UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, D. C. 20555-0001

September 27, 2000

# NRC INFORMATION NOTICE 2000-14: NON-VITAL BUS FAULT LEADS TO FIRE AND LOSS OF OFFSITE POWER

## Addressees

All holders of licenses for nuclear power reactors.

## Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice to inform addressees of equipment and design issues identified following a recent transient at the Diablo Canyon nuclear power plant. The aspect of the transient considered noteworthy was the failure of bus duct, a passive component of known high reliability which often receives little preventive maintenance or attention. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. However, suggestions contained in this information notice are not NRC requirements; therefore, no specific actions or written response is required.

## Description of Circumstances

On May 15, 2000, at Diablo Canyon Unit 1, a phase-to-phase electrical fault occurred in a 12-kV non-Class 1E electrical bus duct from the unit auxiliary transformer to the switchboards that supplied the reactor coolant pumps and the circulating water pumps. The fault caused a turbine trip and consequent reactor trip. As this section of bus could not be isolated from the main generator, the fault lasted for 4 to 8 seconds until the main generator electrical field voltage decayed. The 12-kV bus fault occurred at a point at which the bus duct passes under the 4-kV non-Class 1E bus from the startup transformer. The original fault and the resultant arcing and smoke caused another fault, this time in the 4-kV bus duct directly above the original failure.

The 12-kV circuit breaker that supplied the 4-kV startup transformers and the faulted 4-kV bus duct downstream of the transformer tripped in response to this second fault. This trip resulted in a loss of power to all 4-kV vital (safety-related) and non-vital buses. All three diesel generators started and all vital loads were re-energized. However, the combination of the two faults disabled both power supplies to the non-vital 4-kV buses.

Besides de-energizing all non-vital 4-kV power within the plant, the loss of both sources of non-vital power also caused a loss of the 480-Vac power supply to the switchyard control building. This failure led to a loss of power to the charger for the switchyard batteries; the eventual depletion of the switchyard batteries would have led to a loss of control power in the switchyard serving both Diablo Canyon units. The loss of control power would have disabled remote control of the switchyard high voltage circuit breakers.

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The licensee installed a portable generator to restore power to the charger before the switchyard batteries were depleted. On May 16, 2000, after 33 hours, plant personnel energized the 4-kV and 480-Vac non-vital buses by backfeeding through Auxiliary Transformer 1-2.

## Discussion

### Switchgear Room Arrangement and Bus Duct Construction

The auxiliary and startup transformers are connected to the onsite distribution switchgear by bus bars with a ½ - by 6-inch cross-sectional area. All three phases are enclosed in a single aluminum duct (nonsegregated). The startup and auxiliary 12-kV and 4-kV non-vital switchgear are located within a common room. To connect the two sources of offsite power to multiple switch boards within the room, there are many crossing bus ducts above the switchgear. The non-vital 4-kV bus ducts from both auxiliary and startup power are in close proximity for extended runs. Since none of the bus ducts was designed as safety grade, no regulatory separation criteria apply.

The bus work in the room was a combination of aluminum and copper bus bars connected with aluminum splice plates secured by four ½-inch bolts. The bus bars and splice plates were silver-plated at the connection points to ensure conductivity. The bus bars had a nominal 3/16-inch gap between them at the splice plate to allow for thermal expansion. The 12-kV bus bars had a 6-inch air gap between phases, which is slightly below the required air gap for uninsulated conductors, so bus bars and connections were insulated with a combination of sleeves and wraps. The 4-kV bus bars were similarly insulated.

### Root Cause

The licensee's evaluation concluded that a center bus bar overheated at a splice joint, which caused a polyvinyl chloride boot insulator over the splice joint to smoke. Eventually, heat-induced failure of fiberglass insulation on adjacent phases resulted in phase-to-phase arcing. The fault and resultant fire destroyed any direct physical evidence of the root cause; however, the factors discussed below could individually or jointly have led to the failure. They include inconsistent silverplating, currents approaching bus capacity, undersized splice plates, torque relaxation of connecting bolts, and undetected damage from a 1995 explosion of Auxiliary Transformer 1-1.

(1) Silverplating

Many of the bus bars and splice plates had only a thin layer of silverplating. Laboratory analysis determined that the silverplating on one splice plate had partially separated from the base aluminum, and corrosion products were found on the aluminum surface. If this separation had existed at the point of the fault, it would have created higher resistance and, therefore, more heat at the connection. The laboratory stated that the most likely source of corrosive compounds was the polyvinyl chloride insulating boot. Silverplating was also observed flaking off the aluminum bus bars at two other splice joints not directly affected by the fault.

