ASHE Monograph

Managing Hospital Emergency Power Systems

Testing, Operation, Maintenance, Vulnerability Mitigation, and Power Failure Planning

David L. Stymiest, PE, CHFM, CHSP, FASHE

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The American Society for Healthcare Engineering (ASHE)
of the American Hospital Association
155 North Wacker Drive, Suite 400
Chicago, IL 60606
312-422-3800

ashe@aha.org
www.ashe.org

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David Stymiest is a certified healthcare facility manager, a certified healthcare safety professional, an ASHE Fellow, and a senior consultant at Smith Seckman Reid, Inc., specializing in facilities engineering and regulatory compliance consulting for hospital clients. Before joining SSR in 2000, he was Senior Electrical Engineer for more than 10 years for Massachusetts General Hospital and the other hospitals of the Boston-based Partners HealthCare System, Inc. He has more than 41 years of experience in all facets of facility electrical engineering. He has written many ASHE papers and Health Facilities Management *articles on hospital electrical system management and engineering, and he co-edited the 1200-page McGraw-Hill* Facilities Engineering and Management Handbook for Commercial, Industrial, and Institutional Buildings. *He is chairman of the NFPA Technical Committee on Emergency Power Supplies, which has responsibility for NFPA 110 and NFPA 111. He has a bachelor's degree and a master of engineering degree in electric power engineering, a certificate of special studies in administration and management, and is a registered professional engineer in three states. Mr. Stymiest can be reached at DStymiest@ssr-inc.com.*

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Introduction

When the first predecessor to this monograph was written for presentation at the 1996 ASHE Annual Conference, we had yet to face the 1996 Northwest Blackout; the September 11, 2001, attacks; the August 2003 Northeast/Midwest Blackout; and a multitude of natural disasters that have unfortunately earned their spots in our history books. In 1996, monthly emergency power load testing was no longer in its infancy but was still meeting with resistance in some corners because of its impact on clinical activities. How far we have come since then! Now we know that large, extended, multistate blackouts can occur even in the 21st century. We have learned that natural disasters can defeat a region's entire infrastructure.

As a 1996 conference paper, then as an ASHE Technical Document, and later as a Management Monograph, this document was originally limited to discussion of emergency power testing programs. The 2006 revision expanded its scope to include emergency power operations, maintenance, and emergency management. The 2009 revision expanded its scope to include more information on planning for power failures. This latest revision expands the scope yet further to include finding and then mitigating vulnerabilities. We are now obliged to consider the subject of emergency power system management holistically. Utility management and emergency management are complementary, as are operations and maintenance, load profiling and power system failure analysis, regular testing and continuous quality improvement, and finding and mitigating vulnerabilities to reduce the probability of failures.

Hospitals must have emergency power testing programs in place to meet the requirements of NFPA 70, NFPA 99, and NFPA 110, as well as standards established by accrediting organizations and state or local authorities having jurisdiction (AHJs). These programs include requirements for generator load testing and emergency power supply system (EPSS) maintenance. Both topics were well represented in an excellent Joint Commission monograph[1] shortly after the rules for the originally required "30/50" testing were first promulgated in industry standards. Those requirements have changed several times since their original adoption. Several other comprehensive analyses have dealt with designing the testing program and the code requirements that apply to hospital EPSS testing as well as to the EPSS in general.[2, 3, 4, 5] Other publications have addressed code changes and other pertinent issues such as performance improvement and vulnerability analyses.[6, 7, 8, 9, 10]

This monograph also includes some lessons learned from regional disasters as well as a previously published case study[11] of EPSS testing. The case study discussed issues that might be described as second-order consequences[12] of the emergency power testing effort. To the extent that second-order consequences can have negative effects on a hospital, steps should be taken to follow up on those issues to identify problems and take corrective action. In many cases, the emergency power testing program's second-order consequences also represent problematic system interactions that can negatively affect hospital operations or patient care during a real utility outage.

Emergency power testing programs involve transferring the power sources of operating mechanical, electrical, plumbing, vertical transportation, and clinical systems from normal power to the emergency generators and then back to normal power. These power transfers can disrupt increasingly more complex and sensitive clinical and building equipment, building automation systems, and hospital operations. When the testing process is managed properly and proactively followed through, these disruptions are valuable learning experiences that provide opportunities to improve the hospital infrastructure, hospital operations, and EPSS reliability. Lessons learned from emergency power testing also suggest future system design improvements.

It is important to analyze system interactions, test results, and trends rather than just record generator set parameters or kilowatt test results. Several of the publications referenced here cover only recording and analyzing the test results for the engine and generator operating parameters. This document will address test results that describe kinds of interactions between the electrical distribution system components and their emergency power loads.

Scope

There are several descriptive terms for portions of the backup power systems in a hospital, and this monograph discusses them all. Table 1 identifies the overlap among terminologies in three relevant NFPA standards. For simplicity, this monograph uses the term “emergency power system” (EP system) generically to describe all of the subsystems listed in Table 1.

Hospitals face new requirements and more challenges today than ever before. These challenges demand a holistic approach to EP system management—blending utility management with emergency management and infrastructure master planning. Factoring in continuous quality improvement and staff education means that, moving forward, EP systems must be managed where many hospitals simply operated them in the past. More attention should also be paid to EP system maintenance, and that need brings its own set of issues.

Our hospital EP systems must operate reliably when they are needed, for as long as they are needed, and provide power to their connected loads without failure. These requirements are daunting, and satisfying them is no easy task. This monograph describes a complete EP system management program intended to satisfy these needs that includes all elements of the emergency power reliability equation:

- Designing for reliability with input from the hospital’s hazard vulnerability analysis (HVA)
- Careful construction, augmented by full-system commissioning and installation acceptance testing
- Determining system load profiles to predict accurate peak demand loading during emergencies
- Weekly inspections of all emergency power supply system equipment and locations
- Monthly testing with proactive examination of operational issues and surprises during testing
- Investigation, resolution, and trend analysis of training and/or systemic issues
- Extended run load test every 36 months
- Vulnerability analyses, risk assessments, and vulnerability mitigation activities
- Preparedness for all EP system failures, including contingency planning for all levels of subsystem failures

- Contingency planning for other internal and external failures
- Comprehensive utility management plans with accurate and up-to-date system documentation
- Integration of utility management plans and emergency management programs
- Comprehensive and accurate short circuit and protective coordination studies
- Coordination with construction /renovation and infrastructure upgrade projects
- Consideration of essential electrical system subsystem failure plans in renovation and infrastructure designs
- Awareness and follow-through of the patient safety impact of EP systems
- Maintenance and clinical staff education on EP system-related issues
- Comprehensive EP system maintenance program that also includes the “branch” subsystems

Table 1: Frequently Used Nomenclature* for Backup Power Systems and Equipment in Health Care Facilities

NFPA 70-2014 and NFPA 99-2012				NFPA 110-2013		Commonly Used Components (‡)
Legally required standby system, Art. 701	Essential electrical system, Art. 700 (EES)		Alternate power source	Emergency power supply system (EPSS)	Emergency power supply (EPS)	Generator and energy source (fuel)
						Generator accessories (batteries, cooling and exhaust systems, fuel supply system, controls, local and remote alarms, etc.), unit-mounted generator breaker over current protective device (OCPD)
						Wiring from generator to remote generator breaker/OCPD (‡)
						Generator breaker/OCPD
						Generator breaker/OCPD output wiring
						Generator transformer (‡)
						Generator distribution panel or paralleling switchgear (‡)
						Wiring between generator distribution equipment and transfer switches
						Transfer switches down to load terminals [See specific branches below]
			Life safety branch	Critical branch transfer switches, feeders and branch circuit wiring, panels and transformers [See acceptable load list in 99 and 70] Equipment system transfer switches, feeders and branch circuit wiring, panels and transformers [See acceptable load list in 99 and 70] Other load equipment transfer switches, feeders and branch circuit wiring, panels, transformers (‡)		Life safety branch transfer switches, feeders and branch circuit wiring, panels and transformers [See acceptable load list in 99 and 70]
			Critical branch			
			Equipment system			
Optional standby system, Art. 702		Optional loads				

*For simplicity, this monograph uses the term “emergency power system” (EP system) generically to describe all of the subsystems listed in Table 1. EPSS and EES are used only when the discussion applies to those subsets.

(‡)Where applicable

NFPA 110-2013, Standard for Emergency and Standby Power Systems

NFPA 99-2012, *Health Care Facilities Code* and NFPA 70-2014, National Electrical Code®

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Testing

Value of Testing and Transferring Power

Monthly emergency power testing will cause EPSS failures.[14] This is good. Why? Because electrical and mechanical equipment failures occur while the equipment is being operated, they are more likely to occur during the test itself, when plant operating personnel are on duty and focused on the generators, transfer switches, electrical and mechanical systems, and buildings being tested. The other important benefit is that normal power is available during this test. Many hospitals that experienced equipment failures during tests report that *the failures would have occurred anyway*, probably during the next unanticipated normal power outage. Experienced hospital engineers do not consider EPSS equipment failures during tests as problems. Instead, they take failures as opportunities to fix or improve something, which is the reason they perform tests in the first place.

Problems that might occur during an actual power outage come to light under controlled conditions, while normal power is readily available. These kinds of problems, which could be devastating if discovered during actual utility power outages, include starting battery and battery cable problems,[15] engine fuel oil pump failures, faulty safety switches that shut down the generator set, engine fluid leaks, engine mechanical failures, transfer switch failures, and tripping circuit breakers.

Other unanticipated problems or events occur that, due to the alertness of personnel involved in the testing process, can be documented and followed up with corrective action. Equipment is exercised and control settings can be adjusted to fine tune the overall combined mechanical/electrical system for optimum operation.

Electricians, mechanics, and other maintenance technicians may be stationed in strategic locations during the test to monitor critical equipment and to minimize response time to problems that may occur. Many hospitals use standardized test forms to collect test-related data. Unanticipated occurrences should be reported immediately or right after the test, for analysis by the facilities supervisor in charge of the test. Additionally, mechanical system interactions can be recorded during the test on simple data recording forms to facilitate both data recording and system recovery.[16]

A carefully thought-out testing program tests emergency power transfers while minimizing disruption to hospital operations. Some hospitals have testing policies that state that selected transfer switches are not transferred if doing so will adversely affect patient care. For example, (1) elevators may not be recalled if there is an incoming MedFlight to a rooftop heliport, (2) critical branch transfer switches supplying operating rooms (ORs) where surgery is in progress may not be transferred, and (3) transfer switches feeding major radiology equipment such as MRIs may not be transferred unless the equipment is turned off first. They will need to transfer those switches later that month.

Other hospitals may not transfer certain transfer switches at all because of clinical resistance. However, this approach masks potential latent defects and violates the intent of applicable standards such as the Joint Commision's EC.02.05.07.[17] As an example, a Joint Commission Standards Interpretation Group response to a question about excluding a cath lab transfer switch from monthly testing reemphasized that all transfer switches must be operated every month, stating, "An accredited organization may not exclude any portion of its emergency power system from this important testing."[18] The most effective testing process is one that duplicates as closely as possible what happens in a real power failure without compromising patient safety.[19]

Testing Program Goals

The primary goals of an emergency power testing program are to maintain the EP system in a constant state of operational readiness and to comply with regulatory requirements without adversely affecting the operation of the hospital or the well-being of the patients. Additional goals are to verify the infrastructure's ability to withstand power transfers that will occur when utility power is lost, and to educate clinical caregivers accordingly so that patient care is not at risk during utility power outages or internally caused normal power outages. It is important to be as comprehensive as possible, leaving little to chance with these increasingly complex systems.

A comprehensive, proactive emergency power testing program should

1. train maintenance and clinical personnel to deal with the loss of utility power and power system transfers;
2. test the functionality of all equipment related to generation and distribution of emergency power;
3. test the mechanical and building system responses to power system transfers;
4. test clinical equipment responses to power system transfers; and
5. avoid conditions that compromise patient treatment and safety.

