POWER FOCUS TEAM ANALYSIS

1. Executive Summary

The Network Reliability Council Steering Team established the Power Focus Team as one of seven teams examining the reliability of the United States public switched network (PSN). The mission of the Power Focus Team is to discover and report information that could be used to drive central office[a] power system-related catastrophic outages to zero and minimize the occurrence of less severe outages. The team worked from June 1992 to March 1993. During that period, the team collected data on PSN telecommunications service disruptions related to central office power system outages, analyzed the data to determine the root causes of these outages, and compiled recommendations and industry best practices related to the design and operation of central office power systems. The results of this effort are reported in this paper.

Telecommunications service providers in the United States have made substantial financial investments in central office power systems. These systems convert power supplied from electric utilities and distribute it to various loads within the central office and provide a source of backup power when power from the utility is disrupted. The data collected by the Power Focus Team indicates that central office power systems in the United States are highly reliable. There were only 119 total central office/switch outages reported among over 10,000 central offices during a 27-month period, suggesting a mean time between failure for central office power systems of nearly 200 years. When central office power systems do fail, however, the impact on telecommunications service can be very serious. The Power Focus Team surveyed telephone service providers in the United States to determine the root causes of telecommunications service disruptions related to central office power system failures. Industry response to the questionnaire used to conduct the survey was excellent, reporting details of 294 incidents (both outages and "near misses") that occurred between June 1990 and September 1992.

The results of a root cause analysis conducted using the data in the questionnaires revealed two major groupings of central office power system root causes:

- Operational factors--telephone company worker error, installation vendor error, procedures missing or inadequate, lack of routine maintenance, no alarms or inadequate alarms, and failure to respond to alarms accounted for 58 percent of reported outages.
- Application engineering and design--lightning-related failures, equipment malfunctions, overloaded and/or undersized power equipment, and design deficiencies accounted for 42 percent of reported outages.

This data was compared with data reported to the FCC on significant service outages in the PSN occurring between April and December 1992. There was significant correlation between the FCC data and the data derived from the industry survey. The survey also reported recommendations from the service providers about how these incidents might be avoided in the future. This information was grouped into the same two categories as the root causes:

- Operational factors--vendor method operating procedure (MOP), alarm systems and alarm response, and maintenance accounted for 69 percent of the recommendations.
- Applications engineering and design--design modernization needs, circuit breakers, power distribution diversity, grounding, and environmental concerns accounted for 31 percent of the recommendations.

a The term central office is used throughout this report because the majority of data analyzed was for central offices. However, the findings and recommendations of this report can be applied to any telecommunications facility power system.

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The final step the Power Focus Team undertook was to share information resident within the team regarding recommendations and industry best practices to improve central office power system reliability. The most significant recommendations for telecommunications service providers include the following:

- Place strongest emphasis on resolving the operational factors in central office power system outages related to human activity. Candidates for improvement include equipment design and product selection based on simplicity of design and maintenance, alarm system operation and alarm response procedures, equipment installation and removal procedures especially where vendors are involved, maintenance program design and implementation, and training for craft personnel.
- Ensure that central office power system designs eliminate the possibility of serious service outages owing to single points of failure.
- Employ specialized power teams for central office power system operation and maintenance.
- Maintain and exercise detailed site-specific power failure procedures and contingency plans for all central offices including procedures for disconnecting AC and DC power in a fire emergency.
- Provide tap boxes outside central offices to facilitate connection of large portable generators when stationary central office generators are inoperative.
- Adhere to the following standards:
  - TR-NWT-000063, *Network Equipment Building Systems (NEBS)*[1]
  - ANSI T1.311-1992, *DC Power Systems - Telecommunications Environmental Protection.*[2]
- Coordinate with electric utilities to ensure that critical telecommunications facilities identified in the Telecommunications Electric Service Priority initiative are afforded priority restoration treatment in electric power utility disaster recovery plans. This initiative was developed by the National Communications System and is currently being implemented by the Department of Energy's Office of Emergency Planning and Operations.
- Adhere to established industry best practices[b] for central office power system design and operation. The Power Focus Team compiled recommendations and industry best practices in the report for the following aspects of central office power system operation and design:
  - Commercial power/electric utility issues
  - Standby generators
  - Building AC systems
  - DC plants
  - DC distribution systems
  - Alarms and remote monitoring
  - Operations and maintenance
  - Installation/removal work.

The Fire Prevention Focus Team identified power equipment as their top concern and recommended countermeasures. These are contained in Section 7.2 of their technical paper. The Power Focus Team endorses the power-related findings and countermeasures of the Fire Prevention Focus Team. Countermeasures contained herein relating to "fire prevention" are so designated.

b The expression "best practices" as used in this Technical Paper means: "Best practices" are those countermeasures (but not the only countermeasures) which go furthest in eliminating the root cause(s) of outages. None of the practices are construed to be mandatory; however, a very small number of countermeasures that are deemed by the Focus Team, and concurred by the Network Reliability Steering Team (NO REST), to be especially effective countermeasures will be designated as "recommended" in the Technical Paper.

Service providers are strongly encouraged to study and assess the applicability of all countermeasures for implementation in their companies and products, respectively. It is understood that all countermeasures, including those designated as "recommended", may not be applied universally.

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4.3 Analysis of Industry Power Outage Data

The data analysis subgroup met in closed session for 3 days to review the data compiled from the returned questionnaires. An initial sort of the data provided insight into the distribution of telecommunication service outages occurrences by:

- Time of day
- Day of the week
- Month of the year
- Duration of outage.

To determine the root causes of catastrophic telecommunications service outages, the data was further sorted by the following parameters:

- Number of outages by service affected
- Total downtime by service affected
- Number of outages by equipment type
- Number of outages by cause
- Downtime by equipment type
- Downtime by cause.

These initial sorts of the data indicated that some equipment types were involved in more outages than others and that one cause was a contributing factor in more outages than any other. These results are discussed in detail in Section 5 of the report. Given these initial indicators, the data analysis subgroup examined the particulars of each of the incidents involving the indicated equipment types and causes. The results of the data analysis were reviewed and debated by the entire Power Focus Team in open session. To further ensure the quality of the end result, each contribution to this technical paper was subjected to peer review by all other members of the Power Focus Team.

The subgroup sought to examine and correlate the questionnaire - derived data against another data set for validation. During review of the FCC outage reporting data, it was discovered that between April and December of 1992, 16 FCC reportable outages were attributable to power outages. These 16 outages were used as the second set of data to validate the data received through industry response.

4.4 Identification of Root Causes of Outages and Industry Best Practices

Of the 294 reported events, there were 374 contributing causes. To compile the root causes of outages at a higher level (and because the data lent itself to such aggregation), the team compiled the root causes analysis into two subsets: operational factors and application engineering/design Analysis of the data through these subsets highlighted underlying commonalities among root causes of outages.

To develop best practices, the team relied upon the industry data analysis as well as the extensive experience of the Power Focus Team. Significant quantities of valuable data were available for identification as best practices. To report this data effectively, best practices are reported at the element level (i.e. standby generators, DC plants, operations and maintenance). This approach enables more thorough reporting of best practices data than would have been possible if the data was compiled into the same two subsets used to report the root cause analysis results.

5. Types and Causes of Failures

5.1 Introduction

This section describes the types of failures revealed by examination of the data collected and provides a statistical breakdown of the significant causes. A typical central office[c] power system block diagram is depicted in Figure 1. The figure provides a basis for understanding the failure analysis that follows. The principal functions of the power system are to: convert alternating current (AC) from the electric utility to direct current (suitable for use by telecommunications equipment), provide filtering, and to provide AC/DC backup power if the electric utility loses power.

Understanding the basic operation of the central office power system is essential to understanding the findings and recommendations of this paper. To ensure that level of understanding, the operation of the power system shown in Figure 1 is described as follows:

c The term central office is used throughout this report because the majority of data analyzed was for central offices. However, the findings and recommendations of this report can be applied to any telecommunications facility power system.

Commercially supplied power enters the system through the AC transfer switchgear. If commercial power fails, the switchgear enables the cutover to power supplied by the engine alternator. Cutover is generally automatic, but not immediate. Immediately after a loss of commercial AC, DC power begins to flow from the batteries.[d]

After a suitable period the engine alternator is started and AC power is once more supplied to the rectifiers. DC power flowing from the output of the rectifiers then halts battery depletion. The rectifier output powers all downstream DC requirements either directly or through DC-to-DC converters that step voltage levels up or down to the levels required by the connected loads. Some of the DC output of the rectifiers is passed through an inverter where it is changed back to AC needed to drive downstream loads requiring AC such as minicomputers and tape drives. The engine alternator continues to supply AC power to the office until commercial AC power from the electric utility is restored.[e]

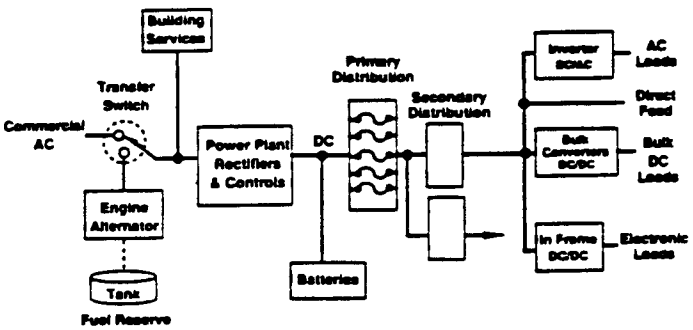


Figure 1. Typical Central Office Power System

d Generally, there is sufficient power in the batteries to sustain operations for a minimum of three hours or as long as 24 hours depending upon whether an office is attended or unattended, and the amount of travel time required to reach the facility.

e Fuel reserves for engine alternators are sized to last 36 hours to 3 weeks, depending on the amount of travel time required to provide fuel resupply and the size of the office.

5.2 Failure Analysis

Figure 2 shows that out of 294 reported events attributed to trouble in the central office power system there were 361 contributing equipment failures. The figure shows that commercial power failed in 70 of the 294 incidents.[f] Therefore, commercial power outages were a contributing factor in slightly less than one-quarter of the reported telecommunications service events attributed to central office power systems.

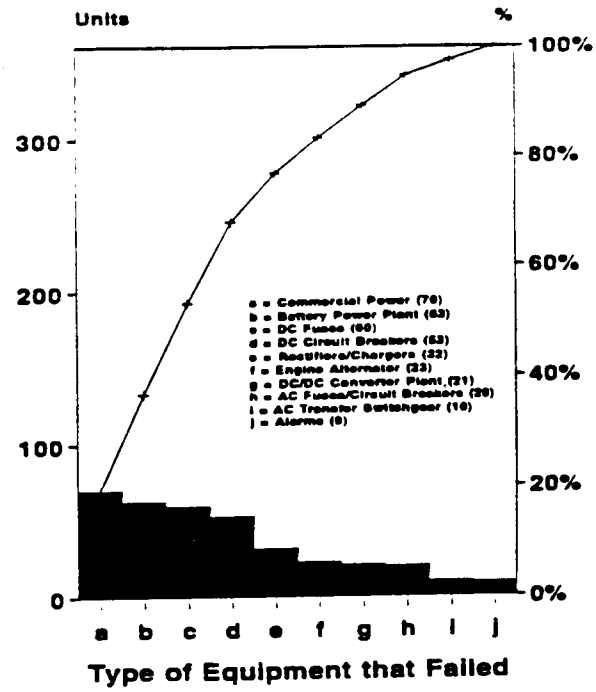


Figure 2. Types Of Equipment Failures

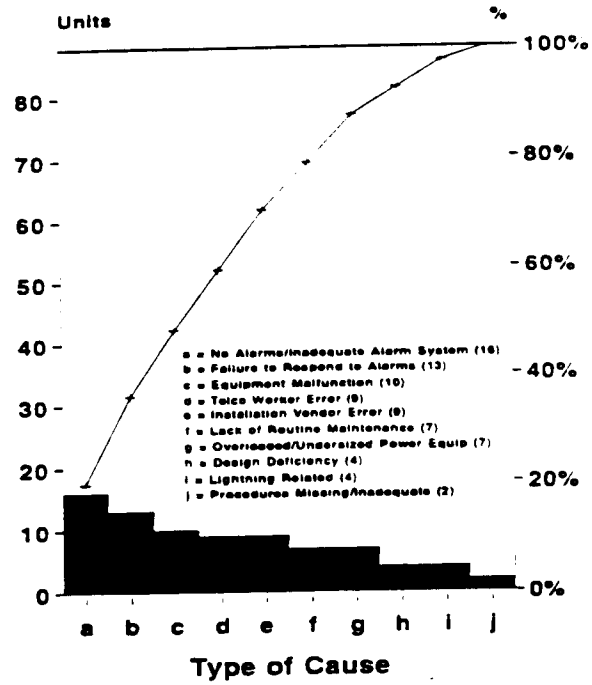
The data represented in Figure 2 shows that batteries compose the largest single category of equipment failure in the central office power system.[g] The total

f When commercial power fails, one or more other power system components must also fail to cause a disruption in telecommunications service. The fact that there were more equipment failures than telecommunications service disruptions indicates that in many incidents the survey results reported that more than one piece of equipment failed.

g There was an Other category that was substantial in quantity (67 equipment failures) but not significant statistically in that the equipment failures represented in it are not homogeneous. Therefore, it does not present great potential for power system reliability improvement.

portion of equipment failure represented by batteries is followed closely, however, by DC fuses and DC circuit breakers. Moreover, the latter two categories could logically be aggregated into one supercategory that is referred to as "DC Distribution Facilities." Doing so makes it readily apparent that problems in the distribution of DC power happen with a frequency that approaches twice that of failures in the batteries.[h] These problems occur due both to failures in the distribution system and faults in the connected load(s).

