AEOD TECHNICAL REVIEW REPORT

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SUBJECT: THE ELECTRICAL TRANSIENT WHICH FOLLOWED THE LOS ANGELES EARTHQUAKE - JANUARY 17, 1994

SUMMARY:

At 7:31 a.m. EST, January 17, 1994, an earthquake which measured 6.6 on the Richter scale struck southern California. At that time and for that reason, the grid in the western states began to separate. Transmission lines tripped and power plants tripped or ran back in Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.[1]

The Western Systems Coordinating Council (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 (Canada), 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.

About 45 transmission lines were reported to have tripped and 40 generating units tripped or ran back. Power was restored to these facilities in a range of times from one minute to several hours, while others are still out of service. Over 100,000 customers outside the quake area, mostly in Idaho, were without power for hours.

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 #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.

The performance of the WSCC grid was within the emergency operating criteria with the possible exception of the blackouts in Idaho. The estimated frequency for an

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[1] All information which concerns events which took place on January 17, 1994, was obtained from the Department of Energy, Emergency Preparedness Office.

earthquake-related LOOP ranges from higher than that of sites with known grid reliability problems and low to moderate severe-weather hazards to higher than that of sites located in a high severe-weather hazard area, depending on the duration of the LOOP. At the present time, offsite power to a nuclear plant has not been lost because of the frequency swings, but the potential exists.

DISCUSSION:

Prior to the earthquake, an event occurred at Diablo Canyon that was to significantly affect the response of Diablo Canyon to the earthquake. On December 26, 1993, a static wire broke and the #11 500/230 KV transformer at the Midway substation tripped on sudden pressure. Midway-Kern 230 KV lines #1 and #2 and the Midway-Vincent 500 KV line #3 tripped (shown as "Lines involved in the December 26 event" in Figure 1). Diablo Canyon 1 tripped from 100 percent power because of the line fault and a pre-existing equipment problem. The excitation system isolation transducer #3 was out of calibration and sensed a non-existent failure, tripping the turbine erroneously. The grid frequency in the area dropped to 59.83 Hz and stabilized at 59.875 Hz. The reactor coolant pumps at Diablo Canyon 1 tripped on underfrequency. Twenty-one minutes later, the frequwncy was returned to 60 Hz, following the correction of an erroneous reading to a grid computer. The faulty transducer was replaced.

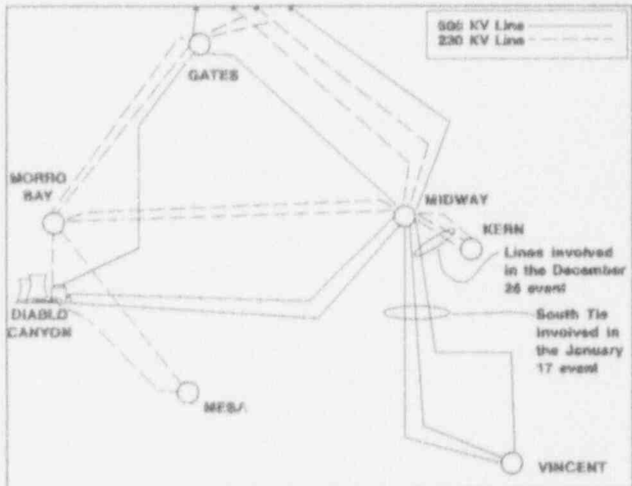

Figure 1 Transmission Map of the Diablo Canyon Area

At 7:31 a.m. EST, January 17, 1994, an earthquake which measured 6.6 on the Richter scale struck southern California. The epicenter was located in the San Fernando valley in the community of Northridge, a suburb of Los Angeles. The Los Angeles Department of Water and Power (LDWP) reported that all generating units in the basin tripped and the Los Angeles area served by LDWP, Burbank Public Service Department, and the City of Glendale Public Service Department was blacked out.

The NRC contacted the San Onofre and Diablo Canyon nuclear plants to determine what effects the earthquake had on them. Control room personnel at San Onofre reported that they felt the shaking, but no motion indicators activated. Motion was neither felt by the Diablo Canyon personnel nor registered on the motion indicators. Both San Onofre and Diablo Canyon personnel reported frequency problems on the grid.[2] Because of the frequency disturbances reported in the event notification and news

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[2] EN 26627 Dated January 17, 1994, Emergency notification provided by the NRC Operation Center.

reports of blackouts in Seattle, Washington and Portland, Oregon, a call was made to the Emergency Preparedness Office of the Department of Energy (DOE) to determine the scope of the grid transient. DOE provided the NRC a copy of the Western States Coordinating Council preliminary report which showed a system-wide massive disturbance.

