages. ESF bus voltages usually are monitored in the control room. Typical design requires manual operation of a switch to verify voltage on a three-phase system. The staff noted that in approximately half of the plants, operating procedures currently call for verification of the voltages on all three phases of the ESF buses.

In summary, all licensees stated that the relay systems were not specifically designed to detect a single-phase open circuit condition in a three-phase system because they considered this to be beyond the approved design and licensing bases of the plants. No formal calculations for this scenario have been performed by most of the licensees to address the design vulnerability identified in the Bulletin. The staff determined that the licensees may not be in compliance with the existing regulations.

### **New Reactors**

There are currently two new reactor sites with two AP1000 units per site with combined operating licenses (COLs). According to AP1000 design control document (DCD), Revision 19, Figure 8.3.1-1, the unit generators have generator breakers. Therefore, the analysis of such plants will be similar to those operating reactors that have generator breakers. The DCD states that the offsite power has no safety-related function because of the passive design of the AP1000. Therefore, redundant offsite power supplies are not required. The design provides a reliable offsite power system that minimizes challenges to the passive safety system. In addition, the DCD states that the onsite power system (i.e., standby diesel generators) supplies ac power to the selected permanent nonsafety loads in the event of a main generator trip concurrent with the loss of preferred power source and maintenance power source when under fast bus transfer conditions. The onsite standby diesel generators are connected automatically to the associated 6.9-kV buses upon loss of bus voltage only after the generator-rated voltage and frequency is established. Loads important for orderly plant shutdown are connected sequentially.

The licensees stated that the AP1000 main ac power system is nonsafety-related and is not relied upon to mitigate design-basis accidents or to bring the plant to a safe shutdown, rather the AP1000 design relies on a reliable safety-related dc power supplied by Class 1E batteries to actuate the safety-related system during transient and accident conditions. In addition, the licensees stated that the AP1000 nonsafety-related electrical system was not designed to detect a single-phase open circuit.

For AP1000 plants, the ac loads do not automatically transfer to the maintenance source (RAT). The licensees stated that, under normal conditions, when fed from the main generator through the UAT, the medium voltage buses would see balanced voltages. In case of an open phase between the switchyard and MT, the main generator would trip on negative sequence current protection. Therefore, the main concern is the open phase between the switchyard and MT after the unit is tripped, which will affect the loads connected to medium voltage buses.

The licensees stated that the AP1000 ac electrical design is in the finalization stage, and relay settings, detailed coordination studies, etc., are not yet available. In addition, the generic AP1000 plant operating procedures are under development and the licensees' review of the generic procedures did not identify specific operator actions related to phase voltage verifications on the three phases.

The staff determined that the offsite power system and the onsite non-Class 1E power system provides power to the safety-related loads through the battery chargers and defense-in-depth capabilities for reactor coolant makeup and decay heat removal during normal, abnormal, and accident conditions. The staff noted that the AP1000 design/licensing bases require that the ac power system is designed such that plant auxiliaries can be powered from the grid under all modes of plant operation and that the reliable nonsafety-related offsite and onsite ac power is normally expected to be available for important plant functions. Therefore, if the AP1000 plants have design features to detect and automatically respond to a single-phase open circuit condition or high impedance ground fault condition on a credited offsite power circuit, then the design vulnerability may not disable either the onsite ac electric power system or the offsite electric power system and would maintain Commission's defense in depth measure in nuclear power plant design.

## **CONCLUSIONS AND RECOMMENDATIONS**

Based on the review of licensees' responses, the NRC staff has made the following conclusions and recommendations:

### **Staff's Conclusions:**

The staff determined that for operating nuclear plants, both trains of ESF buses can be affected by a single open-phase condition or high impedance fault condition between the offsite switchyard and the power transformers for the following power configurations:

- (a) Byron Station type configuration—Both trains of ESF buses normally fed from one or two SATs with a single connection to switchyard (open phase on the single connection).
- (b) Both trains of ESF buses normally fed from UAT with fast transfer to one or two SATs (open phase between switchyard and single SAT).
- (c) Both trains of ESF buses normally fed from UAT through generator output breaker (open phase between switchyard and MT).
- (d) Power supply to ESF buses split between UAT and SAT during normal operation, with UAT loads also fast transferred to SAT after unit trip (open phase between switchyard and SAT).

The staff determined that operating nuclear plants with redundant trains supplied from different transformers and connections to separate transmission systems are unlikely to have simultaneous open circuit or fault conditions on redundant ESF busses. In such configurations, one train of ESF busses can be affected by an open-phase condition or high impedance ground fault condition between the offsite switchyard and one of the power transformers for the following power configurations:

- (a) Both trains of ESF busses normally fed from two redundant SATs with a separate connection to switchyard (single-phase open circuit condition to one of the SATs)
- (b) Both trains of ESF busses normally fed from UAT with fast transfer to two SATs (single-phase open circuit condition to one of the two SATs).

The staff recognizes that the current plant licensing bases documents have not specifically identified this design vulnerability discussed in BL 2012-01. The NRC had not specifically required licensees to address this design vulnerability at the time of licensing or through subsequent generic communications because this design vulnerability and the safety significance was not known to the staff until the Byron Unit 2 event occurred which led to a scenario where neither the offsite power system nor the onsite power system was able to perform its intended safety functions. However, the regulatory requirements discussed above existed at the time of licensing these plants; therefore, NRC may have to take regulatory actions to address this design vulnerability.

For the four new reactors with COLs, as described in their plant's licensing or design basis, the offsite power system (one circuit) and the onsite non-Class 1E power system provides power to the safety-related loads through the battery chargers and defense-in-depth capabilities for reactor coolant makeup and decay heat removal during normal, abnormal, and accident conditions. Therefore, the COLs should be able to detect a single-phase open circuit on the offsite power system using the existing transfer schemes (transfer between ac offsite and onsite sources) to ensure a failure does not disable both the onsite ac electric power system and the offsite electric power system to maintain the plant design basis requirements.

#### Recommendations:

- (1) For current operating plants, the staff recommends the NRC take further regulatory actions to require licensees to provide design features to detect and automatically respond to a single-phase open circuit or high impedance fault condition on the high voltage side of a credited offsite circuit. This will ensure that an offsite and an onsite electric power system with adequate capacity and capability will be immediately available to permit the functioning of structures, systems, and components important to safety in the event of anticipated operational occurrences and postulated accidents.
- (2) For the four new reactors with COLs, the staff recommends the NRC take further regulatory actions to require licensees to provide design features to detect and respond to a single-phase open circuit with or without high impedance fault condition on the high-voltage side of a credited offsite circuit prior to the fuel load. In addition, the staff recommends that NRC verifies the licensees have provided design features and analyses to show that the offsite power system is capable of supplying assumed plant loads as well as required voltages at the interface with the onsite ac power system that will support operation of assumed loads during normal, abnormal, and accident conditions as required by Inspections, Tests, Analyses, and Acceptance Criteria.

- (3) All licensees should have operating procedures and surveillances to monitor the availability and operability of offsite power supplies (all three phases) at the ESF buses, at least once every shift during normal plant operation based on the design vulnerability identified in the Bulletin.
- (4) All licensees should implement corrective actions in accordance with 10 CFR 50, Appendix B, Criterion XVI "Corrective Actions," to ensure that the onsite and the offsite electric power systems can perform its intended safety functions based on the design vulnerability identified in this Bulletin.