AEOD ENGINEERING EVALUATION

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SUBJECT: FAILURES OF ELECTRICAL SUPPLY AND POWER GENERATION EQUIPMENT WHICH DISRUPTED PLANT FUNCTION AT NUCLEAR POWER PLANTS

SUMMARY

This study was initiated because of the occurrence of several events in early 1989 involving major electrical equipment or offsite power problems. A search for similar events identified 79 events in the past 18 months. Twenty-two of those events were considered to be of major interest and are described in this report.

The issues addressed in this report concern disruptions of normal station auxiliary alternating current (AC) power supply caused by grid, switchyard, and non-1E electrical system problems and major electrical equipment failures. Failures in electrical supply or power generation equipment can impact safety equipment in that they often cause scrams or require unit shutdown, they may cause engineered safety features systems to operate, they frequently cause interruptions of offsite power supply to station auxiliaries, they occasionally cause fires, and they complicate post-scram operations by rendering equipment unavailable or unreliable.

Interruptions of offsite power to 1E busses, while they are contributors to the risk of a station blackout, generally cause transfer of the busses to the emergency diesel-generators (EDGs); while interruptions of offsite power to non-1E busses cause scrams, loss of forced circulation, loss of preferred heat sink, and loss of service/instrument air.

An AEOD Engineering Evaluation, AEOD/E905, "Electrical Bus Bar Failures", and an NRC information notice, IN 89-064; and an ongoing AEOD study on main transformer failures address the major equipment failures. Fast bus transfer failure is also being addressed in an on-going AEOD study. The operating experience, particularly maintenance, surveillance, and procedural problems, should be utilized by NRR in developing procedures for the upcoming team inspections.

DISCUSSION

From January 1 to February 7, 1989, there were reports of a breaker and a transformer explosion and fire, a partial loss of offsite power, another breaker fire, another partial loss of offsite power, a fire in the main generator, a bus bar short, loss of offsite power, a second partial loss of offsite power at a startup plant, a loss of offsite power involving two units, turbine high vibration, another breaker fire, and a fire in the turbine area. The quantity of the reports was large enough to warrant a look at the report data bases to determine the scope of the problem and an analysis of the safety impact.

At that time, a preliminary search was performed. All events involving electrical supply equipment up to (but not including) the startup transformer were included as well as events involving power generation equipment. The main turbine and generator were included but not their control systems, instruments, valves, or other attendant systems. Additionally, the initiator must also have caused or contributed to a complicated transient in which there was a turbine trip, reactor scram, engineered safety features (ESF) actuation, and/or other major complications. Several events of significance were found and this study was undertaken.

The NRC's document control system (DCS) was searched for licensee event reports (LERs) which involved a turbine trip or loss of the main generator in the 12-month period from February 7, 1988, to February 7, 1989. Twelve significant events were found which showed the impact of electrical disruptions on plant function. A more thorough search of LERs for the period using the Sequence Coding and Search System (SCSS) found 45 LERs. From daily reports and 10 CFR 50.72 reports made from February 7, 1989, through May 31, 1989, additional reports were selected.

From all these data bases, a total of 79 event reports involving interruptions of offsite power supply to the station auxiliaries or major electric equipment problems was identified. Twenty-two of these, considered to be events of interest, are detailed in the following section. Events involving interruptions of offsite power to the plant (either partial or total loss of offsite power) are shown in Table 2. Appendix 1 is a tabulation of all the other events.

Search Strategies:

The events which are discussed were selected from the LERs written from 02/07/88 to 05/31/89. These events involve failures in electrical supply or power generation equipment which disrupted plant function. These events were selected from a larger number of events found in a variety of Boolean searches of the DCS. The most fruitful search was DTC (document type code) TRLER (the code for LERs) + DA (date range) 880207..890207 + T (term) TURBINE TRIP. Additional events were found by using the same DTC and DA and combining with T GENERATOR and by scanning 10 CFR 50.72 reports. The loss of offsite power information for 1989 was taken from a scan of DCS listings of all LERs submitted in 1989, DTC TRLER and DA 890101..890720 and 10 CFR 50.72 reports.

A Boolean search of the DCS for all LERs written in 1988 describing scrams found about 320 events. A Sequence Coding and Search System search of LERs written in the same period by a variety of strategies found about 141 LERs of which 45 were applicable to this study. The data bases queried were designed to have safety system information readily accessible. The keywords relevant to this study were few and non-specific; that is, a term such as "transformer" would locate a tiny device on a printed circuit as well as a station transformer. Therefore, the strategies used were "reactor scram" and "turbine trip". LERs were then read to determine if they were pertinent.

Major Events of Interest:

The following 22 events were of major interest because of the complexity of the event, the safety consequences of the occurrence, the failures of the equipment involved, and the effects on plant systems - safety related and non-safety related. In general, automatic systems functioned as they were expected to function for the event described unless otherwise indicated. The events described in the following paragraphs are identied by plant name, LER number, date, and event descriptors as defined in Table 1.

Table 1.	Event Descriptors
IOPS	Interruption of offsite power
XFMR	Transformer failure
BRKR	Breaker failure
FIRE	Fire
ESF	Engineered safety features actuation, including ECCS, AFW, EDG, PCIS, SRV
SCRAM	Reactor shutdown, manual or automatic, while critical
RPS	Reactor shutdown signal while shutdown
T-G	Turbine or generator non-electrical problems
COMP	Complications
DUAL	Both units at the site involved

Kewaunee LER 88/001 03/02/88 SCRAM/FIRE

A reactor scram and turbine trip occurred due to an undervoltage transient on two 4160 volt busses which supply power to a reactor coolant pump (RCP) motor and a main feedwater (MFW) pump motor. A section of the bus bar running from the main auxiliary transformer to the bus switchgear was badly damaged due to insulation failure and subsequent fault. The fault caused the voltage at the switchgear to decrease and the undervoltage on both busses caused a reactor scram and turbine trip. The busses were automatically isolated from the main auxiliary transformer and transferred to the reserve auxiliary transformer as expected preventing the trip of the RCP and the MFW pump.