With the goal of driving catastrophic outages to zero in mind, the data analysis subgroup decided to concentrate on and further analyze outages due either to battery plant (batteries depleted) or DC distribution facilities. This appeared to be a reasonable approach because failures of commercial power, engines, AC switchgear, rectifiers, etc., do not typically cause outages unless they result in the batteries being depleted. Battery plant outages are usually serious because they affect an entire switch and associated transmission equipment. Failure of individual fuses is serious only when there is insufficient diversity. The most common characteristic among incidents involving batteries was that the battery operated properly, but while it was being depleted either no alarm alerted office personnel, or an alarm was sounded but not properly responded to. Taken together these account for more than one-third of all reported battery outages and are reported in Figure 3. Defective batteries accounted for only six percent of the reported battery plant outages. The seriousness of failures in the battery power plant should not be overlooked: of the 63 reported failures in the battery power plant, 40 were a contributing factor in a total central office or switch outage. This is equivalent to one-third of all the total central office/switch isolation incidents reported in the data. Twenty-four percent of the battery outages occurred in conjunction with a failure in the AC rectifiers/chargers.



(63 Events/81 Causes)

Figure 3. Causes Of Battery Plant Outages

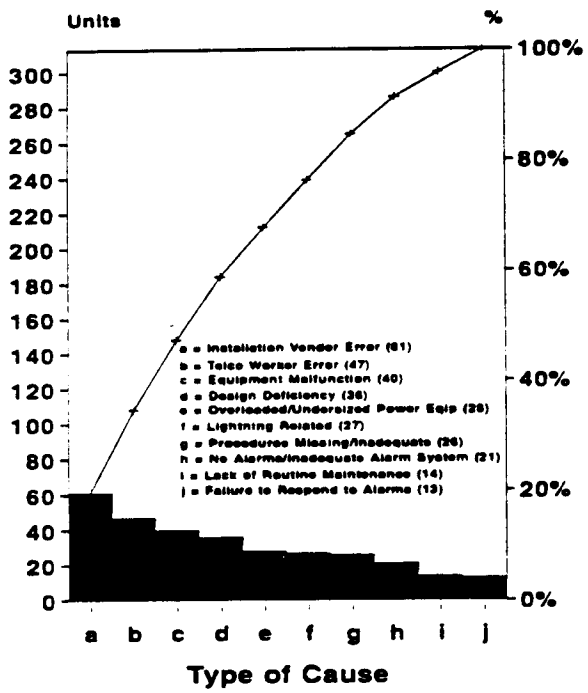
Many power system failures associated with DC fuses and circuit breakers involved unintentional shutdown of the supply of DC power to the facility during maintenance operations. Fully 25% of all outages attributed to DC fuses and 20% of all outages attributed to DC circuit breakers occurred while vendors were engaged in installation operations in the office. These were the largest percentages traceable to a single cause for DC distribution facility failures. In each case the vendor either executed incorrect installation procedures or erred in the execution of proper procedures. The significance of these equipment failures is that 38 of them were a precipitating factor in a total central office or switch failure. The two categories of equipment failure represented by battery power plant failures and DC distribution facilities form two-thirds of the events involving total central office/switch isolation.

5.3 Root Cause Analysis

Figure 4 depicts the data compiled on the causes of telecommunications service outages. Often, there

h Although the supercategory "DC Distribution Facilities" would seem to contain 113 incidents (the sum of the incidents in the categories DC fuses and DC circuit breakers), it really contains 106 incidents. This is because there is some redundancy in the reporting of incidents in the two categories resulting in double counting of seven incidents.

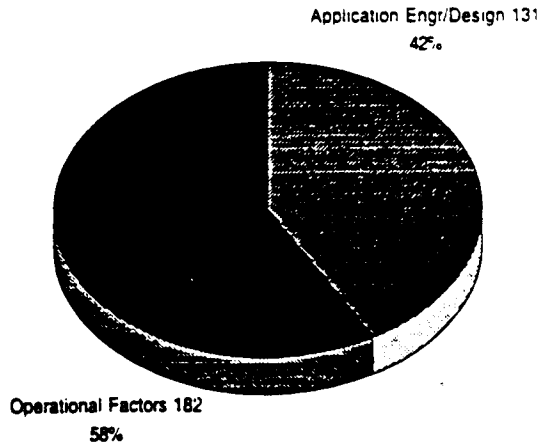
was more than one contributing cause of the telecommunication service outage. Of the 294 events reported in the data there were 313 contributing causes. It is important to note that categories h and j of Figure 4, "No Alarms/Inadequate Alarm Systems" and "Failure to Respond to Alarms", are much more significant than the low reporting indicates. Figure 3 partially reveals the reason they are significant. The figure shows that among the 63 events involving battery plant outages, failed alarm systems and failure to respond to alarms were the two leading root causes cited for the outages. The full significance of this becomes apparent when the impact of a battery plant outage is considered; battery plant outages frequently lead to catastrophic central office failures. Therefore the failure of alarm systems and the failure to respond to alarms categories are extremely significant.



(294 Events/313 Causes)

Figure 4. Types Of Telecom Service Outage Causes

The categories depicted in Figure 4 can be aggregated into two major groups of telecommunications service outage causes related to power systems: operational factors and applications engineering/design.[i] The categories that are included in the operational factors group are telephone company (telco) worker error, installation vendor error, procedures missing or inadequate, lack of routine maintenance, no alarms or inadequate alarms, and failure to respond to alarms. The categories that are included in the applications engineering/design group are lightning related failures, equipment malfunctions, overloaded or undersized power equipment, and design deficiencies.



Legend:
Operational Factors: Telco Worker Error, Installation Vendor Error, Procedures Missing or Inadequate, Lack of Routine Maintenance, No Alarms, Inadequate Alarm Systems or No Alarm Response

Application Engr/Design: Lightning Related Failures, Equipment Malfunctions, Overloaded/Undersized Power Equipment, Design Deficiencies

Figure 5. Major Causes Of Telecom Outages

Figure 5 depicts the data regrouped in these two categories. The regrouping is useful in that it demonstrates the extent to which human activity plays a role in causing telecommunications service outages in the PSN--nearly one-half the causes cited

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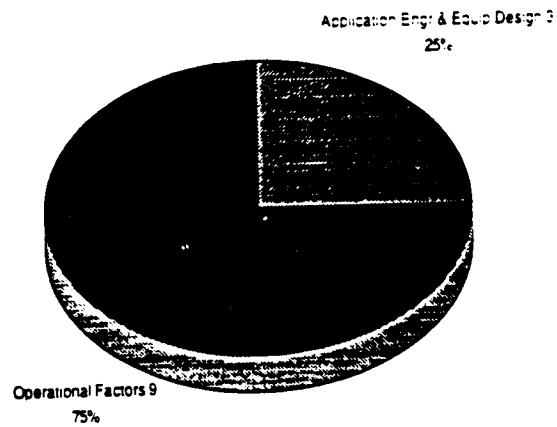
i There were 61 other causes which, after close examination, resulted in the apportioning of the data as follows: operational factors, 7; application engineering/design, 44; and other (not classifiable), 10.

were procedural, meaning, human activity was involved. The significance of this finding is that management attention brought to bear on resolving daily operational issues appears to present greater potential for improving power system reliability than focusing on power systems design changes. Also, resolving daily operational issues is presumably less expensive than system redesign and implementation.

To validate the data received through the survey questionnaire, the Power Focus Team also examined data collected by the Federal Communications Commission (FCC) on 16 power related telecommunications service outages that met the current threshold reporting criteria. These outages occurred between April and December 1992. Four of these involved the failures of power supplies embedded in switching or transmission equipment and were therefore outside the scope of the Power Focus Team's charter. The remaining 12 incidents are summarized as follows:

- Four outages occurred when batteries were fully depleted. In three of these cases, alarms did not function. In one case the alarm functioned but was not responded to.
- Four outages occurred as a direct result of improperly executed procedures.[j]
  - — Circuit breaker turned "off" by mistake
  - — Vendor caused 130 volt fuse to blow while removing equipment
  - — Vendor executed improper procedures while carrying out a change notice to effect greater diversity
  - — Telco executed improper procedures while preparing for removal of an out-of-service switch.
- Two outages were lightning related (tripped circuit breakers or DC-to-DC converters)
- One was due to an installation error (poor connection at the batteries)
- One outage was due to overloaded circuit breakers.

Figure 6 depicts these results graphically using the same categories used in Figure 5 so that the FCC data and the NRC Power Focus Area Team data can be compared. Comparing the two figures shows significant similarity between the two independently gathered sets of data with the FCC data leading the NRC data in the operational factors supercategory by 17 percent. This leads to the conclusion that the data presented here, and the accompanying analysis are in fact representative of the current state of central office power systems in the United States.



Legend:
Operational Factors: Telco Worker Error, Installation Vendor Error, Procedures Missing or Inadequate, Lack of Routine Maintenance, No Alarms, Inadequate Alarm Systems or No Alarm Response

Application Engr/Design: Lightning Related Failures, Equipment Malfunctions, Overloaded/Undersized Power Equipment, Design Deficiencies

Figure 6. FCC Reportable Power/Telecom Outages

6. Key Learnings and Best Practices

This section contains the key learnings and best practices relating to the design and operation of power systems.

Definition of Best Practices

The expression "best practices" as used in this Technical Paper means: "Best practices" are those countermeasures (but not the only countermeasures)

j Although the direct cause of each of these outages was improper execution of procedures, three of them point to a lack of diversity in the power distribution system feeding Signaling System 7 links, i.e., a single fuse or circuit breaker failed and disabled both primary and redundant links.

which go furthest in eliminating the root cause(s) of outages. None of the practices are construed to be mandatory; however, a very small number of countermeasures that are deemed by the Focus Team, and concurred by the Network Reliability Steering Team (NO REST), to be especially effective countermeasures will be designated as "recommended" in the Technical Paper.

Service providers are strongly encouraged to study and assess the applicability of all countermeasures for implementation in their companies and products, respectively. It is understood that all countermeasures, including those designated as "recommended", may not be applied universally.

Many of these recommendations were submitted by companies responding to the outage questionnaire; others were developed by the Power Focus Team while analyzing the outage data.

A graphical representation of the recommendations taken from the survey questionnaire is shown in Figure 7.

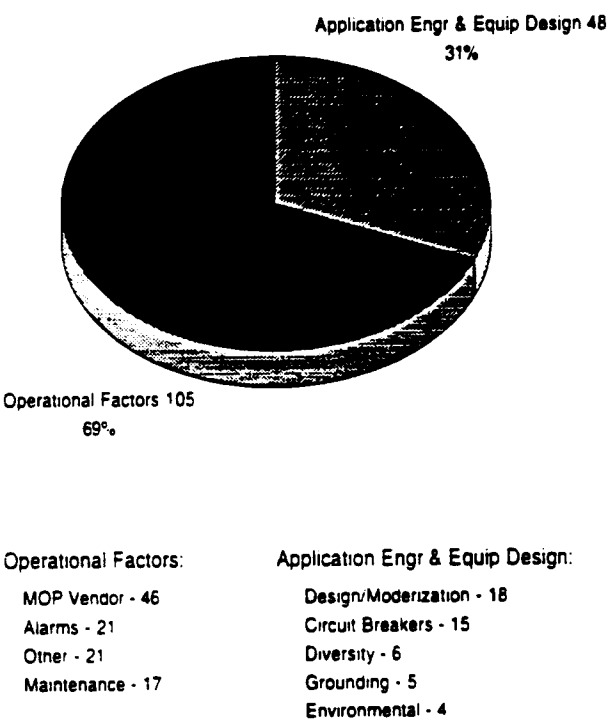


Figure 7. Recommendations From Survey Questionnaire

To summarize, countermeasures for driving catastrophic outages to zero are:

1. Place additional emphasis on human factors. The specific countermeasures in this section are strongly weighted towards human-machine interface, procedures, training, alarms, etc.
2. Provide diversity so that single point failures are not catastrophic, e.g., ensure diverse power feeds (fusing) for SS7 links and other duplex elements.
3. Adhere to the telecommunications industry's existing power engineering design standards. The following were identified as best practices:
   - TR-TSY-000513 *Power LATA Switching Systems Generic Requirements (LSSGR): Section 13*[3]
   - TR-NWT-000063 *Network Equipment-Building System (NEBS) Generic Equipment Requirements*[1]
   - TR-NWT-000295 *Isolated Ground Planes - Definition and Application to Telephone Central Office*[4]
   - TR-NWT-001089 *Electromagnetic Compatibility & Electrical Safety Generic Criteria for Network Telecommunications Equipment*[5]
   - *ANSI T1.311-1991, DC Power Systems - Telecommunications Environment Protection*[2].