Description of Emergency Power Testing Program

A comprehensive emergency power testing program should not be just the monthly equipment load testing. It should also include:

- New EP system commissioning
- New EP system installation acceptance testing
- Annual measurement of EP system load profiles
- Determination of total EP system loading under emergency conditions
- Monthly testing of the EP system using actual installed loads
- Monthly review and analysis of test results
- Trend analysis of results and problems for continuous quality improvement (CQI) purposes
- Investigation and resolution of training and/or systemic issues identified by the trend analysis
- Special EPSS extended run load testing at least once every 36 months[20, 21, 22]

An emergency power testing program not only contributes to maintaining the EP system in a reliable operating state, it can also be a vehicle for maintaining a high state of disaster readiness for the hospital's clinical and facility staff insofar as normal power outages affect the environment of care. If equipment is affected by the 10-second outage that normally precedes the power transfer to the emergency generator in the case of an actual power outage, the clinical staff should know how to deal with those effects. If tests are performed without simulating these effects, the clinical staff may be unaware of the real impact of a power outage on their clinical equipment and critical processes. When the monthly emergency power supply system testing program is used together with regular electrical system normal power outages (shutdowns)[23], the hospital's entire staff is better trained in emergency management.

Emergency Power System Installation Acceptance Testing

Some reported EP system failures could have been avoided if the facilities had required commissioning of their EP systems during construction, and if they had required a full NFPA 110 installation acceptance test[24] at the conclusion of construction. Both of these activities are recommended in future installations to ensure that the EP system is capable of performing as required. The purpose of commissioning (which goes beyond the typical design team construction observation and punch list process) is to ensure that the EP system installation is in full accordance with the contract documents. The purpose of the witnessed NFPA 110 installation acceptance test is to prove that the EP system as installed in its final configuration is capable of powering all required building loads. The requirement in certain situations for a full building normal power shutdown (as described in Item 1 below) also ensures that required EP system auxiliary equipment was not inadvertently connected to normal power during construction.

A summary of the NFPA 110-2013 installation acceptance test follows, with references [in brackets] to the associated paragraph(s) in the 2013 edition. As always, readers are cautioned to review the full NFPA 110 standard since the below-listed steps do not contain all of the test's requirements. This test was rewritten in the 2010 edition.[25]

1. The test is started with the generator in a cold start condition and the emergency load at operating level. The test *in a new and unoccupied building or facility* is initiated by simulating a primary power failure (full normal power outage.) This is done by opening all switches or breakers supplying the normal power to the building or facility. However *in an existing occupied building or facility*, the normal power failure is *simulated* by operating at least one transfer switch test function OR initiated by opening all switches or breakers supplying normal power to all automatic transfer switches (ATSs) that are part of the EPSS being commissioned by the initial acceptance test. *This is a 2010 relaxation of earlier requirements for a complete normal power outage in all buildings.* [7.13.4.1.1 and 7.13.4.1.2.]
2. Where an EPSS includes paralleled generator sets, this first load test portion with actual building EPSS loads must use and test all generators that are intended to be operated simultaneously. [7.13.4.1.3(1).]
3. The first 90-minute load test uses the actual building loads that are served by the EPSS. (Note that this portion of the test has no minimum load percentage stipulated, although some AHJs may have different opinions about that issue.) [7.13.4.1.3(2) and 7.13.4.1.3(10).] *The duration of this first portion was reduced from 2 hours to not less than 90 minutes in 2010.*
4. The engine start function must be confirmed by verifying operation of the initiating circuit of all transfer switches supplying EPSS

loads. [7.13.4.1.3(6).] *This requirement to confirm all engine start circuits was added in 2010.*

5. All other recording and record-keeping requirements must be followed. [7.13.4.1.3(3) through 7.13.4.1.3(10).] *A few of these requirements were changed in 2010.*
6. At the conclusion of the first load test, normal power is re-energized and all transfer switches are then returned to normal power [7.13.4.1.3(11)]. The generator(s) automatically shut(s) off after the cooldown time delay. [7.13.4.1.3(12).]
7. The EPSS then has not less than a 5-minute cooldown period. [7.13.4.2.] *This was changed from a maximum 5-minute cooldown period in 2010 because the shorter period was not always practical in the field.*
8. The 2-hour full-load test then follows the cooldown period, using a load bank with or without building loads. The load bank is usually necessary to attain 100 percent of rated nameplate kW for the final 60 minutes of this second test. [7.13.4.3.] Paralleled generators may be tested individually for this second portion. If paralleled generators are tested individually, each generator is required to run for the 2 hours. [7.13.4.3.3.] After the generator(s) start(s), the load must be applied in at least the following minimum load steps [7.13.4.5.3]:
   a. not less than 30 percent of the nameplate kW rating for the first 30 minutes,
   b. not less than 50 percent of the nameplate kW rating for the next 30 minutes,
   c. and 100 percent of the nameplate kW rating for the next 60 minutes. *This portion of the test was relaxed from a single step 2-hour 100% load bank test in 2010.*
9. Recording and record-keeping requirements must be followed. [7.13.4.3.4.]
10. At the conclusion of the second portion 2-hour load test(s), the generator(s) will be shut down, followed by tests of cycle cranking [7.13.4.4] and all safeties [7.13.4.5].

The EP system includes not only the generator(s) and transfer switches, but the transformers, panelboards, switchboards, wiring, and other components.

Elements of the EP system that are not explicitly covered by the NFPA 110 installation acceptance testing should be fully tested and commissioned as well.[26]

A proposed addition to the 2016 edition of NFPA 110 would require verification during the installation acceptance test that new paralleling and load shedding controls (where provided, of course) are in accordance with the system design documentation. Although one cannot predict the outcome of the NFPA standard update process, facility personnel should be aware of the potential for this proposed future change.

Commissioning[27]

Hospitals and other facilities often discover unwanted operational issues when they first test their emergency power systems. An early case study described clinical and mechanical equipment operational problems that a hospital found during its monthly emergency power system load testing, another article discussed numerous issues that occur when EP loads are transferred from normal power to EP and back again, and several other articles described equipment failures in operating facilities that likely would have been found in a comprehensive commissioning process. Examples include incorrect overcurrent protection settings, unwanted system interactions, and equipment malfunctions and failures during ATS transfers. Lessons learned from most of the large utility blackouts that have occurred over the past 20 years include hospitals and other facilities discovering that equipment thought to be connected to the emergency power system was in fact powered by normal power. In several cases this discovery occurred when a generator failed because its fuel oil transfer pump or remote radiator turned off.

Commissioning is a process, not just a visit or two to the construction site. The commissioning process confirms the work as it is installed and monitors the startup planning and execution. The prefunctional checklists can include verification of every attribute of every component and may be voluminous. Detailed step-by-step functional performance test scripts for large emergency power systems can be more than 30 pages long. No detail (either equipment or operational) is too small to be verified since future failures can often be traced to small errors or omissions, including small parts that were incorrect. Not verifying the correct protective coordination settings can cause larger outages than necessary when future short circuits and overloads occur. Programming errors have resulted in incorrect operation under some scenarios.

Examples of functional performance testing can include:

- Testing individual equipment, such as transfer switches, fuel oil transfer pumps, remote radiator fans, batteries, battery chargers, individual generators, generator room dampers, local alarms, local and remote meters, circuit breakers, motor controllers, uninterruptible power supplies, and installation conditions.
- Testing subsystems, such as engine fuel oil systems, radiator cooling water systems, power monitoring and control systems, engine start wiring systems, paralleling switchgear, remote alarm systems, grounding and bonding systems, insulation resistance, and ground fault alarm systems.
- Testing normal operations, startup, shutdown, failures, and other emergency conditions. Single generator systems are tested to verify all desired operating conditions, the simulated monthly generator load test, and manual operation tests for all potential manual operating conditions. Additional types of tests to be included with most multiple generator systems should be system load tests, multiple load shed tests with different initiating conditions, load demand mode tests, full load pickup tests, and load add tests with different initiating conditions.
- Conducting power interruption tests with multiple failure scenarios. NFPA 110 no longer requires that a full building normal power failure be performed in an existing occupied building or facility, now accepting as an alternate approach the operation of ATS test switches in those situations. The full normal power failure portion of the NFPA 110 Installation Acceptance Test is only required in a new and unoccupied building or facility. However, in the author's experience certain elements of an installed emergency power system can only be effectively ascertained by shutting off normal power. These include proving that needed mechanical and clinical systems are indeed fully powered by the emergency power system and will operate as desired upon the loss of normal power. Some people call these normal power failure tests "black start tests," although the NFPA 110 definition of a black start ("3.3.3 Black Start. Where the stored energy system has the capability to start the prime mover without using energy from another source") only uses that terminology when discussing types of generator starting systems.

- Verifying specified system control, load shed, load add, and switching requirements. Often the building mechanical loads will not be sufficient to verify system ability to operate a full-rated load.
- Testing the integration of new equipment and systems into existing systems for renovation and infrastructure upgrade projects.

Weekly Inspections

NFPA 110 requires weekly EPSS inspections as stated in this excerpt from NFPA 110 (the EPSS consists of the generators downstream to the transfer switch load terminals, inclusive):

> 8.4 Operational Inspection and Testing.
>
> 8.4.1 EPSSs, including all appurtenant components, shall be inspected weekly and exercised under load at least monthly.

A weekly EPSS inspection is not just a generator inspection. If you look at the definition of an EPSS from NFPA 110, EPSSs and all appurtenant components include the generators and all of their auxiliary subsystems, including cooling, exhaust, fuel oil, starting, controls, and alarms (including remote alarm panels); the transfer switches; and all distribution components between those points. The EPSS does not extend downstream beyond the load terminals of the transfer switch; however, an organization should consider whether it also wants weekly inspections of major downstream EP system areas or equipment.

What should be included in a weekly inspection of a transfer switch room or an emergency distribution panel room? In the absence of any guidance from standards, AHJs, or manufacturers, consider the following questions as you walk into the room:

- What do you see? Look at pilot lights, panels, meters, combustible storage, evidence of water ingress from above, below, or nearby rooms. Also look at adjacent rooms. Is there a problem that might affect the EPSS equipment if things aren't taken care of?
- What do you smell? Electrical equipment sometimes warns us of upcoming faults (short circuits) with a distinctive odor, such as a burning smell or any other unusual odor.
- What do you hear? Electrical equipment sometimes warns us of loose components by changing or amplifying its usual sounds.

Many discussions of weekly inspections start with questions about whether it is necessary to start and operate the generators weekly. NFPA 110 does not require weekly emergency generator run tests. In fact, NFPA 110 clarified this issue in the 2010 edition Annex by adding:

> A.8.4.1 Weekly inspection does not require running of the EPS. Running unloaded generators as part of this weekly inspection can result in long-term problems such as wet stacking. See Figure A.8.4.1(a) and Figure A.8.4.1(b).

Some state and local AHJs do require weekly generator run tests. Some major diesel generator manufacturers do recommend weekly generator run tests, particularly if the generators are used in Level 1 applications, such as hospitals.

NFPA 110 gives the default guidance for routine EPSS maintenance and operational testing:

> 8.1.1 The routine maintenance and operational testing program shall be based on **all** of the following: *(emphasis added by author)*
>
> (1) Manufacturer's recommendations
>
> (2) Instruction manuals
>
> (3) Minimum requirements of this chapter
>
> (4) The authority having jurisdiction

The referenced NFPA 110 Annex Figure A.8.4.1(a) and Figure A.8.4.1(b), like all informational Annex material, are not "minimum requirements of this chapter" but do provide guidance on items to be inspected that can be used in the absence of detailed manufacturer recommendations for inspections.

The question of whether generators should be run weekly when it is not a requirement is a perennial source of ASHE listserv debates. ASHE members can see both sides of the issue by searching the ASHE listserv with keywords such as "generator weekly run."

If you must run your generator unloaded and do not have a mandatory minimum run time, consider starting it, operating until the water temperature and the oil pressure have stabilized (basically so that it is warm and fully lubricated) and then shutting it down. This can help minimize the potential for wet stacking from running the diesel generator unloaded.