Due to to amount of smoke in the turbine building, the shift supervisor activated the emergency siren which required all the on-site personnel to assemble for accountability. The root cause of the event was a fault on the bus bar at the bus bar support. Poor housekeeping in the area of the bus bar lead to water and dirt accumulation which hastened the deterioration of the insulation and provided a path to ground.

Palo Verde 1 LER 88/010 07/06/88 IOPS/XFMR/FIRE/ESF/SCRAM/COMP

A B-phase ground fault occurred on a non-1E 13.8KV bus, ionizing the air in the vicinity, precipitating a three-phase fault to ground. The feeder breakers to this and another bus did not immediately trip because they had a 0.7 second time delay (42 cycles). In that time period, the unit auxiliary transformer which was connected to the faulted bus experienced a greater than 24,000 amp fault, exploded, and caught fire. The busses' supply breakers and the generator output breakers opened. The unpowered RCPs coasted down causing the the reactor to scram as expected. Fast bus transfer of the safety busses failed to occur because the sync check relay, which compares the voltage of one of the safety busses with the faulted bus, found them both in sync, but at zero potential due due to the failed unit auxiliary transformer and the faulted bus. (They must be in sync and have the required voltage for the fast transfer to occur.)

Several electrical equipment problems complicated the post-scram transient. The nuclear cooling water system (non-safety related) was lost when the non-1E power was lost. The essential cooling water (ECW) system was cross-tied to the nuclear cooling water system. One of the cross-tie valves was found to be shut when the instruments read both open and closed.

When the control room was notified that a fire was in progress, the fire area auxiliary operator proceeded to the area to check the equipment. Deluge flow to the failed transformer could not be verified because the panel was located inside a wall damaged by the transformer explosion. The operator activated the deluge valves to all the transformers and exited the area. Since electrical power to remotely operate the deluge valves had been lost, the manual actuation was necessary.

Emergency ventilation to the control room was initiated when normal ventilation was lost due to loss of power. The normal source of instrument air was not available due to the loss of power and the nitrogen system provided pneumatic backup according to design.

EDGs were started and the safety busses were loaded onto the EDGs in order to isolate the safety busses from the wet transformers and non-safety busses. The supply breaker to one of the safety busses could not be opened remotely but was opened manually. To determine if the faulted bus could be re-energized, operations personnel proceeded to the switchgear room and noted that the only targets on the bus were undervoltage relays (the bus was de-energized) and the trip flags were recorded and reset prior to re-energized. The room was dart and smile was present. The smoke was thought to be coming from the transformer fire. An attempt was made to re-energize the bus, but the breaker tripped and the bus was reported afire.

Upon restarting RCPs A and B, the pumps tripped on an actuation of the lock-out relay in the speed sensor. The cause of the relay actuation was low direct current (DC) voltage due to a discharged non-1E station battery.

Although all types of errors contributed to complicate the event, the initiator - failed bus bar - was caused in a large part by poor house-keeping in the area of the bus bar. The dirt accumulation contributed directly to the evolution of a single phase fault into a three phase fault. The second fire was caused by personnel error, with the failure to maintain the emergency lighting as a strong contributor.

Ginna LER 88/006 07/16/88 IOPS/BRKR/SCRAM/COMP

An electrical fault in the plant's main electrical substation caused five main breakers in the substation to open. This caused loss of about one-half of the transmission capability of the substation and loss of all normal off-site power to the plant. The four safety busses deenergized and were reenergized with the EDGs in about 30 seconds. In that period, an instrument bus was lost momentarily causing a turbine runback. The plant was stabilized at 75 percent power.

The security department reported hearing an explosion at the substation. Upon investigation, it was discovered that a bushing on a 115KV oil-filled circuit breaker had failed and the breaker exploded. A plant shutdown was commenced at the request of the power control dispatcher because of the damage to the off-site power transmission equipment. The turbine was taken off-line and the reactor trip breakers were opened. After the turbine was off-line, an operator attempting to reset the feedwater isolation on the B-steam generator (S/G), pressed the S/G isolation reset button instead and the MSIV closed.

Other problems reported were a rod which failed to insert manually but did insert when the trip breaker was opened, and an oil leak at the substation in the 115KV underground line from the plant to the substation.

Peach Bottom 2&3 LER 88/020 07/29/88 XFMR/FIRE/ESF/RPS/DUAL

The capacitors which connect the 500KV #1 bus tie line with the A-phase potential transformer failed and the transformer caught on fire. The potential transformer steps line voltage down to that used by equipment in the substation. A voltage disturbance ensued which ultimately resulted in several expected ESF actuations on Units 2 and 3 and a partial loss of telephone services at the site.

The power supply which was established was permissible for the conditional which existed at the site. Both units were shutdown and defueled with equipment out of service for maintenance.

These events occurred as expected while the plants were in off-normal configurations for maintenance outages.

River Bend LER 88/018 08/26/88 SCRAM/ESF/IOPS/COMP

The generator tripped from loss of field excitation, resulting in a turbine trip which caused a reactor scram. Prior to the scram, one of the main generator brushes had been sparking and maintenance procedures were being readied to address the problem. During the post-scram transient, the recirculation pumps transferred to the slow speed motor/generator set on an end-of-cycle recirculation pump trip signal. Reactor pressure peaked high causing five safety/relief valves (SRVs) to lift. Turbine bypass valves opened. The pressure spike collapsed the voids causing reactor water level to decrease. All actuations were expected in an event of this type. An hydraulic perturbation on the wide range level instruments showed a low level spike greater than -29 inches. High pressure core spray (HPCS) and reactor core isolation cooling (RCIC) initiated and injected for about 30 seconds. Subsequently, the HPCS injection line upstream of the injection valve was found to be hot, due to backleakage from the reactor.

