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Potentially Damaging Failure Modes of High- and Medium-Voltage Electrical Equipment

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Prepared for
U.S. Nuclear Regulatory
Commission

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FOREWORD

The Nuclear Safety Information Center (NSIC), which was established in March 1963 at Oak Ridge National Laboratory and is a project within the Nuclear Operations Analysis Center, is sponsored by the U.S. Nuclear Regulatory Commission's Office for Analysis and Evaluation of Operational Data. Support for the technical progress review *Nuclear Safety* is provided by both the Breeder Reactor and Light-Water Reactor Safety Programs of the Department of Energy. NSIC is a focal point for the collection, storage, evaluation, and dissemination of operational safety information to aid those concerned with the analysis, design, and operation of nuclear facilities. The Center prepares reports and bibliographies and has developed a system of keywords to index the information it catalogs. The title, author, installation, abstract, and keywords for each document reviewed are recorded at the central computing facility in Oak Ridge.

Computer programs have been developed that enable NSIC to (1) prepare monthly reports with indexed summaries of Licensee Event Reports, (2) make retrospective searches of the stored references, and (3) produce topical indexed bibliographies. In addition, the Center Staff is available for consultation, and the document literature at NSIC offices is available for examination. All of the above services are available free of charge to U.S. Government organizations as well as their direct contractors. NSIC reports (i.e., those with ORNL/NSIC and ORNL/NUREG/NSIC numbers) may be purchased from the National Technical Information Service. Persons interested in any of the services offered by NSIC should address inquiries to:

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EXECUTIVE SUMMARY

The major electrical equipment used in nuclear power generation (see Fig. 1 in Chap. 2) is basically the same as that used in coal-, gas-, and oil-burning plants; however, the nuclear plant's electrical equipment is often purchased under specifications that include seismic effects and tighter quality control than the fossil plants, even though the functional engineering design is the same. Therefore, the literature dealing with both nuclear and nonnuclear thermal power plants was considered in a study of all the possible disruptive failure modes of electrical equipment in nuclear power plant installations. The only restriction was that the study was limited to power equipment of 4100 V ac or higher, which eliminated instrumentation and control circuitry unless they were directly involved in the events.

The three most likely methods of electrical failure in power circuitry and equipment that will contribute to additional or continuing damage are fire, explosion, and excessive electrical stress. Much has been done to eliminate these elements by close attention to design, procurement, installation, and operating conditions, and by application of standards from the National Fire Protection Association, the Institute of Electrical and Electronic Engineers, and the American National Standards Institute. The application of these standards for nuclear power plant design is illustrated in the Nuclear Regulatory Commission (NRC) Standard Safety Analysis Report GAISSAR.[1]

This report considered the electrical faults of transformers, switchgear (circuit breakers), lightning (surge) arrestors, high-voltage cabling and buswork, control boards, and other electrical equipment which, through failure, can be the initiating event that may expand the original fault to nearby or associated equipment. Data on each generic type of equipment were analyzed to determine:

1. failure experience,
2. impact on surrounding and associated equipment,
3. other consequences of failure,
4. preventive measures, and
5. cost-benefit comments.

Transformers, inherently one of the most expensive (and long delivery) items, also contain large quantities of insulating fluids (oil), some of which contain carcinogenic polychlorinated biphenyl (PCB). Thus, a transformer failure may affect the environment as well as interrupt the electrical circuitry.

The larger switchgear units can fail not only obviously but also by acting spuriously or by simply not functioning at all (either opened or closed) upon command. Because the circuit breaker is originally intended to initiate or to clear a circuit, any functional error can endanger the connected equipment and its intended operation. The failure of lightning arrestors almost always involves other units of equipment because lightning arrestors specifically function to shunt induced surge currents and to limit voltage spikes. Many failures of connected equipment can be traced to complete or partial failure of lightning arrestors.

Power cabling and connectors have improved greatly in recent decades, but both are still subject to heat and mechanical damage and have definite expected lifetimes. The failure of a cable, cleared by its protective circuit, usually does not involve more than the individual cable and its connected circuits; but if the failed cable does involve other cables by its heating or mechanical interaction, the consequences may be extended to additional areas.

The 4100-V or higher control board failures almost always involve the cables, buswork, or circuit breakers that are installed in them, except when some external condition, such as sprinkler activation or mechanical damage, is the initiating event.

Of the electrical failures reviewed, examples of illustrations of each equipment failure are examined and referenced. In this study, it was found that man-machine interface often contributes to, rather than mitigates, the cascading effect of electrical equipment failures. Therefore, two of the report's recommendations concerning the exchange of information are (1) the formation of periodic conference-workshops and (2) the establishment of a data exchange information network. Also, NRC should continue to sponsor research and development activities in the areas of insulation combustibility and aging characteristics and thus use in ultra-high-voltage equipment, as well as to contribute expertise to the various standard and code writing organizations.

Reference

1. Gilbert Commonwealth Companies, *GAISSAR, Vol. 4 — Standard Safety Analysis Report*, Docket STN 50-595 (July 31, 1978).

POTENTIALLY DAMAGING FAILURE MODES OF HIGH- AND MEDIUM-VOLTAGE ELECTRICAL EQUIPMENT

Harry C. Hoy

ABSTRACT

The electrical equipment failures of both nuclear and nonnuclear public utilities were reviewed. Those failures that could pose an additional problem to surrounding and connected equipment were defined. The literature was searched; utilities, repair shops, and large electrical equipment users were contacted for failure information. The data were reviewed in detail, and failure modes were determined. Sample cascade failures are discussed. The failure rate of electrical equipment in utilities is historically quite low. Nuclear plants record too few failures to be statistically valid, but failures that have been recorded show that good design usually restricts the failure to a single piece of equipment.*

1. INTRODUCTION

The purpose of this study is to search out failures in nuclear and conventional power plants to determine if the failure modes of such equipment pose an unrecognized threat to surrounding equipment typical of existing nuclear plant designs, and with this information to both (1) evaluate the adequacy of design, installation, and operation of such equipment as is typically installed in nuclear power stations, and (2) recommend possible design, procedural, or operational improvements. As defined in the Nuclear Regulatory Commission (NRC) statement of work, the specific objectives of this study are to

1. obtain data on physically damaging or disrupting failures of high- and medium-voltage electrical equipment in nuclear and conventional power plants, electrical distribution systems, and other applications;
2. evaluate the adequacy of design, installation, and operation of such equipment as typically installed in nuclear power stations in light of real and potential failure modes, including fire and in-plant environmental hazards associated with insulating oils;
3. recommend possible design, procedural, or operational improvements that would mitigate or limit the consequences of failures that could affect or endanger the safe operation of nuclear power stations.

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*An exception to this, of course, was the December 5, 1982, North Anna Unit 1 failure where the initial fault in one of the main transformers resulted in damage to the generator, the generator bus, and associated equipment.

Nuclear power plants not only produce electric power for the utility grid but also use a great deal of power within the plant. Therefore, any electrical equipment failures, even nonsafety-related items, are of major concern. It is extremely important to understand the failure possibility and to apply this knowledge to eliminate or mitigate the consequences on other nearby equipment or localized environmental conditions. This study was limited to (1) 4100-V ac and above electrical power equipment such as transformers, circuit breakers (switchgear), lightning arrestors, cables, bus and connectors, and control boards, and (2) other associated power generation equipment such as potential and current transformers, grounding transformers and surge-limiting reactors, and the necessary auxiliaries for this equipment. Toward this end, the literature over the last 5 years was extensively searched, but the limited failure experience in this period of time has led to the inclusion of some older data.

So that the information studied would be as complete as possible, the literature of the public utilities, both nuclear and nonnuclear, was reviewed; thermal power plant operators and users of similar large electrical equipment were contacted to determine their reliability and/or failure experience. Where possible, the documented information on equipment failure experiences was obtained. The applicable standards and code documents, such as National Fire Protection Association (NFPA), American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), Institute of Electrical and Electronic Engineers (IEEE), Nuclear Regulatory Guides (NUREG), and where available, state and local building requirements, were studied to determine their impact on the design, installation, and operation of electrical equipment.

The files of the Nuclear Safety Information Center (NSIC), a part of the Nuclear Operations Analysis Center (NOAC), include listings of all Licensee Event Reports (LERs). These LERs were searched by computer using search strategy developed by the staff of NOAC.

The search was extended to use the same basic strategy as the Department of Energy (DOE) Technical Information Center (TIC) Energy Data Base. Other computerized data bases on RECON were checked to obtain listings of electrical equipment failures, not only in the nuclear power generation industry, but in the overall electrical power utilities.

A series of contacts was made with the major domestic equipment manufacturers, such as General Electric Company and Westinghouse Electric Corporation, and with IEEE, NEMA, ANSI, NFPA, the Edison Electric Institute (EEI), the Electric Power Research Institute (EPRI), the NUREG and DOE standards, guides and reports, and the National Electric Reliability Council.

To further define the electrical equipment uses and experiences, the Tennessee Valley Authority's (TVA's) Design and Operations Divisions were contacted. Design, testing, and operational experience were reviewed. Documents made available included TVA engineering publications and some specific failure reports (Appendix D).

Eight of the power generation facilities were visited. The stations selected were chosen not only for their availability but also to represent plants still under construction for observing installation details. Operating thermal plants (both nuclear and fossil) were selected to give as much depth and variety of failure and maintenance records as possible.

The plants chosen were hydroelectric, fossil, and nuclear. The hydroelectric plants were older, representing state-of-the-art equipment and to some extent operating techniques of the public utilities in the 1930s. The two fossil plants span the years from 1940 to the late 1970s and demonstrate the increase in equipment size and capability and also increased automation, not only in accessory equipment but in central and operational ability. Reflected also are the increased environmental and ecological impact abatement considerations.

Of the other nuclear power plants selected, Palo Verde was chosen because there is a generation facility just coming on line, one under construction, and one just starting construction. Diablo Canyon, on the other hand, represents perhaps the latest implemented engineering and design concepts as installed and undergoing final review for licensing. As such, it should embody all of the latest regulatory and/or engineering considerations.

Early in this study, definition of the electrical equipment failure modes that can have a cascading effect was necessary. These failure modes fall into two general classifications: (1) those where the subsequent events occur directly and within essentially the same time frame as the initiating event and (2) those where subsequent events, often subtle in connection, occur in a delayed time frame because of the initial event's excessive stress. These events most often appear as early failures of exposed or connected equipment. Each classification has a further characterization because of the rapid development of events, and all preventive measures must be decided on and be in place before the initiating event takes place. In the second classification, there is usually time, however short, to eliminate or at least mitigate further damages. Each of the two classifications can also be further categorized by the specifics of fire and its effects, explosions, missiles, physical involvement, and by long-term effects such as environmental impacts from toxic and ecological releases.

All information and data obtained were considered in the context of a basic nuclear power plant schematic. While specific installations and equipment may vary somewhat, the same basic components will usually be found in facilities of similar eras.

Examples of events

An illustration of the first event classification would be one where the electrical circuit breaker's catastrophic failure involved adjacent equipment.[1]

An illustration of the second event classification would be the failure of a main-power transformer where the fault is a flashover from the high-voltage (HV) to the low-voltage winding.[2,3] Here the transformer may well be the only obvious item that failed, but all the equipment connected on the low-voltage side had its insulation overstressed and can reasonably be expected to develop early problems.

Of course, there are combinations of these two broad classifications, such as a fire involving an HV cable that has a polyvinyl chloride (PVC) insulation. Upon burning, this insulation gives off vapors[4] that will corrode bare metallic surfaces such as contacts, springs, and mounting fixtures. The total effect may not be immediate and allows some time for preventive measures, but if the response is not quickly undertaken, the damage caused will require replacement of affected items.

When one keeps in mind that all utilities wish to have the minimum unscheduled outages that usually are associated with equipment failures, it is understandable that there are few cascading types of events documented.

2. SYSTEM DESCRIPTION

The electrical components studied were part of the generic nuclear plant electrical schematic (Fig. 1). This system is the source of power for plant auxiliaries during startup, normal operation, and shutdown. It is also the source of power for Class 1E electric loads,* which include the reactor protection system and the engineered safety feature loads under normal and emergency loads. The switchyard is the station's connection with the utilities grid for startup power and distribution of the plant's generated power. When the station is on line and supplying power to the transmission network, the internal loads are supplied directly from the generator unit through auxiliary transformers. Station loads are supplied during startup or shutdown through startup and service transformers that receive power from the transmission network.

Power is distributed from the transformers through HV breakers, HV cable, and buswork. Protective relay systems are designed and installed to monitor the electrical generation, distribution, and transmission systems; if they incorrectly sense conditions or initiate spurious control functions, they can escalate system problems. The protective relay system is responsible for the starting of emergency systems, including the onsite diesel generators. Physical separation and electrical independence are designed into the redundant load groups for safety and reliability.

The equipment considered in this report is 4100 V ac or higher, and its directly associated auxiliaries are shown by the unshaded portion of Fig. 1. The energy available and the rapidity with which it is discharged are always of concern and must be as much a part of the engineering and design factors as any other consideration.

The circuit breakers (switchgear), transformers, and lightning arrestors are typically in rather massive metallic containers filled with electrical insulating fluid. The HV electrical connections are made through large corrugated ceramic oil-filled bushings. These electrical power components are normally located in segregated areas with dedicated fire and environment controls. Indoor areas have the building service transformers and distribution switchgear. Outdoors in the utilities' transmission switchyards is the larger main power network equipment. The equipment locations are determined by engineering and connection requirements: the unwanted physical interactions (e.g., fire and explosion) are limited by separating walls and/or barricades or spatial distribution.

The cable and HV buswork have their own isolation maintained as much as possible by conduit and separated cable trays. In spite of the cables' passive operation, some of the major problems in nuclear power plant operational failures have occurred in the interconnecting cables.[6] Much has been done in equipment ratings, design, and installation techniques; but the often congested cable-spreading rooms will remain a potential problem area for at least the lifetime of present generation power plants.[7]

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*Class 1E is given to equipment and systems that are essential to reactor shutdown, containment isolation, core cooling, and heat removal. The equipment satisfies the criteria set forth in Ref. 5.

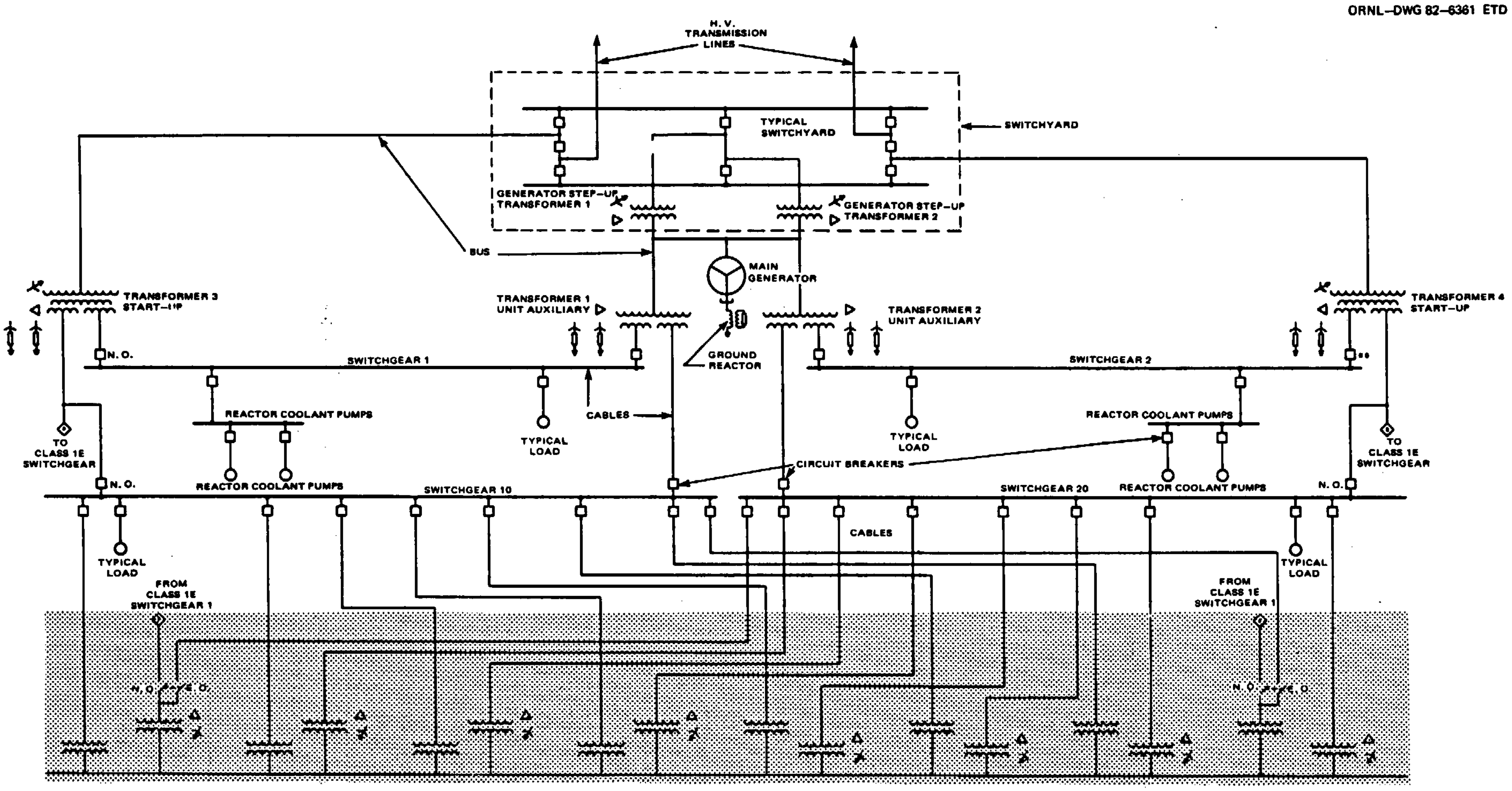

Fig. 1. Schematic of a nuclear power plant generic medium- and high-voltage electrical circuitry.

3. DATA COLLECTION

The limited number of documented electrical failures of any consequence, even end-of-life failures, mandated that data collection for this report include not only searches of the published data files but that contacts with engineering and operations personnel in electrical utilities be used to augment the historic information. Final Safety Analysis Reports (FSARs) of nuclear plants were studied to (1) determine the potential equipment faults to search for and (2) assess the impact of standards, guides, and codes.