The above standards listing is not all inclusive; some companies will have their own equivalent documents. The design best practices may be used for new installations but not necessarily retrofit. Companies choosing to deviate from standards should understand the rationale for the accepted standards and the risks associated with deviation.

The remainder of Section 6 discusses the various power systems elements and countermeasures that may be used for improving the reliability of each.

6.1 Commercial Power/Electrical Utility Issues

6.1.1 Introduction

Generators provide electric power instant to instant as it is demanded by consumer devices. The quantity provided at any instant is that required to satisfy consumer demands and the energy losses

incurred as electricity moves from generators through the transmission and distribution system to the loads. This characteristic requires that the generating capacity must be sufficient at every instant to provide the total of loads and losses. If the capacity is insufficient, voltages and frequency will begin to decrease; continued decline of these quantities will lead to operation of protective devices and disconnection of generators and transmission lines. In the extreme, this situation is described as "system collapse." Utilities plan for capacity sufficient to prevent this undesirable event.

6.1.2 Generating Capacity Reliability

Present practice in most regional systems is to provide capacity such that under reasonable circumstances total load will not exceed total capacity more often than 1 day in 10 years. This criterion is relatively simple to express although the actual measure is complicated to compute. Another commonly used criterion is to provide generating capacity that exceeds the largest expected demand by a specified percentage (15%, 18%, or other amount based on a utility's experience). The measures used are based on the fact that generating capacity is additive: the total capacity of a system is the sum of the available capacities of the individual generating units. Electric energy is provided to the system by individual generators, but once in the system, it is aggregated into a total that is made available to all parts of the transmission segment. An analogy can be made with a group of streams that supply water to a lake or pool: the contribution of each individual source cannot be identified once it becomes part of the aggregate, but loss of one source will result in an equivalent reduction in the magnitude of the aggregate. Similarly, reduction in the output of one generator will reduce the pool of capacity available to all customers, but generally will not affect any individual customer, provided that adequate planning has provided sufficient total capacity for contingencies.

6.1.3 Transmission Reliability

The aim of transmission planning is to provide sufficient redundancy in facilities such that failure of some will not interrupt the flow of power from generating plants to the distribution facilities that serve customers. Just as automobile traffic can follow alternative roads or detours from one point to another when one or more highways are blocked, a well-designed transmission system provides alternative paths for energy flow. Normally a single adverse event affecting the transmission system will not prevent flow of power to the distribution facilities, and will not be noticed by customers. Two adverse events, such as the failure of two transmission lines, may cause the overloading of some lines or transformers, and may cause a temporary change in voltage at some substations; but the operation of system protective devices and intervention of system operators should quickly restore customer conditions to normal, if indeed any customers have been affected.

6.1.4 Distribution Reliability

Measures of reliability for the distribution segment of the power supply system are not closely related to the reliability of the generation and transmission segments. Distribution difficulties affect customers directly and are strongly related to weather phenomena (for example, high winds or heavy snow). Generally there is no alternative route to a customer's service entrance when the distribution circuit in his neighborhood fails; there are, however, alternative sources and paths to replace failures of generation and transmission. Some criteria in use for distribution reliability are the number of interruptions per customer in a specified time period, the average time interval between interruptions, and the average duration of interruptions. Service reliability practices have developed as utilities have gained experience with the interactions of generation, transmission and distribution facilities, and the demand patterns of customers. Service reliability is defined in terms of service continuity, stability and magnitude of voltage level, and freedom from frequency fluctuations. Most customers find these measures satisfactory.

6.1.5 Response to Adverse System Situations

The response by an electric system to an adverse situation depends on the specifics of the occurrence. Failure of one or more generators, or unforeseen demands that exceed the total generating capacity of a system may threaten the supply of power to all customers. Failure of one or more transmission facilities will generally affect the movement of power to one or more locations on the system but

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usually will only affect the delivery of power to some customers. Failure of specific distribution facilities will directly affect a relatively small number of customers but most customers will not be affected.

When a utility experiences an adverse situation or foresees its occurrence within the near future, it will respond by using any or all of the following stratagems, not necessarily in the order listed:

- Depart from economic dispatch (the loading of its generating units so as to achieve minimum fuel cost at all times, consistent with reliable system operation and environmental requirements).
- Purchase capacity from other systems. This will usually be the first effort by the utility to meet its obligations to customers.
- Overload generators to the extent and for the time possible without incurring damage.
- Reduce the utility's use of electricity for its own purposes to the extent possible.
- Appeal to the public via television, radio, or other medium to reduce the use of electricity.
- Reduce voltage at the distribution level.
- Disconnect service to customers (mainly industrial) served under "interruptible" contracts. These contracts provide service at a lower rate because interruptions are permitted under specified conditions.
- Request that large volume customers reduce their use of electricity.
- Disconnect service to specific customer appliances, for instance, water heaters, air-conditioners, swimming pool pumps, where appropriate agreements have been reached previously in return for lower rates.
- Disconnect groups of customers for short intervals (possibly 1 or 2 hours), rotating the groups so that the inconvenience is shared by all customers if possible. This action is taken as a last resort, when all other measures have failed to reduce the total demand below the total capacity available to serve load.
- If a storm or other natural disaster occurs causing damage to the extent that a utility does not have sufficient personnel to repair its transmission and distribution lines, the affected utility will request assistance from other utilities through the disaster coordination programs of Edison Electric Institute, American Public Power Association, or the National Rural Electric Cooperative Association.

6.1.6 Electric Service Priority (ESP) Restoration

To minimize the effect of long commercial power disruptions on telecommunications facilities, the Federal government has developed the Telecommunications Electric Service Priority Restoration Initiative. The purpose of this Federal government initiative is to encourage States and electric utilities to consider incorporating into their existing service restoration plans (if any), a limited number of specific industry telecommunications facilities that support National Security and Emergency Preparedness (NS/EP) functions. The Telecommunications Electric Service Priority (ESP) restoration initiative was developed by the Department of Energy (DOE) in coordination with the National Communications System and the Energy Task Force of the President's National Security Telecommunications Advisory Committee (NSTAC).

DOE has developed and disseminated a brochure to the States and electric utilities to explain the intent of the Telecommunications Electric Service Priority Restoration Initiative. This brochure gives an overview of the Federal initiative for emergency priority restoration of commercial electric power to a limited number of critical telecommunications facilities that support NS/EP users. Also, the brochure addresses emergency fuel resupply for telecommunications companies' back-up generators and electric utility and telecommunications repair crews access to their facilities in the disrupted area.

Most electric utilities have service restoration plans in place for dealing with situations involving electric power supply disruptions to customers under emergency conditions. These plans provide for restoration of electric service in priority order, with the highest priority given to locations related to public safety and health. These locations include fire and police facilities, pumping stations for sanitation and water supply, hospitals, life support facilities and similar installations. Local, State and Federal Emergency Operating Facilities are also addressed in these procedures. Restoration of telecommunications facilities are not currently addressed in electric utilities plans. However,

electric utilities and telecommunications companies do coordinate during disruptions. Because communication among the entities involved in recovery from an emergency condition is such a vital need, telecommunications facilities, especially those needed to support NS/EP functions, should have a high rank in priority of electric service restoration.

The Energy Task Force of the NSTAC developed criteria for identifying critical telecommunications facilities and a process for applying that criteria. The criteria are based on a narrow definition of critical facilities to ensure that the restoration procedures of electric utilities would not be overwhelmed by the number of qualifying telecommunications facilities. The task force defined "critical facilities" to be those that perform functions critical to the monitoring, control, support, signaling, and switching of the voice telecommunications infrastructure. The criteria for designating critical telecommunications facilities are not all-inclusive; that is, other telecommunications network components could fail due to a lack of commercial electric power and disrupt the ability of users to communicate. Examples are repeaters, regenerators, and some devices between telecommunications facilities and user premises. Local coordination by electric utilities and telecommunications companies during disruptions will address these issues.

6.1.7 Interruptible Power Contracts Between Electric Utilities and Industrial Customers

Electrical utilities employ various strategies to deal with situations in which the demand for electricity exceeds, or is likely in the near future to exceed, the capacity available. One of these is to contract with industrial customers for "interruptible" power supply. The form and details of such contracts differ among utilities, and may be different even for the customers of one utility because the contract form depends, to some extent, upon negotiations between the utility and the customer. However, a common feature of the interruptible power contracts is a lower than normal rate for service because under conditions specified in the contract, service may be interrupted or the supply of power may be reduced. The number of interruptions allowable within a given time period, their duration, the notice required when an interruption is scheduled, and other details are worked out between the parties. Telecommunication installations are potential customers for interruptible contracts, because it has long been their practice to install backup generating facilities of their own to ensure uninterrupted communication services to their customers.

A telecommunication facility may initiate a transfer from its electric utility power source to its backup source when it appears that the power supply from the utility source may become temporarily degraded. This action allows the facility to implement on a planned and scheduled basis what might otherwise occur suddenly and unexpectedly during a utility power failure, voltage reduction, or other adverse incident. For the telecommunications company, the planned changeover has the following benefits:

- The risk of damage to the telecommunications company's equipment (standby generators or batteries and associated apparatus as well as the telephone switching equipment) is reduced. When the alternative power source is switched on, equipment powered by this source can be manually added to the system in controlled fashion, instead of being added as a single large block of load. This procedure minimizes the risk of momentary overloads and large fluctuations of voltage.
- The backup power supply can be started, tested, and adjusted before it has to assume the full load of the installation.
- Personnel assigned to operate the alternative power source and those assigned to the other electrical apparatus will be aware of the impending change in power supply; so they can be prepared to monitor devices that may be affected and will be ready to take any required corrective measures.
- The planning, design, installation, and routine testing of the backup power supply, together with the tested procedures for cutover, significantly reduce the probability of a power failure that would disable the communications function of the installation.

Because of the benefits associated with a planned cutover to the alternative power source, some telephone companies have entered into, and others have considered entering into, interruptible

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contracts with their electric utility power sources. An important issue in these contracts is the freedom of the customer to initiate a transfer from utility power to its own source when the customer believes it will be in its own best interest to do so. Because the telephone company must retain the confidence of its customers in the quality and reliability of its communication services, the company must retain the freedom to independently evaluate the advisability of switching to alternative power supply at any time. Close cooperation between the electric utility and the telecommunications facility is necessary, especially in emergency situations, but the freedom to choose the power source is vital to the telecommunications facility. The telecommunication installation must agree to provide adequate notice to the utility before this action, because the drop in demand may have a significant effect on utility operations at that time. Even under normal conditions, the sudden dropping of the communications load might have a significant adverse operational effect on the utility system. The telecommunications facility and the electric utility should cooperate closely at the local level, to ensure that each is aware of the other's needs and capabilities. In addition, close contact between the communications installation and the dispatch center of the utility or the power pool with which it may be associated is advisable.

6.1.8 National Power Laboratories (NPL) Study

The following paragraphs were extracted (with approval from NPL) from an Intelec '92 paper entitled *National Power Laboratory Power Quality Study Results Based on 600 Site-Months*[6] In March 1990, National Power Laboratories (NPL) initiated an extensive power quality study to collect power line disturbance[k] data from locations throughout North America. This study was undertaken in response to the lack of current information on the nature and magnitude of power disturbances at the typical 120 volt AC wall receptacle. The objective of the study was to provide a large, well-defined database of recorded disturbances at typical power usage points.

Data is retrieved by telephone connection to a central NPL computer. Custom Dranetz 626R power disturbance monitors collect data at the randomly selected locations. The monitors capture, store, and format disturbance data in text and graphic format. At the 600 site-month mark, the database contained more than 100,000 recorded disturbances. This translates into 2,000 disturbances per year at the average location.

Each of the reported disturbances may affect sensitive electronic equipment in different ways. Sags and undervoltages, depending on severity and duration, can cause equipment resets, memory loss, data loss, and electronic component overheating. Surges and overvoltages can cause component overheating or destruction. Surges may trigger protective devices resulting in memory and data losses during equipment reset. Impulses can cause data corruption or component destruction, depending on the frequency and energy of the impulse. Typically, high frequency impulses cause data errors and high energy impulses cause component destruction. Unexpected outages cause memory loss, data loss, and costly system failures.

6.1.9 Key Learnings and Best Practices

1. It is recommended that telecommunications companies retain complete authority about when to transfer from the electric utility and operate standby generators. Under no circumstances should the electric utility have control of telco power systems. The benefits

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k Disturbance as used here has the following definitions:
- Sag - a decrease in line voltage for one or more cycles. If a sag lasts more than 30 cycles it is defined as an undervoltage.
- Surge - an increase in line voltage for one or more cycles. If the surge lasts more than 30 cycles, it is defined as an overvoltage.
- Impulse - a high frequency subcycle event (oscillatory decay, spike, transient) having a steep rising or falling departure from the AC sine-wave.
- Outage - a zero voltage condition on the power line lasting for at least one cycle.