Choosing a Monthly Test Time: Pros and Cons

With increasing pressure to control operating costs, it makes sense that the best time to collect all testing personnel would be when they arrive to start work. This is before most of the operating rooms are occupied for the day. Another option is immediately after lunch. Testing at the end of the lunch period, however, may conflict with the hospital's patient focus. The hospital may wish to avoid elevator recalls when there is a high visitor population riding the elevators. Some hospitals schedule EPSS testing for the third shift, or nighttime. This approach can minimize the impact of the testing on daytime hospital operations, but it may become problematic when equipment failures occur during the test and fewer operations and maintenance personnel are on duty to deal with the failure.

Thurston's detailed treatment[28] back in 1992 also provided an excellent analysis of the pros and cons of various emergency power test times. He identified several more constraints to consider. One is that staff members (hospital electricians) performing the test must be organized and at their posts with the necessary test procedures ready to start the test simultaneously. In larger buildings, or in situations where one generator provides emergency power to more than one building, this requires that many staff members be taken away from their normal operating and maintenance tasks.

Emergency Power System Test Procedures

The benefits of written test procedures and test reports are that they

- provide control by the hospital's facility managers of the test process itself;
- require the testing personnel to take responsibility for performing all required tasks;
- reduce the chances that incorrect actions by testing personnel will cause increased risk to the hospital's patients, visitors, or staff;
- provide written documentation of the actions taken during the test in the event that something does go wrong;
- provide a mechanism for potential trends to be explored; and
- provide the source documentation for later trend analyses.

Some hospitals may assign the same testing personnel to the same duties each month. The opposite approach (splitting up the testing experiences) is beneficial with larger staffs, since the testing itself provides important staff training in the EPSS operation. In hospitals whose EPSSs have evolved over time, many different generations and makes of equipment may be present. Different equipment generations and makes often require different operating procedures. This variation is more controllable with detailed test procedures that stipulate the correct approach for operating each distinct component.

The test procedures for the generator personnel will be specific to the needs of the generator documentation. Those procedures are beyond the scope of this document, but have been covered very well in several referenced articles and in NFPA 110.

A current best practice that might make its way into NFPA 110 is the process for determining which ATS starts a monthly load test. Many hospital facility directors consider rotating the starting ATS for monthly tests to be a best practice, and many but not all hospitals have been doing that for years. Hospitals accredited by the Joint Commission have been hearing about this as a best practice recommendation during Joint Commission industry presentations and from surveyors for several years. A proposed addition for the 2016 update of NFPA 110 would include such a requirement. As shown in the public-accessible First Revision for the 2016 edition, explanatory language that has been proposed for the next NFPA 110 Annex includes an explanation of how that requirement might be managed for large EPSSs with more than 12 ATSs. Although one cannot predict the outcome of proposed changes to NFPA standards, this potential change bears watching.

Effects of Monthly Testing

As stated earlier, monthly testing will cause emergency power supply system failures. If failures are not properly managed, they may adversely affect patient safety. Still, equipment failures that occur during regularly scheduled testing usually have a much more benign effect on hospital operations and patient care than failures that occur during a real utility power outage. Two examples of events that may be related to emergency power load testing, exhaust emissions and elevator entrapments, are discussed below. Refer to the discussion of second-order consequences for more information.

The hospital's emergency power system testing program must be coordinated with construction/renovation projects or infrastructure upgrade projects that take out of service, replace, overhaul, or upgrade generator sets. NFPA 110[29] states, "Consideration shall be given to temporarily providing a portable or alternate source whenever the emergency generator is out of service and the criteria set forth in Section 4.3 cannot be met." When existing generator sets are taken out of service for any reason, and their loads still require an emergency power supply due to hospital occupancy requirements, the temporary generator sets that are used in their place must be tested monthly along with the transfer switches they feed. The hospital needs to take into account the indoor air quality effects and other effects of running temporary generator sets for regular monthly testing.

Exhaust Emissions

Some, usually older generators exhaust in locations where building heating, ventilation, and air-conditioning supply fans have their air intakes. The start of an emergency power test with a diesel engine usually involves a large puff of black smoke that disappears as the unit heats up. This puff of smoke, along with the engine exhaust fumes, may be drawn into the building and result in indoor air quality (IAQ) complaints. Solving this problem involves either relocating the air intakes, relocating the exhausts, making other ventilation system modifications, or temporarily turning off the supply fans. Mechanical engineers and hospital operating engineers must carefully investigate this issue to decide the best short- and long-term solutions.

The Clean Air Act requires that sites limit the hydrocarbons and other pollutants that their internal combustion engines emit. This is usually not a licensing problem with standby engine-generator sets, since they do not normally run, provided that the limits are reasonable. Hospitals must be aware of and comply with all U.S. Environmental Protection Agency (EPA) and state regulations. These regulations will often require additional record keeping by the hospital regardless of how often the generator sets run. These records must be current and available for inspection on demand by appropriate authorities.

The EPA issued its notice of final rulemaking in 2010.[30] This rulemaking could affect most hospitals. The National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reciprocating Internal Combustion Engines (40 CFR 63, Subpart ZZZZ) should be reviewed. This rule applies to both new and existing compression ignition (CI) engines and spark ignition (SI) engines. The rule is very complex and should be thoroughly reviewed to understand its full impact on your organization's operations. Facility directors should review the specific issues that potentially affect them with their generator suppliers, design engineering firms, and regulatory compliance consultants to ensure full compliance with this rule and to avoid any potentially costly surprises. Numerous excellent reference documents are available, and organizations would do well to review these references and others to develop a thorough understanding of the constraints and requirements.[31, 32, 33, 34, 35]

Avoiding Elevator Entrapments Due to Testing

The interaction between a hospital's EPSS and its automatic elevator recall controls is complex. Many elevator control systems only operate one elevator at a time on emergency power. This requirement meets most high-rise building codes and may be necessary to keep generator loading within reasonable limits. Some control systems allow the elevators to go automatically to the next floor and open their doors while waiting for their turn to be returned to the first floor to discharge passengers. If the complex control system has a problem during this situation, the result will be an elevator entrapment. Even when there is no entrapment, an elevator with automatic voice floor annunciation may have an automatic announcement that states something like "this elevator is responding to an emergency in the building, please remain calm." Patients, visitors, and staff may respond with concern or even panic to such a situation despite the assurances from the prerecorded message.

Not all elevator failures or entrapments during testing are direct results of the testing, particularly in the early morning. Sometimes elevator door problems, such as dirty tracks or dirty motion sensor screens, may be masked by the emergency power test as test-related failures.

Some hospitals report operational issues with their vertical transportation systems during or after EP system testing. Other hospitals may not transfer the elevators to emergency power automatically, but instead will restart their elevators manually after the transfer switch has operated. Since the purpose of the test is to transfer the required emergency operating elevator load to the generator and prove that the systems work under this condition, anything less than fully automatic operation of all systems, as would occur during a normal power outage, is not a true test.

Some vertical transportation operational issues may be second-order consequences of the EP system testing. These consequences usually point the way to infrastructure improvement opportunities. Some older elevator transfer switches may not include the standard elevator control packages provided with modern transfer switches. Without additional time delays, breakers can trip due to the motor inrushes after power transfers. Simply retrofitting some transfer switches with in-phase monitors or a closed transition transfer feature may solve this problem. Other findings might be that the elevator recall feature does not work automatically, one or more elevator entrapments occur as a result of the testing, and staff and visitors must wait longer in elevator lobbies because of the reduced elevator capacity. The elevator recall problem presents an opportunity to fix a malfunctioning system. The elevator entrapments that occur must usually be analyzed further to determine their actual cause. The lack of elevator entrapments during and after EP testing is not in itself an indicator that everything is okay—it is necessary to verify that the systems were all permitted to function automatically as they would in a true power outage, and that they did function satisfactorily.

Analyzing Monthly Test Results

Monthly test results should be reviewed shortly after each test. One effective method is for the testing personnel to return the signed test procedure to the supervisor immediately after the test, along with a short verbal report of any important events or surprises that occurred during the test. These events or surprises can be noted in writing on the test procedure form for later reference and inclusion in the testing database.

The supervisor should probe verbal reports of failures to make sure that events are correctly recorded. As an example, probing the verbal report "we had to reset that pump set" may reveal that the situation was a simple alarm reset requirement. Without probing, the report may be interpreted by facilities management as a loss of system function requiring even more corrective action. The mechanical supervisor should be present to receive these reports along with the electrical supervisor to allow mechanical equipment reactions and events to be probed as well.

All unexpected events should be analyzed to discover whether they were caused by human error, problem system interactions, test procedure inadequacies, equipment malfunction, or other causes. Corrective action should be planned as appropriate, to deal with the problem and not just the symptom. In determining the proper corrective action, each failure should be considered for its generic relevance, allowing for the circumstances of the failure and its potential for occurrence elsewhere in the hospital or again under the same set of conditions. Failures during testing are valuable learning experiences and opportunities for improvement. The hospital engineering staff and supervisor should review the results of previous tests before the next test of each generator.

Using Management Databases to Discover Hidden Trends

It is necessary to analyze test results and trends, not just record test results. Several references[36, 37, 38, 39] address recording and analyzing test results for the engine operating parameters. That guidance is not repeated in this monograph. In the following analysis, we address test results that describe kinds of interactions between the various emergency power supply system components and their emergency power loads, the second order consequences. The results of the trend analysis can help the hospital's engineers to identify training and/or systemic issues requiring further investigation or resolution.

All unexpected events, failures, and other unexplained occurrences should be entered into a testing event database. A useful list of keywords for analysis, based on several years of experience in analyzing monthly test results, is illustrated in Table 2. Additional keywords should be added to address the additional needs of the specific hospital.

The information typically recorded in the testing database should include the test date, building(s) tested, generator(s) tested, transfer switch number(s), applicable keywords, special action assignments or management attention needed, and comments. Each of these fields is useful for analysis or reporting, depending upon the need.

Different types of database reports can be used for different purposes. Exception reporting, through the use of an "action required" field as a reporting toggle, is a useful tool for focusing the facilities staff's attention on those items that need action. The exception report should be reviewed weekly if possible, but definitely after each test to identify events that have been corrected. Items should not be marked "corrected" unless the requisite action was taken and the appropriate test proved that the problem was indeed corrected. Exception reporting, although important from a corrective action perspective, is not useful for trend analysis because the event record gets deleted from the exception report after it is corrected. Other queries are more useful for trend analysis, including sorts by transfer switch and test date, sorts by generator set and test date, and sorts by keyword and test date with further sub-sorting as appropriate.

Trend analysis is most easily accomplished by sorting the database for the occurrence of keywords by month and year. The number of occurrences of each keyword, or even keywords describing similar issues (e.g., "breaker" and "restart") in a given month can then be charted over time. Seasonal patterns can be investigated as well. A declining incidence of failures indicates performance improvement (PI).

Table 2: Sample Keywords for Emergency Power Testing Databases

KEYWORD	DESCRIPTION OR USE
30%	Generator test load violates 30% requirement
Abort	Test personnel or foreman decided not to transfer a specific ATS or run a specific generator due to unpredicted conditions at test time
ATS	Automatic transfer switch failure or control malfunction, engine start wiring failure from specific ATS
Breaker	Circuit breaker trip
Communication	Complaint received by testing personnel, due to lack of communication within the hospital community
Door	Door found in wrong security mode (access vs. secure), may be due to test
Elevator	Elevator control system failure during power transfer, elevator entrapment
Excluded	Specific ATS excluded from test by official policy due to extenuating circumstances
Genset	Generator set problem, includes engine, alternator, governor, voltage regulator, starting battery, fuel oil system problem, ambient conditions
Hold	Test procedure hold point was not satisfied, resulting in deviation from full test intent but within predetermined hospital administrative parameters
IAQ	Indoor air quality complaint caused by test
Initiate	This ATS initiated this specific test (proves engine start circuit function)
Lamp	Indicator lamp burned out, discovered during test
Meter	Meter failure, bad or questionable load reading
Modify	Problem found during test requires equipment modification
Operator	Operator error, unauthorized action taken that resulted in equipment or test failure
Pretest	Problem found during routine pre-test surveillance, such as an emergency power breaker found open or emergency power control switch not in the automatic mode
Procedure	Problem or unexpected occurrence in test can be rectified for next test by changing the test procedure
Reset	Equipment (not circuit breaker) failed due to lack of power and went into alarm condition, requiring annunciator acknowledge and reset
Restart	Equipment turned off due to test and required a manual restart to return to its normal operating condition, no alarm generated
Sign	Complaint received from patient, visitor, or staff due to lack of appropriate signage explaining the test and its impact
Training	Testing personnel did not follow test procedure, record required information, etc.
UPS	UPS failure during test, may not be due to test itself but personnel became aware due to test conditions

Analyzing Equipment Failures

All equipment failures should be analyzed to discover whether they were caused by human error, problem system interactions, test procedure inadequacies, equipment malfunction, or other causes. Corrective action should be planned regardless of the cause of the failure, and the corrective action should be sure to address the cause of the failure. The Joint Commission requires that if the equipment failure resulted in the EP system failing its test, interim measures be implemented until the necessary repairs and corrections are completed, followed by a retest. Each failure should be considered for its generic relevance as well. Similar circumstances could cause similar failures to occur again elsewhere in the hospital.