3.1 Literature Searches

The computerized data bank of NSIC, which has the NRC-required LERs and reported failures, was searched using strategy developed by the NSIC staff. The files were searched for failures, LERs, and any reports that were listed as containing information on electrical equipment failures. The results were set up in a temporary file that was then used as a source file against which specific units of equipment were checked. The results of these checks were further cataloged as to year and reactor. Of the 49,000 documents identified in the original search, the numbers rapidly reduced to

Transformer failures	196
Circuit breaker failures	307
Lightning arrestor failures	53
Control room/panel failures	525
	1081

These were individually reviewed in an attempt to determine if coupled events or trends could be determined. However, because events as cataloged and indexed by NSIC contain LERs and because reports in different formats contain varying amounts of data, no specific conclusions could be developed. It was then decided to review the general electrical equipment failures in the systems (and not limit the search to LERs), thus yielding 1989 identifiable documents. Again, no failure pattern developed. The very limited electrical power equipment failure data very clearly indicate the low failure probability and great reliability of equipment of nuclear-age manufacture.[8–10]

3.2 Personal Contacts

By phone and visit, the manufacturers (General Electric and Westinghouse), technical societies (IEEE, NEMA, EEI, and EPRI), and geographically nearby public electrical utilities (TVA and North Carolina's Duke Power Company) were contacted and requested to furnish failure information. Little definitive failure description was obtained.

The documentation thus obtained was sparse and variable in quality and completeness. It did, however, provide a basis for determination of the number and types of failures that could or did subsequently involve other equipment. The information was carefully scrutinized to select those events that, because of the very character of the occurrence, were major initiators of a chain of happenings that greatly extended the equipment involvement and the potential for compromising the operational integrity of the plant's safety systems.

The equipment manufacturers, users, and architectural and engineering firms were contacted, from which came vast amounts of information on design and installation criteria but very little definitive information on failures. This is understandable because when equipment is sold and installed, its maintenance and repair is then directly controlled by the user. Often the larger utilities will do their own servicing and repair with only the major overhaul or upgrading being contracted to other parties. Also, many large, cumbersome units such as transformers cannot easily be transported any distance for repair.

The exchange of spare units between facilities of the same utility, as well as the switching of equipment between units on the same site, make it almost impossible to obtain reliable data on equipment failures. The validity of the data is further compounded by the different interpretations of failure. Some operators define failure as any reason for which the equipment is removed from service, even for indicated maintenance; others identify failure only when the unit malfunctions in an obvious way. There is presently an IEEE committee collecting electrical equipment failure data, but as yet it has published no report.

3.3 Applicable Codes and Standards

The NEMA, IEEE, NFPA, and ANSI standards as modified by the NRC regulatory guides and local building requirements all have an impact on the specifications, installation, and operation of electrical equipment. In general, the equipment needed and its applicable codes and standards are shown in Ref. 11 and in NRC regulations, but the detailed specifications must be supplied by the design architect-engineers.

3.4 Plant Visits

As visits to the power plants (Table 1) were limited to roughly 1 d at each site, no in-depth detailed engineering inspections were made. Instead, only those impressions of a conducted tour and brief discussion follow. The obvious things that stand out are the cleanliness of the hydroelectric plants in spite of their approximately four decades of online operation, the inherent dust and noise of the fossil-fuel thermoplants, and the size and complexity of all aspects of the nuclear power stations.

The Diablo Canyon Station, located in one of the most picturesque sites imaginable, seems smaller because the switchyard is somewhat remote and the large air-cooling towers are missing. The memorable features were the unusual seismic considerations in all aspects of design and cleanliness similar to that of hydroelectric plants.

Palo Verde, of those plants visited, gave the most lasting impression of having somewhat different approaches to engineering problems. For instance, the cable-spreading rooms are both above and below the control room. This, plus the inherent large rooms allowed, drastically reduces the congestion and complication of the multitude of cables that must be routed through these areas. Servicing and maintenance problems should be greatly reduced. Any repair that may be required should be easily expedited. Also, in the transmission line connections between the switchyard and main buildings, there were constant tension devices installed to compensate for thermal expansion and contraction strains. Generally, the impression of good engineering plus use of available space prevails.

The TVA sister plants, Watts Bar (which is still under construction) and Sequoyah [which has only recently (1982) gone to full-power operations], offered the opportunity to observe equipment in production and to discuss operation and maintenance with Sequoyah personnel involved and then to compare almost directly with Watts Bar, which is in the final stages of construction. The limitations of equipment access posed by the operations at Sequoyah were not, of course, evident at Watts Bar. TVA arranged contacts with members of their design, operating, and nuclear power divisions. This, with several visits to a variety of their facilities, was most helpful. It was comparatively easy to follow from concept through design, specification, purchase, installation, and operation of the electrical equipment in these plants and to see the equipment and engineering philosophy changes that have occurred over the four decades from the early hydroelectric and fossil units to the present nuclear generation plants. Not only is the present equipment much larger and more sophisticated, but the degree of complexity and automation has greatly increased. The labor-intensive, experienced, skilled, hands-on operation of the older plants has been largely replaced with a programmed automatic response — a response where the operator, though highly trained, must react from an understanding of a display and not from direct association with equipment.

Table 1. Electrical power plants visited

Name	Type	Built	Location
Norris Dam	Hydro	1935	Norris, Tennessee
Watts Bar	Hydro	1943	Watts Bar, Tennessee
Watts Bar Steam	Fossil	1944	Watts Bar, Tennessee
Bull Run Steam	Fossil	1971	Powell, Tennessee
Watts Bar	Nuclear	[a]	Spring City, Tennessee
Bellefonte	Nuclear	[a]	Scottsboro, Alabama
Sequoyah	Nuclear	1980	Chattanooga, Tennessee
Palo Verde	Nuclear	1983	Palo Verde, Arizona
Diablo Canyon	Nuclear	1983	Diablo Canyon, California
Virgil Summer	Nuclear	1982	Jenkinsville, South Carolina

[a] Not in operation as yet.

The Virgil Summer plant was unique in the plants visited in that it was complete and actually producing power (10%) for the grid. It is a single unit with an adjacent pumped-storage hydroelectric peaking plant. Construction activity was much less evident, with access to operating areas more restricted.

Discussions with design, operating, and maintenance personnel indicated that while each utility has its own testing and maintenance schedule, most if not all use Doble equipment and procedures for routine and troubleshooting tests.

3.5 Doble Clients Conference Proceedings

The Doble clients conferences are sponsored each year by the Doble Instrument Company. The proceedings[12] contain papers presented at the conference and the results of surveys made during the previous year. Some of the surveys list failures of electrical power equipment. The papers presented often detail how equipment failed and what preventive measures and/or tests are used to preclude additional failures. This conference is perhaps one of the best information exchanges presently available. It offers a forum where early and unusual problems are discussed and solutions are outlined.

The annual conference proceedings were reviewed from 1976 to date. The information and references provided insight into the equipment failure mechanisms that offer cascading failure potential in power generation and distribution facilities.

4. EVENT DESCRIPTION

Within the time frame studied (from 1977 through June 1982), there were only a few relevant events that were described accurately and completely in the available documents. Of the other events reviewed, many had the very real possibility of being an initiating event (in a series that could result in a major outage or the loss of one safety train); but because of correct personnel response and engineered safeguards, none did.

In many instances, the lack of correct or incomplete human responses clearly played a large part in the final total event, and it is of major concern that some large fraction (20 to 50%)[13] of all failures are attributed directly to involved personnel. A discussion of the impact of fires associated with electrical equipment is included because of the potential consequences of such events.

4.1 North Anna Transformer Failures

The output transformer failures that occurred in 1980 and 1981 are an excellent example of human contribution to the failure sequence. This series of four failures of the main output transformers (920 MW) occurred over the period from November 29, 1980, through July 25, 1981. The failures were characterized by two basic failure mechanisms: (1) the failure of the first and fourth transformers were windings to ground (core) faults and (2) the other transformer failures were HV bushing to ground failures. All failures except one also had high- to low-voltage winding arcing. The transformers were installed in a three-phase circuit with a separate transformer for each phase. In looking at the individual history of the tranformers, it developed that "all transformers had (1) been transhipped several times before being placed in service at North Anna, (2) had been in previous operation where one of the other transformers in the bank had failed prior to their own failure, (3) the transformers high voltage bushings had been handled more than usual, and (4) transformers 1, 2, and 4 had been subjected to several documented over-voltage transients."[14]

Not only were the transformers themselves involved, but the July 3, 1981, incident also had a turbine and reactor trip associated with the event. The incident fire sprayed oil over the transformer case and the side of the turbine building. A voltage transient apparently was great enough to create an erroneous high steam flow signal, which gave a safety injection actuation. The situation was cleared within a few hours. There was no effect on the health and safety of the public.

The detailed description of this event clearly indicates the possibility of a domino cascading series of events that could (but did not) have had far reaching effects. From the associated LERs and the trip report (and, of course, using hindsight), the indications are that had there been better exchange of information between the station and district electricians and the plant engineering and operations personnel and more complete maintenance procedures, the initial and subsequent transformer failures might have been prevented.

The North Anna Unit 1 "C" main transformer failure of November 16, 1982, and especially the "B" main failure of December 6, 1982, illustrate the extent of damage, both mechanical and electrical, that can result from a major transformer fault. In this instance the damage extended to the bus and generator itself and the transformer water diluge system.*[3]

4.2 Y-12 Switchgear Failure

In September 1971, at DOE's Y-12 Plant in Oak Ridge, Tennessee, dual electrical short circuits occurred in 13.8-kV switchgear. These failures involved two similar units connected to the same buswork. Both were explosive in nature and resulted in multiple injuries. The initial fault occurred when the first breaker was disengaged from its feed connection, apparently after the breaker had failed to correctly clear the residual load current. At this time, three people were injured, and oil, fumes, and copper droplets were dispersed in the switchgear cabinet. Sometime later, a larger circuit breaker (bus tie) faulted while being disengaged. Nine employees were injured at this time. Total damage was estimated at \$20,000 (1971 dollars). Electrical outage time was ~2.5 h.

From this report, it can be concluded that the initial violent failure must have been preceded by the breaker's failure to open correctly on signal, and the indicating lights, one of which was burned out, did not indicate correct breaker condition. However, it is almost second nature to one experienced in operation of these breakers to sense the "thump" when the breaker opens or closes and to check for either a closed or open indicating light. One of the two must be on. Apparently, the breaker did not open so that when it was "racked out" the circuit was actually interrupted by the external make-up contacts. These are passive contacts not intended for either making or breaking load, and as a result, there was arcing and an explosive-type electrical fault. To clear the debris, the separating bus-tie circuit breaker was opened. This larger breaker between two major buses had no voltage across it until it was opened, but apparently it had received some damage during the first event, and it too failed when actuated. Had not habit and routine overridden precautions that should have been taken upon lack of indicating light, the initial breaker trouble could have been reduced or eliminated.

4.3 Transformer Fire at ENICO Substation

A transformer fire at the ENICO Substation[14] injured three persons and did an estimated \$166,000 (1982 dollars) damage. The fire and explosion occurred during the phase evaluation testing of two 2400-V feeder transformers with the intent of placing the two feeders in parallel. One of the two transformers had been removed from this service; during the time it was removed, its phase connections had been changed, making it impossible to be reinstalled in its original configuration. (From Beeman, "Industrial Power System Handbook," in the section pertaining to Wye-Delta

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*Notification of unusual occurrence, December 6, 1982, and following status reports.

three-phase transformers, there is an inherent 30° phase shift.[16]) When the power demands on the substation exceeded what could be supplied by the remaining transformer, plans were made to reinstall the second transformer. When attempts were made to match phases for paralleling, diagnostic tests indicated a problem. To obtain additional measurements, a high-voltage connection unit (HVCU) was to be used. The HVCU can be installed in place of a circuit breaker with comparable dimensions and is capable of being "racked in" to make line and load connections in a manner similar to a circuit breaker. During the test, an attempt was made to obtain identical meters, but when none were found, it was decided to install multimegohm resistors between respective phases. Voltage readings could then be taken across the resistors. The devices selected looked like resistors but actually had the electrical characteristic of a surge suppressor (i.e., the limiting or clamping of a dc voltage) and the further characteristic of exponential current conduction with linear increase of applied voltage. When the HVCU was racked in place, these devices quickly overheated and exploded. The explosion destroyed the devices, the HVCU, and the distribution equipment in the immediate vicinity. Power to the HV loop was interrupted for some 27 h. Incomplete engineering, lack of specific responsibilities and authority, incorrect equipment and material use, and failure to obtain HV safety permits were all human contributions to the event.

4.4 Brighton Area Breaker Failure

The Brighton incident[17] points out the possibilities of expanding the original event into one of major consequences. The Brighton incident started with a cable fault that was not interrupted by its 14-kV circuit breaker. The arcing across the circuit breaker resulted in a bus fault. The associated relaying not only cleared the bus fault but also opened the circuit breakers to protect a transformer that supplied two bus sections. The resulting surge caused an insulator failure that created another bus fault. The second circuit breaker exploded in attempting to interrupt power beyond its capacity. The total time involved was <17 s. During this time, some 8 in. of the power cable conductors and 33 in. of the lead sheath had been vaporized. The partition wall between two bus sections was severely damaged, as were two circuit breakers.

The series of events illustrates quite well the closely interconnected features of any electrical power system and the dependent interactions that can and do take place. In this instance, cables, circuit breakers, insulators, interconnecting bus, and relaying and control boards each played its part in the event. Except for incorrect relay settings, these events reflect equipment failures. In the case of the relay settings, it is difficult to calibrate protective relays for rapid fault interruption and at the same time to allow the proper level of operational variations that will occur so the circuit will not be unnecessarily interrupted. Good design coupled with regular complete maintenance and testing are required for greatest reliability. It is important that any change in load be reflected in the sensing level of the overload relaying, which monitors the total load of the circuit (i.e., a partial decrease in load can be replaced by a fault of equal size without the monitor reacting).

4.5 Fires

Fires associated with electrical power equipment have an impact, not only on the directly involved equipment, but also on other nearby facilities because of smoke, toxic fumes, and heat. The heat is of immediate concern (as are the smoke and fumes), but the smoke and fumes may also have long-term consequences on contacts and circuit loads and may coat insulators, causing chemical changes in plastic insulations. Fires and the associated heat soften plastic insulation, fracture ceramic insulators, and may, if there are containment tank ruptures, spread burning insulating oil [often containing polychlorinated biphenyl (PCB)] over floors and into drain systems. The most destructive fires experienced by nuclear power plants involved the vast amount of cabling installed in the plant, for example, the Browns Ferry cable fire. This fire and others in recent history have caused improved design and installation requirements as well as some improvement in the fire characteristics. Recent tests by Sandia[18–20] have been concerned with the consequences of cable fires and the resulting smoke and fumes.

Not all plants have automatic fire-suppression systems; some depend on alarm followed by manual response. In these situations the availability of portable extinguishment equipment and correct evaluation of the situation is extremely important. Training of response personnel and permanent descriptions of equipment and procedures (locally displayed) should be a part of each plant's procedures, especially those depending on manual suppression of fire.

4.6 General Considerations

Although not a failure mode of electrical equipment, the rapid and correct response of emergency and maintenance personnel is a concern. Therefore, it seems extremely prudent to use color-coded and distinctive tags to indicate safety-related equipment, service equipment, and auxiliary equipment. Most plants do this, but there does not seem to be a standard for either color or voltage-level designation.

5. EQUIPMENT FAILURE ANALYSIS

Experience has shown that most electrical equipment failures are randomly distributed in both time and type of equipment. The documentation on these failures is frequently inaccessible and/or incomplete. Most utilities and major industries publicly document only those events that are required by regulation. However, some idea of the number and type of occurrences can be obtained from the *Doble Clients Annual Conference Proceedings*.[12] These proceedings often detail how equipment failed and what preventive measures and/or tests can be used to preclude additional failures.

Descriptions of failures of electrical equipment can be obtained not only from the *Doble Clients Annual Conference Proceedings* but from utility and manufacturers' repair facilities, as well as from companies that specialize in rewind and repair of electrical equipment. Such facilities as TVA's and General Electric's Chattanooga repair facilities were contacted. However, while they can show the damage and can detail what is needed to refurbish the component, little or no information can be obtained on how or why the event was initiated or what other equipment was involved. The damage to the equipment itself does graphically illustrate that the amount of available energy can and does cause physical damage capable of contributing to associated components. The associated toxic fumes and splattering of ejected molten materials, including copper, on nearby insulation and control equipment may well extend the damage potential. Unfortunately, this extention of damage is not often documented, nor is information available in the repair orders.

5.1 Transformers

Of the 96 transformer failures reviewed and identified in the NSIC data base (category 17), none resulted in a major explosion or created any type of missile that was ejected or caused further damage. Several, however, contaminated the surrounding area with fumes and insulating fluid (oil), some of which contained PCB. The PCB, which is carcinogenic, is not biodegradable and therefore creates a problem in containment, cleanup, and disposal.

A more insidious fault occurs when the high-voltage winding flashes over to the low-voltage winding. This event, even though often of short duration, subjects everything electrically connected to the low-voltage terminals to the potential of the incoming line high voltage. This stresses, usually by at least a factor of 20 (and sometimes much higher), the insulation, microchips, cabling, and connectors to the point where decreased service life, if not immediate failure, can be expected. While surges can be generated by switching and rapid load changes, a great number are associated directly with transformer failures, so much so that NRC emphasizes the problems by stating:

> . . . There is evidence to support concern that common failure modes can exist in the nuclear plant safety systems whereby surges of a transient nature could render redundant components

> inoperable. . . . Such high voltage occurring even for short durations could destroy sensitive equipment in onsite distribution buses and render onsite power supplies inoperable. . . . The increasing common use of highly sensitive solid state logic systems . . . accentuates the need for closer scrutiny in the method used for protecting such systems from transient overvoltage.[3]

5.1.1 Failure experience

Two reports of transformer failure rates for main and/or startup transformers give 2.7×10^{-2} failures per year of operation[8] and 7.8×10^{-2} failures per year.[9] Both of these seem rather high compared with the author's experience, but the definition of failure used includes all reasons for the equipment to be taken out of service, including minor maintenance.

Although failure rates are not indicated, the number and type of failures as listed in the *Doble Clients Annual Conference Proceedings* are quite informative (Table 2). Only scattered details are given on the total damage and cost of replacement or repair, but in the number of failures listed there is good evidence to support the need for onsite replacement (spare) equipment. A well-designed and manufactured transformer,

Table 2. High-voltage power transformer failures[a]

Year	Number of failures	Documented faults and failures
1980	220	29 internal faults, 6 bushing failures
1979	218	33 violent internal failures, 2 insulation failures[b]
1978	183	3 ruptured tank failures, 5 insulation failures[b]
1977	246	1 insulation failure[b]
1976	177	83 internal faults, 3 insulation failures[b]
1975	212	2 insulation failures[b]

[a] Adapted from *Doble Clients Annual Conference Proceedings*.[11] Most failures are power transformers of 13.8 kV and above.