Boundary Conditions: Sags and undervoltages less than 104 volts rms. Surges and overvoltages greater than 127 volts rms. Impulses between 100 and 6000 volts peak amplitude. Power interruptions or outages longer than one cycle.

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of a planned cutover to standby power when a commercial power disruption is probable should be recognized. Telecommunications companies should exchange information with the electric utilities at the local level.

Power curtailment or load shedding contracts should not normally be agreed to for telecommunications facilities. If entered into, the contracts should not run counter to Electric Service Priority Restoration initiatives and should address telecommunications service continuity requirements (i.e., telecommunications must not be treated as a low priority industrial load).

2. Telco's and electric utilities should plan jointly to coordinate hurricane and other disaster restoration work. These plans should be reviewed routinely to ensure emergency preparedness (see Section 6.13 - Hurricane Andrew Lessons.) Local contacts should be established. The telecommunications companies should be familiar with power company plans, state requirements, Federal Emergency Management Agency (FEMA) arrangements, etc.
3. Dual commercial power feeds with diverse routing from separate substations should be provided for the most critical network facilities and data centers. The telecommunications companies electrical engineers must consult with the electric utility to evaluate the costs versus benefits of dual power feeds. Consideration should be given to the status of standby generators, battery reserves, and other local factors.
4. Power line disturbances can affect electronic devices in a destructive or disruptive manner. The large number of disturbances found at a typical location suggests a general requirement for some level of power conditioning or protection for computers and sensitive electronic equipment.

6.2 Standby Generators

Because telecommunications service must be continuous, standby power is provided for central offices and other critical locations as a safeguard against prolonged commercial power failures. This standby power is available either from permanently installed or portable standby engine-alternator sets.

Standby power is provided to maintain full operation of DC plants, AC plants supplying power to essential switching and transmission equipment, and essential building facilities (for example, pumps, ventilation, and essential lighting).

Standby engine-alternators are available in a wide range of capacities and options from many different vendors.

National codes or requirements that apply to telecommunications standby power systems include:

NFPA 70 *National Electrical Code*[7]

NFPA 110 *Standard for Emergency and Standby Power Systems*[8]

NFPA 37 *Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines*[9]

TR-EOP-000146 *Engine-Alternator Standby AC Systems provide requirements for standby generators*[10]

These codes or requirements may be used by companies evaluating equipment from several vendors. Also, various equipment manufacturers provide engineering, installation, and maintenance support documentation that should be carefully reviewed by user companies.

A lesson from Hurricane Andrew and the 1989 northern California earthquake is that the presently deployed standby generators do provide a reliable backup during extended commercial power outages.

This reliability was confirmed by a paper presented at the Twelfth International Telecommunications Energy Conference (Intelec '90). The paper summarized in detail power system performance following hurricane force windstorms in Britain in 1987 and 1990.[11] The experience of these two widespread disasters was that less than 1% of telecommunications centers dependent on standby power failed. An analysis of standby power failures resulted in the following conclusion: The underlying cause of the standby generator failure was almost always due to the lack of routine maintenance testing.

Routine maintenance of standby generators must be clearly documented by each telecommunications

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company and carried out as specified. Routine testing should include not only periodically starting and running the engine, but also testing under load.

There are several choices of fuel for standby generators; most commonly these include diesel, gasoline, natural gas and Liquid Petroleum (LP) gas but other fuel types may be considered. Each choice has advantages and disadvantages in terms of safety, reliability, storage, and resupply. In particular, natural gas is not an independent fuel source and service may be interrupted at the same time as commercial power. Typically, the fuel of choice for most telecommunications applications, with permanent standby generators, is diesel. At locations with permanently installed engines, on-site fuel storage sufficient for many hours of standby power generation is maintained. It should be recognized, however, that diesel fuel does deteriorate under long term storage. Periodic engine runs will ideally result in a turnover of the stored diesel fuel about every 2 years. Various test methods exist to assess fuel quality. Fuel additives are available to prolong storage life.

Local disaster planning must include provisions for resupply of fuel to maintain uninterrupted service. Such preplanning may need to include providing for alternative means of transport when roads or bridges are not passable.

6.2.1 Types and Causes of Failures

Generator failure was a contributing factor in less than 10% of the studied outages. AC transfer equipment accounted for about 4% of outages studied. This is not surprising. Battery backup is usually sufficient for all but a few instances of long duration commercial power disruptions. By the same token, a generator failure or AC transfer failure during a long duration commercial power outage can be serious.

6.2.2 Key Learnings and Best Practices

1. Design standby generator system for fully automatic operation but for ease of manual operation when required. Provide a manual override (combat position) that allows an operator to run the engine while monitoring temperatures, pressures, voltages etc.
2. Maintain adequate fuel on-site and have a well-defined resupply plan. Avoid oversizing the tank because the fuel may become stale if not turned over often enough.
3. Provide automatic reserve lubricating oil makeup systems for extended operation of diesels. Otherwise, it is necessary to shut the engine down to check and replenish the oil.
4. Have a well-defined plan that is periodically verified for providing portable generators both for those offices without stationary engines and for stationary engine failures.
5. Engines must be routinely exercised with load. Diesels are normally run for at least 1 hour bi-weekly; gas turbines for at least one half hour monthly. The length of the routine run should be sufficient to achieve normal operating temperature. Turbines do this almost immediately after receiving the load; diesels take longer due to their large mass. Startup places particular stress and wear on turbine engines, but not diesels, which explains why turbines are routinely started less frequently.
6. At least annually, engines should be run for an extended period, at least 5 hours, with all available load. Some companies recommend 24-hour runs. Engines should be run enough to consume at least half of the fuel every year.
7. Coordinate engine runs with all building tenants. The momentary power interruption while transferring to or from commercial power should not affect telephone power plants; however, it may inconvenience operational support systems and/or other operations (PCs) collocated in equipment buildings. Transfer problems must not be allowed to interfere with routine engine runs. These problems can be circumvented by arranging loads so that they are not automatically transferred, providing uninterruptible power supplies, and other methods. Performing routine runs just before normal business hours (6:00--7:30 a.m.) may solve the problem. Routine runs should not be made in the middle of the night because, if there is a problem, expert assistance may be very difficult to locate.

6.3 Building's AC Systems

Except for short-term operation on batteries, central office telephone equipment is dependent on the

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building's AC systems for power from either the commercial source or the standby engine. These systems must be designed and maintained for safe and reliable operation. Particular attention must be given to transfer switchgear and other nonredundant components where a single failure could result in a serious outage.

Desirable attributes of the building's AC systems include:

- Robustness (long mean time between failures)
- Simplicity (easily understood, easily operated, easily repaired)
- Redundancy (single failures do not cause outages).

6.3.1 Key Learnings and Best Practices

1. For large battery plants in critical offices provide dual AC feeds (odd/even power service cabinets for rectifiers) so that a single fault will interrupt no more than about half of the rectifiers. Operation of these will generally extend the battery reserve so that the initial fault can be corrected before service is lost. For maximum diversity, serve the dual feeds via separate transfer switches.
2. Paired air, molded case, and other types of circuit breakers are used in transfer system circuits. The two transfer breakers must be mechanically and electrically interlocked to ensure that only one breaker is closed at a time, yet also allow both breakers to be open at the same time. Interlock problems have prevented closing either breaker.

   Transfer switches (Underwriters Laboratories Standard 1008)[12] should be used in lieu of paired breakers. Automatic transfer switches should be of the "break-before-make" type and should allow safe and easy manual operation should the automatic feature malfunction.
3. To facilitate the understanding and operation of AC switchgear:
   — Provide indicating type control fuses on the front of the switchboard.
   — Provide color coded mimic buses showing power sources, transfer arrangements, essential/nonessential buses, etc.
   — Post at the equipment (or have readily available) single line and control schematics.
   — Keep circuit breaker racking/ratchet tools, spare fuses, fuse pullers, other spare parts (including spare circuit breakers for critical circuits) and a manual hoist for swapping out circuit breakers, on hand.
   — Clearly label the equipment served by each circuit breaker. For critical loads (DC power plants, engine support equipment) designate the serving circuit breaker at the equipment.
   — Provide emergency procedures for AC transfer.
   — Train local forces on the above procedures and stage an occasional rehearsal.
4. Provide surge arrestors (TR-NWT-001011)[13] at the AC service entrance of all telephone equipment buildings.
5. Provide AC tap boxes outside critical central offices to facilitate the safe and rapid attachment of a portable engine alternator should the on-site engine fail or be out of service for repairs.
6. Design a professionally administered preventive maintenance program for each company's electrical systems. Typical programs provide for annual inspections by qualified personnel of all transformers, switchboards, motor control centers, panelboards, etc. During this inspection, circuit breakers are manually operated, equipment is cleaned, and all deficiences noted are corrected. Thermography should be used to identify loose connections and other hot spots.

   At an interval of no more than 5 years, major maintenance should be performed including current injection tests and adjustment of circuit breakers, dielectric breakdown voltage test of insulating liquid in company owned liquid-filled transformers, DC high potential tests of medium voltage cables, insulation resistance test of low voltage feeders, etc.

6.4 DC Plants

Direct current is supplied to telecommunications loads by two basic types of equipment: rectifier plants and DC-to-DC converter plants. A single DC power plant may serve one or more switching,

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transmission, or other telecommunications system.

The overall high reliability of telecommunications power systems is attributed to the batteries that provide critical time to react to AC systems and rectifier problems. In offices with permanently installed standby generators, batteries are usually sized to last a minimum of 3 hours. For offices backed up by portable engines, 8 or more hours battery reserve is the norm. Additional battery reserve is often provided for critical locations and locations where accessibility is questionable.

It is noteworthy that after the explosion at the World Trade Center on February 26, 1993, batteries sustained New York Telephone's switches in that complex for approximately 7 hours until the commercial power was restored. The switches were placed in "simplex" mode (redundant units turned off) to extend the batteries. The generators were inoperative due to lack of cooling water.

The lead-acid storage batteries used in telephone power systems are designed to operate on a continuous float basis, with a long life expectancy.

DC-to-DC converter plants convert a DC voltage to another level. Many are used as a source of relatively small amounts of power at a DC voltage other than that supplied by the main DC power plant in an office. Because these plants do not include batteries as a reserve power source, overload or converter failure can result in complete power loss. Thus, at least one more converter than required under maximum load conditions is provided.

DC plants are designed for long service life with minimal maintenance. Properly engineered, installed, and maintained (following manufacturer recommendations), the DC plants commonly in use are rarely the cause of service-affecting outages.

Modernization of power equipment has improved the reliability of commercially available DC plants. Newer designs have incorporated components with longer mean time between failure (MTBF), greater fire resistance, and improved efficiencies leading to cooler operating temperatures. So-called smart controllers are now incorporated in battery plants to provide improved human-machine interfaces. These controllers can continuously monitor load requirements and operation of components. Historical data such as alarm history and plant drains can be stored by the controller, and accessed locally or remotely. Detailed diagnostics are now available from these controllers to instruct maintenance personnel, enabling them to quickly respond to and clear a trouble condition.

Some companies shared with us their review of older power equipment and plans to phase out older technology. Two areas of particular attention are power plants with emergency cell switches, and silicon controlled rectifiers (SCRs). Similar review by other telecommunications companies is appropriate.

Batteries may become the weakest link in the system if not properly maintained. This is particularly true for single string installations where a single cell or single connection can cause an open circuit. For maximum reliability, two strings must be provided. This also greatly facilitates maintenance because one string at a time can be opened to clean connections.

A fundamental problem with battery systems is lack of a simple, reliable means to predict available capacity and remaining useful life without full discharge of the battery. Work in this area, by the industry, is strongly encouraged with the goal of providing simple, time efficient, reliable test procedures and algorithms for this purpose.

6.4.1 Key Learnings and Best Practices

1. Provide a minimum of 3 hours battery reserve for central offices equipped with fully automatic standby systems. Provide a minimum 8 hours reserve for offices not equipped with stationary engines and dependent on portable generators. Travel time should be added to the 3 hours except for fully attended (24-hour coverage) locations and for sites where it would not be a significant factor such as those near fully attended locations.
2. All new power equipment, including batteries, should conform to NEBS.[1] This includes both spatial and environmental requirements. Key issues are fire resistance, temperature and humidity control, airborne contamination, acoustical noise, lighting, and maintenance access. The power equipment and associated floor space should be given the same

treatment as that given to switching and transmission systems, e.g., placed in properly conditioned space that is not subject to flooding and is well lighted.