At the time of the earthquake, the southern intertie - three 500 KV lines, Midway-Vincent #1, #2, and #3 - tripped and the Pacific D.C. intertie blocked. The resultant power surge flowed eastward, causing the Treasureton, Idaho, out-of-step scheme to activate. The grid in the western states began to separate. The Treasureton out-of-step scheme initiated the breakup of WSCC into islands. Southeastern Idaho separated and the 345/500 KV interties at the Jim Bridger plant in Wyoming opened. Idaho power separated east of the Midpoint substation on three-phase faults, probably due to the out-of-step swing. Other lines tripped, separating Montana from Wyoming and Idaho. The grid within Utah began to separate, completing the formation of 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 (Canada), 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.

Lines Tripped	KV
4	500
13	345
2	500/345 interties
14	220-230
8	115-161
3	55-69
2	HVDC

Units Tripped	State	MW
Intermountain 1&2	Utah	1600
Jim Bridger 2,3,&4	Wyoming	1030
Dave Johnston 4	Wyoming	330
Hunter 3	Utah	400
Navajo 1	Arizona	750
Castaic (All Units)	California	1200
Others	NM,Co,Wy,Ca	1800

About 45 transmission lines were reported to have tripped and 40 generating units tripped or ran back. Figure 2 illustrates the location of the earthquake, nuclear plants, tripped power plants, and blacked-out areas. These units produce about 6000 MW, or 4 percent of the total capacity of WSCC (includes Canadian provinces and some northern

Mexican areas). Power was restored to these facilities in a range of times from one minute to several hours, while others are still out of service. Over 100,000 customers in Idaho; Montana; Portland, Oregon; and Seattle, Washington - some several hundred miles from the Los Angeles quake area - were without power for hours.

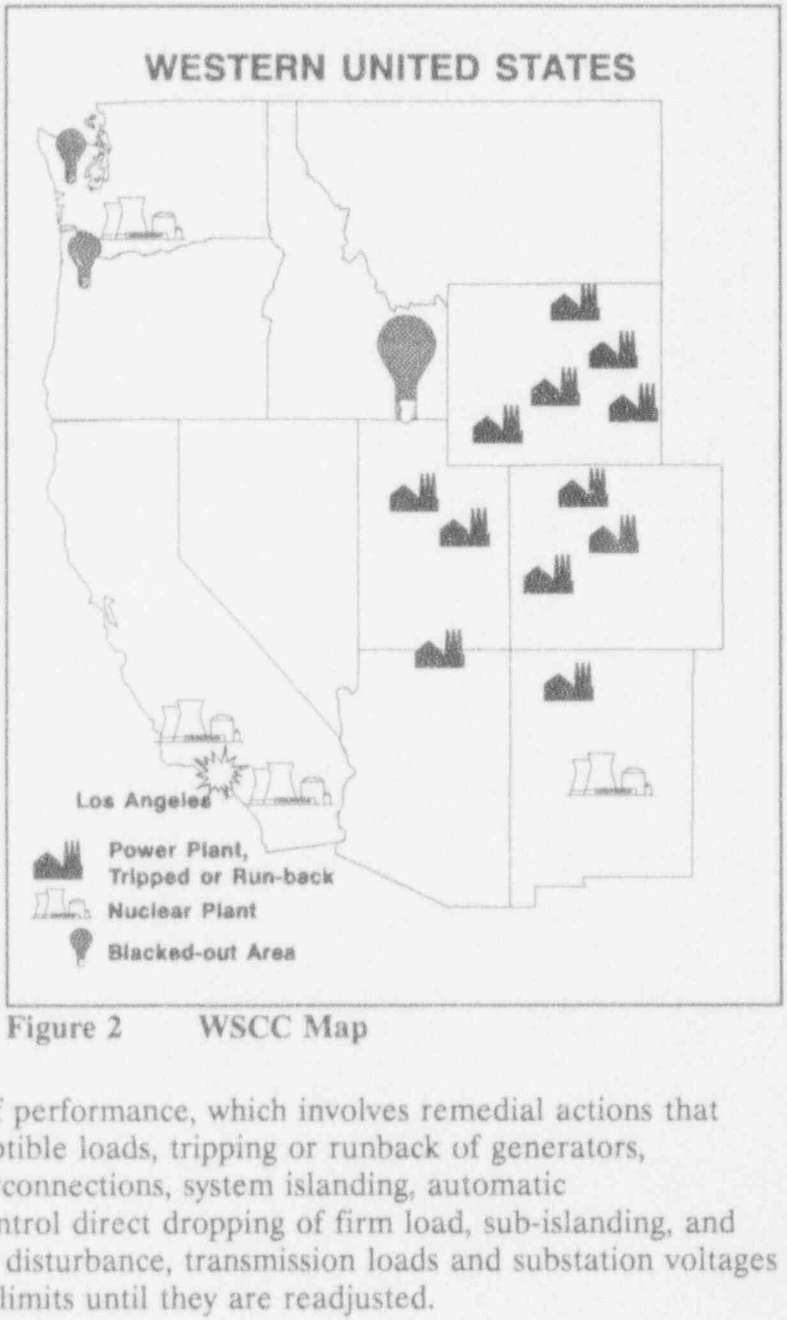

Figure 2 WSCC Map

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 #1, #2, and #3, tripped (Shown as "South tie involved in the January 17 event" in Figure 1). WNP 2 was also in the north island. Operating nuclear plants in the south island were San Onofre and Palo Verde.