[b] Additions from American Nuclear Insurers, private communication with author.

properly protected, should have its operational life limited only by the aging characteristics of its insulation material and/or lack of adequate maintenance.

5.1.2 Impact on surroundings

Because of the adherence to good engineering design practices as indicated in Refs. 21–23, any failure impact on even the immediate surroundings is usually small. Most HV transformers are located in the switchyard, protected by barricades and sprinkler systems and with a curbed crushed stone fluid retention system. The transformers located indoors usually are in their own vault with their own fire protection, containment, and drain systems. Therefore, transformer failures, even those that result in fire and/or insulating fluid spills, have their own direct containment and control that limits the expansion of the event to the immediate area.

5.1.3 Other consequences of failure

In addition to the modes discussed above, the failure of a single-phase transformer (one of three used in a polyphase system) will severely unbalance the system and create circuit-unbalanced loading, requiring the reduction of loading on additional equipment. This load reduction may involve some redundant safety and operating systems that will necessitate the operator's very careful realignment of the loaded circuits.

5.1.4 Preventive measures

Careful on-line monitoring of the characteristics of the major transformers, including the transformer power factor, load vs temperature factors, and any changes that occur in the insulating fluid characteristics (such as viscosity level, dielectric strength value, gas and/or chemical contamination), should be recorded and used as a basis for scheduling preventive maintenance.

High temperatures or temperature changes not associated with loading conditions or ambient temperature require quick attention. The trends indicated by the monitoring and testing often indicate potential problem areas that require additional maintenance.

All power transformers, of course, must be protected from surges caused by lightning strikes, switching, and harmonic circulating currents, as well as the high temperature that could result from exposure to fire or because of reduced cooling.

5.1.5 Cost-benefit comments

With the high initial cost of equipment growing each day, the expense of repair and maintenance, plus the loss of revenue from nonoperating equipment, it is quite clear that failure rates of the major equipment must be minimized. Regular periodic maintenance scheduled in conjunction with other outages (e.g., during reloading) is not only much less costly in equipment and manpower, but allows the system load projections to become part of the calculation.

5.2 Switchgear

Unlike transformers that are a quiescent element, switchgear is an active element that can fail by acting spuriously or by not functioning (either to open or close) upon command. These incorrect functions can create problems in the connected circuits that are quite different from those that result directly from any fire, explosion, or spread of possibly toxic insulating fluids. If a breaker fails to clear upon signal or becomes overloaded for any reason, then the circuit will be subjected to further damage until an upstream breaker (usually larger and set for a higher current rating) can sense and clear the overload. If, on the other hand, a breaker fails to close, this normally means that all circuits that receive power from this feed point cannot perform their expected functions. As in the Brighton area breaker failure[15] (described in Sect. 4.4), the event may well be quite violent and create additional problems such as fire and fumes. Fortunately, most breakers are located in enclosed segregated areas, which provide containment and fire protection capabilities, as well as in their own cabinets, which help limit any physical damage to immediately adjacent equipment.

5.2.1 Failure experience

Although there have been numerous reports of switchgear failures (see Appendix A), few have been violent or have involved other items of equipment. The Brighton, Y-12 Plant, and ENICO events previously described typify the possibilities of switchgear failure where equipment other than the switchgear unit itself becomes involved. These were exceptions; most switchgear failures like the circuit switcher failure in the 345-kV switchyard at Millstone[24] may severely damage or even destroy the switchgear itself but do not physically involve nearby equipment. Any switchgear failures do, however, create problems to and with the connected circuitry and cause unwanted shifting and/or dropping of electrical loads. A listing of circuit breaker failures is presented in Table 3.

5.2.2 Impact on surroundings

Of the documented failures, some 10 to 15% result in the destruction of the switchgear unit itself. Fortunately, however, because of the strict standards and codes[25–30] that deal with location, installation, and protection of electrical switchgear, even violent failures seldom result in direct physical involvement of adjacent equipment. The exceptions previously described did interact with equipment in the same area through fire, fumes, ejected molten material and electromechanical forces. The consequences varied from short power interruption to equipment replacement.

Table 3. Circuit breaker failures[a]

Year	Number of breaker failures	Type of failure
1980	221	22 explosions and/or ruptures (lower voltage vacuum breakers almost always completely destroyed)
1979	89	20 explosions and/or ruptures
1978	62	
1977	61	133 malfunctions
1976	93	
1975	45	99 malfunctions

[a] Adapted from *Doble Clients Annual Conference Proceedings*.[12]

5.2.3 Other consequences of failure

Interruption of any major electrical circuit has the possibility of creating unbalance in the supply circuits which can cause cascading load rejection in addition to the loss of power to the equipment supplied directly by the circuit breaker. Spurious switchgear operation, either opening or closing, can easily be responsible for the creation of unsafe conditions. For instance, an unscheduled opening may disconnect a load vital to some phase of operation, or a breaker closing could subject the system to unneeded load surges.

5.2.4 Preventive measures

Good equipment, brought to nuclear power plant specifications and meeting ANSI, NEMA, IEEE, and NRC regulatory guides, and proper maintenance, which must include periodic testing, are the keys to minimum operational problems. Proper relaying and control devices must also be part of the design and installation.

5.2.5 Cost-benefit comments

NEMA and the specific recommendations by manufacturers on maintenance and service replacement indicate the number of spares required; based on duty cycle and/or time, the testing is prescribed.

5.3 Lightning Arrestors

Lightning arrestors do not have a high duty cycle but must function when called on, or damage to other elements will be excessive. Lightning arrestors for nuclear and other utility power generation facilities make use of three major types of surge arrestors: (1) distribution, (2) intermediate, and (3) station. Most installations in the switchyard and transmission line protection schemes are of the station type. This type is used because of its discharge-current capacity and its near constant voltage-time characteristic. Any consideration of lightning arrestors must be directly coupled to consideration of the associated grounding system.

The purpose of lightning (surge) arrestors and proper grounding is to limit the excessive currents and voltage spikes that occur during lightning or switching-induced surges. Especially vulnerable equipment, such as main and startup transformers, should be protected on both the high- and low-voltage sides, to protect not only the insulation value of the transformer but to keep sensitive electronic monitoring and control equipment in the plant from being subjected to damaging voltages and currents. Very careful engineering design must maintain the matching of protector and protected equipment at all times, and any change in one should be carefully reviewed for the possible corresponding change needed in the other.

The importance of proper selection of the (surge) lightning arrestor and good grounding design cannot be overemphasized. Both arrestor selection and equipment grounding design must be based on an understanding of the rise time, peak value, and time distribution of lightning strikes and the local isoceramic information. Arrestors must be sized not only to protect from overvoltage, but also to be capable of carrying the surge current <u>and</u> responding to the steep wave front. As in the section on transformers, the NRC Regulatory Guide[3] lists the standards and regulations that must be followed.

5.3.1 Failure experience

Lightning arrestors technically fail any time the circuit or equipment they are designed to protect is damaged. Thus, if an arrestor functions correctly on the initial surge but cannot recover fast enough to protect on a rapidly following second spike or if the wave front is too steep for the arrestors adequate response, then the arrestor has failed.

Lightning (surge) arrestor failures are often characterized by physical failure of the ceramic insulator and containment, but because of the physical location of the arrestor as dictated by IEEE, ANSI, and NRC regulations, there is seldom any physical involvement of other equipment. When one does fail (Table 4), there is normally no doubt from the visible damage that the unit is no longer functional. However, in spite of the numbers that are replaced each year, no reliable failure rates are available.

Table 4. Lightning arrestor failures[a]

Year	Number of failures	Type of failure (% violent)
1980	123	95
1979	104	80–85
1978	90	80–85
1977	127	
1976	129	

[a] As reported in *Doble Clients Annual Conference Proceedings*.[12]

5.3.2 Impact on surroundings

The impact on the surroundings from a lightning arrestor failure is normally not as important as the loss of its capability to protect the circuits and elements to which it is connected.

5.3.3 Other consequences of failure

The possibility of additional damage to the lightning arrestor's connected circuitry is a direct function of whether the arrestor failed shorted or open and if there are any subsequent voltage or current surges. Therefore, the service or replacement of an arrestor must be as expeditious as possible.

5.3.4 Preventive measures

With proper installation and periodic maintenance, lightning arrestors can be expected to serve as protective devices for periods of time that will be site specific. Weather conditions, especially snow or ice mist, can be expected to increase exterior current leakage and the resulting tracking, but this should be known from periodic testing before major failure occurs. Care in cleaning, for dust in particular, is also a must.

5.3.5 Cost-benefit comments

The number of spares available and the maintenance schedule depends on the geographic location, the operational characteristics, and the climatic considerations so that the judgments will be site and equipment specific.

5.4 Cables and Connectors

Power cabling, as used in generation stations, is usually limited to <13.8 kV. (Some facilities use cabling of 161 to 230 kV in the switchyards, but because of the large radius turns required by the cables' massive size, such cables are not normally located indoors or used as distribution cables).

Because these cables must be concentrated to some extent near the distribution centers where they often run in a common cable tray, they are vulnerable to cable tray fires. Individual cable faulting, which can be cleared by its series breaker or fuse, typically will not involve more than the affected cable unless that cable by its heating becomes a fire — a fire that may spread to adjacent cables and cable trays. Once a cable tray fire has started, not only does its extinguishment become difficult, but damage potential can spread greatly beyond the limits of the fire. Almost all present-day power cables use polyethylene and PVC insulation, which when heated sufficiently by internal or external means will evolve flammable gas, then char and burn.[17]

Even when protected by coatings and/or located in covered trays, cabling rapidly becomes unusable for electrical circuitry when subjected to fire or extreme heat. There is even some evidence[18] that, depending on the coating and the method of its application, long-lasting deep-seated fire duration is increased by coatings, which will increase the difficulty of quick and complete extinguishment of such a cable tray fire once it is started. For this reason, extra care and attention must be given to prevention and early detection of overheating and possible ignition in any area where cables contribute significantly to the fire loading.

Cables are sometimes used in switchyards (HV) as a means of disconnecting or insulating circuits and are therefore not expected to be physically removed very often. However, when required, their removal becomes somewhat of a problem because of their size and location. The voltage clearance and current-carrying capacity mean long length, and the current rating is reflected in their cross section. Both size and weight make manual handling difficult; during bad weather and emergency conditions it could become almost impossible.

5.4.1 Failure experience

The well-known cable tray fire at TVA's Browns Ferry Plant[19] did not start, of course, as a cable fault, but the fire ultimately involved some 2000 cables in its 7-h period of burning. Cable insulation, coatings, and installations have improved since and largely because of this event. Many failures of the older type of power cables[21] were caused by cable ages of 30 to 40 years, subjecting them to excessive moisture and mechanical strain. Of these factors, only aging should be a consideration in the nuclear power industry. The failures listed in Table 5 are largely of major distribution networks and not in-plant cables as such, but the basic cable size and capacity are similar.

Table 5. High-voltage power cable and connector failures[a]

Year	Number of failures	Type of failure		
		Splice	Pothead	Insulation
1980	1700			
1979	4190	1158	326	2706
1978	5997	2269	563	3165
1977	2922	806	316	1800
1976	5382	936	370	4076

[a] Adapted from *Doble Clients Annual Conference Proceedings*.[12]

5.4.2 Impact on surroundings

Cables, when they do fail, quite often will involve more than the initial cable through fire, mechanical movement under electromagnetic forces, and ejection of molten copper when arcing. In addition, because cables are generally grouped together some place in their run, more than one cable and operational piece of equipment can be involved.

If a fire develops, the toxic fumes from the combustor can coat insulating surfaces and contacts and create unwanted deposits on microprocessors and control equipment.

5.4.3 Other consequences of failure

The mechanical movement of cables under heavy short-circuit currents can create stress on terminals and hangers. The electrical surges can introduce circulating currents in the ground system of sensitive electronic equipment, which will cause spurious signals.

5.4.4 Preventive measures

Careful routing and proper cable restraint can help reduce the stress that may be induced by thermal expansion and contraction of cables having long runs, especially those with vertical sections. Periodic HV testing ("hi-potting") may not reduce the failure rate, but it will allow the repair or replacement of incipient failures during test downtime, not during normal operation.

5.4.5 Cost-benefit comments

Because of the relatively low cost of cables compared with forced outage for replacement, and particularly because a cable failing in operation may cause additional damage, it is important to note any change in operational and testing data and to repair or replace the cable before a major event can occur.

5.5 Control Board

In the available literature, all of the control board failures originated as faults in cable terminations or circuit breaker disruptive failures, or they were caused by some external fault such as fumes from fires, mechanical damage, or water damage from sprinkler activation. It is suspected that the contribution to unwanted outages made by control boards, as such, is small and is the direct result of the initiating events caused by installed electrical or mechanical equipment.

5.5.1 Failure experience

No instances of massive control board failures were found in the literature other than those that originated in circuit breakers. The only major contribution a control board is likely to make would be with a seismic event as the driving force, and all safety-related boards have passed simulated testing.

5.5.2 Impact on surroundings

In the event of a failure induced by a major seismic event, the additional contribution that a control board could make would be small except for the disruption of control and power circuits.

5.5.3 Other consequences of failure

Because the control boards are, in a sense, the nerve centers of the electrical system, their failure could create inability to react to needs; however, the chance of control board failure is extremely remote.

5.5.4. Preventive measures

Use of qualified equipment and good engineering based on IEEE, ANSI, NEMA, and NRC guidelines and regular preventive maintenance will continue to reduce the already low probability of control board failure.

5.5.5 Cost-benefit comments

Good design and accessibility will enable proper maintenance and testing to keep equipment operable.

5.6 Other Equipment

Within the 4.1-kV and upward range, the only other equipment considered was the testing devices. Each power system should have a completely equipped, highly trained crew that can perform the routine testing and maintenance. The crews must have access to power factor meters, phase meters, scopes, HV test probes, acoustical meters, and insulating oil test and filtering equipment. Testing devices must be carefully selected to have adequate intrinsic safety and proper range for the circuit and equipment with which they will be used. Proper maintenance and periodic calibration are required for safety and meaningful results.

6. MAXIMUM POTENTIAL COMPONENT FAILURE MODES

The maximum potential electrical component failure modes that can contribute physically — as opposed to electrically — to subsequent equipment failures are summarized herein based on the insights provided in the preceding chapters of this report. The physical failure modes considered are missile generation, ejected liquid coolant and/or insulation material, fume generation by fire, and mechanical movement. Not considered herein were electromagnetic and directly coupled electrical circuitry effects. The electrical equipment considered includes (1) transformers, (2) circuit breakers and/or switchgear, (3) lightning arrestors, (4) cables and connectors, and (5) control boards.

It has been shown earlier that internal faulting of large electrical equipment can generate energetic missiles,[1,11] spill carcinogenic (PCB) insulating fluid,[14] generate volumes of toxic fumes,[4,15] initiate fire protection systems, and mechanically stress associated equipment. These failure modes, given the right combination of time and location, can become a low-probability high-consequence event that may affect other safety equipment. This is of particular concern if a parallel safety train is compromised. Such consequences are considered in the next chapter. In this chapter each of the major equipment types identified above was considered as having failed in a worst-case manner.

6.1 Transformers

The transformers considered varied from large three-phase main transformers, single-phase main transformers, and startup and auxiliary transformers to distribution and service transformers. Current transformers and potential transformers were also considered but because of their physical location and limited energy capacity were not expected to have any contribution to subsequent events. The large main transformers are generally located in or adjacent to the plant switchyard or just outside the turbine-generator building and are directly connected to the main bus work (see Fig. 1). The startup and unit auxiliary transformers are normally also located outside the building but may on occasion be installed indoors.

6.1.1 Energetic missiles

High internal pressure from intermittant internal arcing, or a flashover, which expends a large quantity of energy in an extremely short time, can rupture the container and launch metallic and/or ceramic missiles. The missiles may be of several pounds and can be thrown for some distance. While documents do not include the specifics, eyewitnesses describe the size as a maximum of 10 lb thrown for some 30 to 40 yards. Smaller missiles may have higher velocity and travel further with a more direct path. (See additional bibliographical references in Appendix C.)

6.1.2 Insulating fluid spills

The same internal pressure as generated from intermittant arcing may mechanically rupture the container so that the insulating fluid (the older variety quite often contains PCB) can spill into the curbed containment space or be projected in a stream or jet for 10 to 20 ft. Usually the fluid is contained within the curbed space and there is no fire so that only a cleanup and disposal problem remains. However, if the fluid catches fire, as could occur if there were arcing, the problem may well escalate in several ways (see Sect. 6.1.4).

6.1.3 Toxic fumes

The burning of insulation and insulating fluids, especially indoors, cannot only create problems in the immediate area but also in other areas because the fumes and combustion products, some of which contain released chlorine, when picked up by the ventilation system may coat insulators and sensitive monitoring and control circuits. Accelerated failure of such affected components may result if they are not properly cleaned. The fumes themselves may make some areas uninhabitable and thus reduce the manual control capability of some areas.[6,15,17–20,31]

6.1.4 Fire protection systems

The fire protection system normally will have a detection system (smoke or heat rise) and a suppression system. The suppression system may be either a direct-acting, a supervisory automatic, or a manual system. The supervisory automatic and direct-acting systems usually have water or carbon dioxide (CO_2) as the suppression material. Halon is quite often manually activated. When sprinkler deluge systems using water are activated, the resultant diluge may overflow the curbed areas and carry the insulating fluid and/or fire into drains and adjacent areas where other equipment can become involved.

6.1.5 Mechanical stress

Rupture of the transformer container may jar the connected or adjacent equipment via interconnected lead whip and by physically inducing a mechanical stress. Either of these may cause ceramic insulation to break or pull cables and connectors apart.

6.2 Circuit Breakers and/or Switchgear

Circuit breakers may fail by not responding to correct signals, but these faults, although potentially damaging, are electrical in nature and were not considered. The maximum potential failure modes of circuit breakers are discussed in Sect. 7.2.