The hospital engineering staff and supervisor should review the results of previous tests before the next test of each generator. Possible types of failures, or other testing problems, are summarized in Table 3 and more fully listed in Table 2.

Table 3: Potential EPSS Failures and Possible Results

Some potential EPSS failures found by the testing program	Possible result if not found and fixed before the next normal power outage
Starting battery or cable problems	No emergency power when needed
Engine fuel oil contamination	Poor operation, possible engine failure
Faulty safety shutdown switches	May shut off the generator set unnecessarily
Engine fluid leaks	Possible engine failure
Engine mechanical failures	Possible engine failure
Transfer switch failures	Failure to transfer to emergency power
Blown control power fuses	ATS fail to transfer, paralleling switchgear failure, generator set fail to start
Tripped or open EPSS circuit breakers	ATS will not transfer to a dead source

Other Examples of Findings from Trend Analysis

Trend analyses of hospital EPSS testing results and the identified second-order consequences over several years indicated several different types of opportunities for improvement. Many of these opportunities for improvement had little correlation other than the fact they were identified through EPSS testing trend analyses. Among the examples were:

- Power transfers of mechanical system controls can cause unnecessary system tripping despite the fact that the mechanical equipment itself can ride through the transfer time with no apparent problems. Field experience in hospitals has indicated tripping problems during power transfers with such diverse equipment as water pressure booster systems and instrument air compressors. Often, putting UPSs on just the control systems can solve these problems.
- Some UPSs have input voltage tolerance settings that work fine when the utility source is feeding the UPS but are too sensitive for the condition where the generator is feeding the UPS. All UPS failures during emergency power tests should be investigated to see if the cause is related to voltage tolerance that is too sensitive for the condition with an engine generator as the power source. Examples of this finding include fire alarm systems that continue to operate, but on battery backup, during the emergency power test, and clinical equipment (such as blood analyzer) UPSs that also transfer to battery during the test.
- Some clinical equipment, such as anesthesia monitors, may be too sensitive for good operation on older emergency generator systems that need new governors and voltage regulators due to the frequency or voltage being out of required limits.
- The unanticipated tripping of normal power circuit breakers on transfer back to normal power could be the result of miswired or incorrectly set ground fault controls. Alternatively, the circuit breaker instantaneous trip element may be out of tolerance.
- Fan VSDs may trip on hot-to-hot transfer of power from normal to emergency (and emergency back to normal) due to back EMF being generated in cases where the transfer switch transfer times were short. Sometimes, increasing the transfer time delay setting can reduce incidence of VSD tripping. Some VSDs may see the momentary loss of power as a fault. If the VSD has an auto restart on fault function, it should be enabled so that the VSD will not have to be manually reset after each transfer. When supply fans feed a common plenum with crossover dampers, all fans (dual supplies and returns) may have to be kept active to avoid back flow causing return fans to run backwards and increase their likelihood of tripping when power is re-applied.

- Mechanical equipment that is powered by normal power rather than by the equipment system may also shut down and have to go through a restart process if its control circuits (direct digital control [DDC], building automation system [BAS], or other controls) are powered from EP system circuits. It is usually not possible to segregate those controls from the EP system since they may also control equipment system mechanical equipment. In such cases, the solution may be installation of uninterruptible power supplies (UPSs) to power the DDC and BAS panels located on each floor and primarily on the mechanical floors. A very short time frame of battery back-up power may be all that is required, since the controls only need to ride through the applicable transfer switch transfer times.

Even mechanical equipment that is powered from the equipment system may be made more reliable during power transfers by putting its control transformer on a UPS. The motors and mechanical systems may be able to ride through power transfers if they are permitted to by their control systems. It is necessary to consult with the system's manufacturer to ensure that this approach is feasible with the specific system being considered.

- All UPSs used in these applications should have their own rigorous maintenance programs to ensure that they continue to run reliably. A UPS without a rigorous maintenance program can result in misplaced confidence and may be worse than having no UPS at all.
- An example of an equipment system ATS load profile during an emergency power test is illustrated in Figure 1. Note the impact of the initial power transfer from normal power to emergency power at 7:11 a.m. Some other mechanical systems take far longer to get back to their steady state than the 5 minutes illustrated in this figure. The retransfer to normal power for this test did not occur until after 8:00 a.m., so the effect of that retransfer is not shown.

Mechanical equipment system transfer time delays should not be any longer than necessary to prevent fan motor trip-out so that fans serving critical spaces like ORs and isolation rooms do not completely stop before power is re-applied.

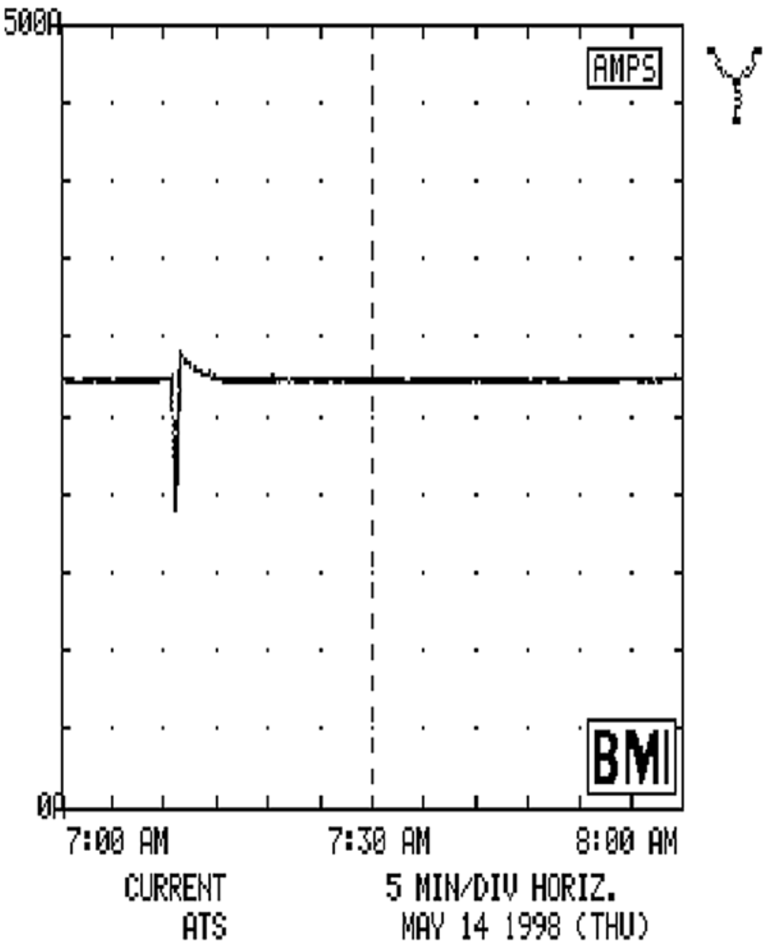

Figure 1: Sample Plot of Automatic Transfer Switch Current During Emergency Power Test

Other Quality Improvement Considerations

Supervisors should review all of the results of the EP system testing, including the second order consequences described elsewhere in this document, and not just the engine parameters. This review should include a report of mechanical system interactions, elevator control interactions, and similar related events. Supervisors should also review any surprises brought to the attention of the supervisors or facilities personnel in the field. If facilities personnel were surprised by an event that occurred during or after an EP system test, it is likely that either something went wrong in the infrastructure or additional facilities training is warranted. If clinical or other hospital support personnel were surprised by some event during or after the EP system test, it is likely that the facilities department's test-related communication (to others) was not completely effective or something went wrong in the infrastructure that needs further investigation and correction. Responding to symptoms and leaving the causes uninvestigated and unresolved is not adequate.

Supervisors should look for trends when analyzing EP system test results. Obtaining trend information may require using a database or spreadsheet to collect test result data.

The lessons learned from EP system testing should be factored into the ongoing competency training for EP system operation and maintenance personnel.

Containing the Direct and Indirect Costs of Emergency Power Testing

An emergency power testing program has direct and indirect costs. The direct costs are those of the test personnel, their supervisors, and those who track and control the test documentation, including the trend analysis. Indirect costs include the labor costs of those who must reset equipment after its power source is transferred twice every month, once at the beginning and once at the end of each test. Other indirect costs include the costs of clinical personnel or technicians who move equipment plugs from the critical branch outlets to normal power outlets before the tests, and then back again if that approach is taken by the hospital. Making sure that only the equipment that must be connected to the EP system (due to code or hospital operational requirements) is indeed connected to it can reduce these costs. It is also important to ensure that the building design team is aware of the monthly testing and considers the impact of the power transfers on all equipment intended to be connected to the EP system. This may affect procurement specifications for mechanical and clinical equipment.

Some sensitive computer-based clinical and research equipment resets when its power source is transferred from normal to emergency power and back, losing alarm limits and other programmed settings. This design feature causes problematic equipment malfunctions until the susceptible electronic equipment has been reset, whether the cause is an EP system test or a power system failure. As a result, many hospitals' clinical and research personnel keep their most sensitive instrumentation plugged into the normal power outlets unless there is a normal power outage. This requires that personnel be present at the beginning of an outage, which may not be possible. It also does not give the maintenance and engineering personnel a clear picture of the real generator loading, since this equipment would not be plugged into the critical branch, equipment system, or optional standby system when those subsystems are monitored.

As a result of the malfunctions of susceptible electronic equipment discussed in previous paragraphs, some hospitals require that each item of equipment to be powered from the EP system be provided with a UPS to avoid equipment problems when the transfer switches transfer between power sources. A small UPS may not be very efficient, and its energy losses when aggregated across the hospital can result in increased utility cost to the hospital. Although the increased energy cost from an individual UPS is not substantial, the total hidden cost of these devices throughout the hospital can become substantial. The total UPS maintenance costs can also be substantial. An alternative approach could be for the susceptible electronic equipment to be specified and purchased with self-contained battery backup. The battery backup will allow the equipment to sustain the power transfers without requiring manual restarts and reconfiguration. Regular PM on that equipment will then have to include battery condition. Another strategy would be for this susceptible electronic equipment to be manufactured to be more electrically rugged to survive power transfers.

Special Emergency Power Supply System Extended Run Load Test

The requirement for an extended run EPSS load test was initially included in the 2002 edition of NFPA 110. After several changes in 2005 and 1010, the requirement in NFPA 110[40] is presently at least once within every 36 months for the duration of its assigned class, not to exceed 4 hours. The class of an EPSS is defined in NFPA 110[41] as the amount of time that the EPSS is required to operate at its rated load without being refueled. Therefore, according to NFPA 110, a facility with a Class 2 EPSS would have to test for 2 continuous hours, and a facility with a Class 24 EPSS, for example, would have to test for 4 continuous hours.

The load to be tested this way is the entire EPSS load running at the time of the test. That load may be supplemented with a load bank if necessary for diesel generators to reach the manufacturer’s minimum recommended exhaust gas temperature, or not less than 30 percent of the nameplate kW rating. NFPA 110 does not have a requirement to turn on such EPSS loads as smoke exhaust fans, fire pumps, stairwell pressurization fans, and the like if they were not already running at the test time. If the organization wishes, it may do the test using only the transfer switch test functions of all ATSs (or it may open the circuit breakers and switches that provide normal power to all of the EPSS transfer switches.) In either case, all EPSS-powered loads will be powered by the emergency power supply for the entire test duration.

