U.S. NUCLEAR REGULATORY COMMISSION
REGION I
LOSS OF 120 VAC VITAL PANEL INSPECTION

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LICENSEE: Baltimore Gas and Electric Company
MD Rts 2 & 4, P.O. Box 1535
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FACILITY NAME: Calvert Cliffs Units 1 and 2

INSPECTION DATES: January 26-30, 1994

INSPECTORS: R. Fuhrmeister, Project Engineer, DRP
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Areas Inspected: The objective of this inspection was to conduct a detailed review of the circumstances surrounding the Calvert Cliffs Unit 1 reactor trip on January 24, 1994. The events reviewed included the loss of vital bus inverter 12, the opening of the normal supply breaker to the 4 kV bus 14 following the reactor trip, and the reverse power trip of emergency diesel generator 12 output breaker. The inspectors assessed the adequacy of the root cause evaluations and corrective actions taken in response to the equipment failures.

Results: The inspectors concluded that the plant safety-related systems responded as designed to the conditions that existed during this event. The root cause evaluations and trouble-shooting activities conducted to determine the causes for the static inverter failures were generally comprehensive and well controlled. The corrective actions taken to repair and test the static inverter were appropriate. The Plant Operations Safety Review Committee demonstrated a conservative approach to safety by establishing sound test criteria prior to restoring the static inverter to service. The modification to improve the engineered safety feature actuation system response to a loss of a vital 120 Vac panel, scheduled for installation during this refueling outage, was noted as a positive trip reduction initiative.

The inspectors noted that a recent failure to properly control work activities had resulted in a loss of ventilation to static inverter 12. The loss of ventilation caused the static inverter to become overheated. The inspectors concluded that this event may have contributed to the failure of static inverter 12. The corrective actions taken in response to overheating the static inverter were appropriate.

DETAILS

1.0 INSPECTION OBJECTIVE

The objective of this inspection was to conduct a detailed review of the circumstances surrounding the Calvert Cliffs Unit 1 reactor trip on January 24, 1994. The events reviewed included the loss of vital bus inverter 12, the opening of the normal supply breaker to the 4 kV bus 14, and the reverse power trip of emergency diesel generator 12 output breaker. The inspectors assessed the adequacy of the root cause evaluations and corrective actions taken in response to these equipment failures.

2.0 INSPECTION FINDINGS (NRC IM 93702)

2.1 Background

Description of Event

At approximately 9:30 a.m., on January 24, 1994, with the reactor at 100% power, the loss of a 120 Vac vital panel inverter resulted in a reactor trip. The loss of vital panel 12 caused a loss of power to the train-B reactor protection system (RPS) logic cabinet. The loss of power to the RPS logic cabinet caused reactor trip breakers 2 and 6 to open. Reactor protection system logic matrix testing was in progress prior to the inverter failure. Reactor trip breakers 3 and 7 were previously opened during the RPS logic matrix surveillance testing. Opening reactor trip breakers 2 and 6 simultaneously with breakers 3 and 7 tripped the reactor. The loss of the vital instrument panel resulted in numerous control room alarms, loss of several control room indications, and initiated certain engineered safety features actuation system (ESFAS) actuation signals. The ESFAS signals included an undervoltage trip of the normal supply breaker to the 4 kV bus 14 and an emergency diesel generator 12 start signal. The control room operators reenergized bus 14 by closing the alternate power supply breaker. After recovering from the reactor trip, operations personnel attempted to synchronize the diesel generator onto bus 14. During this evolution, the diesel generator output breaker tripped. Subsequent attempts to parallel the diesel generator to 4 kV bus 21 were also unsuccessful. Investigation by plant operators in the Diesel Generator Room identified that the breakers were locked out by a reverse power trip. After the reverse power trip was reset, the diesel generator was successfully paralleled and loaded onto both 4 kV busses 21 and 14.