A non-safety related bus failed to transfer from the normal station service transformer and a second bus failed the fast transfer but did slow transfer. The first failure caused a loss of power to to the HPCS bus. The HPCS diesel-generator started and loaded the bus. The turbine building closed cooling water pumps tripped and the instrument air compressors subsequently tripped on high temperature. Power to the RPS bus A was lost resulting in an initiation of the standby gas treatment and annulus mixing systems and the trip of the annulus pressure control system. A spurious high drywell alarm also actuated.

Catawba 2 LER 88/028 09/28/88 T-G/COMP/SCRAM

The generator stator water cooling system circulates high purity water through the stator coil hollow conductors. Either of two AC motor-driven centrifugal pumps will produce the required flow. Pressure actuated switches cause the automatic startup of the reserve pump in the event that the pressure decreases. If the stator cooling water is lost, the turbine runback circuitry will automatically reduce the generator output to the rated capability without stator cooling water circulation (about 23% turbine load). In this event, maintenance personnel bumped the pump switch while removing masking tape after painting the switch panel. The switch was put in the OFF position. The running pump tripped and the reserve pump was prevented from starting by the switch position. The loss of stator cooling caused a turbine runback as designed and reactor power was reduced from 95% to 35% in 3 minutes.

The turbine runback failed to stop at the rated capability without stator cooling water circulation but terminated when the operator restored the stator cooling water pump. Following the runback, the steam dumps erratic operation caused an increase in the reactor coolant system (RCS) average temperature (Tave) which caused a S/G level swell when the steam dumps failed to open properly. Then a steam dump fully opened, aggravating the level swell. The turbine tripped on an indication of S/G high level, isolating MFW and causing the MFW pumps to trip and auxiliary feedwater (AFW) to autostart by design. The reactor was then manually scrammed because of the loss of main feedwater with the reactor above 10% power.

Braidwood 1 LER 88/022 10/16/88 IOPS/COMP/ESF/SCRAM/DUAL

A loss of all off-site power to the unit occurred when the A-phase potential transformer for a 138KV line failed causing a current surge on the low side of a transformer at an off-site substation, causing its sudden pressure relay to actuate. A transfer trip signal was sent to the 345KV breakers associated with both the substation and the plant. The 345KV oil circuit breaker and the 345KV air circuit breakers opened, but the air circuit breaker took longer to open causing a pole disagreement actuation (all three phases not in the same state). This caused another air circuit breaker to open, which resulted in the power being removed from the high side of the station auxiliary transformers. Auto transfer of two 6.9KV busses occurred and EDGs started and loaded two 4KV busses.

An RCP supply breaker tripped on instantaneous overcurrent because of a piece of cardboard in the relay that bypassed the time delay of the relay. The licensee speculates that the cardboard was inserted during the last maintenance on the relay and not removed. This caused a reactor scram on low RCP flow with the reactor above 30% power. The turbine and generator tripped as expected.

Voltage on the unit auxiliary transformers decayed, causing a loss of power on additional busses. Station air compressors tripped and instrument air pressure began to decrease to both units. Several attempts to restore equipment were thwarted by the pole disagreement. The pole disagreement was found to have been caused by an out-of-calibration circuit breaker.

Hope Creek LER 88/029 11/01/88 SCRAM/ESF/COMP

A main generator lockout occurred on the loss of excitation which was caused by the failure of the exciter brush-collector ring assembly from undetermined causes followed by fast closure of the turbine control valves, main turbine trip, and reactor scram. The recirculation pumps tripped on end-of-cycle logic. Reactor pressure increased and the H-SRV lifted. Reactor feedwater pumps tripped on high level. High pressure coolant injection (HPCI) and RCIC actuated and injected for about 10 minutes. Automatic actuations were as expected for this type of event. During the subsequent transient, the P SRV (low-set) failed to lift because of a faulty pressure transmitter.

Although the licensee could not determine the root cause of the exciter brush failure due to the extent of damage to the equipment, it was speculated that a more rigorous inspection may have prevented the failure. To this end, the utility is developing a new procedure.

Clinton LER 88/028 11/11/88 XFMR/SCRAM/FIRE

The C-phase main power transformer experienced a phase-to-ground overcurrent fault causing a generator-to-transformer differential relay trip of the main generator and a consequential turbine trip. The reactor scrammed on turbine stop valve fast closure as designed. A fire had started from oil which had erupted from the transformer bushing. The fire protection deluge initiated in the transformer area and the fire brigade was dispatched. The fire was above the deluge, since the deluge was designed to preclude spraying of the high voltage bushing. The fire brigade extinguished the fire in about 30 minutes. The cause of the event was an internal fault on the high voltage side of the transformer.

Sequoyah 1 LER 88/045 11/18/88 SCRAM/ESF/COMP

A reactor scram occurred as a result of the main turbine being tripped by the main generator neutral overvoltage relay, which had detected a ground fault. Steam dump valves opened, MFW isolated, and AFW actuated. All automatic actuations were as designed. Both motor-driven and the turbine-driven AFW pumps injected. The flow indicator for the turbine-driven AFW pump indicated off-scale, high (greater than 1000 gpm). The overspeed protection should have limited the flow to 880 gpm to prevent pump runout. Consequently the RCS cooled down below the no-load Tave. Also the volume control tank level decreased below 7 percent. Maintenance personnel determined that the cause of the event was a ground fault internal to the main generator. There was an insulation breakdown on a C-phase stator bar.

Oconee 1 LER 89/002 01/03/89 FIRE/SCRAM/COMP

A fire began in the non-1E switchgear while escalating in power. Two RCPs tripped. After 30 minutes, the reactor was manually scrammed and the remaining 2 RCPs were tripped so that water could be safely used to fight the fire after carbon dioxide and dry chemicals had proven unsuccessful.