(Some facilities will not open the normal power switches or circuit breakers serving the EPSS transfer switches because of concerns that the transfer switches would not be able to return to normal power automatically in the event of an EPSS failure during the test. These facilities just use the transfer switches' test functions to simulate a normal power failure.) Regardless of the approach the organization takes, a building normal power shutdown is not required for this test.[42]

As explained in the NFPA 110 Annex, this test was added to NFPA 110 to provide reasonable assurance that the EPSS, including all of its auxiliary subsystems, is capable of running for its assigned class with its running load. The Annex further explains that a total facility normal power shutdown (outage) is not required for this test but is recommended if one has not occurred within three years. This new test appears to be as reasonable as such new requirements could have been, given the lessons learned from years of disasters and blackouts and related emergency preparedness actions. Some have interpreted those lessons learned to suggest that the test should be at full rated EPSS load, that all normal power should be turned off during the test, and so forth.[43] Instead, NFPA 110 has given us a robust full EP system extended run load test that minimizes the impact on normal facility operations.

What might this test not show? It might not indicate an item of generator auxiliary equipment, such as a fuel oil transfer pump or a remote radiator fan, which somehow became improperly connected to normal power. (Such a situation would have been caught by an NFPA 110 initial acceptance test that included a normal power shutdown.) This test might not indicate a restricted generator set cooling airflow path that only becomes problematic near full rated load or on high ambient design days. It might not indicate a fuel oil storage tank level indicator that reads incorrectly. It will not indicate that other critical equipment is not powered by the EPSS but should be. It also might not indicate operational problems when the EPSS loading reaches its maximum demand loading, since the test loading is only required to be the EPSS loading operating that day and not less than 30 percent of the rated nameplate kW.

But these other items should show up if we exercise due diligence in our overall management of this critical utility system of the physical environment (or environment of care) and are regularly conducting normal power shutdowns for maintenance as recommended. Many facility managers who have gone through extended generator run periods and normal power shutdowns in emergency preparedness would agree that conditions came to light during those procedures that made all that effort worthwhile.[44, 45, 46] The extended run test discussed here could bring out some potential problems with EPSS auxiliary subsystems while normal power is still available.

The Joint Commission's Standard EC.02.05.07 contains the Joint Commission's requirements regarding emergency generator testing.[47] Standard EC.02.05.07 requires accredited organizations to test their emergency generators for 4 continuous hours every 36 months. During this test, the generator must be loaded to at least 30 percent of the generator nameplate rating. Either dynamic loads (actual EPSS loads) or static loads (load banks) will be accepted by the Joint Commission, but the better test is the one using the actual EPSS loads as required by NFPA 110-2013. The Joint Commission has also advised that documented generator operation at not less than 30 percent of nameplate rating for not less than 4 continuous hours can reset the 36-month clock for the next triennial load test.

Establishing Test Procedures

Since accreditors do not provide detailed testing procedures, each accredited organization must establish its own procedure for the test. This procedure should be considered for inclusion in the organization's utility management plan. If the recommended dynamic load (actual EPSS loads) approach is taken, then the organization needs to make sure that the actual generator loads during the 4-hour test will exceed 30 percent of the generator nameplate rating. The EP system load profiles discussed elsewhere in this monograph will provide such assurance before the test. If the EP system load is not going to be above 30 percent, the organization will have to arrange for a supplemental load bank to make up the difference for those 4 hours. This has been an NFPA requirement since 2010 and would also be necessary to meet the Joint Commission's Standard EC.02.05.07.

In the absence of industry guidance, Table 4, based in part on the steps of the first (EPSS loads) half of the NFPA 110 initial acceptance test and in part on the standard NFPA 110 testing procedures, could serve as a starting point.[48] The table does not include safeties to be tested or data to be recorded—refer to the standard for that information.

This test will stress the EP system and therefore requires adequate advance notification and communication, along with administration and clinical participation, similar to a disaster drill.

Table 4: Sample Steps for 36-Month Load Test Using Dynamic Loads

Step	**Description, comments, and references** Note that required notifications, safety precautions, and other related activities have been excluded for simplicity
1	The test is started with the generator in a cold start condition and the emergency load at standard operating level. The test is initiated by operating at least one transfer switch test function and then operating the test function of all remaining ATSs, or initiated by opening all switches or breakers supplying normal power to all ATSs that are part of the EPSS being tested [8.4.9.3]. *Some facilities will not open the normal power switches or circuit breaker serving the EPSS transfer switches because of concerns that the transfer switches would not be able to return to normal power automatically in the event of an EPSS failure during the test. They just use the test function at each transfer switch to simulate a normal power outage.*
2	It is not necessary to interrupt power to non-EPSS loads [8.4.9.4].
3	The building load is intended to be the test load, supplemented, if required, by a load bank large enough to load the diesel generator to not less than 30 percent of its nameplate KW rating, or which maintains the manufacturer-recommended minimum exhaust gas temperatures. Non-diesel generators only need available load [8.4.9.5.1, 8.4.9.5.2, 8.4.9.5.3].
4	Where an EPSS includes paralleled generator sets, it is recommended that the load test with actual building EPSS loads should use and test all generators that are intended to be operated simultaneously [7.13.4.1.3, 8.4.9.1].
5	Verify that the generator loading is not less than 30 percent of generator nameplate rating, or maintains the manufacturer-recommended minimum exhaust gas temperatures, using the method normally used for the monthly load tests. Throughout the load test, regularly verify and document that this criterion is met via periodic readings, say every 30 minutes. An electrical power monitoring system or data logger connected to the generator or its distribution equipment will provide documentation of the test load profile that should also satisfy this criterion.
6	Before concluding the test, ensure that the loading did in fact meet the combined minimum loading and duration. At the conclusion of the 4-hour load test, normal power is re-energized to the transfer switches by activating the return to normal power function of the ATS test switches (or by re-closing switches or circuit breakers if they were opened to start the test.) *See the italicized note in Item 1*. Prior to this, facilities personnel should notify all affected areas and services that the test is being concluded and that all transfer switches will shortly be switching back to normal power. The generator(s) will then automatically shut off.
7	Remember to test all safeties and cranking, and to record all system parameters, as required in accordance with the organization's testing procedure.
8	Replenish all fuel supplies.

If the static load (load bank) approach is taken, a load bank sized at not less than 30 percent of the generator nameplate rating is all that is needed to meet The Joint Commission requirements. Again, the better test is with actual EP system loads in accordance with NFPA 110, particularly with EP systems whose actual loading is greater than the 30 percent value. Although the NFPA 110 installation acceptance test permits each generator in a multi-unit installation to be 100 percent load-tested individually, that approach is not particularly wise for the 36-month load test. The purpose of this test is to verify the system's continued viability and minimize the chances of missing any developing reliability problems. Any problematic interactions between generators would not be caught by a test that only tests one generator at a time, so where is the due diligence? The 30 percent minimum total loading requirement also allows the load bank sizing to be reasonable, even with all paralleled generators operating simultaneously.

In the absence of industry guidance, Table 5—based in part on the steps of the second (load bank) half of the NFPA 110 initial acceptance test and in part on the standard NFPA 110 testing procedures—could serve as a starting point.[49] The table does not include safeties to be tested or data to be recorded—refer to the standard for that information.

Table 5: Sample Steps for 36-Month Load Test Using Only Static Loads

Step	**Description, comments, and references** Note that required notifications, safety precautions, and other related activities have been excluded for simplicity
1	The test is started with the generator in a cold start condition. As soon as the generator has reached operating speed and voltage, the load bank should be applied in one step such that the generator picks up not less than 30 percent of the nameplate KW rating [7.13.4.3.1].
2	It is not necessary to switch EPSS loads, nor is it necessary to interrupt power to non-EPSS loads [8.4.9.4].
3	Where an EPSS includes paralleled generator sets, the minimum 30 percent load test should use and test all generators that are intended to be operated simultaneously [7.13.4.1.3, 8.4.9.1]. *See the discussion that precedes this table.*
4	Verify that the generator loading is not less than 30 percent of generator nameplate rating, or maintains the manufacturer-recommended minimum exhaust gas temperatures, using the method normally used for the monthly load tests. Throughout the load test, regularly verify and document that this criterion is met via periodic readings, say every 30 minutes. An electrical power monitoring system or data logger connected to the generator or its distribution equipment will provide documentation of the test load profile that should also satisfy this criterion.
5	At the conclusion of the minimum 30 percent load test, switch off the load bank to remove system load. The generator(s) will then automatically shut off after the built-in cooldown time delay.
6	Remember to test all safeties and cranking, and to record all system parameters, as required in accordance with the organization's testing procedure.
7	Replenish all fuel supplies.

Operation

Determining the Actual Emergency Power System Demand Load

Hospitals must document their actual EP system demand load. It is no longer necessary to calculate 50 percent of the peak demand load for 30/50 testing purposes as required by earlier NFPA 110 revisions. However, it is still important to know the peak EPSS demand load for due diligence and to satisfy the accreditors' utility management requirements, as well as the requirements of other state or local authorities having jurisdiction (AHJs). It is not enough to assume that the highest emergency generator kilowatt (kW) demand during an early-morning monthly test represents the true peak emergency power supply system demand load, due to the variability of mechanical, building, and clinical process loads during a typical hospital workday. If an EP system test time is chosen due to low clinical activity, that avoided clinical load will not be reflected in the EPSS test loading. Additionally, some equipment, such as smoke control systems and fire pumps, will not operate except during atypical situations.

Some options[50] for determining the existing peak running load are illustrated in Table 6. The actual emergency demand load cannot usually be determined through one simple measurement because the EPSS automatic transfer switches will usually be connected to the normal power system along with other normal power loads. However, portable recording instrumentation can be used to sample the branch loads on each transfer switch for two or three days, or preferably 30 days in accordance with NEC® 220.87, a much better approach than short-term sampling with a hand-held ammeter.

An even better solution is now available. Some hospitals are installing remote metering on their emergency generators and transfer switches, with central data recording and storage capability to retain the peak loads and time-of-use load profiles that the remote meters generate. These modern real time power management systems provide verifiable, repeatable, time-of-use load profiles and clearly provide the best load information available to modern hospital engineers and do not involve coming into close proximity to energized conductors.[51]

Table 6: How to Measure Typical ATS Loads and ATS Load Profiles

Effectiveness	Frequency	Approach	Complies with NEC® 220.87?*
Fair	Irregularly	Sample with hand-held ammeter—does not produce load profile. Electrician must use PPE for arc-flash protection in accordance with OSHA and NFPA 70E.	No
	Monthly during test	Sample with ATS-mounted ammeter—does not produce load profile	No
Good	Annually or greater	Record 2–3 days per ATS with portable recording instrumentation (power quality meter or data logger). Electrician must use PPE for arc-flash protection in accordance with OSHA and NFPA 70E.	No
	Annually	Read ATS-mounted demand meter to obtain previous year's demand load—does not produce load profile	Yes
Better	Annually	Record all ATSs for 30 days with portable recording instrumentation (power quality meter or data logger). Electrician must use PPE for arc-flash protection in accordance with OSHA and NFPA 70E.	Yes
Best	Continuously	Use remote electrical power management system with central data recording and storage	Yes

* NEC® 220.87 — "Determining Existing Loads" (summarized)

- Use 1 year of maximum demand data for each transfer switch
- If 1 year of demand data are not available:
    - Use recording ammeter or power meter on highest loaded phase for 30 days
    - Obtain 15-minute demand information for that period
    - Add seasonal heating/cooling and periodic loads by calculation

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Time-of-Use Load Profiles

Although the actual quantities of equipment used in a clinical area may vary from day to day, a track record of recorded loads built up over time will provide the necessary documentation of maximum load. If the peak load in each 15-minute period is recorded using a sliding 15-minute demand window, along with higher peak loads for the same period from the next several days, the hospital engineer has a high degree of confidence that these measures determine the total system average load profile. This approach is not in compliance with the NEC® if only a couple of days are monitored. It should be a close representation of the results that would be obtained by a full NEC®-compliant 30-day recording period.

