AEOD TECHNICAL REVIEW REPORT

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SUBJECT: MAJOR DISTURBANCES ON THE WESTERN GRID AND RELATED EVENTS

SUMMARY:

Two major disturbances on the Western grid occurred in 1994. One was caused by an earthquake, one by a contaminated insulator and two coincidental faults. Additional events from 1987 to the present have also occurred. Initiators of these events have been forest fires, earthquakes, lightning strikes, line faults, and equipment failures, all of which occurred offsite from any nuclear plant. The most significant of these disturbances involved equipment faults severe enough that they actuated a remedial action scheme.

The actuations of remedial action schemes: islanding,.shedding load, tripping transmission lines, and tripping of generating units are not problems, but steps taken to correct problems. These actions are taken to preserve the integrity of the system. The event initiator, be it earthquake or equipment fault, is the problem. The scramming of the two Diablo Canyon units during the December 14, 1994, event was caused by the plants' logic, not from loss of the grid. The grid recovered from the initial fault and the scramming of the two Diablo Canyon units without interrupting power to Diablo Canyon, nor did Diablo Canyon lose offsite power following the January 17, 1994, earthquake transient.

The reactions of the Western grid in response to the transient of December 14, 1994, appear to have been appropriate to the transient. The scramming of the Diablo Canyon units in anticipation of a loss of power to the reactor coolant pumps was premature, but in accordance with plant design.

DISCUSSION:

Information for this report came from reports made to the Department of Energy, from telephone conversations with officials of the Western Systems Coordinating Council (WSCC), from the licensee event report for the December 14, 1994, event at Diablo Canyon, from historical files for emergency notifications, and from licensees' responses to NRC queries.

Attachment

The Grid Disturbance of December 14, 1994

At 26 minutes after midnight PST, Wednesday morning, December 14, 1994, a line fault caused by a contaminated insulator flashing over in a heavy fog on the Midpoint-Borah-Adelaide 345 kV line tripped the line. At the same time, the parallel 345 kV line opened due to a relay misoperation, and the Midpoint-Kinport 345 kV line opened shortly afterward for unknown reasons. See Figure 1. Some seconds later, the 500 kV lines from Midway to Vincent stations in California tripped on overload. Problems were also experienced on other transmission lines in the area. Diablo Canyon Units 1 and 2 saw undervoltage on the reactor coolant pump busses and the reactors were automatically scrammed in anticipation of reactor coolant pump trip.