A failure of the integrated control system (ICS) to control steam generator level using the AFW nozzles (main feedwater is required to change injection from MFW nozzles to AFW nozzles) caused an RCS pressure transient and technical specifications (TS) cooldown rates were exceeded while mitigating the pressure transient as a result of overfeeding the steam generators. The failure of the ICS was caused by fire damage to control cables in the switchgear. The resultant operation in the thermal shock operating range was not properly compensated. Other equipment failures and personnel errors complicated the post-scram transient.

South Texas 1 LER 89/005 01/20/89 FIRE/T-G/SCRAM/COMP

Alarms were received which indicated that there was high vibration in the turbine and a high temperature on the #8 and #9 bearings. A fire was reported at the #9 bearing and the deluge actuated. The turbine was manually tripped causing an automatic reactor scram. The fire brigade extinguished the fire in about 20 minutes and the generator was purged of hydrogen with carbon dioxide and the carbon dioxide with air in the usual manner. The problem with the generator began with a loss of stator cooling due to a loose wire in the temperature sensing unit which caused a temperature increase to go unnoticed and without compensation until the hydrogen seal at the #9 bearing was damaged by the heat causing pressure to increase and leakage. The source of ignition is not known. The visible flames around the bearing were probably caused by heat igniting grease or lube oil.

The generator was disassembled and the rotor removed for inspection. No significant damage was found. The bearings' pedestals were inspected and no damage was found. The lube oil was drained and flushed.

WNP 2 LER 89/002 01/30/89 SCRAM/ESF/COMP

A buildup of a conductive film on the surface of an insulator on the output side of the main transformer caused the insulator to short to ground. The resultant high currents tripped the main generator output breakers. The load rejection tripped the generator and turbine and scrammed the reactor as expected. During the post scram transient, a level transient caused certain containment isolations on low level and subsequent pump trips on high level (due to overcompensation). Six SRVs lifted and reseated properly as expected. The scram discharge volume vent and drain valves did not reopen on the scram reset.

Pilgrim LER 89/010 02/21/89 RPS/ESF/IOPS

Air circuit breakers (ACBs) opened due to a ground fault in the underground portion of one of the C-phase power feeder cables between the secondary side of the startup transformer and a non-safety related 4160 volt bus. The differential ground current relay detected the cable fault and caused the startup transformer to be locked out which, in turn, tripped the ACBs. The EDGs started and loaded the safety busses as expected. An RPS actuation - scram signal, PCIS actuation, reactor building isolation, and SBGT actuation occurred as designed. Offsite power was restored 15 hours later.

LaSalle 1&2 LER 89/009 03/02/89 IOPS/SCRAM/BRKR/COMP/DUAL

The C-phase lightning arrestor on the station auxiliary transformer (SAT) failed resulting in a phase-to-ground fault on the line to the unit 2 distribution system. Oil circuit breakers (OCBs) and unit 2 feeder breaker from the

SAT opened to isolate the fault. Automatic transfer from the SAT to the unit auxiliary tranformer (UAT) was accomplished and an EDG started and loaded a bus as designed.

Because of the lightning arrestor failure, the Unit 1 main generator protective relays sensed a high differential current on phase A and locked out the generator. The load rejection caused a turbine trip and a reactor scram. An OCB failed while opening.

Pre-existing conditions complicated the post-scram transient. The Unit 2 process computer was performing the primary data acquisition and safety parameter display system (SPDS) functions for both units, with the Unit 1 process computer in standby. The Unit 2 process computer was powered from the Unit 1 SAT bypassing the uninterruptible power system (UPS) because of a failed inverter in the UPS. The computer used for core monitoring and off-site dose calculations had also bypassed UPS and was powered from Unit 2 SAT. Additionally, intermediate range power monitors (IRMs) D and F were out of service.

The loss of the process computer made the job of assuring that all rods went to full-in more difficult in that it had to be done manually for each rod by selecting the rod and observing the rod sequence control system panel "full-in" lights.

Service air was lost briefly on Unit 1 making it difficult to reset the A-scram channel. The B-scram channel could not be reset because of the inoperable IRMs. Unit 2 service air was also lost briefly.

The drywell chillers in Unit 2 were lost for about 15 minutes while the unit was in mode 1. Drywell temperature rose to 213 degrees F and pressure rose to +0.6 psig.

The 2A reactor feedpump controller locked up causing a reactor level transient. Vessel minimum was +25.0 inches and maximum was +53.0 inches. Operators took control of the pump to limit the transient. Reactor water cleanup system and the reactor building ventilation system isolated.

Palo Verde 3 LER 89/001 03/03/89 COMP/ESF/IOPS/SCRAM

A fault in a California switchyard caused a grid disturbance which actuated the subsynchronous oscillation protection relay for the unit 3 main turbine/generator. The generator output breakers opened and the steam bypass control system was called upon to dump steam to the condenser while reactor power was run back. Automatic actuations were as expected for this transient; however, four of the steam dumps cycled from 10% to 100% open about nine times while the remaining valves fluttered between 80% and 100% open.

Excessive steam removal caused the pressure in steam generator 2 to go low enough to scram the reactor, and to cause the main steam isolation valves to close. There was a safety injection on pressurizer low pressure as well as a containment isolation actuation.

Fast transfer did not occur because the house loads were connected to the generator which was isolated from the grid. (Reverse power signal from the grid would have dropped the house loads from the generator.) As the generator coasted down, the frequency decayed to 30 Hz. When the house loads were dropped from the generator, they could not be synchronized to offsite power because non-1E busses 3E-NAN-S01 and 3E-NAN-S02 were deenergized.

Two of the RCPs had been manually shutdown. Loss of power to the non-1E busses shut down the other two. Also the condenser circulating water pumps, air compressors, nuclear cooling water, and some control room displays were lost. The atmospheric dump valves malfunctioned for several reasons, one of which was directly related to the loss of 1E power - no lighting in the area made the manual operation more difficult. One main steam safety valve opened lower than the TS limits. Normal pressurizer spray was unavailable because the RCPs were not running. RCP 1B seals were degraded when charging was secured. The MSIV bypass valve could not be operated remotely.