6.2.1 Energetic missiles

Because circuit breakers are designed to control the electrical power flow (open or close circuit) and are expected to dissipate large amounts of energy for short periods of time, they are sturdily constructed and mounted. However, should a fault occur that exceeds design limits of the circuit breakers, the resulting failure (similar to an exposion) may eject pieces of the ceramic insulators, bolts, and/or cover plates from the main body of the circuit breaker. These missiles are most likely contained within the breaker cabinet or vault of indoor breakers. When the electromechanical forces exceed the designed capability of the breakers to the extent that matter is ejected from the breaker, the material is usually insulation, insulation fluid, or molten metallic spray. The damaged area extends only a few feet to the nearest cold surface usually, but there is a possibility that the insulating fluid or molten insulation may leak or drip through cracks or gaps into other areas. The large switchyard and transmission line breakers that may generate larger missiles have wide physical spacing in limited-access areas and seldom initiate other faulting.

6.2.2 Insulating fluid spills

Large-capacity high-speed circuit breakers are going more and more to gas (SF_6) insulation, but many of the currently installed units contain mineral oil or Askeral. Both of these fluids are highly flammable under the right temperature and ignition-source conditions and will burn quite vigorously once ignited. In addition, Askeral (and similar trade names) contains the carcinogen PCB. However, the quantity contained in circuit breakers is measured in tens of gallons (instead of thousands of gallons as in a main transformer) and is subject to heating only briefly during its operating cycle. If a spill does occur, its results and cleanup are usually a minor problem unless the fluids are allowed to flow into systems not designed for their containment. If the drain, for instance, is into a local system that empties into the storm drain, then there may be environmental contamination requiring considerable effort to mitigate.

6.2.3 Toxic Fumes

The fumes that can be generated by circuit breakers in a fire situation are limited by available materials and normally will be contained within their own cubicle or vault, thus not exposing equipment physically separated from them. The fumes that do escape the local circuit breaker containment are very irritating and can be toxic, depending on the source material. Personnel access and ventilation must be carefully controlled in these circumstances.

6.2.4 Fire protection system

The protective systems for circuit breakers may vary from water-sprinkler diluge arrangements in the switchgear room where the largest indoor breakers are located to CO_2 and/or Halon in the load center vaults. The protective system is designed so that its operation does not directly affect the functioning of the breakers, and because of the limited amount of flammable fluid and material available, the possible extension of any fire situation is quite limited. Although the fire may be largely confined, it may disrupt the nearby control and metering circuitry such that incomplete or incorrect information is displayed.

6.2.5 Mechanical stress

As a breaker acts, in particular when it opens the circuit, its containment is designed to withstand the forces involved. Even functioning under excessive loading conditions, which may destroy the circuit breaker itself, does not produce strain or involve physically more than the cabling or buswork directly attached to the unit itself.

6.3 Lightning and/or Surge Arrestors

The lightning and/or surge arrestors reviewed were mainly those of the switchyard itself. These are normally located on the high- and low-voltage sides of the station, auxiliary, and startup transformers. Such arrestors have a long history of reliable performance under their design conditions. Through scheduled service and with careful maintenance, their availability and reliability are quite high. However, if there are multiple surges in rapid succession that do not give the arrestor time to recover or to dissipate the heat built up, the unit may fail.

If the line terminating an arrestor functions as designed, the smaller surge elements located indoors are seldom required to function. Most failures are therefore confined to the units associated with the switchyard and transmission lines.

6.3.1 Energetic missiles

The very function of the lightning arrestor involves the dissipation of large amounts of energy in a short time span. Any failure of the unit is therefore sometimes characterized by the ejections of portions of the ceramic insulator container as missiles. These missiles may weigh up to 10 lb and may be projected some 30–50 ft.

6.3.2 Insulating fluid spills

Lightning arrestors presently being installed in nuclear facilities are solid-state or gas-filled units and do not contain any quantity of toxic or flammable liquids.

6.3.3 Toxic fumes

(See Sect. 6.3.2.)

6.3.4 Fire protection system

(See Sect. 6.3.2.)

6.3.5 Mechanical stress

When it fails, the arrestor may import a mechanical jerk to the transmission line or buswork to which it is connected. It may also conduct enough current that the self-induced magnetic field interaction may physically move the connecting cable or buswork, but it is highly unlikely that either of these effects could contribute to spatially separated parallel circuits.

6.4 Cables and Connectors

The transmission line and switchyard cabling is quite widely spaced by design and has little potential for failure coupling modes between circuits. "Galloping" bore conductors on long transmission line spans can and do cause phase-to-phase flashovers, but this condition is limited to the same circuit. Interior cabling, which is generally insulated, is often placed in close proximity to cables of other circuits and is located in the same or adjacent mechanical supporting device (tray or racks). The cables with their own ground shield and mechanical protection will short together only under most unusual conditions (fire, excessive heat, or repeated cyclic movement), but surge currents and temperature-caused forces may place mechanical strain on their own connectors and mountings. Physical contact with adjacent cables may also induce problems in other circuits.

The problem of overheating and burning, always present in any single- or multiple-cable installation, was demonstrated by the Browns Ferry cable fire (see Sect. 4.4 and Refs. 6, 7, 17, and 31). However, recent developments in retardant coatings and new insulation compounds promise to reduce the risk of cable fires starting and spreading.

6.4.1 Energetic missiles

The only damaging missiles from cables and connectors that were considered were droplets of molten insulator or insulator material that could result from arcing and/or burning. These droplets, propelled by rapidly expanding gases or induced magnetic fields, can cause damage to nearby insulators and associated equipment. Because of their small size, however, the droplets have limited range and tend to deposit on rather than penetrate impacted surfaces. The range limitation plus cooling in flight confine the additional damage usually to the same curcuitry, except when the initial fault is in a cable tray or rack with other circuits.

6.4.2 Insulating fluid spills

With few exceptions, the cables considered do not have any fluids as such associated with them. There are a few oil-insulated and oil-cooled HV cables whose use is characteristically limited to individually carefully designed situations. These installations are unique and have special consideration for containment and/or fire protection. (Municipal power distribution systems use a great number of oil-filled cables in congested areas.)

6.4.3 Toxic fumes

Cable insulation and protective coverings used in older cables were usually oil-impregnated paper or varnished cambric, but most of the currently installed cables have plastic insulation that is some form of PVC.* When PVC burns, it melts and generates dense smoke and large quantities of soot. The fumes and soot deposited from combustion of the insulation can cause insulator coating and failure. The molten, dripping, burning PVC material can itself propogate the fire by dripping and depositing on flammable substances.[4,6,18-20] The burning PVC releases chlorine which when combined with water will react with metallic electrical circuitry components. The chlorine will also react with other metallic equipment.

6.4.4 Fire protection system

Cabling or buswork areas normally have fire detection systems (ionization or heat rise) and some means of fire suppression. The fire suppression systems may be supervized automatic, direct-acting sprinkled CO_2, or Halon diluge systems. The choice is site, location, and designer specific. Most facilities use a supervised sprinkler system, but in some cable-spreading areas (different from cable tray runs throughout the building) CO_2 diluge and soak systems are preferred.

6.4.5 Mechanical stress

The whipping action caused by fault currents and the expansion and contraction from interior cable temperatures can place mechanical stress on the mountings and electrical connections of power cables. Electromagnetic forces between cables carrying large fault currents, other cables, and metallic conductors can result in physical displacement, breakage of mounting insulators, and rupturing of containment. The effects of temperature are generally accumulative and can be measured so that corrective action can be taken. Connections and mounting points may also be overstressed during assembly or disassembly unless proper support and procedures are provided. The support and procedures are especially needed if the cables are used as removable links where handling is much more frequent.

6.5 Control Boards (High Boards)

A control board functions as the mechanical mount of various pieces of electrical equipment such as meters, switches, circuit breakers, cables, low-voltage distribution transformers, and display equipment. The control board itself can only fail structurally, which is very unlikely unless the floor and/or building moves from a seismic or some other large-scale event. Thus, any control board faulting will be the direct result of some of the attached equipment, as described previously for the various components.

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*Some gas-filled (SF_6) breakers are under design studies.

7. CONSEQUENCES OF COMPONENT FAILURES IN NUCLEAR POWER PLANTS

The consequences of component failures in nuclear power plants are potentially very great, but good engineering based on applicable standards, codes, and regulations and many years of design and operating experience in the public utility industry have reduced the probability of equipment-initiated events.[9],[10] Single-failure fault probability for major pieces of electrical equipment is on the order of 0.01 failure per year.[10]

The review of the FSAR drawings and plant visits for this report were an effort, by inspection, to determine if a unique installation existed where a fault (~0.01 failure per year) could be expected (at least one out of ten times) to propagate an extension of the basic failure. Attempts were made to place known faults of record, personal experience, or those faults whose potential could be delineated into circumstances where the initial fault became the precursor.

The plants and their electrical equipment varied greatly, from single generating units to multiple units, 115- to 500-kV switchyards, oil-filled to dry transformers indoors, and alarm-only to completely automatic fire systems. All plants, in their own ways, show good engineering and the impact of NRC regulations, applicable codes, and standards. In the plants visited, the separation of the essential safety function was quite evident. As would be expected, equipment not related to safety does not have the same separation and protection and may thus be more easily involved in a cascading event (that would not jeopardize the plant's safety). For instance, one plant with dry transformers has a distribution transformer installed adjacent to several nonsafety-related instrument and service vertical cable trays. A massive failure of this transformer possibly could disrupt elements of these cable trays. Also, one plant has its nonsafety-related station service switchgear located in two adjacent rows such that any violent major switchgear failure might not only involve the buswork of the failing switchgear but the buswork connecting adjacent gear as well. However, visits to plants and examination of drawings and FSARs revealed no installation whereby even a massive electromechanical failure of any electrical component could prevent the ability of any additional safety system to function properly.

7.1 Transformers

In all cases reviewed, transformers were protected by fire shielding walls and spatial separation and were provided with either a direct-acting or supervised automatic sprinkler or fire alarm system.

7.1.1 Energetic missiles

Although no failures can be traced to missiles generated from and by transformers, in several instances missiles from the ceramic insulators have been recorded. These missiles were 3 to 7 lb in weight and had been projected some 30 to 40 yards, in one case severely denting an access door. They could obviously have damaged other ceramic insulators on adjacent equipment and other impact-sensitive elements.

7.1.2 Insulating fluid spills

The oil-filled transformers may contain mineral oil or an insulating oil containing PCB. Both fluids are flammable, but the PCB poses the additional problem of carcinogenic material cleanup. The large size of the external main and auxilliary transformers and the volume of fluid they contain (thousands of gallons) create problems in filtering and changing the oil unless the connections are permanent. For permanent connections, the pipe is placed in a trench through the switchyard, between the transformers and the filtering-pumping station. This could lead to trouble if there is a leak from the pipe into the trench which could be ignited by an external source such as a flaming oil spray from a faulting transformer. Fumes from such a burning transformer in some instances are exhausted directly to the outside air through roof vents placed directly over the transformers. The fumes would then be spread by the wind to other areas. Because of the possible toxic nature of these fumes and the characteristically thick, dense smoke from the burning oil, visibility and mobility of personnel in these areas for control and repair may be severely limited.

The indoor oil-filled transformers observed were all protected by a supervized sprinkler system and were curbed to contain the fluids. The problem here would be toxic fumes and cleanup, especially if the insulating fluid contained PCB. The only drains were floor drains to tankage not intended for carcinogenic material.

7.1.3 Fire protective systems

The oil-filled transformers were all protected, but some of the interior dry transformers were protected by alarms only. The alarm-only system is geared to a fast human investigation and response with manual equipment. The problem of toxic fumes from burning insulation would require the use of self-contained air masks as well as fire extinquishment equipment for those entering the area.

7.1.4 Mechanical stress

The structural strength of the switchyard bus associated with the main transformers, although not seismic qualified, is mechanically sturdy enough that the chance of failure is quite remote for any force resulting from a transformer failure. The indoor distribution transformers are usually connected by flexible cable and can through cable whip overstress cable tie-down clamps and connectors to the point of failure.

7.2 Switchgear

Switchgear varied from the 500-kV magna and pneumatic circuit breakers through the oil circuit breakers used in switchyards to the indoor medium-voltage air circuit breakers. Although they were not specifically addressed, load and isolation disconnect switches were considered when convenient.

7.2.1 Energetic missiles

Circuit breaker failure rarely generates missiles large enough in themselves to be damaging, but because of the very concept of interrupting (and dissipating) large amounts of power in extremely short times the potential for an explosive failure is always present. The indoor circuit breaker, usually air or in some cases oil, is more likely when failure occurs to spray molten copper or oil[15,17] on the connecting bus and its insulators and to damage contiguous cabinets and control circuits.

7.2.2 Insulating fluid spills

Little documentation was found on the long-term effects of the gas SF_6; none of the plants visited had any information. The Askeral (and its PCB) used in the oil circuit breakers is of small volume and seems to make only a minor contribution to failure problems.

7.2.3 Toxic fumes

Not applicable.

7.2.4 Fire protection systems

Reference 17 was the only document giving any applicable information.

7.2.5 Mechanical stress

Not applicable.

7.3 Lightning Arrestors

Failure of lightning (surge) arrestors usually involves failure to correctly function because of insufficient time for proper recovery between demand strokes. In this case it effectively remains a shunt on the line, dissipates energy far beyond its rating, and destroys itself. The other failure mode is where the gaps and grading elements become ineffective and the arrestor ceases to function as a suppressor or fails to withstand impressed voltage. The first fault mechanism possibility is greatly reduced by correct selection of the arrestor; the second mechanism can be almost eliminated by scheduled maintenance.

7.3.1 Energetic missiles

Although several destructive failures (Table 4) were listed as noted in Appendix A, there were no reports that indicated any subsequent failures of other equipment from missiles originating from the lightning arrestors.

7.3.2 Insulating fluid spills

See Sect. 6.3.2.

7.3.3 Toxic fumes

See Sect. 6.3.2.

7.3.4 Fire protection system

See Sect. 6.3.2.

7.3.5 Mechanical stress

No instances of the mechanical contribution of lightning arrestors were found (see Sect. 6.3.5).

7.4 Cables and Connectors

The large connectors used in switchyards are usually hollow tubing, but some installations connect bus to units such as circuit breakers with large heavy unshielded cables. These cables are sometimes also used as disconnecting links to be used when the breakers or other units are undergoing testing or maintenance. The greatest use of insulated cables is indoors where the distribution voltage is generally limited to not more than 13.8 kV.

7.4.1 Energetic missiles

Not applicable (see Sect. 6.4.1).

7.4.2 Insulating fluid spills

Because few cables containing insulating oil or gas are used in nuclear plants, there is no record of failures involving other than the initial fault. However, facilities that do use such cables (in trays or trenches) must give consideration to the proximity of the cables to sources of ignition and potential fuel.

7.4.3 Toxic fumes

Actual generation of fumes by cable fires in practice is rather rare,[4,6,7,17–20] but the possibility is always present. Indoor cabling is now required to meet coding and installation requirements designed to further reduce the potential for failure.

7.4.4 Fire protection systems

Most facilities have automatic fire protection systems (Sect. 6.4.4), but the suppression mechanism may be manual.

7.4.5 Mechanical stress

Cables mechanically work in the cable trays and will occasionally mechanically abrade the insulation to the point of failure. The use of cables as disconnecting linkage should be carefully considered because of their size and required length. Such linkage usually will require the use of scaffolds or a cherry picker and manual handling of the lines (cables). In bad weather or emergency situations the potential for problems surely exists, and it does not seem to be cost effective to use such a system in place of a mechanical no-load switch.

7.5 Control Boards

Control boards as such will fail only if some installed equipment initially faults.[15,17] Possible problems for equipment servicing in the boards may result from backfitting of seismic supports, but this will likely be more of an inconvenience than a real problem.

8. DISCUSSION

Reaction to an unscheduled event, electrical or otherwise, is quite easy to predict after it has occurred, but it is extremely difficult to accurately predict for future events because the events themselves and their ramifications often do not become clear until the event actually occurs. Modern nuclear power plant engineering uses standards, good design techniques, and fault-tree analysis to limit the occurrence of unscheduled events and to curtail their damage potential. But the one element that interfaces with the equipment and is often incompletely programmed is the operator. If failure to take action as well as incorrect action is considered, it seems that 30 to 50% of disruptive events are caused by human error.[13,32,33] In all fairness, it should be pointed out that the multitude of correct human responses go undocumented and unpublished and receive very little recognition except in the exemplary nuclear industry safety records.

The very size and complexity of nuclear power plants has as a direct result introduced a degree of specialization in engineering and operation that makes keeping in mind the overall picture most difficult. But in spite of the magnitude and sophistication of nuclear power plants, more hands-on training and interaction between operations, engineering, and maintenance personnel at all levels is a must. This information exchange can be fostered by a series of "exchange-professor" systems whereby a design specialist works with maintenance on an exchange basis for a prescribed time period or an operator is assigned to maintenance scheduling. Knowledge of the equipment operating conditions, necessary environment, and possible failure mechanisms can help avoid initial failures and the contribution these failures can make to additional damage.

One of the feelings that became apparent from talks with personnel at the plants and with construction and design engineers was that the person who remotely controls the equipment has less and less contact with the equipment and its characteristics. This is unfortunately true; but time limitations place quite severe restrictions on the appreciation of equipment capabilities received through hands-on experience. The turning of a switch in the control room does not always fully indicate (except by displays) the events that take place at the other end of the control circuit. Few operations or design staff have the chance to develop the "sense" that something is not quite right. This sense, developed through experience, is made up of sounds, feelings, and timing that are mentally integrated and coupled with past experience to indicate that something is not quite as it should be — something needs checking.

The tremendous amount of technical and scientific knowledge that must be assimilated and used daily by the staff is so different from the highly specialized skills of the craftsman that no longer does the staff sense directly the conditions of operations and equipment. Instead, the staff now must rely on displays and communications. Gone also is the feeling of "that is my piece of equipment." The locomotive engineer senses something is not right with his traction unit, so he compensates in his control until he can get to the shop. Once in the shop, he will discuss the problem directly with the repairman, and if it is not corrected he will be back face-to-face with the repairman. In this example, the operator is directly and physically involved — which is not possible in a nuclear power plant. Increased communication loops on a continuing basis can be of great assistance in reducing the problem.

Electrical equipment, properly designed and installed according to NFPA, IEEE, and ANSI standards and the Standard Safety Analysis Report GAISSAR,[11] plus NUREG and DOE publications, has little chance of failure,* but sneak circuits and spurious couplings can create problems. Engineering and fault-tree analysis, coupled with ongoing quality assurance (QA) in installation and maintenance activities, is necessary to ensure that all standards are met and failure rates are kept at a minimum. TVA and the Arizona Public Service have a QA section in their design engineering that is part of the engineering process from concept through design specification, procurement, installation, and, finally, startup testing. The responsibility of these QA people is to ensure that the total equipment capability is available to the operators. This type of commitment will, in the long run, mean that equipment operates as expected and failures will be minimized.