The differences between the 15-minute demand load and the instantaneous peak loads should be noted so that the hospital engineer can assess how much additional allowance, if any, should be made for short-duration load variations. The assessment should differentiate between the instantaneous peak loads that last only a few seconds, typically representing motor starting inrushes, and the longer but still short-duration peak loads that last for one or two minutes. These one- or two-minute peak loads should be noted for later determination of an overall allowance for short-duration load variations. The equipment discussed above can be programmed to provide these data.

If a power management system is not available, record the load side of each automatic transfer switch for 30 days in accordance with NEC® 220.87.[52] Add the separate transfer switch load profiles together, along with allowances for other unrecorded loads, to determine the total EPSS load. If a power management system is available, a 30-day report of simultaneous time-of-use transfer switch load readings will provide a reliable load analysis. In both cases, adjustments will have to be made for variations between the loads that were running when the measurements were taken and additional loads that could also run during a normal power outage as stated below.

If 1 year of maximum demand information is available for each transfer switch, these demands can be added together in accordance with NEC® 220.87, but there is a downside to this approach. The maximum demands for each transfer switch are not likely to coincide with each other, and the calculated sum of the non-coincident demands (also called the "sum of the peaks") will most likely be higher than the real EP system peak loading (also called the "peak of the sums") that one would obtain by adding together the actual load profiles.

Figure 2 illustrates the daily load profiles of separate branches in a sample hospital building. It also illustrates allowances for certain other types of loads. Figure 3 then illustrates the total EP system load profile that results when the individual load profiles and allowances are added to obtain a composite generator load profile for that same building. Figure 3 is a simple spreadsheet stacked area chart, showing how this graphical addition can easily occur.

This strategy gives repeatable values because most hospital loads and processes are repeatable. The author's experience reviewing thousands of load profiles indicates that daily branch load profiles taken in the same hospital building over time tend to show similar characteristics and values. Only load growth and space or occupancy changes will generally cause the load profiles to change significantly.

The load profiles of one building or branch should not be used to predict the load profiles of other buildings or branches, since variables such as building size, specific occupancies, occupancy patterns, and energy conservation features all affect the load profiles. Note that certain types of loads are not likely to be running during normal operating conditions (i.e., the fire pump, the smoke control system, the fire alarm system in "alarm" condition.) These atypical but necessary items can be modeled as shown in Figures 2 and 3.

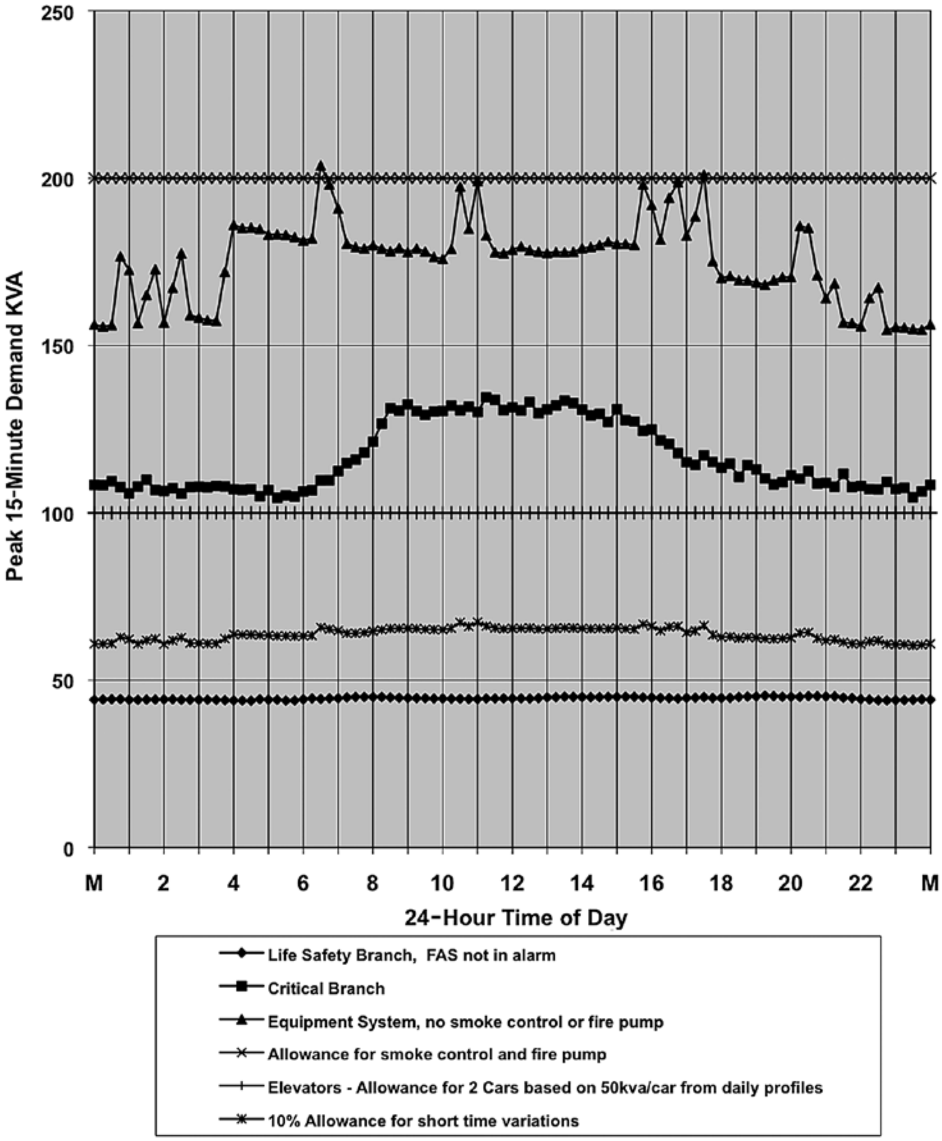

Figure 2: Sample Hospital Emergency Power System ATS Load Profiles Using 15-Minute Demands

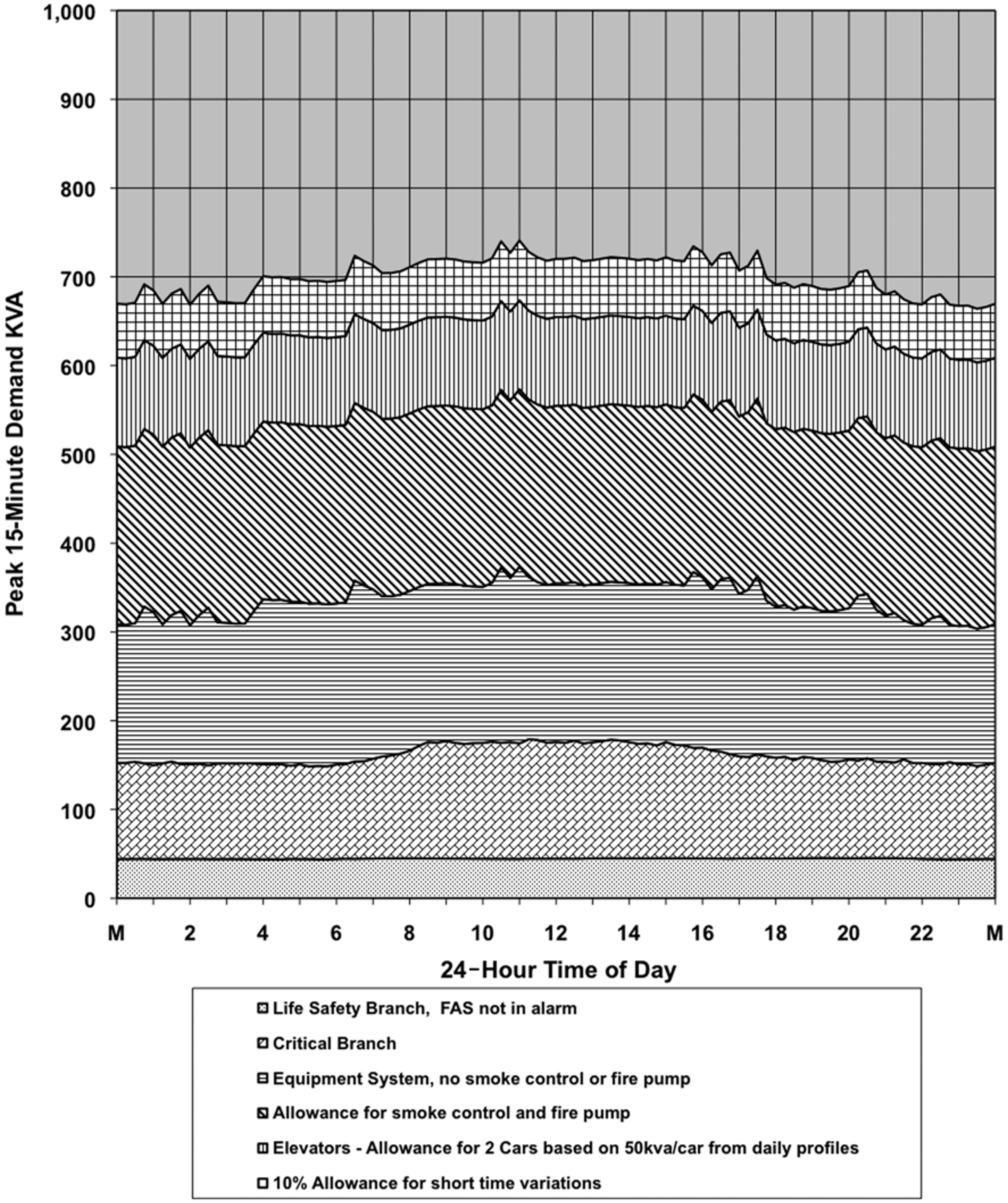

Figure 3: Sample Hospital Emergency Power System EPSS Load Profile Using 15-Minute Demands

The mechanical equipment system ATS load profile illustrated in Figure 2 is also shown in Figure 4, but this time as 1-minute sampling interval raw data directly from the recording instrumentation. Note the differences in appearance between the motor inrushes (single vertical lines) and the short time variations.

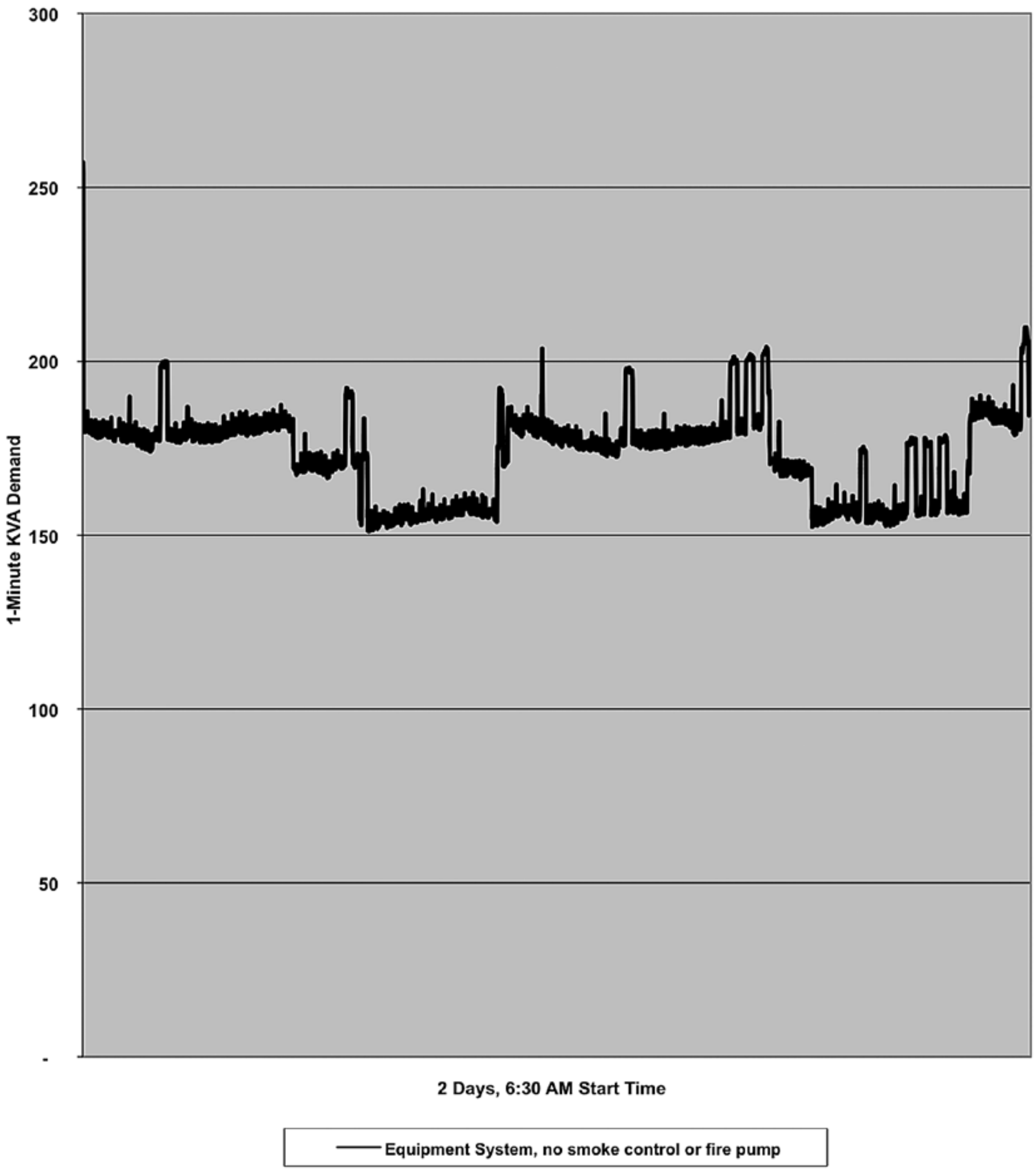

Figure 4: Sample Two-Day Load Profile for Mechanical Equipment System ATS Using One-Minute Demands