3. When valve regulated batteries are used, provide temperature compensation on the rectifiers or some method to detect/prevent thermal runaway (this is a best practice from the fire focus team).
4. A modernization program should be initiated or continued to ensure that outdated equipment is phased out of plant. Consideration should be given to maintenance, reliability, parts availability and fire resistance. Rectifiers, DC-to-DC converters and inverters can be expected to last about 20 years depending on the environment (temperature) and how loaded. Over time heat degrades components and wiring thereby making older units more failure prone and more susceptible to fires. Parts availability is also often an issue. The modernization programs of several companies include replacing emergency cell switch plants and the older SCR type rectifiers. Any modernization program should be developed with input from experienced operations personnel. Plans for individual offices should be based on field reviews and inspections.
5. For new installations, multiple smaller battery plants should be used in place of single very large plants serving multiple switches, etc. The purpose is to mitigate the service affected by a single point failure. An added benefit relates to grounding--there can only be one ground window per power plant, reference TR-NWT-000295.[4] With multiple power plants there can be multiple ground windows serving smaller isolated ground planes. This simplifies cabling arrangements and facilitates "policing" the ground system.
6. Two hardware items, contributed to noteworthy battery plant outages: low voltage disconnect switches and rectifier sequence control units. The low voltage disconnect switch monitors the battery voltage and disconnects the load if the voltage falls below certain limits. The reasons for doing this include protecting the equipment (load) from low voltage and protecting the battery from deep discharge and cell reversal. The problem is that maladjusted relays and other "human factors" have caused these switches to operate at normal bus voltage, thus interrupting service. Low voltage disconnects should not be used at the battery plant. Any protection required against low voltage should be provided with the load equipment.
7. The rectifier sequence controller performs two functions: 1. sequences rectifiers on in four steps when the load is transferred to/from the standby generator and, 2. turns off excess rectifiers to limit load when the engine is running. The controller has the capability of turning off all connected rectifiers and that is what happens when the controller loses input power (-48V fused at 1-1/3 amperes). One major outage occurred when power to the controller was disconnected on a removal project, thus turning off all rectifiers and resulting in battery depletion (alarms were also inadequate). The rectifier sequence controller should be used only where necessary to limit load on the engine. When used, connect only those rectifiers to the controller that must be turned off during engine runs.
8. Telecommunications companies should consider and include the capabilities of smart controllers, monitoring, and alarm systems as they update their power equipment maintenance procedures.
9. Manufacturers are encouraged to continue to improve the human-machine interfaces of power equipment in light of the continuing trend to unattended offices and fewer expert operating personnel.

6.5 DC Distribution Systems

Maintaining the supply of DC power to its loads is critical to the operation of a telecommunications system. Power is transferred, through bus bar or cable, from the batteries to the primary distribution board that consists of multiple panels of fuses or circuit breakers. There is no overcurrent protection on the feeder from the battery to the distribution board. This distribution board is often termed a "power board" by the suppliers.

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6.5.1 Primary Distribution

The primary distribution system physically refers to the interconnection of the rectifier output, battery, input to the primary distribution, and the feeder wire and cable to the input of the secondary distribution systems. (Note: Historically, the "charge/discharge network" is part of the primary distribution system.) Typically, the input to the secondary distribution systems are the Power Distribution Frame (PDF), Battery Distribution Fuse Board (BDFB) Power Distribution Center (PDC). See ANSI T1.311-1991, Figure 1.[2]) The primary distribution point contains the first location for overcurrent protection devices. The interconnection of the rectifier output, battery and input to the primary distribution is physically designed to help ensure that short circuits between wires do not occur and to limit the potential that short circuits will be caused by users or maintenance personnel. The interconnections are sized to withstand a short circuit without causing damage to the distribution system or surrounding equipment. The usual connections between battery and rectifiers for system voltages less than 60 volts are insulated conductors with uninsulated bus bars providing the electrical path between battery strings and rectifiers to the input of the overcurrent protection devices in the primary distribution. Interconnections between the primary overcurrent protection devices and the input to the secondary distribution point are insulated wires for all system voltages.

Overcurrent protection devices typically installed in the primary distribution are greater than 60 amperes. However, the primary distribution may directly provide protection for low power applications. These low power applications are fused appropriately, typically below 60 amperes. The wire and cable from the output of the primary overcurrent protection devices to the input of the secondary distribution system is mechanical supported by horizontal and vertical ladder (cable) rack.

The wire size for all system voltage levels is designed to limit the voltage drop to small values, less than 0.25 volt between the rectifiers, batteries and input to the primary overcurrent protection devices to help reduce the power loss in the distribution system. Typically, the voltage drop from the input to the primary overcurrent protection devices to the telecommunications load equipment is engineered for 1.75 volts. The combination of the two voltage drops, 2.0 volts, causes large size wire gauge wire and cable to be used, regardless of the ampacity needed for the telecommunications load equipment.

6.5.2 Secondary Distribution

The secondary distribution system includes all the interconnection and overcurrent protection devices connected to the end of the feeder wire or cable of the primary distribution to the succeeding levels of overcurrent protection devices, including the telecommunications load equipment. This includes the Power Distribution Frame (PDF), Battery Distribution Fuse Board (BDFB) Power Distribution Center (PDC) and the wire, cable and overcurrent protection within the telecommunications load equipment. The wire and cable are usually insulated wires for all system voltages regardless of voltage level. Mechanical support for the secondary distribution wire and cable is by horizontal and vertical ladder rack. Primary and secondary wire and cable are usually installed on the same ladder rack.

6.5.3 Overcurrent Protection

6.5.3.1 Fuses

Fuses require replacement after operation and the wrong size and type can easily be inserted into the fuse holder if care is not taken. Their operating point is affected by ambient temperature, but, it is a second order effect for the ambients normally expected. Usually, fuses placed adjacent to each other and with restricted air flow will be in a higher ambient temperature than the surrounding environment. This results from the power losses in the fuses (I^2R) and the inability to remove the heat caused by these losses. Because the fuse is a thermally operated device, the increased temperature will cause the fuse to open at a lower current value than its rating. Therefore, fuses are often engineered to operate with no more than 80% of the current expected during normal operation at worst case steady-state load current.[1] Conversely, if

1 The 80% value does not account for coordination or inrush current. Typically, circuits are engineered to operate at no greater than 66% to account for coordination and inrush

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a fuse is placed in an open or free air area and equipped with heat sinking materials (such as a large copper wire) connected to the fuse, the fuse will operate at a higher current value than its rating or take longer to open. In general, the operate times do not change radically for short circuit current faults. However, for the overload current region, the thermal changes resulting from the power dissipation of the fuses may cause a shift in their operate time versus load current curve. In selecting the ampere rating of a fuse, consideration must be given to the fault interrupt rating, the type of load connected to the fuse, and the protection required.

In selecting the rating of fuses for feeders, the National Electrical Code (NEC) ampacity tables should be used.[14] As an example, if a 750 KCM wire is used and the NEC permits 535 amperes through the conductor, a 600 ampere fuse could be used because it is the next higher standard rating given in the NEC.[14]

The ampere rating of a fuse should normally not exceed current carrying capacity of the feeder (circuit). For instance, if a conductor is rated to carry 20 amperes, a 20 ampere fuse[m] is the largest that should be used. However, there are some specific circumstances where the ampere rating is permitted to be greater than the current carrying capacity of the circuit. A typical example is the motor circuit; dual-element fuses generally are permitted to be sized up to 175% and nontime delay fuses up to 300% of the motor full-load amperes. Generally, the ampere rating of a fuse and switch combination should be selected at 125% of the load current (this usually corresponds to the circuit capacity and is also selected at 125% of the load current). There are exceptions, such as when the fuse-switch combination is approved for continuous operation at 100% of its rating.

current. The fuse size used is 150% of the worst case steady-state current anticipated.

m This is a standard current rating as listed in the National Electrical Code.[7]

6.5.3.2 Circuit Breakers

There are three basic types of circuit breakers commonly used and they are described by their tripping mechanism: thermal, hydraulic-magnetic, and magnetic.

Hydraulic action is a common addition to circuit breakers. Hydraulic action in a circuit breaker permits the overload current characteristics of the circuit breaker to be controlled. This creates a time-delay mechanism in the circuit breaker and helps to eliminate nuisance tripping from current transients without lessening overload current protection.

Thermal (and thermal-magnetic) breakers are operated when a bimetallic latch is curled by the heating of the overcurrent and triggers a contact opening mechanism. The magnetic, hydraulic-magnetic, and thermal-magnetic breakers (on high overcurrents) function like relays: that is, the latch mechanisms are triggered magnetically by the field of the current-carrying coil.

6.5.3.3 Comparison of Devices

Circuit breakers can be applied in the same applications as fuses. Nevertheless, there are differences in how they operate; these are explained below.

Circuit breakers are typically rated at the steady state current they will carry without tripping. In contrast to fuses, magnetic-hydraulic circuit breakers may be used at 100 percent of their ampere rating because they are unaffected by ambient temperature changes. Fuses and thermal type circuit breakers, however, are used at 80 percent of their rating because they are subject to operate time variations from ambient temperature.

Magnetic circuit breakers are typically designed to operate between 101 percent and 125 percent of rating and to operate at 125 percent after a delay specified by the circuit breaker curves. Thermal circuit breakers and fuses will also operate under sustained overload currents, but the "must-operate" point is not as precisely defined. For fuses and thermal circuit breakers, it is necessary to consult the operate (melting) time versus current curves to determine the average operate time for a specified sustained overcurrent.

Replacement of the devices, once operated, does differ. Fuses must be replaced once they operate because they cannot be reset or the fusible element replaced. Therefore, spare fuses are required. Circuit breakers can be reset once operated. They do not need to be replaced nor spare devices stored. However, fuses are usually smaller and less expensive than circuit breakers for the same current, voltage, and interrupt ratings.

6.5.4 Analysis

Of the 294 reported telecommunications events within telecommunications central offices, 58 were associated with DC fuses and 48 were associated with DC circuit breakers. The table below indicates why the fuses or circuit breakers operated:

Reason	Fuses	Circuit Breakers
Worker Error	22	25
Storms	7	4
Other	29	19

Worker error (telco craftspersons, contractors, switch vendors, etc.) accounted for 44% (47/106) of the total fuse/circuit breaker operations. The amount of fuse/circuit breaker operations due to storms was isolated from the total to show the effect of a powerful external event. Storms accounted for 10% (11/106) of the total operations.

Review of the remaining operations indicated that 48 fuses or circuit breakers operated to protect equipment or wiring. A fuse or circuit breaker is supposed to operate to protect equipment and wiring from damage, but the operation of a single fuse or circuit breaker should not be catastrophic. In at least three cases, one fuse operation caused the failure of a significant portion of the central office telecommunications load equipment. An example of this is the fuse powering the Building Integrated Timing Supply (BITS) clock used for synchronizing digital transmission. One fuse failure caused a total shutdown.

6.5.5 Key Learnings and Best Practices

1. Provide diverse feeds for SS7 links, BITS clocks, and other duplex circuitry.
2. Provide protective covers and warning signs on all vulnerable circuit breakers to prevent inadvertent operation.
3. Reliability - ensure that the fuses and breakers meet quality level III.[n]
4. Power wire and cable and signaling cables that meet NEBS[1] should be required in all telecommunications locations.
5. Wherever possible, DC power cables, AC power cables and telecommunications cables should not be mixed (see Fire Focus Team report for more information).
6. Verify dc fusing levels, especially at the main primary distribution board to avoid overfusing on significantly underused circuits and fuse at a level not to exceed the smallest conductor used in the feed or 200% of the maximum operational current of the feed, which ever is smaller. The maximum operational current should consider the worst case conditions that the overcurrent protection device will see for the application. (see Fire Focus Team report for more information).
7. Provide smaller (distributed) power plants closer to the load as part of modernization.
8. Methods and Procedures
   - Detailed methods and procedures are needed to identify all protection required around the energized DC bus when there is a possibility of ground fault during the installation process.
   - Load test all circuit breakers prior to connecting load.
   - Update installation handbook to include verification of front to rear stenciling.
   - Perform high-risk operations at night.
   - Procedures and restoral process are required for any cable mining job. Telco observers are required for such work.

n Quality Level III[15] - assigned to devices that meet requirements (a) through (e) of Quality Levels I and II, plus the following: 1. devices must be requalified periodically, 2. lot-to-lot controls must include 100 % screening (temperature cycling and burn-in) which, if the results warrant it, may be reduced to a "reliability audit" (i.e., on a sample basis). 3. where screening is used, the percent defective allowed (PDA) should be specified.

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Clamp-on ammeter should be used to identify hot circuits.

6.6 Alarms and Remote Monitoring

6.6.1 Alarm Discussion

Alarms serve two purposes: they alert personnel to a problem, and provide sufficient information (what and where) so that appropriate action can be taken.

Alarms can be classified as either:

- Local--bells, horns, or voice annunciators to alert and visual indicators to show where the problem is
- Remote--transmitted to operations centers that are not near the equipment monitored. Because most telecommunications facilities are unattended at least part of the time, remote alarms are almost always required.

Alarms are also classified by severity: critical, major, minor. Events requiring immediate response are classified as either critical or major. Examples are blown fuses, engine failures, and battery on discharge. Events not affecting service for which response can be deferred (perhaps to normal working hours) are classified as minor; failures of maintenance spare rectifiers and converters are examples.

The historically high overall reliability of telephone power systems is due largely to the batteries that provide critical time for personnel to react to problems with the AC systems. To be able to use this time properly, operations personnel must be alerted to the problem. The classic direct cause of battery plant outages, particularly for offices with standby engines and multiple battery strings, is failure of the alarms. Central office battery plant failures are usually catastrophic due to the service affected and the time required to restore systems, e.g., all digital systems do not come back up gracefully.