Manufacturers and industry servicing, testing, and maintenance procedures and schedules must be followed rigorously with any deviation in the data thoroughly investigated. Utilities the size of TVA have a large enough system and enough equipment of various sizes that statistical analysis can be used to project needed changes in testing or maintenance.

It may well be that the already low electrical equipment failure rate cannot be greatly reduced, but if the correct response can be programmed by both the automated equipment and the operations personnel, the circumstances that contribute to follow-on failures can be eliminated. It could just be that the time has come to take a hard definitive look at when and how the operator enters into the event cycle.

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*WASH-1400 (Ref. 10) gives failures per year ranging from 0.3 (breakers) to 0.003 (transformers).

9. CONCLUSIONS

The difficulty of finding electrical equipment failure information is indicative of the very infrequent and random nature of the events. In addition, because each failure is uniquely characteristic in fault mode and type of equipment, no valid statistical analysis for trends could be established. In fact, no instances were found during plant visits or on examination of plant drawings or FSARs where any failure in one electrical safety system would affect the safe shutdown capability of the plant. The lack of data does, however, seem to indicate a high reliability and low failure rate of modern electrical power equipment. Diligent application of the appropriate codes, standards, and regulations will continue to establish the basis on which safe design and operation will be founded. Research on materials and development of improved techniques and methods will continue to provide improved reliability and safety in the nuclear power industry.[10,34-36] Based on the information presented and discussed throughout this report, we have come to the following conclusions.

9.1 Transformers

Transformer failures, while infrequent, are usually the culmination of a series of events: unusual loading, impressed surges (from protective circuitry failure or local switching), or improper maintenance. Nearly always, incipient failures can be determined by instrumentation, and preventive maintenance will ensure resolution of the condition. If, however, the transformer does fault, other connected or adjacent equipment is protected by the sensing elements and series circuit breakers. Any fluid spill or fire activates the required extinguishment system. There is very little probability that even a major transformer fault will mechanically damage any equipment other than itself. The mechanical damage will largely be confined to nearby piping, support structures, or electrical connections. The possible spill of flaming transformer oil into a trench carrying either oil-filled cables, hydrogen supply lines, or the transformer oil-filtering piping could easily involve areas and elements of equipment not electrical in nature.

There is, of course, a small chance that projectiles from the bushings could impact on ceramic supports or feedthroughs of other nearby equipment and contribute to their failure. However, with the required spatial separation and/or protective walls and with the required alternate sources of power, plant safety will not be jeopardized even if a transformer does fault this way.

If the transformer fault involves arcing between the high-voltage and low-voltage windings, the physical damage resulting from the fault may well extend into the low-voltage buswork and connections. With the required alternate sources of power, plant safety will not be jeopardized even by this type of fault.

9.2 Switchgear

Switchgear, because it is an active element, has a very definite service life determined by number of operations (wearing of parts) as well as the inherent long-time component deterioration. Periodic testing and scheduled replacement of worn parts greatly increase the reliable service life of these units.

Circuit breakers may fail, not only in an obvious event, but also by simply not actuating (either opening or closing) on command or actuating in a spurious manner. Quite often the circuit breaker receives the blame for the event when in reality the fault was caused by incorrect sensing and control circuitry. Faults of circuit breakers can be locally violent and offer the possibility of fire; but because of their location within metal cabinets and/or their own steel-ceramic shells, the likelihood of further damage is minimized. Spurious operation can create unwanted situations, but careful design and adherence to codes, standards, and regulations, plus engineering analysis for sneak circuits, will maintain high reliability of unit and circuitry. Periodic testing will ensure that protective relaying is adequate and properly calibrated.

9.3 Lightning Arrestors

Lightning (surge) arrestors, like transformers, are on-line, but their capabilities are required only during abnormal circumstances. An arrestor is designed as a protective device so that its inability to respond may endanger the equipment and circuitry it is intended to protect. Unless circumstances demand its function, an arrestor's inability to respond may go undetected for some time. Therefore, lightning (surge) arrestor failures are largely found during scheduled periodic testing or when apparent problems with associated equipment are being resolved.

It is fortunate that circuit monitoring (recording voltmeters, oscillograph and oscilloscope traces) indicates the conditions under which arrestors respond; these records should trigger inspection, testing, and service. Unless the unit self-destructs from excess load, with proper care it will be capable of long reliable service.

9.4 Cables and Connectors

Cables and connectors properly installed and not subjected to mechanical forces, moisture, or extreme temperatures have a predictable long service lifetime. This lifetime is dominated by the aging of the cabling material, especially its insulating medium. Cable failures, very random in nature, normally only affect a short length of a specific cable and are cleared by the protective relaying and feeding circuit breakers. Usually, if required, the cable can be repaired by splicing and replaced in service. In conduit, cables seldom can involve other cables or equipment, but when the cable is in an open tray with other cables, it can directly affect others through mechanical motion or by heating (fire). Relays with sensors, properly designed, installed, and kept calibrated, will clear cable faults in an extremely short time (a few cycles ac) and thus restrict the damage to the faulting cable.

9.5 Control Boards

Control boards are made up of many electrical components, such as sensitive monitoring and control devices as well as smaller circuit breakers. The circuit board and its components are subject to mechanical and environmental (water and fumes) damage; but usually the control elements, not the installed circuit breakers, buswork, or cabling, are most likely for externally induced damage. Regular hi-potting (high potential testing) for changes in insulation and power-factor measurements will disclose incipient faults and will allow repair or replacement during scheduled outages rather than after a fault.

9.6 Other Equipment

Test equipment is a vital part of electrical equipment service and maintenance; as such it must be kept calibrated and available. Inaccurate readings, improperly used as functional data, can easily contribute to a subsequent failure of an in-service component. Regularly scheduled and documented calibrations ensure that monitored and/or tested equipment is correctly evaluated.

It is extremely important that within the codes, standards, regulations, and the utilities' own specifications, good maintenance and operations records be kept. These records, intelligently analyzed, will often indicate a potential fault or area of concern long before any actual event occurs, thus keeping minor troubles from repeating or becoming major problems.

As new information or requirements from technical or regulatory bodies become available, they must be included in the operational requirements of present plants and should be made available for design and procurement groups. This updating will continue to improve the reliability and reduce the failure rate of electrical power equipment. Assessment of data and information obtained in this study indicates that initial equipment failures that require a man-machine interaction offer a very definite opportunity for an incorrect response. The conclusion was reached that the greatest decrease in fault cascading will be the result of increased realistic training and better diagnostic information displays. While most events reviewed were very dissimilar in both equipment and fault mechanism, many instances of incorrect or incomplete man-machine response contributed to the damage total. Only the best training and the most complete information will enable the operator to assess adequately the situation and to respond correctly.

10. RECOMMENDATIONS

Recommendations derived from this study fall into two categories: (1) those of a general nature that apply to the entire electrical system and involve such activities as better quality assurance, better procedures, better failure documentation, and better information exchange and (2) those specific to individual electrical components. Even though the discussion of those recommendations specific to individual components may appear to be directed solely to the prevention of the failure of that component, it is through a gross failure of one component that the failure is propagated beyond the component itself. In addition recommendations are included whose specific intent is to minimize the potential of failure propagation beyond a failed component itself.

10.1 General Recommendations

10.1.1 Color coding

So that the chance for error during normal operations and maintenance can be minimized and emergency response can be expedited, a color coding and numerical standard should be developed and implemented for use in plant electrical systems. This system should include a distinctive color (e.g., orange, purple) and voltage level indication (e.g., 1, 2, 3) for each safety and/or service system. This is normally done in most plants during the initial installation phase, but in any event some coding should be used on electrical equipment. Such markings will reduce error, will speed service response for operations, and will be helpful in emergency situations.

10.1.2 Emergency procedures

A locally available manual should describe both the concerned equipment and the actions to be taken in fire and other emergency conditions. Emergency procedures in use at Oak Ridge National Laboratory require that each area have a posted emergency evacuation route, a means of notification, and an emergency manual (located in a central spot in a plastic container). This manual describes the expected response of personnel normally within the area (and an index of their training) and the actions to be taken in an emergency. The hazards and restrictions of the area are indicated, and the authorization requirements for access and action are outlined. The location of fire suppression equipment, communications capability, and lighting and ventilation controls must be adequately described. It is recommended that consideration be given to the development of a guide that can be used by nuclear plants to implement the writing and installation of similar manuals.

10.1.3 Electrical system display

All nuclear plants' plans for upgrading should include as an ongoing effort continued training improvement and more informative diagnostic displays. The growing use of ergonomics is to be commended, but diagnostic displays that portray changing conditions and trends will enable better judgments to be made of the situation at the man-machine interface and thus will minimize the opportunities and likelihood of human errors. It is therefore recommended that (1) research be continued on computerized data display and (2) generic simulators be programmed to test the results.

10.1.4 Diesel generator switching

Final Safety Analysis Reports and discussions with operators show that all plants have procedures and automated controls of the onsite emergency diesels that properly connect to the system in an emergency. The return to offsite power operation is not so well described, and the problem of synchronizing the diesel and its load to the network before reconnecting needs to be clearly understood and provided for. If the system is to be fast switched (within five cycles), then there must be a method of synchronization; if the return to normal supply is other than fast switched, then it must be done after the diesel has been disconnected and the loads (motors especially) have coasted down to where the back electromotive force is 25% or less of that rated. This slow-switching will of course again create startup current surges, but they will be within normal limits and will not be destructive in nature.

Therefore, the recommendation is made that the plant safety analysis reports and electrical operating procedures be reviewed to ensure that the problem of reconnection to the transmission network is defined and that either fast or slow switching is designated.

10.1.5 Maintenance scheduling

With the cost of equipment growing higher each day, the expense of repair and maintenance, plus the loss of revenue from nonoperating equipment, clearly failure rates of major equipment must be minimized. Regular periodic maintenance scheduled in conjunction with other outages (e.g., during fuel reload) is not only less costly in equipment and manpower, but it allows system load projections to become part of the calculation.

10.1.6 Electrical advisory panel

A panel of engineering experts should be established to assess failure information pertaining to electrical power equipment. This panel would be available to consider potential or actual problem areas, to make recommendations for their correction, and to give input to the various agencies that write national standards and codes, the Advisory Committee on Reactor Safeguards, and various NRC divisions as needed.

10.1.7 Equipment failure data systems

Clearly a system such as the Government Industry Data Exchange Program (GIDEP) (see Appendix B) or an improved nuclear plant reliability data system (NPRDS) tailored directly to the nuclear power industry would be most useful. Such a system should be capable of providing (1) notification at the level needed; (2) rapid, specific notification of occurring and potential problems and failures of systems; and (3) components and materials of interest to the operations and maintenance supervisors. This notification and information exchange network must be operated by an obviously impartial group. The GIDEP system, while similar to the NRC inspection and enforcement (IE) information notices and the Institute of Nuclear Power Operations NPRDS, has additional features that could be advantageously incorporated into both IE and NPRDS. These features include (1) extremely short times between initiation and issuing of notice and (2) unique packing with copies of the initial report and the equipment manufacturer's comments presented on distinctive, easily identified paper. For information input, GIDEP has an onsite representative who is responsible for formulating the original factual submission to the central clearing house and publishing agency. This same individual is also responsible for proper and complete onsite distribution of "alerts" and "safe alerts." Of major concern to the GIDEP system is the timely distribution of concise factual information in an easily recognized and readable format. This designated individual contact is also listed on a roster that each active participant is given, so that quick contact can be made for more detailed information and the direct exchange of ideas.

10.1.8 Failure documentation

Present plant equipment maintenance and failure documentation is often incomplete. LERs report Technical Specifications violations and do not completely reflect the full picture of equipment problems. The only way the additional information can be obtained is by surveys of specific equipment histories in a designated time span. For this additional information it is recommended that information from LERs (and other available reports) for a representative number of plants be compared with documentation of work requests and repair costs from those plants. This should provide a direct comparison and statistics that could be used for scheduling and projecting maintenance costs and manpower needs. As an alternative this could be a specific part of the present IEEE Electrical Reliability Study. Better testing techniques and probabilistic data that the utilities can use to coordinate their service schedules should emerge from these studies.

10.1.9 Quality assurance

In spite of the detailed specifications under which medium- and high-voltage electrical equipment is purchased, a rigorous QA program must be followed. Maintenance, servicing, and QA records can form the basis for design and installation modifications.

10.1.10 Training program

Incorrect human response was the aspect of the reviewed electrical failures that was repeated too often. Operators with more experience and maturity had significantly fewer errors of judgment. The present in-service time of junior and soon-to-become senior managers is not adequate for them to get enough hands-on experience with the equipment. During the early on-the-job time, experience in several fields (e.g., design, procurement, maintenance) can help when judgments are required at the staff and managerial levels. The junior management training program should provide the opportunity for experience in all areas of equipment operation. The broadening of the experience base cannot be emphasized too much or too often because of the large contribution human responses play in all failure modes.

10.1.11 Information exchange

At the present time information on electrical failures in the nuclear utilities is collected and distributed by a number of organizations, such as NPRDS, NSIC, and EEI. However, no one organization has complete files of information or distribution capability. One of the keys to further reducing the consequences of equipment failures is the exchange of information between regulatory bodies, the utility users, and equipment manufacturers. So that the exchange of information can be free and unlimited, it is suggested that regularly scheduled workshop conferences be held. These conferences might be similar to the present annual Doble Clients Conference. The Doble conferences are some of the most current sources of information on electrical equipment uses, maintenance, and operating experience available. Although these conferences are not presently nuclear-industry specific, they do cover power operating experience and preventive maintenance testing of distribution, generation, and power equipment.

Accomplishment of information exchange can take place any of the three following ways. As a minimum, nuclear power plant electrical design and service personnel should be encouraged to attend the present conferences and familiarize themselves with the experience of others in the public utility sector. This would be the quickest and least costly approach, but it would be limited largely to the experience of nonnuclear plants.

The second alternative would be to work out an agreement with the Doble organization to set up a specific parallel series of workshops for the nuclear power generation group. These sessions could be in the same format as Doble's other sessions but should recognize the special conditions imposed by nuclear plants.

The third procedure would be for NRC to sponsor regular workshops through an independent group. The sponsoring organization of record must be not only impartial by name but by reputation so that the flow of information will not be restricted in any way.

10.2 Recommendations on Specific Electrical Equipment

From the review of electrical equipment failures reported herein, it was concluded that the relatively few damaging failures for which documentation was obtained were a direct consequence of failure to follow any or all of the well-established and well-known practices of electrical engineering, design, construction, operation, and maintenance of high-voltage electrical equipment. Therefore, a general recommendation pertaining to the high-voltage electrical system components that follow is to urge strict adherence to established practice. In addition, the following recommendations address certain aspects concerning the safety of specific equipment.

10.2.1 Transformers

Many of the present power transformers, located both inside and outside, are filled with insulating oil that contains PCB. Not only must provision be made to contain the spillage, but care must be taken to ensure that insulating fluid is not introduced into drain systems and areas where cleanup and disposal become a problem.

If the inflammable insulating fluid does burn, the problem of containment may be exacerbated because the fumes must also be controlled and/or contained. Therefore, it is first recommended that a specific written procedure be followed for fire suppression and/or cleanup of fluid spills where oil-filled transformers are used. Second, it is recommended, in addition to regular periodic servicing, that after any overvoltage, excessive surging, or system faulting, the electrically connected and associated equipment be analyzed and tested before being returned to service.

Any time a transformer is opened for inspection, repair, or storage, there is a chance that air (and moisture) may replace the inert cover gas or insulating fluid. For this reason it is recommended that the procedures and practices provided by the equipment manufacturer be strictly followed, particularly if periods of storage are necessary.

10.2.2 Circuit breakers and/or switchgear

Medium-voltage circuit breakers, both oil and air, are designed to be easily removable for testing, calibration, and maintenance. This capability to be mechanically repositioned is not intended for use in electrically closing or interrupting the circuit. Because the mechanical movement involves the electrical connection point, correct alignment for each reinstallation is critical. If the contact points (stabs) are incorrectly aligned or insufficiently inserted, a hot spot and a potential for failure result. Therefore, the QA program for operators should ensure that (1) the manufacturers' test, calibration, and reinstallation procedures be carefuly followed; (2) if upon inspection evidence is present of overheating or arcing, the mechanical alignment mechanism be checked for wear and out-of-tolerance adjustments; and (3) if any evidence is present of external arcing, insulating fluid spillage, or other indications of abnormal conditions, a job plan be established before further maintenance or service is performed.

10.2.3 Lightning (surge) arrestors

Historically the installation or elimination of lightning arrestors has been a cost vs risk consideration. Because of increased size and replacement costs (downtime, replacement power, and public image), system fault response calculations should be ongoing, with the cost-risk consideration periodically considered.

The lightning arrestor, in spite of being a passive element, is one of the most important protective units that can be applied to an electrical system. Its properly designed installation, maintenance, and servicing therefore cannot be overemphasized. If it fails in its function, so also will some other (perhaps more expensive and less easily replaced) part of the system fail.

10.2.4 Cables and connectors

Records of periodic inspection and testing of cables need to be incorporated into trends analysis from which service and replacement schedules can be projected. Accordingly, it is recommended that a central collection and analysis system be developed. This system would be helpful in establishing site and generic failure mechanisms and the projected trends that can be used in scheduling preventive maintenance.

Connectors fastened by screws, bolts, or spring-loaded contacts require routine cleaning and retorquing to reduce excessive local heating, which can ultimately lead to failure.

Development of a cable insulation that has better flame retardant and aging characteristics is greatly needed. Therefore, it is recommended that NRC, jointly with other organizations (e.g., EPRI, IEEE, NEMA), continue to sponsor research and development activities such as the Sandia work[18,19] on (1) solid cable insulation (its combustibility and aging characteristics); (2) gas insulation used in cables, transformers, and switchgear; and (3) environmental impacts of distribution systems with ultra-high voltages.

10.2.5 Control boards

Control boards have been known to fail mechanically because of faulty welds or inadequate structural design. However, unless the installation or subsequent additions increase the stress levels appreciably, the greatest fault potential is from an outside event such as fire, water diluge, or loss of building structural support. Routine, periodic inspection of the control board and its attached components should provide information on potential structural problems long before maintenance is required.