Certain EP system branch loads do not normally vary during the day. The code limitations on what kinds of loads may be connected to the life safety branch usually make its demand stable, except for the impact of a fire alarm condition on the fire alarm system demand. One facility was recording the load profile on a life safety transfer switch in a high-rise hospital building when such a fire alarm condition occurred (fortunately a nuisance alarm) and the load demand profile (see Figure 5) that resulted proved a clear indication of this impact. In this case, the life safety branch load doubled as a result of the fire alarm.

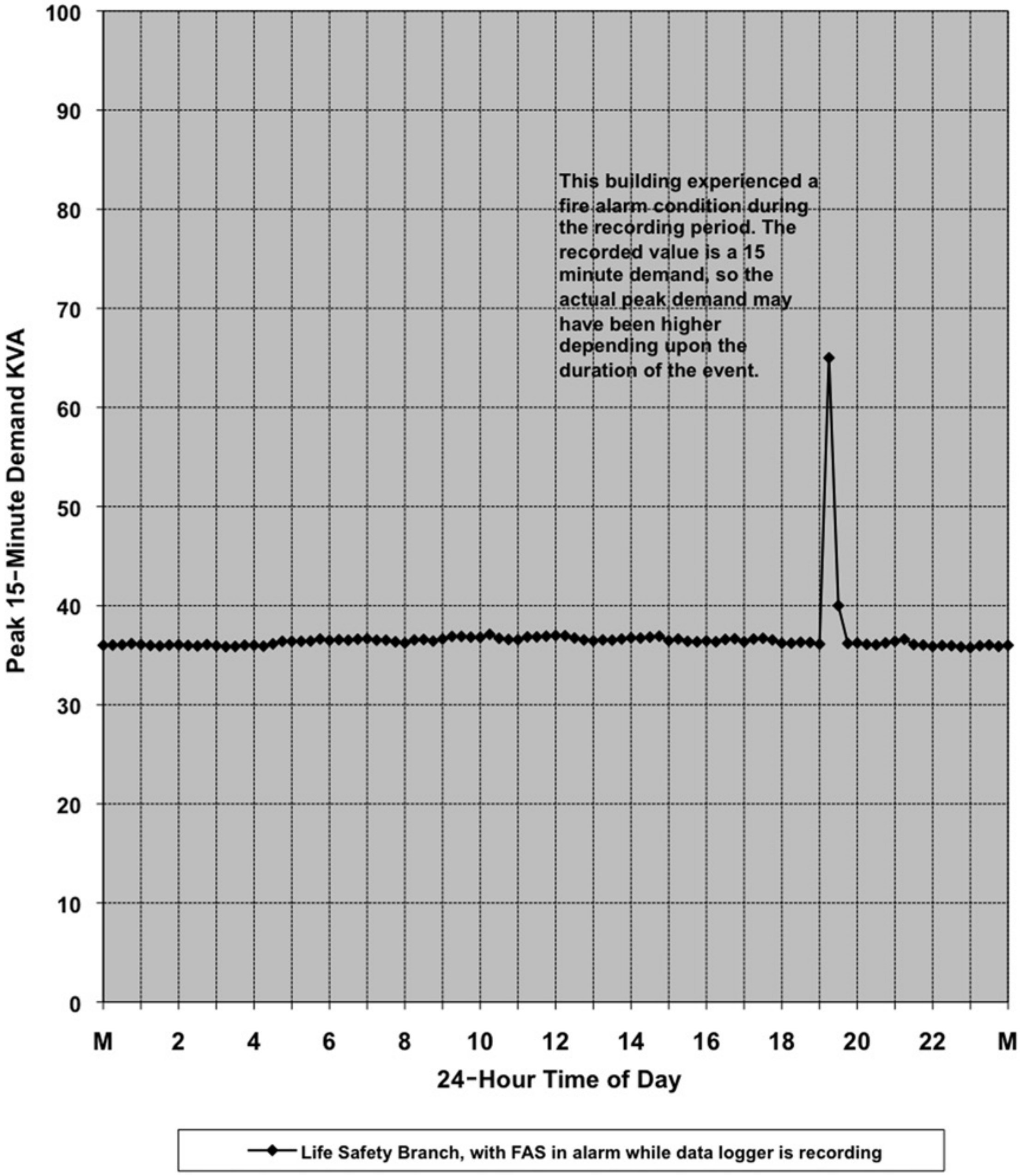

Figure 5: Impact of Fire Alarm Condition on Life Safety ATS Load Profile

Similarly, critical branch loads in many patient care areas tend not to change very much throughout the day unless portable radiology equipment is brought into the area and plugged into the critical branch outlets. Operating room critical branch loads, of course, vary significantly depending on the status of the operating room. All patient care unit critical branch loads will vary, of course, based on the unit's census and patient acuity.

Equipment system loads, however, will often vary during the day. This is particularly true if energy management strategies are used to turn off loads like operating room ventilation fans when the operating rooms are not in use. Elevator and radiology loads are the most variable, even during regular working hours. In addition, elevator and radiology loads can provide the highest inrush impact on the generator. The effect of elevators on an emergency power test is illustrated in Figure 6, where the difference between generator loading with and without elevators can be seen after the elevator transfer switches were returned to normal power halfway through the emergency power test. Figure 7 illustrates the impact of radiology loads. It is obvious from these load profiles that monitoring of elevator loads under normal power conditions does not allow one to predict the elevator loads under emergency power conditions with much accuracy. It can also be seen that several days of radiology load profiles are required before one can accurately model the radiology load impact on the emergency generator.

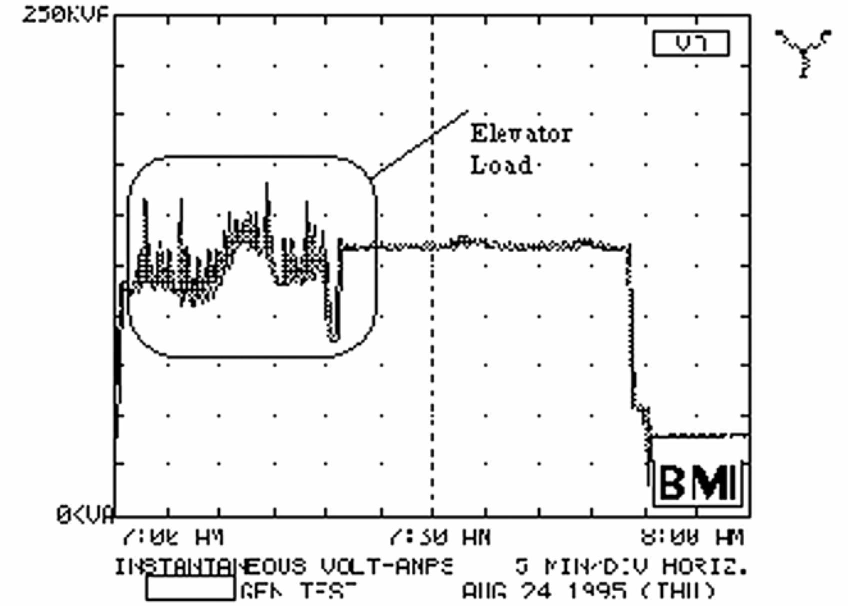

Figure 6: Sample Plot of Elevator Loading During an Emergency Power Test

The previous load profile is that of a generator set load during an actual hospital emergency power test. This particular test lasted 48 minutes. Note that the elevator load (the variable load) was removed after approximately 23 minutes.

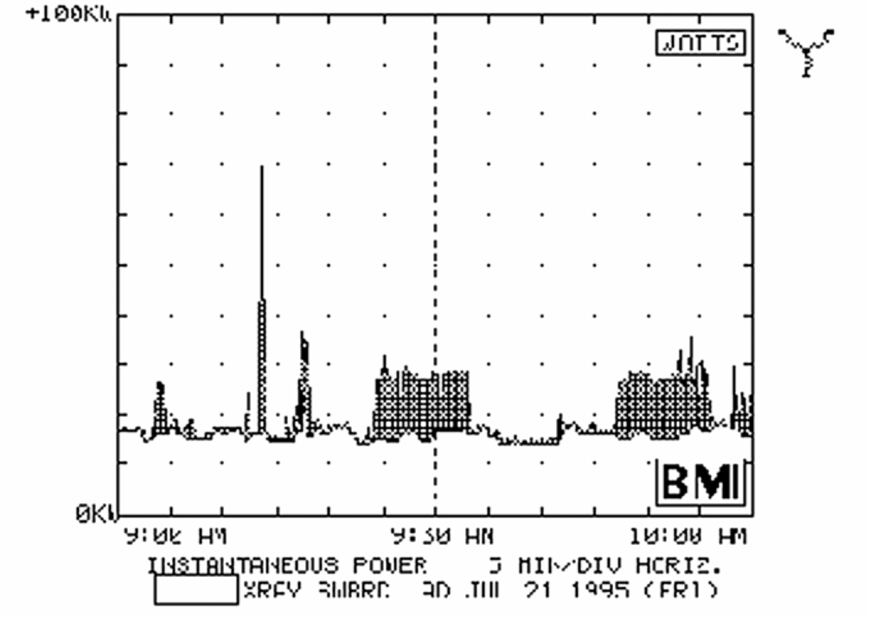

Figure 7: Sample Radiology Load Profiles

Figure 7 illustrates the varying radiology load in one hospital building. Note that some pulses last fractions of a second or minute, while other pulses last up to 10 minutes.

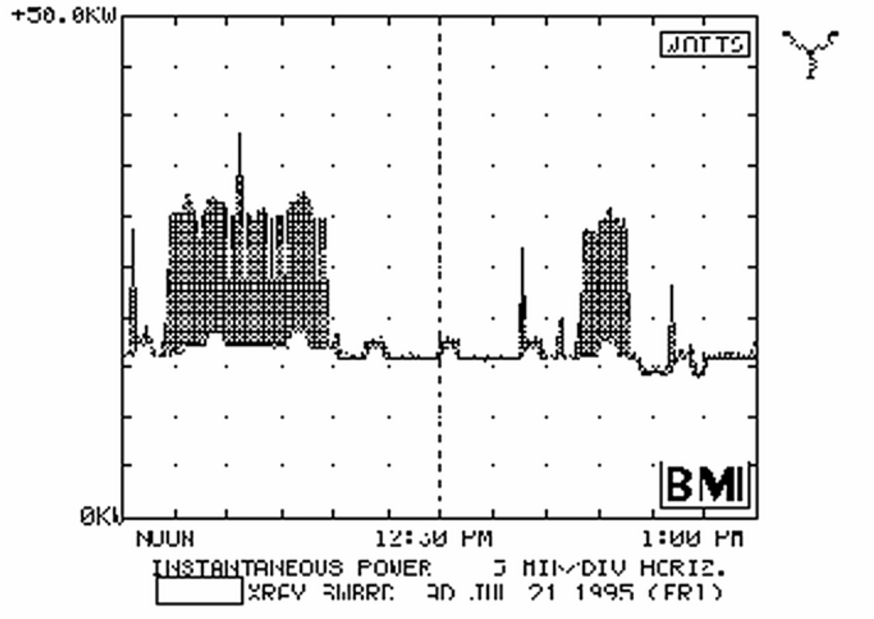

Figure 8: Varying Radiology Load in a Hospital

Figure 8 represents the varying radiology load in a hospital building. Note that the 15-minute peak was followed by more than 20 minutes of effectively standby loading.