Blown fuses should be replaced quickly. Without fuse alarms, failures may be extended for hours while technicians look for the problem in the wrong place, sometimes far from the failed fuse, for example, riding the toll route when the problem is in the central office.

Failure to repair redundant equipment (n+1 rectifiers and converters) in a timely manner due to no alarm can result in outages when the second unit fails. Likewise, lack of low fuel and other preliminary warning alarms on standby systems may cause outages.

Power alarm problems may be categorized as follows:

- Not properly provided initially either due to inadequate company standards or failure to implement standards.
- Worked properly at one time but became broken. Items that can cause power alarms to fail include power plant hardware (relays, circuit packs), wiring between power plants and alarm scan points, switch or other scan point circuitry, switch software and operational support system problems.
- Alarm system worked but personnel did not respond properly.

The importance of power alarms can hardly be overemphasized if catastrophic power failures are to be driven to zero.

6.6.2 Remote Power Monitor Discussion

Remote power monitors are flexible microprocessor-based devices that are used to monitor power and other systems within unattended central offices. Binary channels are used to monitor alarm contacts and other on/off devices. Analog channels can monitor AC and DC voltages, loads in amperes or KW, temperatures and other parameters if the proper transducer is provided. Power monitors perform data acquisition, recording, and reporting functions. Many can be accessed using a computer, data terminal, or telephone; and some have the ability to dial out to a remote phone or terminal to report power plant status and alarms. Some power monitors have a local display panel; others have only a terminal port.

Power monitors can collect data on an hourly, daily, weekly, or other basis. The data is held in a battery-backed random access memory (RAM) to protect against loss during a power failure. Hourly, daily, monthly, etc., minimums, maximums, or average values can be retained. Data channels can be described as standard, derived, and trace.

Analog channels are commonly used to monitor:

— AC bus voltage

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— Voltages of all DC plants
— DC plant loads (amperes)
— Loads on key fuses/circuit breakers
— Engine loads in KW or amperes
— Battery pilot cell voltage
— Battery room temperature

Binary channels usually monitor:
— Power alarms
— Rectifier failure
— Fuse alarms
— Battery discharge
— Low fuel
— Engine fail
— Engine proper operate

Power monitors benefit both the planning engineers and operations. The engineers are able to automatically obtain the load data required to size power plants and feeders and thus avoid overload situations. Operations personnel are able to obtain real time or historical data on alarms, or the status of voltages and other analog parameters.

6.6.3 Key Learnings and Practices

1. Each company must have an alarm strategy that ensures that power problems are promptly identified and efficiently addressed. This strategy must incorporate a host of operational and organizational factors. Initial provisioning, ongoing maintenance, and alarm response must be integrated. In general, simple systems should be used.
2. Provide a separate "battery discharge" alarm for all battery plants. Arrange the alarm to repeat every 15 minutes, whenever feasible. This feature has been available for several years via electronic switch software. It can also be incorporated into operational support systems:
   — Redundancy must be provided, so that no single point alarm system failure will lead to a battery plant outage. As an example, power monitors and voltage sensing relays can be installed to generate an alarm independent of all power plant circuitry and wiring. The redundant alarm may be sent to a secondary remote monitoring location (one company sends the fire and battery discharge alarms to two centers).
   — Highlight the battery discharge (and other critical alarms) at the remote center so that it is virtually impossible to ignore. This can be accomplished with flashing lamps, voice annunciation, or other means. Provide escalation procedures (refer to higher authority) for handling battery discharge alarms that stay in, particularly for major facilities.
3. For critical alarms produced by single contacts (one on one), use "normally closed" contacts that open for alarm. (Normally closed means closed when no alarm condition exists regardless of whether the device is energized) The advantage is that loss of continuity/cut leads produces an alarm. Several "closed" contacts should not be connected in series to produce a single alarm. Troubleshooting this configuration is similar to working on series Christmas tree lights.
4. One power plant vendor has recently developed an LED alarm integrity monitor circuit to assist in maintaining "normally open" alarms. This circuit "borrows" a small amount of current from the internal voltage source associated with the alarm surveillance systems sensing interface to light a low current visual display device, i.e., LED. With the integrity circuit deployed, the technician can immediately visually determine alarm continuity.
5. Power monitors should be integrated into engineering and operational strategies. Power monitors have proven to be particularly worthwhile during widespread power outages such as those produced by hurricanes and ice storms. As noted above, the monitors can provide redundant battery discharge and other voltage sensitive alarms independent of power plant hardware and wiring. The historical data can be useful in post-failure investigations.

   Companies using power monitors for control functions and/or primary alarms should be aware of the potential security threat inherent with dial up-access. The security threat is being addressed by many users through the use of private networks, e.g., X.25 packet network.

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6. Maintain the power alarms. Test the alarms on a scheduled basis by simulating the trouble condition as nearly as possible without interrupting service. Verify that the alarms are received and properly identified at remote locations. Particular attention should be given to maintaining the integrity of alarms during equipment removal.

6.7 Operations and Maintenance

As noted in Section 5, the greatest potential for improving power systems reliability lies in addressing human factors, primarily operations, maintenance, and process issues. An effective maintenance/operational program is essential to power systems reliability. Some attributes of a good maintenance program are:

- Upper management support and mandate for detailed attention to maintenance
- Frequent review of company standards, practices, methods and procedures (a well documented maintenance plan)
- Adequate staffing both qualitatively and quantitatively
- Expertise (experience and training)
- Adequate resources (tools, test equipment, vehicles, communications, etc.)
- Management controls to ensure that company standards are followed and updated when necessary.

Specialized power teams are recommended wherever practical, including all metropolitan areas. The alternative to specialization is many technicians doing a little power work as a small part of their job. This approach seldom leads to the experience and expertise required to resolve difficult problems. In rural environments it may not be economical to have all power work done by power specialists. One option is to have the local forces perform the short interval routines (engine runs) and have specialists visit each site quarterly or annually to perform the more involved work.

Typical power team responsibilities are:

- Maintenance and repair of all power equipment and associated alarms and power monitors
- Response to power alarms unless local forces are on-site and can easily clear the trouble
- Installation : vendor monitoring and job acceptance for all power work
- Preparation of local power procedures
- Training for local forces on power equipment and procedures
- Coordination of fuel delivery for standby plants
- Coordination of transportation and hook-up of portable engines
- Inventory and consolidation of spare parts, tools, and test sets
- Power equipment surveys and minor modifications as requested by company staff (Maintenance Engineering)
- Monitoring of central office grounding and building environmental items.

Staff power specialists are required to direct the power maintenance program. Their responsibilities typically include:

- Power program documentation, methods and procedures, etc.
- Oversight of power maintenance program implementation
- Technical and administrative support for power teams such as training arrangements and conducting power conferences
- Power reviews
- Investigation of power related outages and "near misses"
- Meetings with vendors and other departments to resolve power problems
- Grounding standards, methods, and reviews.

Central office routine maintenance work typically includes:

- Bi-weekly: 1 hour diesel engine runs with load, visual inspections, battery float voltage, and other basic checks.
- Quarterly: Battery readings and inspections, verification of critical alarms, rectifier, DC-to-DC converter and other operational checks.
- Annually: Detailed inspections and operational checks of all systems.

Safety must be emphasized in any power program. The special hazards associated with AC and DC electrical systems, batteries, engines, etc. must be recognized and dealt with in company procedures, training, and reviews. Work on AC systems should be performed only by qualified personnel and only with the equipment de-energized.

6.7.1 *Key Learnings and Best Practices*

1. Provide hands-on training for operation and maintenance of power equipment for management and craftpersons.
2. Place utmost emphasis on the maintenance of power alarms and on the response to power alarms (see Section 6.6, Alarms).
3. Vendor work was one of the leading causes of power outages. Emphasize methods of procedure (MOPs) and vendor monitoring. Perform risky work at night. Take all necessary precautions to avoid service interruptions, but have restoration plans available should they occur.
4. On removal projects, check for current flow in power cables with AC/DC clamp on ammeter before removing the associated fuses or opening circuits.
5. Provide and test detailed action plans to address emergency situations such as when both the commercial AC power supply is interrupted and standby engines fail to start (See Section 6.9, Local Procedures/Contingency Plans).
6. Perform annual evaluation/maintenance of all power equipment. This includes detailed inspection, cleaning, adjustment, lubrication, verification of all features, operational tests, fuel and lub oil sampling, etc. Correct all deficiencies.
7. As part of the annual maintenance, run engines with all available load (air conditioning and any other loads not transferred during bi-weekly or monthly runs) for an extended period, at least 5 hours. Some companies recommend 24 hour runs.

   To test the ability to function without commercial power, commercial power should be disconnected from the building for at least part of the annual run; coordinate this test with the electrical utility. This will identify any loads operating on commercial power that should instead be connected to the engine. Possibilities include engine support systems (pumps and fans), air conditioning, lighting, some telephone sets, modems carrying alarms, etc. Of course, if the facility has experienced recent commercial power failures or if the engine carries the entire building, this is not necessary.
8. Use infrared thermographic scanners to check power connections. Small hand-held units are available for about 500 dollars. These can be used for checking battery connections (with batteries on discharge), fuse holders, AC connections, etc.
9. In addition to the conventional training, one telecommunications company has undertaken an initiative, identified as "Ask Yourself," to help create a new operating culture within its company. This initiative is intended to reinforce the responsibility every employee has to ensure flawless network service. The program is based upon the following principles:
   - Prevention: preventing problems before they occur
   - Doing the right things: rather than doing anything to get the job done
   - Empowerment: being personally responsible for our own work with the power to resolve problems if quality is being compromised
   - Intolerance for poor quality: questioning why things are the way they are
   - Interdependence: realising the benefits of partnerships in problem prevention.

   Central to the program is the management support for employees to "stop the line" and resolve problems when they can't answer yes to any of the "Ask Yourself" questions. The "Ask Yourself" program (Exhibit 2) was identified as a best practice.

6.8 Installation/Removal Work

The single greatest cause of outages examined by the data analysis subgroup is installation/removal activity. This is not an unexpected finding--the telecommunications industry generally recognizes this as a vulnerable area with a need for special precautions.

Power equipment installations and removals may be performed by personnel provided by the equipment manufacturer, by telephone company personnel or by third-party installation/removal vendors.

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6.8.1 *Types and Causes of Failures*

Service interruptions during installation or removal activities typically result from one or more of the following:

- Inadequate protection of working equipment
- Inadequate analysis of the job to be done
- Faulty methods of procedure
- Deviation from the method of procedure
- Installation errors
- Deviation from test methods.

6.8.2 *Key Learnings and Best Practices*

1. Equipment suppliers should provide clear and specific engineering, ordering, installation, testing, and maintenance information in support of their products. This information should include text material, supporting illustrations, drawings and specifications.

   Telecommunications company personnel should evaluate support documentation as an integral part of the equipment selection process. Operating personnel must be familiar with the information provided with the equipment.

2. Many telecommunications companies have documented installation guidelines, specifying both administrative procedures and workmanship standards that apply in their company. Formal training classes have proven useful in implementing these guidelines.

   The best such practices incorporate guidelines for preparing a written Method of Procedure (MOP) to detail how, when, and where installation work is to be performed to preclude the likelihood of service interruption.

   Technical requirements for bonding and grounding, assembly and erection of ironwork, cabling, wiring and connecting, and general safety procedures are appropriately part of these practices.

   Example documents include the following:

   Technical Reference TR-73503 *Installation Standards Central Office Equipment.*[16]

   Technical Publication TP76300 *Installation Guide.*[17]

   Technical Publication 77350 *Central Office Telecommunications Equipment Installation and Removal Guidelines.*[18]

   TA-NWT-001275 *Central Office Environment Installation/Removal Generic Requirements.*[19]

   Telecommunications companies should clearly communicate their installation guidelines to all involved parties. These guidelines should be periodically reviewed and updated to reflect current conditions.

   On-site installation acceptance should include a quality review of conformance to the company's installation guidelines, and adherence to the manufacturer's outlined installation and test procedures.

3. Some telecommunications companies have procedures for prequalification or certification of installation vendors. Such procedures ensure that the vendor can meet the company's installation guidelines and is familiar with specific equipment types. Assurance is also obtained that the vendor's personnel are experienced and adequately trained, that the vendor has ready access to necessary tools and test sets, and that attention is given to quality workmanship.

   Prequalification of installation vendors should be a best practice. Applicable standards should also apply to in-company installation crews. It is appropriate to recertify periodically, such as every 3 years, to account for changes in personnel and methods.

6.9 Local Power Failure Procedures and Contingency Plans

Site-specific power procedures and contingency plans are important factors in preventing outages and shortening their duration when they do occur. As noted previously, the high overall reliability of telephone power systems is due largely to the batteries that provide time to react to abnormal conditions. Thoroughly developed procedures are essential to optimize the use of this limited time, which often occurs under adverse conditions, such as limited lighting and no elevator service. The

difference between a long duration catastrophic outage and a short event may well be good restoration plans.