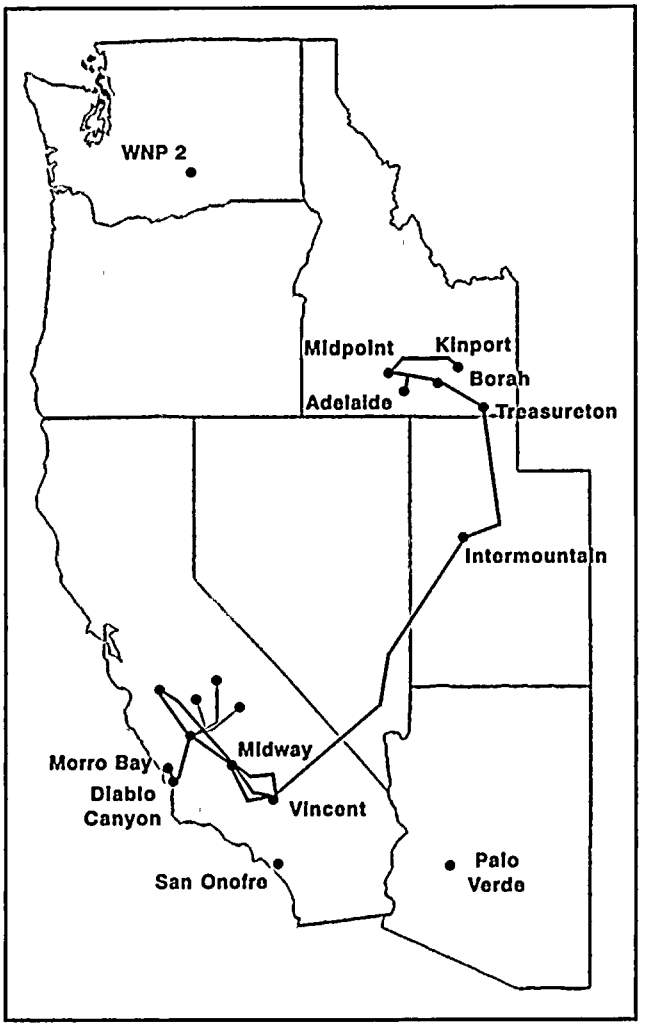

Figure 1: Interconnections Involved in the Disturbance

After the loss of about 2169 MW from Diablo Canyon, interconnections began to open. Additional generating units in WSCC tripped and system frequency oscillated significantly. Additional transmission lines tripped and customer load were lost. The disturbance became system-wide, resulting in the tripping of thirty 138-500 kV lines, both poles of the Intermountain-Adelanto 1000 kV dc lines, as well as numerous lower voltage lines. Twenty-nine generating plants tripped. More than 4800 MW of load (customers) were lost, from British Columbia, Canada, to Southern California.

The Western Systems Reliability Council reported the splitting of the grid into four islands. Northern California, northern Nevada, Idaho, Oregon, Washington, Montana, and British Columbia, Canada, comprised one island in which load was shed by underfrequency relaying (58.7 Hz). Southern California, Arizona, New Mexico, southern Nevada, and El Paso, Texas, comprised a high frequency island (as high as 60.43 Hz). Utah, Colorado, and Wyoming formed the third island whose frequency went as high as 60.76 Hz. Alberta, Canada, formed the fourth island where the frequency remained nearly normal. See Figure 2.

These events occurred between 0026 PST and 0027 PST.

The island formed of northern California, northern Nevada, Idaho, Oregon, Washington, Montana, and British Columbia, Canada, experienced load shedding on underfrequency (58.7 Hz). High voltage transmission lines tripped, generation was tripped, and load was shed for a total of two HV-dc lines, four 500 kV lines, nine 345 kV lines, eleven 230 kV lines, six 138-161 kV lines and numerous lower voltage lines. Larger plants that tripped were Diablo Canyon Units 1 and 2 (2160 MW), Morro Bay Unit 4 (338 MW), Jim Bridger Unit 2 (520 MW), Hunter Units 1 and 3 (801 MW), Naughton Units 1 and 2 (330 MW), Dave Johnson Unit 4 (340 MW), Colstrip Units 1 and 4 (1020 MW), Craig 3 (200 MW), Intermountain Units 1 and 2 (1600 MW), Haynes Unit 5 (341 MW), and Mohave Unit 1 (730 MW). Customer load shed include 2800 MW firm load and about 2000 MW interruptible. The other islands experienced normal or over-frequency (60.43 and 60.76 Hz).

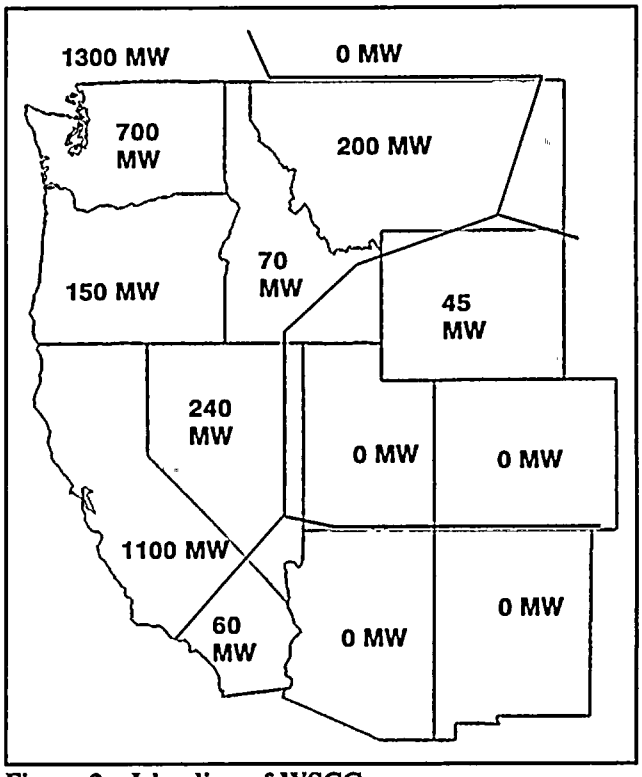

Figure 2: Islanding of WSCC

Palo Verde 1, 2, and 3 experienced a 5 minute transient that the licensee called "a roller coaster ride" during which the frequency increased to 60.4 Hz then dipped to 59.3 Hz before it recovered. Power swings of 1500 MW peak-to-peak were seen on the 500 kV line to Devers, California, and over 1000 MW peak-to-peak on the North Gila, Arizona, line. See Figures 3 and 4.