Plant Response

The inspectors reviewed the plant computer generated sequence of events and alarm printout to verify that plant equipment responded appropriately following the plant trip. Based on the documentation reviewed and interviews with plant personnel the inspectors concluded that the plant equipment responded as designed for the conditions present at the time of the trip.

Following the reactor trip, the normal supply breaker for 4 kV bus 14 opened and deenergized the bus. The loss of a 4 kV bus was caused by the loss of power to the engineering safety feature actuation system (ESFAS) logic and actuation cabinet power supplies. One train of the ESFAS power supplies are powered from the 120 Vac vital panel 12 which deenergized during this event. When vital panel 12 deenergized, the ESFAS logic generated a undervoltage trip signal for the 4 kV bus 14 feeder breakers. The generation of the undervoltage trip signal to the 4 kV bus supply breaker is expected on a loss of power to the ESFAS power supplies.

Following the reactor trip, alarms were actuated and cleared several times indicating low voltage on 120 Vac vital panel 11. Investigation by BG&E personnel determined this to be due to a fuse holder in inverter 11 (supplying an indicating light and the alarm relays) having loose contact with the fuse. Manually shaking the fuse resulted in duplicating the alarm condition, and an approximate 40 volt decrease in the voltage sensed by the relays.

Operator Response

The inspectors reviewed the post-trip documentation and interviewed plant personnel to assess the adequacy of the operator response during this event. The control room operations personnel promptly identified the loss of the 4 kV electrical bus 14. Appropriate actions were taken to promptly restore power to the bus. The senior control room operator delineated responsibility to the reactor operators by having one reactor operator assist with troubleshooting the electrical system failure, while the other reactor operator was instructed to remain at the reactor control panels to monitor available instrumentation.

The plant computer sequence-of-event printout indicated that the time between the reactor trip breakers opening and the control room operator generating a manual reactor trip signal was approximately 41 seconds. Generating a manual reactor trip is the first immediate action step in the emergency operating procedures. One of the entry conditions for the emergency operating procedures is a reactor trip. The licensee Significant Incident Finding Team (SIFT) had also noted this fact and had planned to evaluate the timeliness of the operators response to the reactor trip. The loss of both 4 kV bus 14 and 120 Vac vital panel 12 resulted in numerous alarms and losses of control room indication. The reactor trip was caused by the coincidence of surveillance testing and loss of a 120 Vac vital panel opening reactor trip breakers and was not generated by exceeding a legitimate reactor trip setpoint. Based on the control room indications at the time of the trip, the inspectors concluded that 41 seconds to diagnose the plant trip and to manually insert a reactor trip was acceptable. The Calvert Cliffs SIFT had not completed their evaluation at the conclusion of this inspection.

2.2 Root Cause Failure Analysis

Inverter Failures

The Calvert Cliffs Unit 1, 120 Vac vital ac system is normally powered by four single-phase Exide model 120/7.5F1 static inverters, furnished as part of the original plant design. A manual switch was provided to bypass the inverters during maintenance. The inverter converts the dc input supply to an ac power output by alternately switching the polarity of the dc source through silicon controlled rectifiers (SCRs) that are controlled by solid-state logic signals. An output filter converts the square waveform into a smooth sinusoidal ac power supply. Overcurrent protection is provided by an input circuit breaker and a current limiting fuse F6.

The operations staff stated that the No. 12 static inverter had recently been overheated. The inverter was inadvertently wrapped in plastic to prevent debris from entering the inverter from work being performed near the inverter. The reduction in the ventilation to the No. 12 static inverter caused the ac voltage output of the inverter to degrade. The voltage degraded to a point where the two reactor trip breakers opened. The plastic wrap was removed from the inverter and the voltage returned to the normal range. The inspectors reviewed the root cause evaluation of this event and concluded that the corrective actions taken were appropriate. The Unit 1 inverters are scheduled for replacement during the 1995/96 refueling outage.