(2) Heavy Bus Loading and Splice Joint Configuration

The 12-kV 6-inch aluminum bus bars were rated at 2250 amps. The bus was routinely loaded to 2100 amps with an actual worst case operating load of about 2250 amps. The vendor stated that all bus bars supplied to Diablo Canyon met the design requirements of Institute of Electrical and Electronics Engineers (IEEE) 37.20-1969, "IEEE Standard for Switchgear Assemblies Including Metal-Enclosed Bus," which stipulates an operating temperature limit of 65 C. Vendor-supplied test data reported a maximum temperature rise of 46 C at 2000 amps and 63 C at 2200 amps for the bus bar type that failed. Since the test temperature increased 17 C for a current increase of 200 amps, a temperature increase of only 2 C for an additional load of 50 amps seems improbably low and it is reasonable that the bus and its insulation had exceeded design conditions for some time. In addition, the vendor heat rise tests of aluminum bus bars for 2200 amps were conducted with two splice plates at the splice joint. The vendor test used 3 - by 4-inch copper splice plates instead of the 2½ - by 4-inch aluminum splice plates used at Diablo Canyon.

The inspectors noted that the splice plates connecting the bus bars were considerably smaller than the bus bars themselves. Some splice joints had two aluminum plates on each phase sized 2½ inches by 4 inches by ⅜ inch. Also, the splice plates were not always centered between the bus bars. The lack of centering of splice plates and splice plates smaller than the tested configuration reduced the contact area, causing increased heat generation.

(3) Torque Relaxation

The as-found torque values for many of the splice plate connecting bolts was 10 to 20 foot-pounds indicating that thermal relaxation had occurred since initial installation. The bolts had an initial torque value of 40 foot-pounds. Torque relaxation on the bolts could have allowed the splice plate to lose contact with the bus bar, leading to arcing and overheating.

(4) Undetected Damage from 1995 Auxiliary Transformer 1-1 Explosion

A 1995 explosion of Auxiliary Transformer 1-1 had displaced the 12-kV busing several feet into the turbine building. Most of the bus bar connections upstream of the failed connection had been disassembled and repaired where necessary. Records for the failed connection were incomplete. The inspectors determined that the failed joint had been visually inspected and micro-ohm tested; however, no evidence was found to verify that the joint had been torqued. Inadequate torque could have resulted in increased resistance and heat generation if the joint became loose.

Corrective Actions

All damaged components were repaired and refurbished, accessible splice joints on the 12-kV auxiliary bus and 4-kV startup bus were inspected and torqued, and post-maintenance tests were conducted to ensure that the bus bars were properly restored. The licensee concluded that a similar defect was unlikely to occur on Unit 2 because the splice plates for the Unit 2 bus, although similar in construction to the one that failed in Unit 1, had previously been inspected and torqued. The licensee also tested the affected startup and auxiliary transformers to ensure no breakdown had occurred in the winding insulation.

The licensee examined the various design issues associated with the 12-kV and 4-kV buses. The buses with operating currents near design limits were judged to be operable because the expected temperature at the Diablo Canyon site was considerably lower than the ambient temperature assumed in the vendor heat rise test acceptance criteria. The licensee grouped renovation and maintenance of the undamaged runs of bus into three groups by decreasing order of failure susceptibility to prioritize remedial actions: (1) bus sections where normal load has little margin relative to the continuous duty design rating, (2) bus sections in which the auxiliary buses pass near the startup buses, and (3) bus sections that cannot be isolated from the main generator (i.e., have no breaker to quickly sense and interrupt the fault).

During upcoming refueling outages, planned actions to prevent recurrence include the following: (1) inspect and torque the booted connections on the 3750-amp bus for Startup Transformer 1-1 and replace splice plates on the booted connections with full-face copper splice plates; (2) inspect and torque splice plate connections on the 4-kV auxiliary buses; and (3) upgrade the 2250-amp 12-kV buses from aluminum to copper bars. The same inspection and replacement activities will occur on taped connections during the subsequent Unit 1 refueling outage.

This information notice requires no specific action or written response. If you have any questions about the information in this notice, please contact one of the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

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| 2000-12 | Potential Degradation of Firefighter Primary Protective Garments | 9/21/2000 | All holders of licenses for nuclear power, research, and test reactors and fuel cycle facilities |
| 2000-11 | Licensee Responsibility for Quality Assurance Oversight of Contractor Activities Regarding Fabrication and Use of Spent Fuel Storage Cask Systems | 8/7/2000 | All U.S. NRC 10 CFR Part 50 and Part 72 licensees, and Part 72 Certificate of Compliance holders |
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| 95-03, Supp 2 | Loss of Reactor Coolant Inventory and Potential Loss of Emergency Mitigation Functions While in a Shutdown Condition | 7/03/2000 | All holders of OL for nuclear power reactors except those who have ceased operations and have certified that fuel has been permanently removed from the reactor vessel |
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