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Appendix A

SELECTED CITATIONS FOR EXAMPLES

TRANSFORMERS

ACCESSION 122392

POWER LOST TO 161 KV/4160 V HOUSE SERVICE TRANSFORMERS AT FT. CALHOUN 1
5 PGS, LTR W/LER 50-285/77-4 TO U.S. NRC, REGION IV, FEB. 28, 1977, DOCKET 50-285, TYPE--PWR, MFG--COMB., AE--GIBBS & HILL

ACCESSION 125132

4160/440 VOLT TRANSFORMER FAILS AT FT. CALHOUN 1
4 PPS, LER RO-285/77-16, MAY 24, 1977, DOCKET 50-285, TYPE--PWR, MFG--COMB., AE--GIBBS & HILL

ACCESSION 125450

TWO SUCCESSIVE PARTIAL LOSSES OF OFF SITE POWER OCCUR AT TROJAN
4 PGS, LTR W/LER 77-10 TO NRC, REGION V, MAY 24, 1977, DOCKET 50-344, TYPE--PWR, MFG--WEST., AE--BECHTEL

ACCESSION 125700

AUXILIARY TRANSFORMER DE-ENERGIZED AT THREE MILE ISLAND 1
4 PGS, LTR W/RO 77-15/3L TO NRC OFFICE OF I & E, REGION I, JUNE 28, 1977, DOCKET 50-289, TYPE--PWR, MFG--B&W, AE--GILBERT ASSOC.

ACCESSION 132926

STARTUP TRANSFORMER LOST DUE TO TRANSMISSION LINE FAULT AT DAVIS-BESSE 1
3 PGS, LTR W/RO NP-33-77-106 TO NRC OFFICE OF I & E, REGION III, DEC. 22, 1977, DOCKET 50-346, TYPE--PWR, MFG--B&W, AE--BECHTEL

ACCESSION 133041

BOTH STARTUP TRANSFORMERS TRIP AT HATCH 1
3 PGS, LTR W/RO 50-321/1977-71 TO NRC OFFICE OF I & E, REGION II, OCT. 26, 1977, DOCKET 50-321, TYPE--BWR, MFG--G.E., AE--SSI

ACCESSION 136011

PREFERRED RESERVE AUXILIARY POWER SOURCE LOST AT COOK 1
2 PGS, LTR W/RO 78-014/03L-0 TO NRC OFFICE OF I & E, REGION III, MARCH 8, 1978, DOCKET 50-315, TYPE--PWR, MFG--WEST., AE--UTILITY

ACCESSION 136469

STARTUP TRANSFORMER BANK 5 TRIPS AT OYSTER CREEK
4 PGS, LTR W/RO 50-219/78-03/3L-0 TO NRC OFFICE OF I & E, REGION I, MARCH 15, 1978, DOCKET 50-219, TYPE--BWR, MFG--GE, AE--BURNS & ROE

ACCESSION 139565

OFF SITE POWER LOST AT ST. LUCIE 1
4 PGS, LTR W/RO 335-78-17 TO NRC OFFICE OF I & E, REGION II, JUNE 13, 1978, DOCKET 50-335, TYPE--PWR, MFG--COMB., AE--EBASCO

ACCESSION 139826

STARTUP TRANSFORMER INOPERABLE AT OCONEE 1
3 PGS, LTR W/RO-269/78-15 TO U.S. NRC, REGION II, JULY 3, 1978, DOCKET 50-269, TYPE--PWR, MFG--B&W, AE--DUKE

ACCESSION 139975

STATION POWER TRANSFORMER LOST AT SALEM 1
4 PGS, LTR W/RO 78-35/03L TO NRC OFFICE OF I & E, REGION I, JULY 20, 1978, DOCKET 50-272, TYPE--PWR, MFG--WEST., AE--PSE&G

ACCESSION 140145

4160/480 VOLT DRY TYPE TRANSFORMER CAUGHT FIRE AT FT. ST. VRAIN
5 PGS, LTR W/RO 50-267/78-28/01-T-0, FINAL, TO NRC OFFICE OF I & E, REGION IV, AUG. 14, 1978, DOCKET 50-267, TYPE--HTGR, MFG--GA, AE--SGT & LUNDY

ACCESSION 140190

SUDDEN PRESSURE RELAY TRIPS S/U TRANSFORMER FEEDER BREAKER AT FARLEY 1
4 PGS, LTR W/LER 78-055/03L-0 TO NRC OFFICE OF I & E, REGION II, SEPT. 11, 1978, DOCKET 50-348, TYPE--PWR, MFG--WEST., AE--BECHTEL & SSI

ACCESSION 140335

ELECTRICAL FAULT OCCURS IN STATION MAIN TRANSFORMER AT BEAVER VALLEY 1
7 PGS, LTR W/LER 78-43/01T-0 TO U.S. NRC, REGION I, AUG. 11, 1978, DOCKET 50-334, TYPE--PWR, MFG--WEST., AE--STONE & WEBSTER

ACCESSION 140654

LIGHTNING STRIKE CAUSES LOSS OF TWO OFF SITE POWER SOURCES AT PRAIRIE ISLAND 1
2 PGS, LTR W/LER 78-018/01T-0 TO NRC OFFICE OF I & E, REGION III, SEPT. 26, 1978, DOCKET 50-282, TYPE--PWR, MFG--WEST., AE--PIONEER SERV.

ACCESSION 149941

GROUND FAULT RESULTS IN LOSS OF 3 STATION POWER TRANSFORMERS AT SALEM 1
LTR W/LER 79-038 TO U.S. NRC, REGION 1, MAY 15, 1979, DOCKET 50-272, TYPE--PWR, MFG--WEST, AE--PSEG CONTROL--026008

ACCESSION 149947

SWITCHING ERROR CAUSE TRANSFORMER FAILURE AT PRAIRIE ISLAND 2
LTR W/LER 79-011 TO U.S. NRC, REGION 3, MAY 16, 1979, DOCKET 50-306, TYPE--PWR, MFG--WEST, AE--PSE CONTROL--026015

ACCESSION 150927

EMERGENCY TRANSFORMERS HAVE DEGRADED INSULATION RESISTANCE AT BEAVER VALLEY 1
LTR W/LER 79-021 TO U.S. NRC, REGION 1, AUG 09, 1979, DOCKET 50-334, TYPE--PWR, MFG--WEST, AE--S+W CONTROL--026482

ACCESSION 152187

STARTUP TRANSFORMER FAILS AND DIESEL GENERATOR FAILS TO START AT ST. LUCIE 1
LTR W/LER 79-028 TO U.S. NRC, REGION 2, SEP 17, 1979, DOCKET 50-335, TYPE--PWR, MFG--COMB, AE--EBASCO CONTROL--027012

ACCESSION 152271

GROUND FAULT RESULT IN LOSS OF THREE STATION POWER TRANSFORMERS AT SALEM 1
4 PGS, LTR W/RO 79-38/03L TO NRC OFFICE OF I & E, REGION I, MAY 15, 1979, DOCKET 50-272, TYPE--PWR, MFG--WEST., AE--PSE&G

ACCESSION 154894

RESERVE AUXILIARY TRANSFORMER FAILS AT KEWANNEE
LTR W/LER 80-002 TO U.S. NRC, REGION 3, FEB 15, 1980, DOCKET 50-305, TYPE--PWR, MFG--WEST, AE--PIONEER

ACCESSION 156027

ONE OFF-SITE POWER SOURCE TRIPS AT PEACH BOTTOM 2
LTR W/LER 80-006 TO U.S. NRC, REGION 1, APR 3, 1980, DOCKET 50-277, TYPE--BWR, MFG--GE, AE--BECH

ACCESSION 164312

TWO SWITCHYARD BUSES TRIP AT DAVIS-BESSE 1
LTR W/LER 81-008 TO U.S. NRC, REGION 3, FEB 26, 1981, DOCKET 50-346,
TYPE--PWR, MFG--B&W, AE--BECH, DCS NO.--8103030826

ACCESSION 165907

EMERGENCY BUS TRANSFORMER FAILS AT NORTH ANNA 1
LTR W/LER 81-020 TO U.S. NRC, REGION 2, APR 22, 1981, DOCKET 50-338,
TYPE--PWR, MFG--WEST, AE--S&W, DCS NO.--810422476

ACCESSION 165987

BUS FAILS TO ENERGIZE TWICE AT TURKEY POINT 4
LTR W/LER 81-004 TO U.S. NRC, REGION 2, APR 21, 1981, DOCKET 50-251,
TYPE--PWR, MFG--WEST, AE--BECH, DCS NO.--8105120415

ACCESSION 166020

OFF SITE POWER LOST AT GINNA
LTR W/LER 81-007 TO U.S. NRC, REGION 1, MAY 11, 1981, DOCKET 50-244,
TYPE--PWR, MFG--WEST, AE--GIL, DCS NO.--8105180305

ACCESSION 166069

OFF SITE POWER LINE TRIPS AT BROWNS FERRY 1
LTR W/LER 81-013 TO U.S. NRC, REGION 2, MAY 19, 1981, DOCKET 50-259,
TYPE--BWR, MFG--GE, AE--TVA, DCS NO.--8105260468

ACCESSION 166852

SHUTDOWN TRANSFORMER BREAKERS OPEN AT PILGRIM 1
LTR W/LER 81-024 TO U.S. NRC, REGION 1, JULY 3, 1981, DOCKET
50-293, TYPE--BWR, MFG--GE, AE--BECH, DCS NO.--8107130401

ACCESSION 167550

SPURIOUS SAFETY INJECTION ACTUATION AT NORTH ANNA 2
LTR W/LER 81-055 TO U.S. NRC, REGION 2, JUL 15, 1981, DOCKET
50-339, TYPE--PWR, MFG--WEST, AE--S&W, DCS NO.--8107280592

ACCESSION 167624

LIGHTNING STRIKE CAUSES LOSS OF ALL AC POWER AT CRYSTAL RIVER 3
LTR W/LER 81-033 TO U.S. NRC, REGION 2, JUL 14, 1981, DOCKET
50-302, TYPE--PWR, MFG--B&W, AE--GIL, DCS NO.--8107280585

ACCESSION 168664

OFF SITE POWER FEED TO EMERGENCY BUS LOST AT NORTH ANNA 2
LTR W/LER 81-058 TO U.S. NRC, REGION 2, AUG 19, 1981, DOCKET
50-339, TYPE--PWR, MFG--WEST, AE--S&W, DCS NO.--8108280182

ACCESSION 172348

OFF SITE POWER FAILS TO AUTOMATICALLY SUPPLY ONSITE SYSTEM AT LACROSSE
LTR W/LER 81-014 TO U.S. NRC, REGION 3, JAN 19, 1982, DOCKET 50-409,
TYPE--BWR, MFG--AC, AE--S&L, DCS NO.--8202010254

CIRCUIT CLOSURES

ACCESSION 134629

DEFICIENCY IN STATIONARY ARCING CONTACTS OF CIRCUIT BREAKERS AT SHOREHAM 1
2 PGS, LTR TO NRC OFFICE OF I & E, REGION I, DEC. 16, 1977, DOCKET 50-322, TYPE--BWR, MFG--G.E., AE--STONE & WEBSTER

ACCESSION 136719

IE BULLETIN 78-05 MALFUNCTIONING OF CIRCUIT BREAKER AUXILIARY CONTACT MECHANISM-GENERAL ELECTRIC MODEL CR105X
6 PGS, LTR W/ENC. TO CINCINNATI GAS & ELECTRIC CO., APRIL 14, 1978, DOCKET 50-358, TYPE--BWR, MFG--GE, AE--SGT & LUNDY

ACCESSION 137043

DEFICIENT GE RELAYS ASSOCIATED 4160 VOLT CIRCUIT BREAKERS AT SHOREHAM
5 PGS, LTR W/ENC. TO NRC OFFICE OF I & E, REGION I, APRIL 1, 1978, DOCKET 50-322, TYPE--BWR, MFG--GE, AE--STONE & WEBSTER

ACCESSION 137355

DEFICIENCY IN GENERAL ELECTRIC TYPE NEC FUSE HOLDERS AT SHOREHAM
5 PGS, LTR W/ATTACH. TO NRC OFFICE OF I & E, REGION I, MAY 1, 1978, DOCKET 50-322, TYPE--BWR, MFG--GE, AE--STONE & WEBSTER

ACCESSION 137356

DEFICIENCY WITH SNAP RINGS IN GE 4160 VOLT CIRCUIT BREAKERS AT SHOREHAM
4 PGS, LTR W/ATTACH. TO NRC OFFICE OF I & E, REGION I, APRIL 28, 1978, DOCKET 50-322, TYPE--BWR, MFG--GE, AE--STONE & WEBSTER

ACCESSION 146444

IE BULLETIN NO. 79-09 FAILURES OF GE TYPE AK-2 CIRCUIT BREAKER IN SAFETY RELATED SYSTEMS
11 PGS, LTR W/ENC. TO JERSEY CENTRAL POWER & LIGHT CO., APRIL 17, 1979, DOCKET 50-219, TYPE--BWR, MFG--GE, AE--BURNS & ROE

ACCESSION 152971

REACTOR TRIP BREAKER FAILS TO OPEN AT ZION 2
LTR W/LER 79-049 TO U.S. NRC, REGION 3, NOV 08, 1979, DOCKET 50-304, TYPE--PWR, MFG--WEST, AE--S+L CONTROL--027356

LIGHTNING

ACCESSION 125187

OUTSIDE POWER LOST AT INDIAN POINT 3
2 PPS, LTR W/RO 77-3-5(B) TO NRC OFFICE OF I & E, REGION I, JUNE 3, 1977, DOCKET 50-286, TYPE--PWR, MFG--WEST., AE--UE&C

ACCESSION 130111

BLACKOUT CONDITION OCCURS AFTER REACTOR TRIP AT COOK 1
4 PGS, LTR W/RO 50-315/77-30 TO NRC OFFICE OF I & E, REGION III, SEPT. 28, 1977, DOCKET 50-315, TYPE--PWR, MFG--WEST., AE--UTILITY

ACCESSION 130119

A COMPLETE LOSS OF OFF-SITE POWER OCCURS AT PALISADES
3 PGS, LTR W/LER 77-047 TO NRC OFFICE OF I & E, REGION III, OCT. 18, 1977, DOCKET 50-255, TYPE--PWR, MFG--COMB., AE--BECHTEL

ACCESSION 135006

LOSS OF OFF SITE POWER OCCURS AT FARLEY 1
5 PGS, LTR W/LER 77-012/01T-0 TO NRC OFFICE OF I & E, REGION II, SEPT. 29, 1977, DOCKET 50-348, TYPE--PWR, MFG--WEST., AE--BECHTEL & SSI

ACCESSION 135785

100 FOOT SHIELDING MAST FALLS ACROSS 345 KV YARD BUS WORKS AT PILGRIM 1
5 PGS, LTR W/LER 78-002/01T-1 TO NRC OFFICE OF I & E, REGION I, FEB. 17, 1978, DOCKET 50-293, TYPE--BWR, MFG--G.E., AE--BECHTEL

ACCESSION 140140

LOSS OF ALL OFF SITE POWER SCRAMS THE REACTOR AT PILGRIM 1
2 PGS, LTR W/LER 78-035/01X-0 TO NRC OFFICE OF I & E, REGION I, AUG. 8, 1978, DOCKET 50-293, TYPE--BWR, MFG--GE, AE--BECHTEL

ACCESSION 140654

LIGHTNING STRIKE CAUSES LOSS OF TWO OFF SITE POWER SOURCES AT PRAIRIE ISLAND 1
2 PGS, LTR W/LER 78-018/01T-0 TO NRC OFFICE OF I & E, REGION III, SEPT. 26, 1978, DOCKET 50-282, TYPE--PWR, MFG--WEST., AE--PIONEER SERV.

ACCESSION 140871

LIGHTNING STRIKES CAUSE REACTION TRIP AND SAFETY INJECTION AT FARLEY 1
6 PGS, LTR W/LER 78-033/01T-0 TO NRC OFFICE OF I & E, REGION II, JUNE
20, 1978, DOCKET 50-348, TYPE--PWR, MFG--WEST., AE--BECHTEL & SSI

ACCESSION 150943

REACTOR SCRAM FROM LOSS OF ALL OFF SITE POWER AT PILGRIM 1
LTR W/LER 79-027 TO U.S. NRC, REGION 1, AUG 10, 1979, DOCKET 50-293,
TYPE--BWR, MFG--GE, AE--BECH CONTROL--026498

ACCESSION 151635

ALL OFF SITE POWER LOST AT PILGRIM 1
LTR W/LER 79-033 TO U.S. NRC, REGION 1, SEP 11, 1979, DOCKET 50-293,
TYPE--BWR, MFG--GE, AE--BECH CONTROL--026781

ACCESSION 158228

ALL OFFSITE POWER LOST AT PRAIRIE ISLAND 2
LTR W/LER 80-020 TO U.S. NRC, REGION 3, JUL 29, 1980, DOCKET 50-306,
TYPE--PWR, MFG--WEST, AE--PIONEER

ACCESSION 158232

OFFSITE POWER LOST AT INDIAN POINT 2
LTR W/LER 80-006 TO U.S. NRC, REGION 1, JUN 17, 1980, DOCKET 50-247,
TYPE--PWR, MFG--WEST, AE--UE&C

ACCESSION 159238

OFFSITE POWER LOST AT INDIAN POINT 3
LTR W/LER 80-008 TO U.S. NRC, REGION 1, JUL 2, 1980, DOCKET 50-286,
TYPE--PWR, MFG--WEST, AE--UE&C

ACCESSION 159267

OFF SITE ELECTRIC POWER LINE TRIPS AT BROWNS FERRY 1
LTR W/LER 80-059 TO U.S. NRC, REGION 2, SEP 4, 1980, DOCKET 50-259,
TYPE--BWR, MFG--GE, AE--TVA

ACCESSION 159553

SAFETY INJECTION ACTUATES AT SALEM 1
LTR W/LER 80-031 TO U.S. NRC, REGION 1, JUL 8, 1980, DOCKET 50-272,
TYPE--PWR, MFG--WEST, AE--PSE&G

ACCESSION 164312

TWO SWITCHYARD BUSES TRIP AT DAVIS-BESSE 1
LTR W/LER 81-008 TO U.S. NRC, REGION 3, FEB 26, 1981, DOCKET 50-346,
TYPE--PWR, MFG--B&W, AE--BECH, DCS NO.--8103030826

ACCESSION 167624

LIGHTNING STRIKE CAUSES LOSS OF ALL AC POWER AT CRYSTAL RIVER 3
LTR W/LER 81-033 TO U.S. NRC, REGION 2, JUL 14, 1981, DOCKET
50-302, TYPE--PWR, MFG--B&W, AE--GIL, DCS NO.--8107280585