Dresden 3 LER 89/001 03/25/89 IOPS/COMP/SCRAM/DUAL

A 345 KV circuit breaker developed a phase-to-ground fault and tripped. Local breaker backup logic tripped additional breakers, isolating busses 8 and 15 and de-energizing the reserve auxiliary transformer (RAT) 32. Bus 32, which was powered from RAT 32, transferred to RAT 31 in 14 seconds (slower than design). Bus 32 developed an undervoltage condition because of this and the 3B reactor feedpump tripped and reactor feedpump 3A sped up to the point where runout flow control took control of the pump. The 3B recirculation pump also tripped and the 3C standby feedpump would not start until the 32 bus transfer was completed. At that time, still in runout flow control mode, the 3C feedpump started and its flow increased rapidly until the high level trip setpoint was reached, whereupon the feedpump tripped and the turbine stop valves closed tripping the turbine and scramming the reactor.

Other problems were a loss of an annunciator panel - an alert level condition, a transfer of a low pressure coolant injection system motor control center which should not have occurred, spurious breaker trips, failure of the isolation condenser supply valve to open, HPCI lube oil problems, failure of a breaker to remain closed, HPCI turning gear motor failure, security electronics problems, oxygen analyzer failure, and loss of instrument air. Loss of instrument air also affected unit 2.

South Texas 2 LER 89/009 04/05/89 IOPS/SCRAM/COMP/ESF

On initial synchronization, with a jumper missing between two terminals of the generator backup distance relay in the generator protection circuit causing an open circuit on the phase C current transformer of the protection circuit, the breaker pole failure relay actuated causing a generator lockout. (Another wiring error in the protection circuit on the negative phase sequence relay would have also caused a generator lockout.)

Two 345 KV switchyard breakers, the generator circuit breaker, the generator exciter field breaker, the generator voltage regulator, the main turbine, and the 13.8 KV feeder breakers to auxiliary busses 2F, 2G, 2H, and 2J tripped as designed. The tie breaker to the 13.8 standby bus from the auxiliary bus 2F opened as designed deenergizing the bus and 4160 volt bus E2A.

The RCPs lost power on the loss of the auxiliary busses and the undervoltage coils on their trip breakers generated a low flow signal to the solid state protection system which scrammed the reactor. The digital rod position indicator had lost power so all rods on bottom could not be verified and the RCS was borated.

The EDG for the emergency bus started and loaded the emergency bus as expected. When bus 2J was reenergized, RCP 2D restarted because its breaker failed to trip on loss of voltage. The additional flow caused a loss in S/G water level and an actuation of AFW.

RCS temperature was decreasing and the MSIVs were closed to prevent overcooling.

The non-ESF balance-of-plant diesel-generator could not be started in auto or manual. The Technical Support Center diesel-generator was out of service for maintenance.

Nine Mile Point 2 LER 89/014 04/13/89 SCRAM/IOPS/ESF/COMP

A disconnected wire in the main generator potential transformer cubicl[illegible] a signal to be sent to the main generator protective circuitry which [illegible] a turbine trip. The reactor scrammed on the turbine trip. Fast transf[illegible] offsite power was only partially successful: one of the 13.8 KV busses failed to transfer.

This caused a loss of feedwater and subsequent reactor level reduction to level 2. HPCS and RCIC actuated and injected. After water level reached normal, HPCS and RCIC were shut down. Water continued to be injected into the vessel from the feedwater lines. RCS pressure had been lowered to the point where the condensate booster pump could (and did) inject water into the vessel through a failed-open valve.

Due to a series of personnel errors and equipment failures, the remaining 13.8 KV bus was deenergized momentarily. This tripped the operating condenser circulating water pump and the decrease in water box level prevented the immediate restart of the pump. In the face of falling condenser vacuum, the MSIVs were closed but auto-closure occurred before the manual closure could be accomplished.

The uninterruptible power supply to an instrument bus was interrupted causing loss of communications in the control room and partial loss of emergency lighting. Water level was reported to have risen slightly above the lowest elevation of the main steam lines.

Oyster Creek LER 89/016 06/25/89 XFMR/SCRAM/ESF

A fault in one of the two main transformers caused the main generator to be tripped on a phase differential condition. Subsequently, the turbine tripped and the reactor scrammed. Rapid closure of the turbine stop valves caused a reactor pressure spike to 1067 psig. The isolation condensers auto-actuated, two safety/relief valves lifted, all five reactor recirculation pumps tripped, and the reactor water clean up system tripped and isolated. All automatic responses were expected for this transient. The cause of the transformer failure was attributed to a failure of an internal winding which caused the phase differential condition which cause the generator trip.

Oyster Creek LER 89/017 07/11/89 XFMR/SCRAM

The second of two main transformers failed due to a failed internal winding which caused a phase differential condition on the main generator. The generator tripped, the turbine tripped, the reactor scrammed, and all anticipated automatic responses occurred. Since this was the second main transformer failure in a month, the licensee initiated a study to determine the root cause of the transformer failures.

Summer LER 89/012 07/11/89 IOPS/ESF/COMP

Technicians working inside the generator stator cooling water cabinet shorted the power leads on the temperature converter causing the AC power fuses to blow, giving a false indication of loss of stator cooling water. A turbine runback relay in the circuitry failed to operate; instead, the turbine tripped and the reactor scrammed.

Summer was supplying 860 megawatts of power to the grid at 440 megavolt-amperes, reactive (MVAR) [89.7% power factor]. The McMeekin generating station and the Saluda hydro units (older units with their generator backup relays set below the utility's standard) tripped. The subsequent loss of voltage tripped the four Fairfield Pumped Storage units whose backup relays were set at the utility's standard. The cascading failures caused a degraded voltage to be sensed by the ESF busses at Summer.

The ESF busses tripped on undervoltage and transferred to the EDGs as designed. Non-1E busses remained on the grid and equipment supplied from them experienced the degraded voltage.