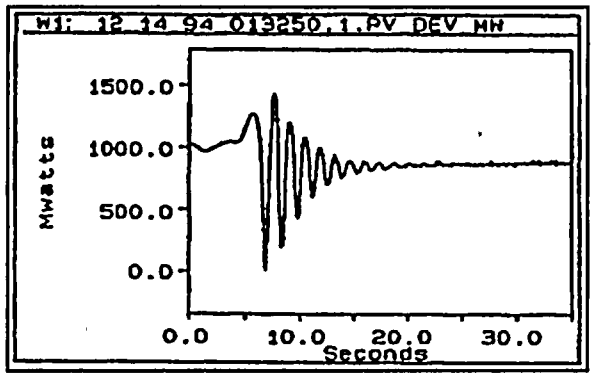

Figure 3: Disturbance on Devers Line

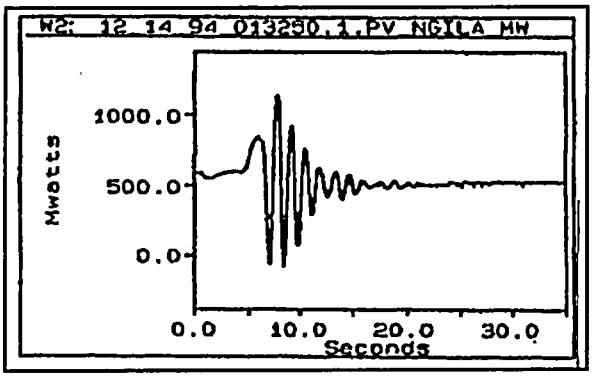

Figure 4: Disturbance on N. Gila Line

Diablo Canyon Units 1 and 2 were at 100 percent power when the reactor coolant pumps, which are powered from offsite via the 230/12/4 kV auxiliary power system, experienced an undervoltage condition at their feeder busses. Voltage was depressed to 11.8 kV. The undervoltage relays would have tripped the pumps at 8050 V. The reactors were automatically tripped in anticipation of a loss of the reactor coolant pumps. The reactor coolant pumps remained in operation throughout the event because the electrical transient was momentary.

The scramming of the two units removed about 2169 MW from the grid.

Since Diablo Canyon units 1 and 2 scrammed at the onset of the event, the generator power and frequency traces are not of interest, but offsite power showed perturbations. The 12 kV voltage decreased to 11.8 kV and the 4160 V busses saw 3150 V (-24 percent instantaneous) minimums.

Information from WNP 2 indicated that the main generator output voltage fluctuated between a maximum of 25,637 V and a minimum of 21,942 V. Nominal voltage is 25,000 V. Frequency varied from 60.03 Hz to 58.93 Hz. Electrical power varied from 1405 MVA to 884 MVA. The voltage at the 4160 V busses varied from 4176 V to 3740 V (-10 percent instantaneous).

Generators cannot be safely operated at frequencies below about 58.5 Hz except for a brief period of time. WCSS reliability criteria recommend load shedding to restore frequency, or isolation of the generating unit on local load to permit rapid restoration. Neither WNP-2 nor the Palo Verde units generators were seriously challenged by this transient.

<u>The Los Angeles Earthquake, January 17, 1994 (Excerpts from AEOD/T94-01)</u>

At 7:31 a.m. EST, January 17, 1994, an earthquake which measured 6.6 on the Richter scale struck southern California... About 45 transmission lines were reported to have tripped and 40 generating units tripped or ran back. The WSCC bulk transmission system (the grid) separated into north and south islands. Wyoming, Utah, Colorado, New Mexico, El Paso (Texas), Arizona, southern Nevada, and parts of southern California and Mexico became the south island. British Columbia and Alberta, Canada, Washington, Oregon, Idaho, Montana, northern Nevada, and northern California became the north island.