ACCESSION 170051

69KV ALTERNATE SOURCE LOST WHEN JUMPER FAILS AT COOK 1
LTR W/LER 81-049 TO U.S. NRC, REGION 3, OCT 30, 1981, DOCKET
50-315, TYPE--PWR, MFG--WEST, AE--UTILITY, DCS NO.--8111090695

CONTROL PANELS

ACCESSION 125196

MG6 RELAYS FOUND WITH INTERNAL SHORT CIRCUITS AT SEQUOYAH 1 & 2
3 PPS, LTR W/REPORT TO NRC OFFICE OF I & E, REGION II, MARCH 31, 1977, DOCKETS 50-327/328, TYPE--PWR, MFG--WEST., AE--TVA

ACCESSION 125203

SHORT CIRCUIT IN RELAY CAUSES FIRE IN CONTROL PANEL AT PEACH BOTTOM 3
5 PPS, LTR W/RO 3-77-14/1T TO NRC OFFICE OF I & E, REGION I, MAY 2, 1977, DOCKET 50-278, TYPE--BWR, MFG--G.E., AE--BECHTEL

ACCESSION 142297

CARRIAGE BOLTS USED ON 480V MCC BUS SPLICES FAIL AT SUSQUEHANNA 1 & 2
9 PGS, LTR W/ATTACH. TO U.S. NRC, REGION I, SEPT. 18, 1978, DOCKETS 50-387/388, TYPE--BWR, MFG--GE, AE--BECHTEL

ACCESSION 171041

FIRE PROTECTION ALARM PANEL FAILS AT PALISADES
LTR W/LER 81-046 TO U.S. NRC, REGION 1, NOV 19, 1981, DOCKET 50-255, TYPE--PWR, MFG--COMB, AE--BECH, DCS NO.--8111300446

CABLES AND CONNECTORS

ACCESSION 123040

ELECTRICAL FAULT TRIPS BUS 1C AT OYSTER CREEK
5 PGS, LTR W/RO 50-219/77-4-1T TO NRC OFFICE OF I & E, REGION I, MARCH 30, 1977, DOCKET 50-219, TYPE--BWR, MFG--G.E., AE--BURNS & ROE

ACCESSION 125124

4160/480 VOLT TRANSFORMER FAILS AT FT. CALHOUN 1
5 PPS, LTR W/LER 50-285/77-13 TO U.S. NRC, REGION IV, MAY 12, 1977, DOCKET 50-285, TYPE--PWR, MFG--COMB., AE--GIBBS & HILL

ACCESSION 126484

DEFICIENCY FOUND IN STATIONARY DISCONNECT OF 4160 V SWITCHGEAR AT SHOREHAM
2 PGS, LTR TO NRC OFFICE OF I & E, REGION I, JUNE 6, 1977, DOCKET 50-322, TYPE--BWR, MFG--G.E., AE--STONE & WEBSTER

ACCESSION 130119

A COMPLETE LOSS OF OFF-SITE POWER OCCURS AT PALISADES
3 PGS, LTR W/LER 77-047 TO NRC OFFICE OF I & E, REGION III, OCT. 18, 1977, DOCKET 50-255, TYPE--PWR, MFG--COMB., AE--BECHTEL

ACCESSION 137355

DEFICIENCY IN GENERAL ELECTRIC TYPE NEC FUSE HOLDERS AT SHOREHAM
5 PGS, LTR W/ATTACH. TO NRC OFFICE OF I & E, REGION I, MAY 1, 1978, DOCKET 50-322, TYPE--BWR, MFG--GE, AE--STONE & WEBSTER

ACCESSION 139825

A HOLE FOUND IN CABLE SHEATH FOR ONE PHASE OF CAR FAN MOTOR AT CONNECTICUT YANKEE
2 PGS, LTR W/RL 78-13/3L TO NRC OFFICE OF I & E, REGION I, JULY 5, 1978, DOCKET 50-213, TYPE--PWR, MFG--WEST., AE--STONE & WEBSTER

ACCESSION 140132

ARCING FAULTS FOUND IN MOTOR CONTROL CENTERS AT HATCH 2
3 PGS, LTR W/ATTACH. TO NRC OFFICE OF I & E, REGION II, MAY 17, 1978, DOCKET 50-366, TYPE--BWR, MFG--GE, AE--SSI & BECHTEL

ACCESSION 140140

LOSS OF ALL OFF SITE POWER SCRAMS THE REACTOR AT PILGRIM 1
2 PGS, LTR W/LER 78-035/01X-0 TO NRC OFFICE OF I & E, REGION I, AUG. 8, 1978, DOCKET 50-293, TYPE--BWR, MFG--GE, AE--BECHTEL

ACCESSION 148770

OFF SITE POWER LOST WHEN JUMPER CABLE BURNED OFF AT COOK 1
LTR W/LER 79-026 TO U.S. NRC, REGION 3, MAY 02, 1979, DOCKET 50-315,
TYPE--PWR, MFG--WEST, AE--AEP CONTROL--025580

ACCESSION 149180

IMPROPER ROUTED POWER AND CONTROL CABLES AT PEACH BOTTOM 2
LTR W/LER 79-010 TO U.S. NRC, REGION 1, MAR 12, 1979, DOCKET 50-277,
TYPE--BWR, MFG--GE, AE--BECH CONTROL--025316

ACCESSION 149321

POTENTIAL OVERLOAD CONDITION FOUND ON STATION TRANSFER BUSES AT NORTH ANNA 1
LTR W/LER 79-057 TO U.S. NRC, REGION 2, MAY 04, 1979, DOCKET 50-338,
TYPE--PWR, MFG--WEST, AE--S+W CONTROL--025749

ACCESSION 149941

GROUND FAULT RESULTS IN LOSS OF 3 STATION POWER TRANSFORMERS AT SALEM 1
LTR W/LER 79-038 TO U.S. NRC, REGION 1, MAY 15, 1979, DOCKET 50-272,
TYPE--PWR, MFG--WEST, AE--PSEG CONTROL--026008

ACCESSION 150285

INSULATION CRACKS FOUND IN BUS SLEEVING AT CRYSTAL RIVER 3
LTR W/LER 79-054 TO U.S. NRC, REGION 2, JUN 15, 1979, DOCKET 50-302,
TYPE--PWR, MFG--B+W, AE--GIL CONTROL--026209

ACCESSION 152271

GROUND FAULT RESULT IN LOSS OF THREE STATION POWER TRANSFORMERS AT SALEM 1
4 PGS, LTR W/RO 79-38/03L TO NRC OFFICE OF I & E, REGION I, MAY 15, 1979, DOCKET 50-272, TYPE--PWR, MFG--WEST., AE--PSE&G

ACCESSION 153603

CRACKING NOISE HEARD COMING FROM BREAKER OUTPUT CABLE AT NORTH ANNA 1
LTR W/LER 79-136 TO U.S. NRC, REGION 2, NOV 01, 1979, DOCKET 50-338,
TYPE--PWR, MFG--WEST, AE--S+W CONTROL--027601

ACCESSION 153801

CABLES DAMAGED WHEN PULLED THROUGH CONDUITS AT SUSQUEHANNA 1
LTR W/LER - TO U.S. NRC, REGION 1, JUL 17, 1979, DOCKET 50-387,
TYPE--BWR, MFG--GE, AE--BECH CONTROL--027731

ACCESSION 154453

NEUTRAL LEADS FROM DG TO TRANSFORMER CUT AT CONNECTICUT YANKEE
3 PGS, LTR W/LER 80-02/3L TO NRC OFFICE OF I & E, REGION I, JAN. 18, 1980, DOCKET 50-213, TYPE--PWR, MFG--WEST, AE--S&W

ACCESSION 155413

OFF-SITE POWER SOURCE LOST AT SALEM 1
LTR W/LER 80-014 TO U.S. NRC, REGION 1, MAR 31, 1980, DOCKET 50-272, TYPE--PWR, MFG--WEST, AE--PSE&G

ACCESSION 156960

FEEDER BUS FAULT TRIPS RECIRCULATION PUMP AT BROWNS FERRY 1
LTR W/LER 80-031 TO U.S. NRC, REGION 2, MAY 14, 1980, DOCKET 50-259, TYPE--BWR, MFG--GE, AE--TVA

ACCESSION 158232

OFFSITE POWER LOST AT INDIAN POINT 2
LTR W/LER 80-006 TO U.S. NRC, REGION 1, JUN 17, 1980, DOCKET 50-247, TYPE--PWR, MFG--WEST, AE--UE&C

ACCESSION 159238

OFFSITE POWER LOST AT INDIAN POINT 3
LTR W/LER 80-008 TO U.S. NRC, REGION 1, JUL 2, 1980, DOCKET 50-286, TYPE--PWR, MFG--WEST, AE--UE&C

ACCESSION 160554

ELECTRIC POWER DISRUPTED AT SURRY 2
LTR W/LER 80-035 TO U.S. NRC, REGION 2, NOV 13, 1980, DOCKET 50-281, TYPE--PWR, MFG--WEST, AE--S&W

ACCESSION 164310

UPDATE ON LOSS OF ONE OFF SITE POWER SOURCE AT CALVERT CLIFFS 1
LTR W/LER 80-043R TO U.S. NRC, REGION 1, FEB 23, 1981, DOCKET 50-317, TYPE--PWR, MFG--COMB, AE--BECH, DCS NO.--8103040654

ACCESSION 165482

ESF VENTILATION TRAIN INOPERABLE FOR VALVE POWER CABLE WORK AT COOK 1
LTR W/LER 81-006 TO U.S. NRC, REGION 3, APR 9, 1981, DOCKET 50-315, TYPE--PWR, MFG--WEST, AE--UTILITY, DCS NO.--8104160370

ACCESSION 166069

OFF SITE POWER LINE TRIPS AT BROWNS FERRY 1
LTR W/LER 81-013 TO U.S. NRC, REGION 2, MAY 19, 1981, DOCKET 50-259,
TYPE--BWR, MFG--GE, AE--TVA, DCS NO.--8105260468

ACCESSION 166070

OFF SITE POWER LINE TRIPS AT BROWNS FERRY 1
LTR W/LER 81-012 TO U.S. NRC, REGION 2, MAY 19, 1981, DOCKET 50-259,
TYPE--BWR, MFG--GE, AE--TVA, DCS NO.--8105260475

ACCESSION 166479

OFF SITE 115KV SUPPLY BREAKER TRIPS AT FITZPATRICK
LTR W/LER 81-042 TO U.S. NRC, REGION 1, JUN 11, 1981, DOCKET
50-333, TYPE--BWR, MFG--GE, AE--S&W, DCS NO.--810617007

ACCESSION 170051

69KV ALTERNATE SOURCE LOST WHEN JUMPER FAILS AT COOK 1
LTR W/LER 81-049 TO U.S. NRC, REGION 3, OCT 30, 1981, DOCKET
50-315, TYPE--PWR, MFG--WEST, AE--UTILITY, DCS NO.--8111090695

ACCESSION 172660

RESERVE STATION SERVICE TRANSFORMER LOST AT SURRY 2
LTR W/LER 82-008 TO U.S. NRC, REGION 2, FEB 17, 1982, DOCKET 50-281,
TYPE--PWR, MFG--WEST, AE--S&W, DCS NO.--8203080222

ACCESSION 172713

UPDATE ON SHUTDOWN DUE TO LOSS VITAL AC AT COOK 2
LTR W/LER 81-027 REV 1 TO U.S. NRC, REGION 3, MAR 17, 1982, DOCKET
50-316, TYPE--PWR, MFG--WEST, AE--UTILITY, DCS NO.--8203260260

OTHERWISE SIGNIFICANT

ACCESSION 129293

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ACCESSION 131157

HUMAN FACTORS REVIEW OF NUCLEAR POWER PLANT CONTROL ROOM DESIGN. FINAL REPORT
EPRI-NP-309(FINAL REPORT) +. 375 PPS, TABS, FIGS, REFS, MARCH 1977

ACCESSION 143495

600 VAC INTRODUCED INTO 115 VAC REFUELING INTERLOCK CIRCUIT AT FITZPATRICK
3 PGS, LTR W/LER 77-43 TO U.S. NRC, REGION I, AUG. 11, 1977, DOCKET 50-333, TYPE--BWR, MFG--GE, AE--STONE & WEBSTER

ACCESSION 152844

CABLE LEADS TO EMERGENCY FEEDWATER VALVES WERE LIFTED AT ARKANSAS NUCLEAR 1
2 PGS, LTR W/LER 79-NA/99X-0 TO NRC OFFICE OF I & E, REGION IV, AUG. 1, 1979, DOCKET 50-313, TYPE--PWR, MFG--B&W, AE--BECHTEL

ACCESSION 154694

A FIRE IN SOME ELECTRICAL RACEWAYS COULD EFFECT REDUNDANT TRAINS AT PILGRIM 1
3 PGS, LTR W/LER 80-001/01T-0 TO NRC OFFICE OF I & E, REGION I, FEB. 1, 1980, DOCKET 50-293, TYPE--BWR, MFG--GE, AE--BECH

ACCESSION 161016

HUMAN FACTORS METHODS FOR NUCLEAR CONTROL ROOM DESIGN VOLUME 4: HUMAN FACTORS CONSIDERATIONS FOR ADVANCED CONTROL BOARD DESIGN
EPRI-NP-1118(VOL.4) +. 115 PPS, FIGS, MARCH 1980

ACCESSION 161704

OUT OF PHASE POWER TRANSFER POSSIBLE AT NORTH ANNA 1 AND 2
LTR W/LER 80-096 TO U.S. NRC, REGION 2, NOV 21, 1980, DOCKET 50-338, TYPE--PWR, MFG--WEST, AE--S&W, DCS NO.--8012010363

ACCESSION 163959

SUMMARY OF RESULTS OF NRC HUMAN ENGINEERING AUDIT OF NORTH ANNA 2 CONTROL ROOM
5 PGS, LTR W/ENC. TO VIRGINIA ELECTRIC & POWER CO., APR. 11, 1980, DOCKET 50-339, TYPE--PWR, MFG--WEST, AE--S&W, DCS NO.--8004250031

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Appendix B

GIDEP SYSTEMS

Alert System

The ALERT system provides the GIDEP participants with wide, early, and rapid notification of actual and potential problems and failure trends on parts, components, materials, manufacturing processes, test equipment, or significant safety (SAFE-ALERT) problems of general concern. This is accomplished by ALERT and SAFE-ALERT reports. The ALERT data constitutes a large portion of the computerized Failure Experience Data Bank (FEDB).

Scope

The ALERT system is utilized by participating agencies to provide a rapid closed-loop interchange between the GIDEP participants and the product manufacturer.

General

The timely submittal of data from the GIDEP participants to the GIDEP Operations Center is essential. Timely submittal allows rapid dissemination of data to all participants.

Participants are required to be a member of the Failure Experience Data Interchange in order to receive ALERTS.

ALERT/SAFE-ALERT reports are submitted on an approved ALERT Form (DD Form 1938) which has been cleared for joint contractor and Government use.

ALERT and SAFE-ALERT Requirements

The GIDEP participant initiates an ALERT for certain situations involving a problem of general concern pertaining to parts, materials, or manufacturing processes, or a SAFE-ALERT pertaining to a "safety" problem.

The ALERT is intended to define an actual or potential problem/failure of a common or generic part, component, material, or process. ALERTs will not be prepared to report a random failure of a part, component, material, or process.

The problem must be clearly, concisely, and objectively described, stating the exact conditions and circumstances surrounding the problem, as well as the failure mode, causes and corrective actions, if known. The ALERT must stand alone for interpretation since participants receiving the ALERT will not have the background information available to the originator.

Copies of all necessary supporting documentation shall be submitted with the ALERT including any affected manufacturer's comments and a copy of the transmittal letter that forwarded the proposed ALERT to the manufacturer for coordination.

A copy of the ALERT shall be submitted to the manufacturer. The manufacturer must be provided an opportunity to review, comment, and/or present corrective action on the problem identified in the ALERT prior to distribution through GIDEP. The coordinating time has been established as a minimum of 15 working days.

Due to criticality and possible injury to personnel, SAFE-ALERTs should be submitted concurrently and coordinated with the manufacturer simultaneously with submittal to the GIDEP Operations Center.

The recommended method for transmittal of the ALERT to the manufacturer is by "Certified Mail," with return receipt requested.

GIDEP Representative Responsibilities

a. Develop a program to ensure that all problems at his facility which constitute the basis for a potential ALERT are reported to him.
b. Ensure that the manufacturer's comments are solicited to give the recipients a complete picture of the problem.
c. Define the problem as specifically as possible.
d. Include all backup data.

GIDEP Representative Responsibilities (ALERT Recipient)

a. Screen ALERT for applicability and distribute.
b. Provide all additional and pertinent experience information immediately to the originator and to the GIDEP Operations Center.
c. Report to the GIDEP Operations Center follow-up information or corrective actions that result from the ALERT and would be of interest to the ALERT originator or other Representatives.

ALERT Processing and Distribution

a. To distinguish between the ALERT and the SAFE-ALERT, the ALERTs are reproduced on light red (pink) paper, and the SAFE-ALERTs are reproduced on green paper.
b. All ALERTs are abstracted and key-entered into the computer at the GIDEP Operations Center.
c. The GIDEP Operations Center issues monthly and cumulative indexes of all ALERTs to GIDEP participants.

GIDEP representatives

Participant-to-participant communication is effective by use of the Roster of Representatives.

Reliability-Maintainability Data Interchange

Introduction

This section describes the operating procedures for the Reliability-Maintainability Data Interchange portion of the Government-Industry Data Exchange Program.

Scope

The Reliability-Maintainability Data Interchange was established to provide an interchange of reliability and maintainability data on parts, components, assemblies, equipments, subsystems and systems based on field performance information and reliability/maintainability demonstration tests on operational systems and equipments.

General

Participants submit data to the Reliability-Maintainability Data Bank (RMDB).

Government and Contractor Organizations developing or monitoring hardware systems and equipment submit failure rate, failure mode, replacement rate, and mean repair time data on parts, components, assemblies, equipment, subsystems and systems.

Manufacturers

Reliability-Maintainability data may be submitted by manufacturers of parts, components, assemblies, equipment, subsystems and systems provided the supporting test data are included and the data meet requirements for Manufacturer Test Data.

Data Dissemination and Retrieval

The GIDEP Operations Center reviews, compiles, and summarizes the Reliability-Maintainability Data received from a GIDEP participant and distributes these data to other participants by the following media:

Microfilm
Printed summaries
Remote computer terminal
Technical document file.