Site-specific power procedures should be available for all central offices. For small offices with simple systems, the procedures will be brief. Large buildings with complex electrical systems require correspondingly more detailed procedures. The procedures should be conspicuously posted near the power equipment and maintained on a PC or other automated system for ease of updating as rearrangements are made.

The procedures should cover the normal automatic and manual operations required when commercial power fails, manual operations that may be required when automatic systems malfunction, and emergency actions and contingency plans for the failure of key elements. In summary, the procedures represent the basic planning that can reasonably be expected to cover power plant emergencies.

All personnel who would normally respond to power problems in an office should be familiar with the procedures so that in a real emergency the written procedures would only be needed as a "memory jogger."

Provide appropriate sketches, signs, labels, color coding, etc. on the equipment to complement the written procedures.

Procedures are also required for disconnecting AC and DC power on both a zone or full building basis in the event of a fire emergency. These procedures should be as straightforward as possible and should be reinforced by appropriate signs and floor plan diagrams. The fire disconnect procedures are intended for use only in a dire emergency and do not cover steps required to take systems down gracefully. The preparation of these procedures should be coordinated with the local fire department so as to best meet their needs. The impact on service of disconnecting DC power must be clearly understood, i.e., loss of emergency communications such as E911, fire, and police.

The outline in Appendix 12.3 may be used as a guide in preparing site-specific procedures.

6.10 Operational and Engineering Reviews--Continuous Improvement

A management review (audit) process should be in place to measure compliance with company engineering and operational practices. The reviews are also an opportunity to identify changes needed in those practices. Without reviews to identify and correct weaknesses, power systems may be neglected until there is that serious outage that invariably results in a short-term power improvement program.

Typical power review checklists cover the design, operation, and maintenance of building electrical systems, standby engines, DC power plants, alarms, central office grounding, and key environmental items that could affect service, e.g., sump pumps and environmental alarms. See Exhibit 1 for an example of a power checklist.

For a review program to be effective, however, it must have management support. Weaknesses must be addressed so that the same deficiencies do not repeat on subsequent reviews. A good review program should reduce the risk of serious outages and lead to continuous improvement. All power related service outages should be thoroughly investigated, their causes determined, and appropriate countermeasures taken to prevent reoccurrences. Also, all near misses, such as extended unplanned operation on batteries, should be investigated and corrective action taken.

By tracking review results, outages and near misses, power reliability trends can be monitored on a company wide basis and management action taken to address weak spots.

6.11 New Technology and Architecture

6.11.1 Emerging Battery Technologies

Although flooded lead acid cells for Central Office (CO) applications and VRLA cells for confined locations will be the choice for the near term, there are some new and developing technologies that may be employed in the future. Among the issues that need to be addressed are high cost of the technologies and recycling problems. The technologies of interest are:

- Nickel Cadmium (NiCd) cells

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- High-temperature NiCd cells
- Low-pressure metal hydride cells
- Secondary (rechargeable) lithium (Li-ion) cells
- Aluminum air primary cells.

Both the NiCd and high-temperature NiCd cells are available today. The motivation for using NiCd technology is its longer cycle life and the fact that it can be designed to withstand temperatures as great as 65°C. The limitation of the NiCd technology is the capacity of available cells. The largest commercially available NiCd cells are 5 watt-hours (D cells). Cells of this capacity have possibilities for applications that require small amounts of power (e.g., remote electronics for a single customer). Although it is possible to produce larger NiCd cells, such cells will not be available in the near term. NiCd cells may also cause difficulties when disposal is required.

The motivation for exploring secondary Lithium technology is energy density (or volumetric efficiency). Secondary Li cells should yield energy densities on the order of ~ 2 times that of the NiCd technology. Safety is a major issue with this technology.

The motivation for exploring low-pressure nickel (Ni), metal hydride cells is volumetric efficiency, possibly good high temperature life, good cycle life, and easier disposal than other technologies. The energy density of low-pressure nickel, metal hydride cells is ~ 2 times that of the NiCd technology.

Although the other technologies discussed are rechargeable (or secondary), aluminum-air batteries are not rechargeable (primary). Interest in aluminum air batteries is as a long-term backup in lieu of engine-alternators. This technology has excellent volumetric efficiency compared to secondary technologies but can only be employed once. Aluminum-air batteries could provide energy densities on the order of ~ 4-5 times that provided by NiCd batteries. An issue with this technology is the stopping and restarting of discharge once a discharge has been initiated. Once the aluminum air battery is completely discharged, the aluminum electrode and electrolyte can be replaced and another discharge cycle can be initiated. Because the aluminum air battery cannot instantaneously provide energy, a secondary battery will still be required to provide energy immediately after the start of a power outage.

6.11.2 Valve Regulated Lead Acid (VRLA) - Prediction of Battery Capacity

A fundamental problem with battery systems is the ability to predict or estimate their available capacity without fully discharging the batteries. How to estimate the capacity of a string of batteries from the beginning of discharge is the problem. The estimate is very important for planning purposes because it could provide an ordered list of remote locations that need portable engines or extra batteries sent to them.

There are several failure modes for VRLA batteries and each could have a characteristic impedance/conductance signature. For example, a cell that is corroded and has extensive grid growth would not respond the same as a cell that has simply dried out.

The problem of identifying failure modes through impedance/conductance measurements is very difficult. The instruments used for the measurements operate at different frequencies and results will vary depending on the failure mode; therefore, strict comparisons cannot not be made. Also, the sensitivity of the instruments will vary depending upon the predominant battery failure mode encountered. The instruments need a calibration point, so a new cell of a particular type should be measured using all available instruments. If that is not possible, perhaps the battery or system vendor has measured enough of these type cells and a reliable calibration chart is available.

The overall change in impedance or conductance that signals a problem cell or string depends on the design of the battery. However, as a general guideline, an increase in impedance or a decrease in conductivity amounting to 30% or more should be cause for concern. The actual values for all cells when first installed should be recorded and kept to facilitate future comparisons. If a cell shows a large change, such as ± 30%, it should be tested for capacity as soon as feasible. An entire string could perhaps be discharged partially to check performance.

As these measuring tools are used more frequently, a more complete database will be established so

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time/variation paths in impedance/conductance for various batteries can be developed.

Testing done on VRLA batteries indicates that they may not have the life expectancy claimed for them. The extreme spread of cell capacities documented, apparently due to dry-out, must be viewed as a warning. Thus, it would be prudent to check any early VRLA batteries deployed.

A final point is that a power plant does not have to contain exactly the same manufacturers batteries for each string. Each string should contain the same manufacturer's cells, but all strings could be different. This could be made a deliberate policy in the future so that the failure modes of the strings would not overlap and thus catastrophic failures could be avoided. However, this decision should consider the possible problems, such as making prediction of "state-of-health" unreliable.

6.12 Standards

6.12.1 Valve Regulated Lead Acid (VRLA) Batteries for the Telecommunications Environment

National standards to describe and define the primary characteristics, installation, maintenance and replacement requirements, sizing, and corresponding tests associated with VRLA are being developed in T1E1.5. The standard will apply to telecommunications load equipment operating from a centralized DC power source.

The draft standard *American National Standard for Valve-Regulated Lead-Acid Batteries (Immobilized Electrolyte) Used in the Telecommunications Environment*, T1E1.5/93-003 (formerly T1Y1.4/93-028R3) is being developed by T1E1.5, DC Power Systems Working Group, T1E1.5. The working group is a public forum and its members are from the telecommunications industry. The thrust of the proposed standard is to have uniform product available from battery manufacturers for the telecommunications industry with the high degree of service reliability that this industry requires. The draft document contains a table of contents listing the subjects to be addressed. Major subject areas that consensus agreement has been reached on are thermal runaway, physical size, disposal, and marking.

6.12.2 Voltage Levels for DC Powered Equipment Used in the Telecommunications Environment

National standards for the DC input voltage range of telecommunications load equipment are being developed in T1E1.5. The standard will apply to telecommunications equipment operating from a centralized DC power source and will not apply to equipment powered at or downstream from the Network Interface. The standard also addresses the associated noise voltages that appear with the DC voltage. The standard will not require existing power plants or equipment to be modified.

Objective(s) Of The Standards Committee:

- Provide DC voltage ranges that telecommunications load equipment shall meet for the different plant voltages with the exception of equipment powered at or downstream of the Network Interface.
- Provide a better understanding of the voltages in centralized DC power systems available to telecommunications load equipment.

American National Standard for Telecommunications - Voltage Levels for DC Powered Equipment - Used in the Telecommunications Environment, T1E1.5/93-002 (formerly T1Y1/91/080) has been prepared. The ANSI public review and T1 ballot process have been completed. There were no comments received from the public review. However, the T1 ballot response contained disapprovals and, according to the ANSI procedural guide, had to be resolved. These disapprovals have been resolved and a new draft document is being prepared for the default T1 ballot. It is expected that the draft standard would be balloted on and be available as an ANSI standard in the later part of 1993.

6.13 Hurricane Andrew Lessons

6.13.1 Central Offices

During and in the aftermath of Hurricane Andrew more than 150 BellSouth central offices in South Florida, Louisiana, and Mississippi were without commercial power for periods varying from hours to a few weeks. Overall, the power systems performed satisfactorily. No central office outages were attributed to power systems. As one would expect

with a storm of this magnitude, there were problems and some near misses. Recommendations and items to be reemphasized include:

1. Place standby engines on-line and verify the proper operation of all subsystems before the commercial power fails. (Most BellSouth locations did this. Some that didn't had problems, particularly with paired breaker transfer switchgear schemes, see item 5 below. Momentary "hits" on the commercial power prior to it going out entirely caused some rectifiers to shut-down.)
2. In coastal areas, design standby systems to withstand high winds and wind-driven rain and debris. Provide wind breaks for diesel air intake and exhaust louvers. Place diesel radiators in protected locations, inside the building whenever possible. Avoid roof-mounted radiators.
3. Improve fuel systems reliability. Reemphasize both design and maintenance items:
   - For day tanks provide redundant pumps. A manual priming pump is always required.
   - Provide low-level alarms on day tanks.
   - Obtain quality fuel from a dependable supplier. (One vendor delivered contaminated fuel.) Run engines sufficiently to turn the fuel over about every 2 years; test the fuel and use additives to prolong storage life. Service and maintain fuel filters and water separators.
4. Provide automatic reserve lubrication oil makeup systems for extended operation of diesel engines. (Otherwise it is necessary to stop the engines to check and replenish oil.)
5. Specify automatic AC transfer switches (UL Standard 1008)[12] in lieu of paired circuit breaker transfer schemes. Experience with transfer switches has been excellent. Paired breaker schemes have been less than satisfactory.
6. Reemphasize the need for local procedures and contingency plans for power emergencies (refer to Section 6.9).
7. Provide AC tap boxes outside the central office to facilitate the connection of portable engines should the on-site unit fail.
8. Remote power monitors were valuable during and after hurricane Andrew and other widespread commercial power outages, particularly for remote, unmanned offices. The ability to read AC and DC voltages, loads in amperes or KW, etc., provides confidence when systems are working properly and helps prioritize dispatches when they are not.
9. Reemphasize the need for power expertise/power teams (refer to Section 6.10).

6.13.2 Digital Loop Carrier

Hurricane Andrew disrupted commercial power to more than 1000 BellSouth digital loop carrier remote terminals (RTs). Hardest hit was the Miami area with 722 RTs affected. The RTs are equipped with batteries sized to support service for a nominal 8 hours. Longer outages require that portable generators be taken to the sites.

About 700 portable generators were used to support RT sites in the aftermath of Andrew, 500 in the Miami area and 200 in Louisiana. The number of generators required is less than the total outage number for a variety of reasons. Commercial power was restored at many sites before generators were needed or could be deployed. Some sites were inaccessible due to downed power lines, which when cleared restored power. At others, damage to telephone lines or the RT structures themselves made power a moot point initially. However, it is desirable to repower the electronics as soon as possible to control humidity and limit corrosion.

BellSouth has detailed disaster recovery plans for restoring power to RTs after hurricanes and other disasters. These plans were refined after Hurricane Hugo and are being revised to reflect lessons from Andrew.

The RT power restoration plans call for all districts outside the disaster area to be prepared to ship at least one-half of their generators to the stricken area. Additional generators are held in central pools just for widespread emergencies. During Andrew, additional generators were purchased and leased. The movement of personnel and equipment to disaster areas is coordinated on a company-wide basis from an Emergency Operations Center activated for that purpose. Initially, resources from Georgia, North Carolina, and South Carolina went

to Florida while equipment from BellSouth's five western states was reserved for the Gulf Coast.