The initiating disturbance for this grid transient appears to be the loss of the three 500 KV Midway-Vincent lines, which makes it a loss of three or more circuits on one right-of-way. In the "Criteria for Dynamic Performance of Interconnected Bulk Power Systems,"[3] Section I, Performance Levels, four performance levels (A, B, C, D) for the grid are defined. The initiating disturbance for this transient would cause a D-level of performance, which involves remedial actions that could include dropping of interruptible loads, tripping or runback of generators, controlled opening of system interconnections, system islanding, automatic underfrequency load dropping, control direct dropping of firm load, sub-islanding, and generation separation. After the disturbance, transmission loads and substation voltages may be outside of the emergency limits until they are readjusted.

The "Basic Criteria" of the "General Operating Reliability Criteria" include the following statements: 1) "The bulk power systems will be operated at all times so that general

[3] All information concerning the operating reliability criteria for WSCC was obtained from their 1992 IE-411 report to the Department of Energy, sections 5 and 6.

system instability, uncontrolled separation, cascading outages, or voltage collapse will not occur as a result of the single most severe contingency." 2) "Multiple contingency outages of a credible nature will be examined, and the system will be operated to protect against general system instability, uncontrolled separation or cascading outages for these contingencies." 3) "Continuity of service is the primary objective of the Minimum Operating Criteria." Preservation of the interconnections during disturbances is a secondary objective except when preservation of interconnections will minimize the magnitude of load interruption or will expedite restoration of service to load."

In the "Emergency Operating Procedures," it is recognized that regardless of many precautionary procedures, emergencies do occur. For load shedding and separating into islands, each WSCC member is required to determine separation points and islands and to initiate a program of automatic load shedding to arrest any frequency decay. This program would minimize the occurrences of total grid collapse and prevent damage to equipment that grid collapse would cause. Island formation and load shedding would leave the system in a condition to rapidly restore loads and reestablish interconnections.

The initial underfrequency relays operate at 59.3 Hz, the next relays operate at 59.1 Hz. In areas which are isolated with excessive generation, automatic generator tripping or run-back to prevent excessive over-frequency is warranted. In this event, Intermountain units 1 and 2 tripped for this reason.

The utilities are required to "provide startup power to generating stations and off-site power to nuclear stations, where required." In this event, no nuclear unit lost off-site power. Restoration is to be accomplished only when the systems conditions have recovered to the extent that lost loads can be restored without adverse effect.

ANALYSIS:

The December 26, 1993, event uncovered the faulty transducer at Diablo Canyon 1 which, if left uncorrected, might have sensed the Midway-Vincent lines fault and caused Diablo Canyon to trip during the January 17, 1994, earthquake. If the trip had occurred, the grid frequency may have fluctuated even more, increasing the possibility of a LOOP at Diablo Canyon.

NUREG-1032, "Evaluation of Station Blackout Accidents at Nuclear Power Plants,"[4] discusses LOOPs at nuclear plants. It categorizes LOOPs as plant-centered, grid-related, and weather-related. Weather-related LOOPs were said to be influenced by plant location. Significant factors were (1) the reliability of the grid and (2) the likelihood of severe weather. Severe-weather related grid disturbances were described as infrequent but may result in a longer duration LOOP. Events after the Los Angeles earthquake suggest a similarity between severe weather and earthquake-related LOOPs not due to

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[4] P.W. Baranowsky, "Evaluation of Station Blackout Accidents at Nuclear Power Plants," NUREG-1032, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1988.

direct seismic effects. While NUREG-1032 does address a seismic event causing a LOOP, it assumes a safe shutdown earthquake at the site occurring once in a thousand reactor years and recovery from it taking 8 to 24 hours. This 1994 earthquake occurred over a hundred miles away from a nuclear plant and did not cause a LOOP by damaging the transmission lines, but it did have the potential to cause a LOOP due to degraded frequency of the grid. The direct seismic effects of the earthquake to the plants were insignificant.