South Texas 2 LER 89/017 07/13/89 XFMR/SCRAM/IOPS/ESF/COMP

An internal fault ocurred on the main transformer 2A causing the main transformer differential relay and the primary side pilot wire differential relay to actuate the main transformer lockout relay which tripped the main generator breaker, the offsite power feeds from the switchyard, the auxiliary transformer, and the main turbine. The reactor scrammed on the turbine trip. Loss of the auxiliary transformer caused loss of one 1E bus and the non-1E busses which supplied power to the RCPs. The 1E bus was loaded on its EDG. AFW initiated. All responses to the incident were as expected.

<u>Events Involving Interruptions of Offsite Power:</u>

Twenty-four events in the first 6 months of 1989 were found involving an interruption of offsite power to the plant. These events are tabulated in Table 2 by plant, LER number, date, number and type of busses involved, and duration of the loss. Note that the time begins at the loss of power and stops at its restoration. "Available" power which is not used to energize busses is not considered in computing the duration of the incident.

Table 2. Interruptions of Offsite Power in 1989:

Plant	LER #	Date	Description	Time
Palo Verde 2	89/001	01/03/89	2 1E busses	21h8m
South Texas 2	89/001	01/06/89	2 1E busses	Not known
Catawba 1	89/012	01/07/89	1 1E bus-blackout*	28m
Fermi 2	89/003	01/10/89	2 1E busses	20m
ANO 1	89/002	01/20/89	1 non-1E bus	Not known
South Texas 2	89/006	01/21/89	All non-1E, train A 1E	2h53m
Pilgrim	89/010	02/21/89	All	15h45m
Palo Verde 3	89/001	03/03/89	2 non-1E busses	30m/41m
South Texas 2	89/005	03/20/89	2 1E busses	32m
Dresden 3	89/001	03/25/89	All	6h35m/7h33m
South Texas 2	89/009	04/05/89	4 non-1E, 1 1E busses	Brief
Surry 1&2	89/010	04/06/89	1 1E, non-1E bus ea unit	4h5m
Surry 1&2	89/013	04/13/89	1 1E, non-1E bus ea unit	3h17m
Nine Mile Pt 2	89/014	04/13/89	1 non-1E lost, 1 dropped	Not known
North Anna 1&2	89/010	04/16/89	1 1E bus, each unit	40m/45m
South Texas 2	89/014	04/18/89	1 1E bus	51m
Millstone 1	89/012	04/22/89	All	Brief
WNP 2	89/016	05/14/89	2 1E busses	50m
Millstone 2	89/009	05/23/89	1 1E bus	Brief
River Bend	EN 15855	06/13/89	1 1E bus	Not known
River Bend	EN 15858	06/13/89	2 non 1E busses	Not known
Crystal River 3	EN 15886	06/16/89	All	1h6m
Brunswick 2	EN 15895	06/17/89	All	9h45m
Crystal River 3	EN 15986	06/29/89	All (and 1 EDG)	Not known

ANALYSIS

The issues addressed by this study are disruptions of normal AC power as manifested by grid, switchyard, and non-1E electric systems (including the power generation system) problems and major electrical equipment failures.

The equipment whose failures caused these events (the 22 detailed in the Major Events of Interest, the 24 listed in Table 2, as well as the 57 in Appendix 1) were busses, circuit breakers, capacitors, potential transformers, switchgear, exciter brushes, neutral grounding transformers, lightning arrestors, stator cooling systems for the main generator, and main transformers as well as the main turbine and the main generator.

Fires have been caused by the catastrophic failure of transformers and circuit breakers, oil filled devices which have both fuel (oil) and ignition source (electrical failure). In other cases, the failure of devices such as switchgear

* Loss of all AC power to the bus, assigned EDG out of service.

and bus bars provide the ignition source with the fuel being provided by nearby combustible material sometimes the result of poor housekeeping. The results of fire are often equipment damage and personnel hazard.

A common factor to many of these events is maintenance. At Kewaunee and Palo Verde, poor housekeeping contributed to the breakdown of the bus insulation and complicated the event. Maintenance errors at Catawba initiated and complicated the event. At Palo Verde, poor maintenance of emergency lighting complicated the recovery from the event by contributing to personnel error that caused a second fire. A piece of cardboard left in a relay from a previous maintenance at Braidwood complicated recovery from the event by tripping the RCPs and causing a scram. Peach Bottom was vulnerable to the problems they experienced because they were in an alignment for a maintenance outage.

The events at Kewaunee and Palo Verde 1 had virtually the same initiator, a bus failure caused by insulation degradation complicated by dirt in the cubicle; yet consequences at Kewaunee were normal and expected, while the consequences at Palo Verde 1 were complicated by equipment failures, design errors, personnel errors, and pre-existing plant conditions. AEOD has issued a report AEOD/E905, "Electrical Bus Bar Failures," based on these two events. An NRC information notice, IN 89-064, based on this report was also issued.

River Bend had two events on the list, an exciter brush failure while preparations for maintenance were being completed, and a fault on a neutral grounding transformer caused by a stray cat grounding the high side of the transformer. The latter event led to a rather "normal" load rejection and scram while the former was complicated by a partial failure to transfer to offsite power, several ESF actuations, and a coincidental, but potentially serious, backleakage from the reactor into the high pressure core spray lines.

The Braidwood incident was caused by the failure of an off-site potential transformer and affected both units on the site. General Design Criterion 17 (10 CFR 50, Appendix A) calls for "two physically independent circuits ... 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." A common point is vulnerable to a failure that could cause simultaneous loss of more than one circuit.

Loss of offsite power is identified as the main contributor to risk of station blackout. The staff states in NUREG 1109, "Regulatory Backfit Analysis for the Resolution of Unresolved Safety Issue A-44, Station Blackout," that "the estimated frequency of core damage from station blackout events is directly proportional to the frequency of the initiating event." Table 2, compiled from all LERs and 10 CFR 50.72 reports made in 1989, lists the events in the first 6 months of 1989 that have met parts of the blackout criteria (turbine trip or off-line, loss of offsite power to 1E and non-1E busses, and unavailability of onsite emergency AC power).