The timely movement of large numbers of generators requires detailed planning and good execution from many BellSouth organizations plus numerous vendors. Flexible plans are required at the receiving end to process the arriving equipment and deploy it as efficiently as possible. Lessons learned and items to be reemphasized from the Hurricane Andrew experience include:

1. Engineer for fewer but larger RTs serving larger areas. Use bulk power plants instead of distributed power. Provide stationary engines for the largest most critical RTs. Bellcore Special Report SR-NWT-001701[21] discusses this issue. Also, refer to TA-NWT-001293,[22] Generic Requirements for Permanent Engine-Generators for Remote Electronic Sites.
2. Security from theft of portable generators was a significant problem during Hurricane Andrew and Hugo. Trailer-mounted generators equipped with wheel locks are recommended. All locks, chains, and keys should be standardized. Radio activated satellite locators are recommended for particularly vulnerable units. (Use of 48V DC generators would make security much less of a problem).
3. All future portable generators should be diesel. Diesel is easier to handle than propane tanks and requires less frequent refueling.
4. Better coordination is required with the electric utilities. It is suggested that both the telephone company and utility designate local single point contacts for coordinating restoration. The telephone company should be familiar with power company emergency restoration plans, State requirements, and FEMA arrangements. Mutual plans should be made and routinely reviewed prior to any emergency .
5. Numerous logistical items were identified for improvement:
   - Better methods are required for tracking what is sent to the stricken area. Tracking should be mechanized using a bar coding system.
   - Methods for loading and unloading generators onto flatbed trucks must be standardized. Do not use forklifts--they can damage the equipment. Wreckers or cranes are the only acceptable method.
   - Better coordination is required with trucking companies and crane/wrecker vendors to insure timely loading/unloading. Truckers must be flexible with respect to the delivery destinations, which may change while in route.

7. Metrics

There are two reporting vehicles that hold potential for monitoring trends developing in the causes of power related telecom outages in the PSN. One is the ARMIS Quarterly Service Quality Report, the other is the reporting of telecom outages that meet the FCC thresholds for major telecom outages. The Power Focus Team found that the major causes of telecom outages reported in the survey data and in the FCC reportable data are very closely correlated. The incidents reported to the FCC therefore appear to be representative of the causes of power related telecom outages throughout the PSN.

The FCC reportable outages also have the advantage of containing substantial narrative describing the circumstances of the outage. ARMIS reports, while greater in number than major service disruption reports, have no narrative associated with them and provide for the reporting of only one causative factor. In addition, ARMIS reports are not required to be filed by interexchange carriers. The Power Focus Team, therefore, recommends that the FCC reportable data is sufficient for monitoring network performance with respect to power systems. The information contained in these reports should be classified according to the type of equipment that failed and root cause using the same categories found in Figures 2, 3 and 4.

A matrix of Network Reliability Industry Initiatives is provided in Appendix 12.4.

8. Path Forward

The Power Focus Team recommends that the Exchange Carriers Standards Association (ECSA) monitor the metrics proposed in Section 7 of this

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paper. The ECSA staff will collect and macro-analyze the data. When necessary, industry forums such as the Network Operations Forum will be asked to do further analysis and undertake other actions. The ECSA is described in its own literature as "the national problem-solving and standards-setting organization where local exchange carriers, interexchange carriers, manufacturers, vendors, and users rationally resolve significant operating and technical issues---." The ECSA's Network Operations Forum is well positioned to debate and resolve issues of network reliability in the PSN.

Again, ECSA is being asked by the NRC to do the monitoring via FCC outage reports. The Network Operations Forum or any other industry forum may be asked to undertake micro-analysis and other action if ECSA monitoring of data detects negative trends.

9. Conclusions

In this report, the Power Focus Team has compiled recommendations and industry best practices for the following aspects of central office power system operation and design:

- Commercial power/electric utility issues
- Standby generators
- Building AC systems
- DC plants
- DC distribution systems
- Alarms and remote monitoring
- Operations and maintenance
- Installation/removal work.

The most significant recommendations for telecommunications service providers include the following:

- Place strongest emphasis on resolving the operational factors in central office power system outages related to human activity. Candidates for improvement include equipment design and product selection based on simplicity of design and maintenance, alarm system operation and alarm response procedures, equipment installation and removal procedures especially where vendors are involved, maintenance program design and implementation, and MOP training for craft personnel.
- Ensure that central office power system designs eliminate the possibility of catastrophic service outages owing to single points of failure.
- Employ specialized power teams for central office power system operation and maintenance.
- Maintain and exercise detailed site-specific power failure procedures and contingency plans for all central offices including procedures for disconnecting AC and DC power in a fire emergency.
- Provide tap boxes outside central offices to facilitate connection of large portable generators when stationary central office generators are inoperative.
- Adhere to the following standards:
  - TR-NWT-000063, *Network Equipment Building Systems (NEBS)*[1]
  - ANSI T1.311-1992, *DC Power Systems - Telecommunications Environmental Protection.*[2]
- Coordinate with electric utilities to ensure that critical telecommunications facilities identified in the Telecommunications Electric Service Priority initiative are afforded priority restoration treatment in electric power utility disaster recovery plans. This initiative was developed by the National Communications System and is currently being implemented by the Department of Energy's Office of Emergency Planning and Operations.

10. Acknowledgements

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11. Exhibits

- **Power Checklist**
- **Ask Yourself**

Exhibit 1. Power Checklist

CENTRAL OFFICE POWER/BUILDINGS REVIEW

The purpose of the Power/Buildings Review is to evaluate a building's electrical systems and key environmental factors which have the potential for causing service problems. The objective is to identify and correct design and operational weaknesses. The reviews are conducted by experienced network and buildings power/electrical specialists with the assistance of and input from the local operations personnel.

All deficiencies and recommendations are documented and referred to the responsible organization for correction.

The attached checklists, which are not all inclusive, provide a guide for conducting the reviews.

The following documentation is required:

- Buildings:
  - — Electrical plans (including single line diagram),
  - — Records of last AC switchgear tests and annual inspections and any follow-up work,
  - — Inspection findings and follow-up,
  - — Records of last routine building inspections.
- Network:
  - — Equipment Engineers database printout with battery reserves,
  - — All power plant W L & Block Schematics including AC feeds for battery plants, power alarm and grounding schematics.
  - — CIMAP printout showing power routines,
  - — Configuration printout for power monitor,
  - — Records from last power review and any follow-up work,
  - — Records from last Fire Safety Inspection.

The following tools are required:
— Digital VOM,
— AC/DC clamp-on ammeter,
— Flashlight,
— Hand tools,
— Camera & thermographic equipment (optional).

CHECKLISTS

- Buildings Electrical System
- Standby Engine
- Battery
- Power Plants
- Building/Power Alarms
- Fire/Safety
- Environmental

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Exhibit 1. Power Checklist - Cont'd

BUILDINGS ELECTRICAL SYSTEM CHECKLIST		
ITEM	*	----------REMARKS/NOTES----------
Routine Maintenance:		
(770-280-601SV)		
-Three/five year tests		
-Annual inspection		
Commercial Power:		
-Reliability?		
-Pwr curtailment contract?		
-Inspect XFMR's		
Documentation:		
-Emer. Procedures		
(171-120-302)		
-Single line schematic		
-Control schematic		
-Switchgear manuals		
House Service Bd:		
-Medium voltage locked?		
-Transfer switchgear		
-Indicating fuses		
-Mimic bus		
-Meters		
-Lightning arrestor		
Circuit breakers: **		**particular attention to CB's for DC plants
-Size/trip settings		
-Coordination		
-Identification (PDSC #'s)		
Switchgear tools:		
-Hoist		
-Cranking tools, etc.		
CO Grd System:		
-Grd electrodes		
-OPGP		
-AC Service		
-ACEG's		
-Vertical risers		
-CO Grd bus's		
-CEF		
-Tower		
Panelboard directories		
AC lighting		
DC lighting		
Spare eqpt./fuses?		
Modernization/update rqmts.??		

* "Check" for OK, X for deviation, NA for not applicable.

Electrical Systems Data and Notes:

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Exhibit 1. Power Checklist - Cont'd

STANDBY ENGINE CHECKLIST		
ITEM	*	----------REMARKS/NOTES----------
Documentation:		
-Run Log		
-Local procedures		
(171-120-302)		
-BSP's, SD's, Manuals		
-Wall chart (155-010-300)		
Capacity vs load		
Air cond. on engine?		
Routines:		
-Regular runs		
-Annual run		
-Annual PF test		
(155-003-003)		
-Water check (fuel tank)		
-Oil change/analysis		
-Fuel sample		
-Safety shutdowns/alarms		
Start battery:		
-Records		
-Condition		
-Charger output/voltage		
Check:		
-Oil level (crankcase & oil filter)		
-Coolant		
-Belts/hoses		
-Leaks?		
Fuel system:		
-Main tank		
-Day tank		
-Pumps/controller		
-Fuel filters		
Ventilation system:		
-Louvers		
-Fans		
-Filters?		
Exhaust system		
Electrical system & controls		
Tools?		
(CB reset ratchet)		
Remote stop switch (safe location)		
DC light		
Ear protection		
Plan for portable?		

* "Check" for OK, X for deviation, NA for not applicable.

Engine Data and Notes:

Exhibit 1. Power Checklist - Cont'd

BATTERY CHECKLIST		
ITEM	*	----------REMARKS/NOTES----------
Battery Records		
-Float voltage routine		
-Three month routines		
-→post insp. (round cells)		
-Annual evaluation		
(157-601-710)		
-Questionable cells		
Battery reserve (hrs)		
(list for all plants)		
Check float voltages		
Inspect all cells		
(155-003-010 3.4)		
Environment/temp.		
(RL91-02-052SV)		
Seismic bracing?		

* "Check" for OK, X for deviation, NA for not applicable.

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Exhibit 1. Power Checklist - Cont'd

POWER PLANT CHECKLIST		
ITEM	*	----------REMARKS/NOTES----------
Documentation:		
-AMPS/PEERS accuracy		
-SD's, BSP's, WL&BS's		
-Local instructions		
(end cell switches, etc.)		
Operational checks:		
-End cell switches		
-CEMF switches		
-Rectifiers		
-DC/DC converters		
-Inverters		
-Ring plant transfer		
Meter calibration		
Overloaded plants		
Excessive capacity		
Fusing:		
-AC (for rectifiers)		
-DC		
-Spare fuse panel		
-CB covers		
-Warning signs		
DC distribution & cabling		
Rectifier seq. control unit		
Remote power monitor		
CN's, updates,		
modernization rqmts??		

* "Check" for OK, X for deviation, NA for not applicable.

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Exhibit 1. Power Checklist - Cont'd

BUILDING/POWER ALARMS CHECKLIST		
ITEM	*	----------REMARKS/NOTES----------
Three month routine		
for power/envir. alarms		
(CIMAP & BLDGS)		
Bldg alarms:		
-Fire alarm		
-Fire alarm trouble		
-Sump pump		
-High temperature		
-Low temperature		
-High humidity		
-Low humidity		
-Lightning arrestor		
(e/w contacts)		
Network power alarms:		
-Battery discharge (BD)		
-Power Major		
-Power Minor		
-Commercial power fail		
-Engine proper operate		
-Engine major		
-Engine minor		
-Fuel system		
-Ring plant (MJ)		
-Ring plant (MN)		
-Power Monitor "BD"		

* "Check" for OK. X for deviation. NA for not applicable.

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Exhibit 1. Power Checklist - Cont'd

FIRE/SAFETY CHECKLIST		
ITEM	*	----------REMARKS/NOTES----------
Marsh & McClennan		
Firesafety audits		
(770-310-120SV)		
Quarterly firesafety		
inspections (E5689)		
EMER OP BINDER		
(770-300-200SV)		
Network items:		
-Cable holes sealed		
-Fire doors closed		
-Storage of flammable		
liquids & combustibles		
Fire detector zone diagram		
Evacuation plans posted		
Fire extinguishers		
Misc. safety eqpt.:		
-Goggles/face shield		
-Ear muffs		
-Gloves (insulating & acid)		
-Aprons		
-Neutralizing agents		
-First aid kit		
-Warning signs		

* "CHECK for OK, X for deviation, NA for not applicable.

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Exhibit 1. Power Checklist - Cont'd

ENVIRONMENTAL CHECKLIST		
ITEM	*	----------REMARKS/NOTES----------
Sump pump:		
-Essen. AC power		
-Routine tests		
-Operation		
-Drains clean		
Cable vault:		
-Water intrusion		
-Firestopping		
-Bonding/grounding		
Environmental:		
(RL91-02-052SV)		
-Temp/humidity per RL		
-Temp/humidity recorders		
-Hot spots??		
-Filtration		
-Positive air pressure		
Normal & emergency		
procedures for HVAC		
(RL 2.1, 2.2 & 2.3)		
Roof:		
-Regular inspections		
-Condition		
-Drains clean		
Security:		
-Outside doors secured		
-Eqpt. areas restricted		
Routine Inspections:		
-Mtce., RF1511A		
-Eqpt., RF1511B		
-Emer. Prep., RF1511C		
-House Serv., RF1511D		
-Energy, RF1511E		
Structural integrity		

* "CHECK" for OK, X for deviation, NA for not applicable.

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Exhibit 2. Ask Yourself Program©

Ask Yourself

1. Do I know why I'm doing this work?
2. Have I identified and notified everybody -- customers and internal groups -- who will be directly affected by this work?
3. Can I prevent or control service interruption?
4. Is this the right time to do this work?
5. Am I trained and qualified to do this work?
6. Are work orders, MOP, and supporting documentation current and error-free?
7. Do I have everything I need to quickly restore service if something goes wrong?
8. Have I walked through the procedure?

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