The frequency in the south island increased to a maximum of 60.8 Hz, while the frequency in the north island decreased to a minimum of 59.03 Hz and some loads were lost. A portion of southeastern Idaho was blacked out as were Los Angeles, Burbank, and Glendale, California; parts of Portland, Oregon; and parts of Seattle, Washington.

Diablo Canyon, in the north island, experienced a minimum frequency of 59.03 Hz and a sustained frequency under 59.83 Hz for 20 minutes when the southern intertie, Midway-Vincent Units 1, 2, and 3, tripped. WNP 2 was also in the north island. Operating nuclear

plants in the south island were San Onofre and Palo Verde. Grid disturbances were reported by the licensees, but the plants continued operating.

Other Related Events

Two 500 kV lines in Montana tripped, tripping all four units of the Colstrip, Montana, power plant on October 15, 1994. Subsequently, system frequency dropped to 59.42 Hz and Portland General Electric, in Oregon, shed interruptible loads.

On August 15, 1994, brush fires in the area caused the tripping of the Morro Bay-Gates #1 and 2-230 kV lines, a Diablo Canyon-Gates 500 kV line, and the Morro Bay-Midway #1 and 2-230 kV lines. Three generating units at Morro Bay tripped and a significant area of Morro Bay, San Luis Obispo, Santa Maria, and Atascadero was blacked out. Diablo Canyon Units 1 and 2 operated at 100 percent power during the event. Emergency diesel generators (EDGs) at Diablo Canyon started on loss of an offsite power line signal, but did not load their emergency busses since power was not lost. Power to 90 percent of the emergency sirens for Diablo Canyon was lost for a short period of time.

An event on December 26, 1993, discussed in AEOD/TR94-01, occurred when a static wire faulted tripping two 230 kV lines from Midway to Kern substations. Coincidentally, a Midway-Vincent 500 kV line tripped and Diablo Canyon 1 scrammed, though only partly due to grid problems. The result was a frequency transient and loss of customer load.

On October 12, 1993, the Victorville-Adelanto #2-500 kV line tripped when contaminated insulators on two towers flashed over in a heavy fog. Both poles of the Intermountain-Adelanto dc lines blocked and both Intermountain generating units tripped. Frequency dipped to 59.978 Hz.

On November 14, 1992, a fault on a 500 kV line from Oregon to northern California caused the protective relays to trip the line. The Pacific intertie remedial action scheme, a system protection device, sent a separation signal to the Four Corners power plant (in New Mexico). Transmission lines tripped separating WSCC into a northern and a southern island. Frequency in the northern island rose to 60.17 Hz.

Faults of unknown origin caused tripping of the Kinport-Bridger and Borah-Bridger 345 kV lines on September 12, 1991. Subsequently, 9 transmission lines, 200,000 customers, and 2288 MW of generation were tripped. Restoration took less than 3 hours.

On July 1, 1991, the Sylmar, California, converter tripped and Bonneville Power dropped 1760 MW of generation in accordance with procedures, but an additional 770 MW of generation also tripped. The system frequency dropped to 59.71 Hz and Pacific Gas and Electric Company's (PG&E's) underfrequency relays operated to shed 400 MW of interruptible load.

Lightning tripped the Hanford, Washington-John Day, Oregon, 500 kV transmission line on September 7, 1990. When it was being tested prior to being re-energized, an equipment fault caused an instability on the 500 kV ac Pacific intertie which resulted in an out-of-step condition at the Malin, Oregon, substation and the tripping of transmission lines. The remedial action procedures separated the WSCC into northern and southern islands, tripping additional transmission lines, generating units, and customer loads from Washington to southern California. Both WNP-2 and Trojan reported the start of EDGs due to undervoltage signals on vital busses. In both cases, the EDGs did not load the emergency busses since normal power was not lost and were shutdown.

Major forest fires in the Northwest during August 5-7, 1990, caused the tripping of two lines of the 500 kV ac Pacific intertie resulting in tripping of additional lines and islanding of WSCC. Frequency fluctuations and tripping of generation and loads were reported.