- First Inverter Failure (January 24, 1994)

On January 24, 1994, the failure of inverter No. 12 resulted in the loss of the associated vital instrument panel and the consequent trip of the Unit 1 reactor. The ensuing troubleshooting determined that the loss of the inverter was due to blowing fuse F6. This fuse, with a continuous rating of 200 amperes, is located in the negative line of the inverter dc input to protect the SCRs. The cause of the fuse blowing was attributed to a faulty voltage regulator card. Testing of the inverter components according to the vendor technical manual identified that the voltage regulator output was inconsistent with the expected waveform. Following replacement of this card and completion of troubleshooting activities, the inverter was load tested for four hours and returned to service. An evaluation of the inverter performance during the subsequent load test and following the addition of the normal inverter loads concluded that the inverter was satisfactory. The inverter was declared operable.

The licensee evaluated the static inverter failures by using established root cause analysis techniques. The evaluation addressed each of the eight potential problems discovered during the troubleshooting of the inverter and their potential effects on the performance of the equipment. Based upon this analysis, the licensee concluded that the first failure was caused by an inadequate performance of the voltage regulator module. The failure of this module was most likely caused by either a loose fuse, F1, in the input ac signal to the module or by a screw lodged between the two component circuit boards of this module. The screw was not part of the inverter and was believed to have fallen during maintenance activities conducted above the inverter.

- Second Inverter Failure During Testing (January 25, 1994)

On January 25, 1994, approximately two and a half hours following its restoration to service, inverter No. 12 failed again. Once again troubleshooting found that the loss of the inverter was due to blowing fuse F6. This time, testing of the inverter components determined that the oscillator and power supply module had failed. Testing of this module during the troubleshooting activities of the previous day had found it was performing satisfactorily. Load testing of the inverter, following the replacement of this card and the preventive replacement of the buffer amplifier module that showed some signs of discoloration, indicated acceptable performance.

The second failure was attributed to a degraded oscillator module that caused two SCRs to fire simultaneously which resulted in blowing the F6 fuse. Degradation of this module may have resulted from the replacement of the voltage regulator card. The analysis identified two additional potential causes, a loose connection at commutating capacitor C9 and current spikes on the dc input. The licensee did not consider these causes reasonable since they did not explain a degraded output voltage that was observed.

- Subsequent Inverter Failures During Testing

On January 26, 1994, while the licensee was off-loading the resistor bank used to load test the inverter, fuse F6 blew again. Removal of the resistor bank from the inverter, during subsequent troubleshooting activities, resulted in the fuse F6 blowing two more times, on January 28 and 29, 1994. The licensee identified that blowing these fuses was caused by the removal of the resistive load bank. A review of oscilloscope traces of the current through the F6 fuse identified a large current spike during rebooting of the load test bank computer. This observation coincided with the large inverter output voltage drop that also occurred during computer rebooting. The problem with the load bank was verified on January 29, 1994, when the computer was intentionally rebooted and fuse F6 blew. The licensee stated that the load bank was shed using the circuit breaker at the inverter following the January 25, 1994, load test. Removal of the test load bank using the circuit breaker at the inverter did not result in blowing the F6 fuse. The licensee concluded that the removal of the test load bank by rebooting the computer placed a temporary short circuit across the inverter and thus blew the F6 fuse to protect the inverter. The test load bank instructions did not provided instructions on the proper load bank removal method. Following the replacement of the fuse, the inverter was load tested and restored to service without further incidents.

During troubleshooting activities, a newly installed buffer amplifier module was inadvertently damaged and was replaced with the buffer amplifier that had been previously installed in the inverter. The original buffer amplifier card had been functioning properly and had been replaced as a precautionary measure. The inspectors concluded that the buffer amplifier card was damaged because of poor pre-planning by the technicians. This failure was an isolated event in an otherwise well controlled troubleshooting effort.