Of the 24 events in Table 2, only one involved a 1E bus blackout (a total loss of AC power) - a short duration event caused by a loss of offsite power to the bus with its EDG unavailable. Twenty events involved the loss of one or more 1E busses and 14 events involved the loss of one or more non-1E busses. The duration of the events ranged from momentary to 21 hours. Four plants reported more than one event. Three events involved both plants on the site. The 24 events involved 19 plants at 15 sites. The causes of the events are nearly equally divided between human error and electrical failure with weather being a minor contributor.

Six of the total events reviewed involved either total or partial interruptions of offsite power to the station auxiliary power system because of problems with the "fast bus transfer" scheme, Palo Verde 1 - 07/06/88; River Bend - 08/25/88; Palo Verde 3 - 03/03/89; Dresden 3 - 03/25/89; Nine Mile Point 2 - 04/13/89; and South Texas 2 - 07/13/89. In all cases, the EDGs provided power to the plants' safety busses.

The fast bus transfer scheme is designed to permit the station's auxiliary electric loads (both 1E and non-1E) to be continued to be supplied from offsite power sources, the preferred source per GDC 17, following a generator/turbine trip with reactor scram. This is done by quickly transferring power to the various auxiliary busses from the UAT (connected to the generator) to the reserve or startup transformer (connected directly to the switchyard). The transfer is quick enough so that the associated busses and loads see virtually uninterrupted power supply. Improving the reliable operation of this scheme would, per GDC 17, "minimize to the extent practical, the likelihood of simultaneous failure" of electrical power from the transmission network to the onsite distribution system.

The results of the loss of power to the 1E busses have, in all but one case, been the immediate transfer to EDGs. The loss of non-1E busses have resulted in the loss of condenser circulating water pumps, consequent loss of condenser vacuum, and unavailability of the condenser as heat sink; the loss of one or more RCPs, subsequent reactor scram, and loss of forced circulation; and the loss of cooling water to air compressors and subsequent loss of service and instrument air.

FINDINGS

1. The enumerated events show that failures in electrical supply or power generation equipment impact safety equipment in that they often cause scrams or necessitate unit shutdown in operating plants, they cause ESF systems to operate, they frequently cause interruptions in offsite power, they occasionally cause fires, and they complicate post-scram transients by rendering needed equipment unavailable or unreliable.

<u>Table 3.</u> <u>Summary of Findings</u>

	Total	IOPS	Fire	Comp.
Detailed Events	22	13	6	18
Other Reports	57	20	1	31
Total	79	33	7	49

The comparison of the number of interruptions of offsite power in 1989 in Appendix 1 (4) which was compiled by a variety of automated searches to the number in Table 2 (24) which was compiled from reading expanded titles of each LER shows that the scope of the problem to be even greater than Appendix 1 would suggest. Expanding that idea, it may be said that for each failure in electrical supply systems and power generator equipment found by computer searches, there may be several others not found.

2. Interruptions of offsite power to 1E busses generally cause transfer of the busses to EDGs while interruptions of offsite power to non-1E busses cause scrams, loss of forced circulation, loss of heat sink, and loss of service and instrument air. From Table 2, it can be seen that several plants have multiple events and several events involve multiple units.

3. Seven fires occurred which damaged equipment and caused complicated transients and involved exposure of personnel to fire and smoke.

4. After a scram initiated by and coupled with electrical power problems, there may be a failure of the fast bus transfer scheme and a resultant complication of the post-scram transient in which the skill and training of personnel; the accuracy and completeness of procedures; and the design, construction, operation, and maintenance of many systems and components in the plant can be challenged. As with every scram, additional duty cycles on the RCS pressure boundary due to the cool down and reheat also occur.

5. a. Several ESF actuations occurred as a consequence of the initiator, the normal actuations (expected to occur as a result of the transient caused by the initiator) were - EDG autostart and load, PCIS actuations, HPCI and RCIC injection, and AFW initiation.

b. The abnormal actuations (not an expected response to the initiator, occurred as a result of equipment failure caused by the initiator in the ensuing transient) were - EDGs manually started and loaded, emergency control room ventilation actuated, nitrogen backup for instrument air actuated, all area radiation monitors alarmed, standby service water actuated, standby gas treatment system actuated, annulus mixing system actuated, HPCS and RCIC actuated, and AFW autostart.

c. Coincidental equipment failures (occurring in the transient but not caused by the initiator) include atmospheric steam dump malfunctions, valve position indicator malfunction, flashing in the letdown line, pressurizer level transient, malfunctioning letdown isolation valve, operator errors, failure to remotely operate of various devices, backleakage of RCS into HPCS, and other instrument malfunctions.

CONCLUSIONS

Failures in electrical supply or power generation equipment impact safety equipment. They often cause scrams or require unit shutdown, they may cause engineered safety features systems to operate, they frequently cause interruptions of offsite power supply to station auxiliaries, they occasionally cause fires, and they complicate post-scram operations by rendering equipment unavailable or unreliable.

Interruptions of offsite power to 1E busses, while they are potential contributors to the risk of a station blackout, generally cause transfer of the busses to EDGs while interruptions of offsite power to non-1E busses cause major plant transients and complicate scrams. Of the 24 events involving interruptions of offsite power supply, six were total losses of offsite power as considered in the blackout rule, but the remaining events are equally important. Interruptions which are not recoverable from the offsite power source due to either equipment or system failures lead to the same consequences as a station blackout due to a total loss of offsite power. Therefore, improvement in the operation and reliability of equipment such as EDGs, transformers, busses, switchgear, fast bus transfer scheme, etc. are necessary. Furthermore, improvement of the reliability of the non-1E power supply and equipment has the potential of lessening the impact of problems with electrical supply on the safety systems by decreasing the number of scrams, ESF actuations, and complicated post-scram transients.