Urgent Data Request System

The Urgent Data Request System allows any participant to query all other participants to solve problems on specific parts, components, materials, processes, or to request other critical information not available from other sources.

The ALERT system
Participant-to-participant communication.

Appendix C

BIBLIOGRAPHY

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Appendix D

SAMPLE FAILURE REPORTS

To the Files

____________, Power Plant Maintenance Supervisor, Electrical

May 15, 1968

500-KV ____ TRANSFORMER, SERIAL NO. ________

On May 6, 1968, at 4:28 a.m., a high- or low-gas pressure alarm on No. 5 transformer bank was recorded. At 7:30 a.m. the shift engineer passed this information along verbally to __________, Assistant Electrical Maintenance Supervisor. __________ made out a maintenance report and had electricians assigned to the job. The first step was to find which transformer had the high- or low-gas annunciation on it. There are two contacts on each of the four transformers in parallel and all are common to one annunciator point. The annunciation was found to be on spare transformer which was being used on AØ at this time.

Mr. _________________ erecting engineer, was on the job erecting AØ transformer. He was contacted and told about the high-gas pressure alarm. While the electricians were gone to get the Johnson & Williams combustible gas analyzer Mr. ______ opened the sampling valve and used a cigarette lighter to determine if the gas was combustible. The gas proved to be highly combustible, and when ignited it set fire to the plasic hose that was being used on the valve. The transformer was checked and an arcing noise was heard in the high side bushing well. The transformer was taken out of service immediately.

Mr. ______ contacted his company and they decided that the arc was corona at the bottom end of high side bushing between the conductor or live part of bushing to the shielding body called a "torrid" by ____. The 500-kV bushing was removed from the bushing well. The shielding body had been shaken loose or had vibrated loose from its attachment on the conductor just below where the conductor entered the bushing. The shielding body showed some signs that the bushing well in which it was installed had some very hard blows during shipment. One of the three aluminum fingers which attach the shielding body to the bushing conductor had a 90 degree bend in it. This bent finger had no signs of arcing on it but the other two fingers showed signs of considerable arcing on the ends of each where they had been loose between the attachments on the bushing conductor. This no doubt, was causing the combustible gas to form in the transformer.

Mr. ________________ design engineer, arrived on the job May 7, 1968. He made several calls to ______ regarding how to correct the trouble on the transformer. He suggested to the factory that the complete bushing well assembly from A phase be installed on the spare, but the factory said that the bushing wells were not interchangeable. They told Mr. _________ to remove the shielding body from A phase bushing well and install it in place of the bad one on the spare. Someone decided to pull the complete bushing well of the spare transformer and take it to the turbine room for repairs. The oil was pumped out of the transformer and the transformer filled with nitrogen as the oil was pumped down to below the bushing well boss. The bushing well was removed and taken to the turbine room where it was partially disassembled.

An attempt was made to install the shielding body in the insulating tube without complete disassembly but they found this could not be done, so the bushing housing was completely disassembled and all the insulation removed from it. The shielding body was installed in the insulator tube and tied off, and the insulation was retied with cotton and linen tape and reinstalled in bushing well. The bushing well was reassembled and each end closed up. Electric heaters (4 each 4 kW) were installed in one end of bushing well and the temperature raised to 90 degrees F for approximately six hours on May 10, 1968. A vacuum was pulled on bushing well after noon on May 10, 1968, and left until 7:00 a.m., May 11, 1968.

The bushing well was installed on the spare transformer May 11, 1968. The transformer was purged with nitrogen during the installation of the bushing well and bushing. The bushing was also installed about noon May 11, during a rain shower.

During the time the spare transformer bushing was being repaired with parts from A phase the shielding body removed from the spare was repaired. Crepe paper was flown in from ______, also some cotton tape, and the shielding body was reinsulated with the crepe paper to a thickness of 50 millimeters, (about two inches) or enough for 2 million volts. The shielding body was placed in the electric shop drying oven at a temperature of 212 degrees F and left for 24 hours. After this it was installed in the insulator tube, and the bushing well and insulation reassembled. After being reassembled it was heated and a vacuum pulled on it same as the other bushing well.

TO: ______________

FROM: ____________, Power Plant Maintenance Supervisor, Electrical

DATE: June 4, 1970

SUBJECT: POWER CIRCUIT BREAKER 5224

On June 3, 1970, at 10:01 a.m. breaker 5224 was opened by operator to deenergize the ______________________. At 10:02 a.m. on this date the motor-operated switches 5223 and 5225 were opened to isolate breaker 5224. At 10:30 a.m. on this date the operator received an air pressure abnormal annunciation on breaker 5224. At 10:42 a.m. the switchboard operator received a telephone call from Mr. ______, electrician foreman for Power Construction, who was working in the switchyard, that breaker 5224 had blown up.

The writer received a call for shift engineer ___________ at approximately 10:45 a.m. about the trouble on 5224 breaker.

An immediate investigation was begun to try and determine what damage was done and what caused it.

We found that on A phase head number 4, the tripping resistor assembly had blown completely off the breaker and was scattered over a wide area of the switchyard.

When the resistor assembly blew parts of it were blown into the capacitor on the respective head and had damaged the capacitor; also considerable damage was done to the main chamber porcelain by flying parts. Further investigation revealed that the guy insulator on pole # 4 had several broken skirts on it.

The writer contacted _________ with Electrical Maintenance in ___________ and explained to him what had happened and asked him to contact _______, the manufacturer of the breaker and find out if these resistors, which have been known to cause trouble for some time on other breakers like this, had caused this type of trouble before.

_________ called back later and said that Mr. _______ and Mr. _____, both _______ representatives, would be at _______ on the morning of June 4, 1970, and that they would like for us to leave the breaker as it is until they could inspect it.

As for the cause of the trouble it is my opinion that the resistor was broken off of its mechanical support but was still connected electrically and when the breaker was opened the resistor contact closed as it should but never opened as it should, thus letting current pass through the resistor and through the capacitors on the other three heads until the disconnect switches were opened.

POWER CIRCUIT BREAKER 5224

After the disconnect switches were opened the capacitor on the respective head was discharged through the resistor. The current passing through the resistor caused a tremendous amount of heat to be generated inside the resistor chamber which is filled with air at 365 psi. The heat caused the air to expand until the pressure built up beyond the bursting pressure of the porcelain resistor chamber so it exploded.

As has been stated before, on this type of breaker the tripping resistor supports have been known to break off. We have known for several months that these resistors were to be removed from the breaker and the holes blanked off with a special cover to be furnished by _______. The latest correspondence from _______ on this matter was that the blank covers would be furnished to ___ in July 1970.

TO: ________________, Steam-Electric Generation Branch, 905 EB-C

FROM: ________________, Power Plant Superintendent, ________________

DATE: March 13, 1973

SUBJECT: 1H UNIT STATION SERVICE TRANSFORMER INTERNAL EXPLOSION - ____________________

On February 17, 1973, at 12:51 p.m. operating time, the 1H unit station service transformer was severely damaged by an internal explosion. This transformer was built by ______. It is a type TCR, 13,500 kVA S.C./ 18,000 kVA F.A., 22,500 volts delta to 6,900-V wye, serial No. 2056225.

Following is a list of events that occurred when the transformer went into trouble. The events are listed in the order that they were printed out on the electrical control room Lundell sequential annunciator recorder although this does not mean that they necessarily happened in this order.

12:51-14		1H U.S.S. transformer high temperature -	abnormal
12:51-14	2 Cy.	'' '' '' low oil level	''
12:51-14		Turbine shut down	''
12:51-14	4 Cy.	1H U.S.S. transformer high temperature -	normal
12:51-14	4 Cy.	'' '' '' relay operation -	abnormal
''	''	'' '' '' low oil level -	normal
''	''	'' '' '' high or low gas pressure -	abnormal
''	''	OCB 878 open -	abnormal
''	''	OCB 874 ''	''
''	''	1H transformer sprinkler system on -	abnormal
''	''	'' '' differential or sudden pressure relay operation -	''
''	''	1H U.S.S. high or low gas pressure -	normal
''	''	Generator backup relay operation -	abnormal
''	''	250-Volt d.c. or 480-V d.c. ground -	abnormal
''	''	1H U.S.S. transformer high or low gas pressure -	abnormal
''	''	'' '' '' '' '' ''	abnormal
''	''	250-Volt d.c. or 48-volt d.c. ground -	normal
''	''	1H U.S.S. transformer relay operation -	normal
''	''	'' '' '' high or low gas pressure -	abnormal
''	7 Cy.	1H U.S.S. transformer high or low gas pressure -	normal
''	''	Unit 6.9 kV board transfer -	abnormal
''	''	Oscillograph operation -	normal

March 13, 1973

1H UNIT STATION SERVICE TRANSFORMER INTERNAL EXPLOSION -

12:51-14	7 Cy.	1H generator overcurrent relay operation -	abnormal
''	''	1H generator neutral overvoltage relay operation -	normal

This Lundell recorder has been fairly reliable in the past with the exception that it will give erroneous annunciations at times when switching is being performed in the station or when grounds occur on the annunciation system. There are at least two points that were missed on the above list. One is the oscillograph annunciation that was not printed abnormal and the other was 1H generator neutral overvoltage relay abnormal annunciation. We have no reason to doubt that what annunciations that were recorded are correct. There is a very good possibility that these are not recorded in the sequence as they actually happened due to some things such as the transformer high temperature and low oil level coming in directly off a switch and not having to come through a relay. Also, there are others such as the turbine shutdown annunciation that are relayed by a much faster operating relay than the transformer relay operation annunciation.

The Lundell sequential annunciator recorder in the unit control room recorded the following events:

12:51-24		Power available 1H auxiliary oil pump -	abnormal
''		'' '' a.c. turning gear oil pump -	abnormal
12:51-24	3 Cy.	'' '' 1H auxiliary oil pump -	normal
''	5 Cy.	Power available 1H auxiliary oil pump -	abnormal
''	7 Cy.	Turbine tripped electrical trouble -	abnormal
''	''	Power available 1H auxiliary oil pump -	normal
''	10 Cy.	Generator oil circuit breakers open -	abnormal

The above listed annunciations are most likely in the sequence as they actually happened and are correct annunciations. The unit control room system was ten seconds faster than the electrical control system when checked after the fault. There is no possible way of comparing the two annunciator system annunciations to tell which may have occurred first since the same annunciations, such as oil circuit breakers open, are actuated from different switches and relays.

We are confident that we lost the voltage on the 1H 480-volt unit board at 14 seconds after 12:51 p.m. when the power available - 1H auxiliary oil pump abnormal annunciation was received in the unit control room since the relay that gives this annunciation is connected across the 1H 480-volt board bus potential transformers. Also, the power available a.c. turning gear oil pump abnormal anunciation was received in the same cycle; this relay also is fed from the 1H unit board bus.

The following protective relays had targets on them as recorded by the electrical operator:

1. 1H main transformer differential A, B, and C phase
2. 1H unit transformer overcurrent A and B phase
3. 1H unit station service differential A phase
4. 1H generator overcurrent A and B phase
5. 1H generator backup impedance
6. 1L generator overcurrent A, B, and C phase

We know by the annunciations that were recorded that other auxiliary relays such as the neutral voltage auxiliary relay and possibly the sudden pressure relay operated but apparently did not knock the target down.

At some point shortly before or during the fault on the transformer, 1B5 pulverizer was tripped by overcurrent relay. This was caused by a phase-to-phase fault behind the 1H 6,900-volt unit board where the pulverizer motor leads tie to the bus. A welding rod was found laying across B phase bus. There was slight damage to the bus on all three phases (see attached photo No. 1) and some damage top the tape on the bus for approximately 18 inches above the fault. It is very possible that the primary of the transformer shorted to the secondary and the 24-kV got back on the 6.9-kV bus about the time the feeder breakers were opened and the welding rod across B phase was the weakest spot on the bus so it arced across. No other damage was found on the 6,900-volt bus. It is possible that the fault on the pulverizer circuit occurred before the fault on the transformer and could have contributed to the transformer fault, but due to the slight amount of damage on the pulverizer circuit and the high overcurrent relay setting, we think the transformer fault occurred first. The pulverizer circuit damage appeared to be caused by a high voltage and a low current condition which lasted only a cycle or so.

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1H UNIT STATION SERVICE TRANSFORMER INTERNAL EXPLOSION - ____________ ____________

It seems to be almost impossible to tell whether or not all protective relays and auxiliary relays functioned as they should have. The Westinghouse sudden pressure device and the circuit were checked and no trouble was found except that the control cable to the unit was blown into, but no doubt this was done after the fault. The bellows in the sudden pressure device were distorted indicating the device may have operated. We believe that sudden pressure relay may have picked up and it should have but the target apparently was not activated. We are positive that the generator neutral over-voltage relay picked up but probably did not activate the target. This is the same type relay as the sudden pressure which is a Westinghouse type SV and the targets are not very reliable on this type relay. Also, the transformer pressure relief device was inspected and no trouble was found on it. It did have a target showing that it had been activated. Apparently the internal pressure was built up so fast that the pressure relief device set at 10 psig could not relieve the pressure as fast as it was accumulated.

The generator backup relay, generator overcurrent relay, and generator neutral voltage relay all apparently operated after the oil circuit breakers and exciter field breakers were opened. The reason for this being the voltage generated by the residual magnetism in the field and the exciter. The low-pressure turbogenerator rolled for 100 minutes after it was tripped and the high-pressure turbogenerator rolled 27 minutes after it was tripped. This means that some amount of current was being pushed through the faulted transformer at a rate governed by the gradual decrease in speed on the turbogenerators. The sprinkler system was shut off after approximately twenty minutes of continuous operation and as soon as it was shut off the oil and insulation reignited and the sprinkler system was turned back on. This happened several times when the sprinkler system was turned off.

After making an assessment of the damage and evaluating the sequential annunciator data and the relay operations as recorded by the operator, a clearance was obtained and grounds placed on the unit.

The 1H unit transformer was disconnected from the generator isolated phase bus. Most of the isolated phase bus housing and bus connectors between the unit transformer and the generator bus was damaged and this had to be

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removed and the opening on the generator bus housing closed. This required some heli-arc welding on the housing.

The bus housing cooling fans had pulled oil and soot into the 1H generator isolated phase bus housing, thus coating the insulators especially on C phase. All these were cleaned. All main transformer bushings and insulators had to be cleaned. After cleaning, the 1H generator isolated phase bus was disconnected at the generator and meggered. Also, the 1H generator was meggered. Each was within normal limits. A bushing was broken on the 1L main transformer neutral reactor and this was patched with epoxy.

The 1H and 1L main transformers were disconnected, bridged, tested using the Doble procedure, meggered, and a ratio check made. Both transformers indicated abnormal Doble readings, but the readings on each transformer were identical. A different Doble set was secured from ________ and the check made. This set indicated the tests were within normal limits. The transformers and 1H generator were reconnected and the unit was released for service at 9:00 p.m. February 18, 1973, which was 32 hours and 9 minutes after the trip.

It is the writer's opinion that the most likely cause of the fault was a breakdown in turn-to-turn insulation on the winding which caused a rapid rise in oil and hot spot temperatures. We base this statement on the facts that we received; a transformer high temperature annunciation and that the transformer oil temperature gauge maximum temperature indicating hand was locked off scale at 120°C and the hot spot temperature gauge maximum temperature hand was locked at 145°C.

The fault on the transformer winding was no doubt adjacent to the bulbs on the temperature indicators which are located approximately one foot from the top, down on the side near the center of the transformer. The fault most probably started on (B) phase winding or the no load tap changer although the contacts on the tap changer were not burned or pitted.

Combustible gas tests have been made monthly on this transformer since it was put in service in 1966 and no excessive gas readings have been recorded. The last test was made February 5, 1973, at which time the combustible gas reading was .05 percent. The transformer temperature has never been excessive and the fans only needed to run on the hottest summer days. The O_2 analysis has also been run monthly on this transformer and the readings were always within the established limits.

There has been some doubt expressed as to whether the basic insulation level voltage is as high as it should be on this type transformer due to the way it is being used. There seems to be some proof that it may not be high enough due to the fact that each time the transformer winding is tested using the Doble procedure the power factor readings continue to show a slight increase. We think this problem merits some further study to see if this may be the cause of some transformer failures.

Our conclusions are that the transformer and auxiliaries were damaged to the extent that it would not be economically feasible to repair it. Six of the eight radiators were damaged beyond repair. These radiators are machine made and welded onto the transformer. Three cooling fans were damaged. All current transformers were damaged. The temperature and liquid level indicators were damaged. The transformer tank walls and top were damaged beyond repair (see attached photographs). The no-load tap changer was damaged beyond repair. All bushings were broken and the bus housing adaptors on the transformers were damaged. See attached estimate made for repairing transformer by service shops.

There is no record here as to how much voltage is generated at any given rpm on the turbogenerators with the exciter field breakers open, but a recording amp meter and volt meter will be installed to record the current and voltage from turning gear to half speed before the exciter field breakers are closed. A rough check was made at 300 rpm when the unit was restored to service after the fault, and approximately 300 volts were read with exciter field breakers <u>open</u>. With a turbogenerator and transformers connected as these were, we feel that a breaker to open the exciter output to the generator field with short circuiting resistors might be of some value.

We also feel that a sprinkler system around the hydrogen regulating station in the transformer yard might prevent a hydrogen explosion in the

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1H UNIT STATION SERVICE TRANSFORMER INTERNAL EXPLOSION - ____________

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future. A considerable amount of insulation oil and debris were blown onto the hydrogen station when the transformer exploded.

Under conditions such as this the isolated phase bus cooling system should be deenergized. This should be done when any electrical trip relay is picked up. Also, there should be an annunciator point on each exciter field breaker connected to the electrical control wing sequential annunciator recorder. There should be at least two common circuits from electrical trip relays connected to both the electrical control room sequential recorder and the unit control room sequential recorder. There should be a separate annunciator point for the transformer differential relay operation and the transformer sudden pressure relay operation, both on the unit station service transformer and the main transformer relays.

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RLT:DJS
Attachments

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The electrical equipment failures of both nuclear and nonnuclear public utilities were reviewed. Those failures that could pose an additional problem to surrounding and connected equipment were defined. The literature was searched; utilities, repair shops, and large electrical equipment users were contacted for failure information. The data were reviewed in detail, and failure modes were determined. Sample cascade failures are discussed. The failure rate of electrical equipment in utilities is historically quite low. Nuclear plants record too few failures to be statistically valid, but failures that have been recorded show that good design usually restricts the failure to a single piece of equipment.

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