Engineered Safety Feature Actuation System

During this event, the normal supply breaker (152-1414) to the 4 kV bus 14 opened and deenergized the bus. Emergency diesel generator 12 started but did not automatically reenergize 4 kV bus 14. Emergency diesel generator 12 is shared by Units 1 and 2 and will only automatically reenergize 4 kV bus 14 when a safety injection actuation signal is present. The normal supply breaker to the 4 kV bus 14 would not normally open during a reactor trip without a loss of normal power. The inspectors discussed the reason for the normal bus 14 supply breaker opening with the cognizant licensee technical staff.

The licensee stated that the normal supply breaker opening was caused by the loss of power to the train-B engineered safety feature actuation system (ESFAS) logic and actuation cabinets. The 120 Vac vital panel 12 deenergized when static inverter 12 failed. The 120 Vac vital panel 12 supplied power to the ESFAS train-B logic and actuation cabinets power supplies. The ESFAS logic and actuation trains each had 15 Vdc and 28 Vdc power supplies. The 15 Vdc power supply provided power to the coincident logic circuity. The 28 Vdc power supply provided power to the final output circuity of the modules that actuate various engineered safety feature equipment. The ESFAS was designed such that the 15 Vdc deenergizes and the 28 Vdc system energizes for the system to initiate an actuation signal. If the 15 Vdc power is lost prior to the loss of the 28 Vdc power supply, then various ESFAS signals may actuate and various engineered safety feature equipment may inadvertently start. When power was lost to the ESFAS power supplies, the 15 Vdc power supply voltage may have decayed faster than the 28 Vdc system. This could have caused the ESFAS to open the normal supply breaker to 4 kV bus 14.

Based on the current design of the ESFAS power supplies, the opening of the normal supply breaker to the 4 kV bus 14 was not unexpected when a 120 Vac vital panel is deenergized. The undesirable actuation of the ESFAS when a 120 Vac vital panel is lost has been the subject of several licensee event reports.

Emergency Diesel Generator Reverse Power Breaker Trip

During the recovery of the electrical distribution system, problems were experienced loading the No. 12 emergency diesel generator onto 4 kV bus 14. The operators were attempting to parallel the diesel generator onto bus 14 for a loaded run. The No. 12 EDG output breaker closed onto the 4 kV bus and then automatically opened a short time later. When the breaker closed, a BREAKER SPRING CHARGING alarm annunciated. A subsequent attempt to close the diesel output breaker onto 4 kV bus 21 was also unsuccessful. The operators in the diesel generator room determined that the reverse power trip had actuated on the EDG output breaker to bus 14. A reverse power trip of the EDG output breaker to bus 14 would also prevent closing the EDG output breaker to bus 21. After resetting the reverse power relay, EDG 12 was successfully loaded on both the 21 and 14 busses. The reverse power trip was most likely caused by an actual reverse power condition. The reverse power trip relays are set at approximately 10 kilowatts, which makes the EDG susceptible to reverse power trips at low loads. The licensee's technical staff stated that the BREAKER SPRING CHARGING alarm may have momentarily distracted the operator and delayed the operator from increasing the load on the EDG. A delay in increasing load on the diesel would have made the diesel susceptible to a reverse power trip. The inspectors noted that the reverse power trip is only enabled when the EDG is in parallel operation. During accident conditions, the reverse power trip is blocked.

2.3 Corrective Actions

Static Inverter

Following the identification of the causes for the fuse failures, the licensee prepared Engineering Test Procedure ETP 94-04, "#12 Inverter Testing," that addressed in detail the tests the monitoring instrumentation and the steps to be followed to restore inverter No. 12 to service. This procedure and the associated safety evaluation were discussed among the engineering root cause analysis team and the plant operations safety review committee during a meeting on January 29, 1994. The inverter was tested and restored to service without further incident.

Engineered Safety Feature Actuation System

On February 4, 1993, the NRC issued Information Notice 93-11 "Single Failure Vulnerability of Engineered Safety Feature Actuation Systems." The licensee reviewed the information notice and determined that the design deficiency identified was not applicable to Calvert Cliffs. The licensee's task group to reduce reactor trips used the information provided in the notice and recommended several engineered safety features actuation system trip reduction enhancements. One of the enhancements was to replace the logic cabinet power supplies.