Recent examples of failure in the fast bus transfer scheme point to the need to find the root cause of the failure and to make effective corrective actions so that the simultaneous failure of offsite power sources is truly minimized. Failure of the fast bus transfer scheme is being addressed in an on-going AEOD study.

Fires are easier to prevent through surveillance and maintenance than to fight. Fires occur when an electrical fault ignites a fuel source. Personnel and equipment are at risk in fires. Preventive maintenance and good housekeeping practices can minimize both ignition sources and fuel for fires.

The bus bar failures at Palo Verde 1 and Kewaunee were addressed in AEOD/E905, "Electrical Bus Bar Failures" and an NRC information notice, IN 89-064. Transformer failures which have occurred are being investigated in an on-going AEOD study.

The electrical maintenance, surveillance, and procedural problems identified in this report should be utilized in the development of the instructions to be used in the upcoming electrical team inspections being formulated by NRR.

APPENDIX 1

OTHER REPORTS

INITIATOR	DKT	LER NO.	DATE	SCRAM	IOPS	FIRE	#ESF	COMP
LOSS OF EXCITATION	029	88/008	880517	A	P	N	Y	Y
LOAD REJECT	155	88/002	880307	M	Y	N	Y	Y
GROUND FAULT ON BUS	219	88/022	881002	(SD)	N	N	Y	Y
LOW VOLTAGE	220	88/015	880725	A	N	N	N	N
BUS DEENERGIZED	237	88/021	881113	(SD)	P	N	Y	N
IOPS	245	89/012	890429	(SD)	P	N	N	N
BUS DEENERGIZED	259	88/045	881129	(SD)	P	N	Y	N
GENERATOR GROUND	265	88/001	880127	A	N	N	Y	Y
TURBINE VIBRATION	271	88/008	880719	A	N	N	Y	N
ANTI-MOTORING RELAY	275	88/026	880930	A	N	N	N	N
BREAKER FAILURE	280	89/005	890303	(SD)	P	N	Y	Y
LOSS OF EXCITATION	287	89/002	890306	A	N	N	N	Y
LOSS OF EXCITATION	295	88/011	880606	A	N	N	N	N
DEGRADED BUS	295	88/015	880813	(SD)	Y	N	N	N
BREAKER FAILURE	296	88/005	881108	(SD)	Y	N	Y	N
ARC IN ISOPHASE BUS	298	88/019	880715	M	N	N	Y	N
TRANSFORMER FAILURE	301	89/002	890329	A	P	N	Y	Y
GRID PERTURBATIONS	309	89/003	890505	A	N	N	N	N
FAULTED MAIN XFMR	309	88/006	880819	A	Y	N	Y	Y
PHASE VOLT IMBALANCE	312	88/015	881014	A	N	N	Y	Y
GENERATOR GND	321	88/003	880226	A	N	N	N	Y
LINE FAULT	322	88/016	881011	(SD)	N	N	Y	N
LOAD REJECTION	323	89/005	890416	A	N	N	N	Y
LIGHTNING STRIKE	328	88/034	880815	N	D	Y	Y	Y
TURBINE VIBRATION	331	88/008	880724	A	N	N	N	N
IOPS	333	88/011	881031	(SD)	Y	N	Y	Y
IOPS	336	88/005	880304	(SD)	Y	N	Y	Y
LOSS OF VACUUM	338	88/002	880203	M	N	N	Y	Y
DUAL UNIT IOPS	338	89/010	890416	(SD)	Y	N	Y	Y
GROUND FAULT ON XFMR	341	88/019	880606	M	P	N	Y	Y
TURBINE VIBRATION	341	88/030	880912	A	N	N	N	Y
XFMR FAULT	358	88/021	880906	A	N	N	Y	N
LOSS OF EXCITATION	369	88/001	880107	A	N	N	Y	Y
LOAD REJECT	387	88/006	880304	A	N	N	N	N
GROUND FAULT, LINE	387	88/010	880618	A	N	N	N	N
LOAD REJECT	410	88/012	880305	A	N	N	Y	Y
MAIN XFMR FAULT	416	88/002	880110	A	N	N	N	Y
GEN FIELD GND	424	88/006	880215	A	N	N	Y	N
HIGH STATOR COOLING	424	88/008	880407	A	N	N	Y	Y
OVEREXCITATION	424	88/022	880808	A	N	N	Y	N
FAULT ON DISCONNECT	424	88/024	880730	A	N	N	N	N
LOSS OF STATOR COOLING	425	89/018	890422	N	N	N	N	Y
TURBINE TRIP	440	88/026	880623	A	N	N	N	N
IOPS	443	88/004	880810	(SD)	Y	N	Y	N
GRID INSTABILITY	454	88/005	880804	A	N	N	Y	Y

APPENDIX 1 (CONT.)

OTHER REPORTS

INITIATOR	DKT	LER NO.	DATE	SCRAM	IOPS	FIRE	#ESF	COMP
BUS DEENERGIZED	455	88/008	880714	A	N	N	Y	Y
GENERATOR LOCKOUT	457	88/012	880620	A	N	N	Y	N
LOSS STATOR COOL	458	88/003	880128	A	N	N	N	Y
XFMR FAULT	458	88/005	880314	N	P	N	Y	N
PARTIAL IOPS	498	88/026	880330	A	P	N	Y	Y
STATOR COOLING LOW	498	88/049	880826	A	N	N	Y	Y
IOPS	499	89/005	890320	N	P	N	Y	N
GEN PROT CIRCUIT ACT	499	89/014	890418	(SD)	N	N	N	N
IOPS	528	88/003	880216	(SD)	Y	N	Y	Y
LOAD REJECT	528	88/011	880419	A	N	N	N	Y
LOW STATOR COOLING	528	88/021	880821	A	N	N	N	Y
IOPS	530	88/004	880505	N	Y	N	Y	N

KEY:
SCRAM - A AUTOMATIC
M MANUAL
(SD) SHUTDOWN

IOPS - P PARTIAL
T TOTAL
D DUAL UNIT