On February 28, 1990, an earthquake in the Los Angeles area caused blocking of power flow on the dc intertie for several hours. Some of the power was replaced by diverting to the ac intertie and some was replaced by peaking units brought online by Southern California Edison. San Onofre reported that the earthquake was felt onsite, but did not report any grid disturbance.

On November 1, 1989, a short circuit of one phase to ground on the 500 kV Broadview-Garrison, North Dakota, line was closely followed by a similar fault on the second line. The resultant disturbance on WSCC tripped units in Montana, Colorado, New Mexico, Utah, and Wyoming. Low frequency was reported in WSCC and South Dakota.

The October 17, 1989, earthquake which was centered near Hollister, California, called the Loma Prieta earthquake, also caused a significant transient on the WSCC transmission system, but it was limited to the Pacific Gas and Electric system. Diablo Canyon reported the occurrence of the earthquake but was unaffected by it, seismically. PG&E reported that frequency dropped to 59.94 Hz momentarily and rose to 60.16 Hz and remained high for 90 minutes. Outside of the PG&E system, Southern California Edison maintained sufficient generation online to supply PG&E and Montana Power reported that Colstrip Unit 3 tripped on high frequency. Diablo Canyon reported ground motion felt at the site but no grid disturbances.

A Richter 6.1 earthquake in the Los Angeles area on October 1, 1988, caused some equipment damage and loss of 570,000 customers for less than 24 hours.

A spurious signal caused lines and generation to trip and loads to be lost in Colorado, Montana, and Wyoming. Voltage and frequency fluctuations were also reported. Nine days later, in an event that may be related, a line fault occurred causing other lines to trip and out-of-step relaying separated part of Montana from WSCC. Fort Saint Vrain initiated a manual scram from 73 percent power because of excessive perturbations on the turbine/generator (200 MWe). The shutdown was routine.

On November 24, 1987, The Imperial Irrigation District, California, lost 80 MW of generation and 20,000 customers due to an earthquake. San Onofre personnel reported feeling ground motion and instruments measured seismic activity.

On October 1, 1987, a Richter 6.0 earthquake in Los Angeles, California, caused a loss of 500 MW of generation and 200,000 customers. San Onofre reported earthquake alarms and personnel felt ground motion inside and outside of the plant.

The licensee event report (LER) for the December 14, 1994, event (LER 50-275/94-020) reported one previous actuation of the reactor coolant pump undervoltage trip, in 1987, when an airplane crashed into the Diablo Canyon-Gates 500 kV transmission line causing a three-phase fault to ground. Unit 1 scrammed, because the generator voltage regulator was in manual control at the time of the event. Unit 2 did not scram because its generator voltage regulator was automatically controlled, according to LER 50-275/87-004. This event was not connected with any grid disturbance.

ANALYSIS:

The events described have caused grid disturbances in the WSCC area. The initiators of these events have been forest fires, earthquakes, lightning strikes, line faults, and equipment failures, all of which occurred offsite from any nuclear plant. The most significant of these disturbances involved equipment faults severe enough that they actuated a remedial action scheme.

There have been six earthquakes of Richter 6 or higher intensity in the area of California from south San Francisco to south Los Angeles named in reports of grid disturbances from January 1, 1987 to December 31, 1994. One of these, the Loma Prieta earthquake in 1989, was at least as severe as the January 17, 1994, Los Angeles earthquake, but the grid disturbance which followed the Loma Prieta earthquake was limited to the PG&E service area. Earthquakes can cause major grid problems if they involve equipment faults sufficient to actuate remedial action schemes.

Ten instances of line faults and equipment failures since January 1, 1987, have caused major grid disturbances. The most significant disturbance occurred when the fault involved additional failures and actuated remedial action schemes.

Fires, brush or forest, near transmission lines have caused grid disturbances, which are more severe if they involve equipment faults that cause the actuation of remedial actuation schemes.

A nuclear plant is typically four times as large as a coal-fired plant. Tripping of two nuclear plants during a transient may be expected to greatly increase the severity of the grid disturbance.

Islanding of WSCC results in frequency transients in each island.

FINDINGS AND CONCLUSIONS:

The reactions of the Western grid in response to the transient of December 14, 1994, appear to have been appropriate to the transient. The scramming of the Diablo Canyon units in anticipation of a loss of power to the reactor coolant pumps was premature, but in accordance with plant design.