The Unit 2 ESFAS power supplies were replaced during the last refueling outage. The licensee has scheduled replacement of the Unit 1 ESFAS power supplies during the upcoming refueling outage. The Unit 2 modification replaced five power supply drawers in the two logic cabinets. The new 15 Vdc power supplies are redundant so that the failure of one will not affect the 15 Vdc power supplied to the logic modules. In addition, a relay was added to block the 28 Vdc power to the actuation cabinet until power to the logic modules is stable.

This design would prevent spurious ESFAS actuation when vital 120 Vac panels are deenergized. The inspectors concluded that the installation of this modification is a positive initiative by the licensee to enhance the performance of the ESFAS.

3.0 CONCLUSIONS

The licensee post-trip review positively identified the cause of the reactor trip and had clearly established the cause for the loss of the 4 kV bus 14. Based on an independent review of the event, the inspectors concluded that the reactor protection system responded appropriately to the loss of the 120 Vac vital panel 12 and plant equipment operated as designed in response to the reactor trip and loss of the 4 kV bus and 120 Vac power panel. The control room operators' response to this event were acceptable. The licensee's post-trip review process was thorough.

The root cause for the failure of the static inverter on January 24, 1994, was positively identified as a failed voltage regulator card. The failure of the static inverter on January 26, 1994, was positively identified as a failed oscillator card. The inspectors concluded that the troubleshooting and testing following the January 24, 1994, inverter failure were appropriate. The January 26, 1994, oscillator card failure was not the result of a failure overlooked during the previous troubleshooting, but an independent failure that occurred after returning the inverter to service. The licensee's root cause evaluation team identified several potential root causes for the logic card failures. While not establishing the exact cause of the failure, the process used by the licensee to identify potential root causes was extensive and used well-established root cause evaluation techniques. The root cause evaluation of the failures was detailed, thorough, and an overall excellent effort by the root cause analysis team. However, the inspectors noted that a failure to preplan one troubleshooting activity resulted in the failure of a buffer amplifier card. This failure was an isolated event in an otherwise well controlled troubleshooting effort.

The inspectors noted that a recent failure to properly control work activities had resulted in a loss of ventilation to static inverter 12. The loss of ventilation caused the static inverter to become overheated. The inspectors concluded that this event may have contributed to the failure of static inverter 12. The corrective actions taken in response to overheating the static inverter were appropriate.

The corrective actions taken to repair the static inverter were appropriate. The licensee developed a detail test plan which verified that the inverter was operating correctly before placing the inverter back in service. The licensee's extensive test plan and overall attention by the plant operations safety review committee to establishing proper inverter operation prior to declaring the inverter operable demonstrated a sound conservative approach to safety by Calvert Cliffs management. The inspectors also noted a positive initiative by engineering to install a modification to eliminate the inadvertent engineered safety features actuation upon a loss of a 120 Vac vital panel.

4.0 MANAGEMENT MEETING

The inspectors discussed the preliminary inspection finding with those individuals denoted in Attachment 1, on February 2, 1994. The discussion was conducted via a conference telephone call. The licensee did not express any disagreement with the inspection findings during the exit meeting conference call.

ATTACHMENT 1

Persons Contacted

Baltimore Gas and Electric

M. Milbrandt, Compliance Engineer
J. Stanley, Sr. Engineer QAU
* R. Wenderlich, Operations Superintendent
* J. Thorp, GS - E&C Maintenance
G. Pavis, GS - Plant Engineering
* T. Camilleri, Maintenance Superintendent
* C. Cruse, PGM
* G. Detter, Director - Nuc. Reg. Mtrs
* S. Collins, PE- E&C SEU

U. S. Nuclear Regulatory Commission

* P. Wilson, Sr. Resident Inspector - Calvert Cliffs
F. Lyons, Resident Inspector - Calvert Cliffs

Asterisk (*) denotes those present at the exit meeting conference call.