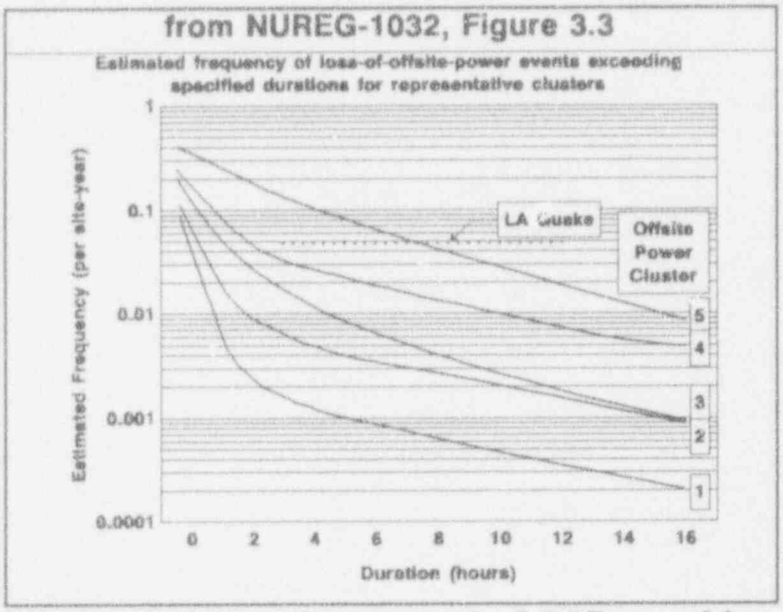

Figure 3 Estimated Frequency of a LOOP caused by an Earthquake

Cluster	Characteristics
1	Sites with demonstrated high grid reliability and multiple sources of offsite power available through independent switchyard circuits and low severe-weather hazards or design features to limit loss of offsite power or hasten recovery from severe weather events.
2	Sites with demonstrated high grid reliability and low severe-weather hazards with design features to limit loss of offsite power or hasten recovery from severe-weather events.
3	Sites located in moderate to high severe-weather hazard area and with limited design features to preclude loss of offsite power or hasten recovery from severe-weather events.
4	Sites with known grid reliability problems and low to moderate severe-weather hazards or design features to limit loss of offsite power or hasten recovery from severe-weather events.
5	Sites located in a high severe-weather hazard area and without design features to preclude loss of offsite power or hasten recovery from severe-weather events.

Table 1. Characteristics of Loss-of-Offsite-Power Event Clusters

Figure 3.3 of NUREG-1032 plots the estimated frequency of a LOOP (per site year) versus the duration in hours for five groups of plants called "Offsite Power Clusters." This figure is reproduced in Figure 3 and Table 1 gives the definition of Offsite Power Clusters.

The estimated frequency of a LOOP from an earthquake was calculated by assuming that the probability of a LOOP was 1 in 2, given the WSCC grid conditions following the earthquake, and that the plant had operated for 10 years. This gives a frequency of 0.05 which is shown as a dashed line in Figure 3 for a duration of 3 hours to 12 hours. Three hours is an estimate of the time to determine that the system is undamaged and to restore offsite power. Twelve hours is an estimate of the time to restore a damaged system and to restore offsite power.

This puts the estimated frequency for an earthquake-related LOOP exceeding specific durations in a range from higher than that of an Offsite Power Cluster 4 to higher than that of an Offsite power cluster 5, depending upon the duration of the LOOP.

The earthquake precipitated a three-line in one right-of-way fault which caused the WSCC grid to lose load, island, experience frequency problems, and other problems within the D performance level predicted for this kind of occurrence. Outside of the quake area, the system was rapidly restored in one to three hours.

All plant trips or runbacks and transmission line trips occurred within seven minutes or less and at least 80 percent of the transmission line trips occurred within less than one minute. There was no time for operator action to mitigate the circumstances. Should nuclear plants ever experience a loss of offsite power as a result of a natural disaster, WSCC has made the reestablishment of off-site power to the nuclear units a priority on the level with providing power to restart other generating units. This is reasonable because power must be generated to have off-site power available for the nuclear units.

CONCLUSION:

1. The performance of the WSCC grid was within the emergency operating criteria with the possible exception of the blackouts in Idaho.

2. Events after the Los Angeles earthquake suggest a similarity between severe weather and earthquake-related LOOPs not due to direct seismic effects. The estimated frequency for an earthquake-related LOOP ranges from higher than that of sites with known grid reliability problems and low to moderate severe-weather hazards to higher than that of sites located in a high severe-weather hazard area, depending on the duration of the LOOP.

3. No new issues involving nuclear plant safety were identified; however, the breadth and speed of the grid reaction to the initiating event should be recognized.

4. This kind of event is not limited to the WSCC, because interactions between other Reliability Council member units can and do occur. The breadth of the reaction to the initiating event would depend upon its cause, where it occurred, time of year, time of day, and many other things; but an earthquake on the New Madrid fault in the Midwest should be expected to affect a large grid area of the United States and it could occur just as fast, with the potential to impact many more nuclear plants than the California earthquake because there are many more plants in the midwest and eastern United States.