Again, it must be noted that NEC® 220.87 requires 30 days of continuous load monitoring per transfer switch if the past year's peak demand load is not available.

Test Loading vs. Real Time Emergency Loading

Does test loading accurately represent real emergency loading during a utility power failure? The EP system monthly test was probably selected to minimize its effect on hospital operations, so the clinical activity and visitor load will be reduced. This timing is also reflected in reduced EP system loading, so the short answer is "probably not."

Seasonal loading considerations (heating or cooling loads that are powered by the equipment system, for example) may also apply. It is possible to simulate the typical daily EP system load profile by graphically adding together the individual transfer switch typical daily load profiles as shown in Figures 2 and 3. Again, it will be necessary to make allowances for loads (seasonal and periodic) that were not running when the loads were being monitored. Figure 5 illustrates a sample emergency power test generator load profile. The hospital engineer should compare such test load profiles with the composite load profile discussed earlier to get a true understanding of the difference between EPSS test loading and projected maximum loading.

The actual EP system demand load during a real normal power outage will reflect the scope of the outage (facility-wide, building-wide, or localized), the time of the outage (weekday or weekend, daytime or nighttime), any confounding factors such as external (local or regional) or internal (fire) disasters, the extent of the outage (minutes, hours, days, or weeks) and perhaps other issues as well. External disasters will likely include more clinical activity (emergency department surge), and internal fire disasters will likely include extra fire alarm load, smoke control systems, and the fire pump. The longer outages will likely include some of the lessons learned from planned normal power shutdowns.

Utility Management Considerations

When one considers the EP system, neither its utility management planning nor its emergency management planning should stand alone. The importance and role of the EP system require that each function support the other.

EP system documentation must be complete and accurate. The facility's main one-line diagram should be accurate and should be updated regularly to incorporate construction/renovation (C/R) projects. In this regard, "as found" is much better than "as built" because changes happen and changes can trigger unwelcome surprises when normal power fails. The C/R project riser diagrams are necessary for those projects and can be used for utility management if there are no changes since the C/R project was completed. Multiple projects, each with its own riser diagram, can create complexity and confusion if all of the riser diagrams are needed when the normal power fails. Accurate and up-to-date all-inclusive main one-line diagrams of the entire facility are better than a series of project-specific riser diagrams for internal disaster emergency management.

Finding and Mitigating Vulnerabilities

Facility personnel can find emergency power vulnerabilities by assessing their installations, operations, knowledge, communications, maintenance, electrical safety, contingency planning, and hidden common-mode failure potential for their effect on reliability, availability, and dependability. This section ties together many of the concepts found elsewhere in this monograph.

Consider the terms *reliability, availability,* and *dependability*. Sources may have different definitions of these terms. In systems engineering, *dependability* is a way to measure a system's availability, reliability, and maintenance support. *Reliability* is often considered the probability that a system operates and gives the same result on successive trials. *Availability,* on the other hand, can be considered the probability that a system will be able to function at any instant required, including within the next instant and for as long as required from that point. We postulate that no facilities system can guarantee 100.000 percent reliability; therefore no facilities system can promise 100.000 percent availability. Even modern data centers might only have five nines (99.999 percent) system availability and four nines (99.99 percent) facility availability. Needless to say, it is incumbent upon us to find our vulnerabilities and mitigate them. We do this with gap analyses, risk assessments, and vulnerability assessments, and through other means.[53]

Emergency Power Gap Analyses

What is a gap analysis?

Quite simply, a gap analysis is a process for change. It enables the user to determine what changes are needed or wanted, and then it facilitates the process of getting there. A gap analysis requires that the user answer the following questions:

1. Where are we now?
2. Where do we want to be?
3. What do we need to do to get there?
4. How do we do this?

An emergency power (EP) gap analysis asks the following questions:

1. What is connected to EP now?
2. What else needs to be connected to EP?
3. What should we do in the short term, and how do we get there in the long term?

A gap analysis can also be used to address the results of a power system vulnerability analysis:

1. How vulnerable is my EP system to failures?
    a. Where are my vulnerabilities, and to what types of postulated failures?
    b. What vulnerabilities do I want to eliminate?
    c. What do I need to do to eliminate or reduce those vulnerabilities?
    d. How do I do that?
2. How vulnerable is my normal power system to failures?
    a. Where are my vulnerabilities, and to what types of postulated failures?
    b. What vulnerabilities do I want to eliminate?
    c. What do I need to do to eliminate or reduce those vulnerabilities?
    d. How do I do that?

Gap Analysis Strategy for Power Failures

A detailed gap analysis strategy for power failures might look like the following. There are parallels with a power failure vulnerability analysis since the two analyses are complementary.

1. Define the concerns, policies, urgency, data needed, and metrics.

    a. Are we concerned about external disasters or internal disasters, or both?
    b. Are we concerned about full power loss, partial power loss, or some combination of those?
    c. What needs to continue operating?
    d. What codes, standards, and policies apply?
    e. Are there areas where the organization desires operational flexibility beyond what is presently required by codes?

2. Assess current situation.

    a. This activity requires load lists and power source identification for all loads of interest.
    b. Another helpful approach is to review the last several power shutdowns and look at the temporary wiring that was needed.
    c. This assessment will usually identify areas, services, and loads that needed to continue operating even when the power was no longer available.
    d. Another helpful approach is to look at the lessons learned from actual power outages, whether caused by external or internal events. The lessons learned by the organization itself and by others are instructive.

3. Analyze data; summarize gaps.

    a. This analysis will look at equipment (clinical, support services, and infrastructure) and systems (mechanical, electrical, etc.).
    b. This analysis considers specific areas and the power systems that serve those areas.

4. Develop recommended actions.

    a. The recommended actions for a power system gap analysis might involve additional generation, distribution, modifications to existing systems, and power failure procedures to address infrastructure gaps.

   b. The recommended actions will also include assessing funding needs and avenues for acquiring the necessary funding.

5. Brainstorm strategies to bridge gaps and recommendations.

   a. A typical brainstorming session could include a group of clinical and facilities stakeholders who consider specific clinical services or areas, and then look at options for dealing with power failures occurring right now that affect those services or areas.
   b. A brainstorming session does not reject any ideas. Rather, it just records them for later consideration and ranking.
   c. A brainstorming session to discuss an infrastructure issue (such as one generator with radial distribution serving a critical service or area) could start with postulating a generator or distribution riser failure that occurs right now and short-term options to address that failure.
   d. Further brainstorming can than address options for long-term improvements to mitigate the effects of, or protect against, future failures of that type.

6. Determine best options (short and long term).

   a. Once the brainstorming sessions are completed and all possible options have been identified, the consideration, analysis, and ranking of preferred approaches can occur.
   b. The best short-term options would come from the "failure that occurs right now" brainstorming.
   c. The best long-term options often, but not always, involve the need for capital funding. The delays inherent in most capital funding processes drive the need for short-term options.

7. Develop action plans.

   a. Action plans include clinical procedures for power failures that document the best course of action developed for the "right now" analysis.

   b. They might also include acquiring new generating capacity or contracting for rental generators.
   c. These action plans should be as specific as possible (how portable generators will be wired into a power system and removed safely later).
   d. All stakeholders need to participate in action plans or implementation will be difficult.

8. Implement action plans.

   a. This could necessitate acquiring more funding if infrastructure improvements are required, even in the short term.

Gap Analysis of Supplied Services

When there are supplied services of a critical nature (fuel oil deliveries if the existing onsite storage is deemed inadequate in the short term, for example) the facility manager (FM) needs to understand any vulnerability in that supplied service. The FM's contingency plan should begin where the service provider's crisis management capabilities end.

Table 7 gives examples of questions that might be included in different types of gap analyses—one for equipment connected (or not) to the EP system, one that responds to a normal power vulnerability analysis, and one that responds to an EP system vulnerability analysis.

Tables 8 and 9 give examples of how issues uncovered by emergency power gap analyses are addressed.

Table 7: Examples of Gap Analysis Questions

Generic Gap Analysis	Emergency Power Gap Analysis	Gap Analysis Responding to NP* Vulnerability Analysis	Gap Analysis Responding to EP** Vulnerability Analysis
Where are we now?	What is connected to EP now?	How vulnerable is our normal power system to failures? Where are our vulnerabilities, and to what types of postulated failures? [List]	How vulnerable is our emergency power system to failures? Where are our vulnerabilities, and to what types of postulated failures? [List] Are there potential NP and EP common-mode failures? [List]
Where do we want to be?	What else needs to be connected to EP?	What vulnerabilities do we want to reduce or eliminate?	What vulnerabilities do we want to reduce or eliminate?
What do we need to do to get there?	What should we do in the short term? How do we get there in the long term?	What do we need to do to reduce or eliminate those vulnerabilities in the short term? What do we need to do to reduce or eliminate those vulnerabilities in the long term?	What do we need to do to reduce or eliminate those vulnerabilities in the short term? What do we need to do to reduce or eliminate those vulnerabilities in the long term?
How do we do this?	How do we do this?	How do we do this?	How do we do this?

* NP–normal power system; ** EP–emergency power system or essential electrical system

Table 8: Example of Emergency Power Gap Analysis: Emergency Power System

Current State	Desired State	Gap (Next Actions)		Date Fixed and Verified
		Short Term	Long Term	
Generator 1 is a single point of failure	Backup generation capability in the event of Gen 1 failure	Establish rental agreement for portable generator, wire existing system into exterior connection box located in secure area	Provide additional generation capacity	Short term: Long term:
Critical branch (load side of transfer switch to panels) is not maintained regularly	Regular maintenance outages are also used by clinical staff as practice drills for possible branch failures	Use thermographic scanning regularly while planning first branch outage	Establish critical branch master plan that allows for maintenance outages	Short term: Long term:

Table 9: Example of Emergency Power Gap Analysis: Essential and Optional Loads

Current State	Desired State	Gap (Next Actions)		Date Fixed and Verified
		Short Term	Long Term	
Only limited cooling is connected to generator, generator has insufficient spare capacity	Sufficient cooling with generator backup to sustain essential facility operations during extended power blackout	Arrange rental agreement for portable generator, wire existing chiller plant and auxiliaries into exterior connection box located in secure area	Acquire additional generation capability or portable generation	Short term: Long term:

Power System Vulnerability Analyses and Risk Assessments

Power system risk assessments and vulnerability analyses consider events that can cause internal power failures and their probabilities. They also consider the potential for common-mode failures. Risk elements considered include business and staff impacts and disruption to health care. Other elements are preparedness, the cascade impact of electrical failures on other utilities (such as ventilation of cooling), and mitigation of the effects of power system failures.

Vulnerability analyses should consider all possible causes of potential common-mode failure. In the discussion below we will consider potential common-mode failures in a mechanical system that supports the emergency power system—the fuel oil system. One example of a potential source for common-mode failures is a single fuel oil storage tank containing fuel oil that serves multiple generators, including redundant generators. Flooding of the fuel oil pumping system, its control panel, the power to its control panel, or even fuel oil contamination could adversely affect all the generators served by the fuel oil system. Even dual storage tanks served by a common header could fall victim to some common-mode failures.

Examples of other fuel system common-mode failure causes are the fuel transfer system components, such as pumps, controls, and their power sources. The failure of fuel oil transfer pump power or controls can bring down an entire emergency power system unless the design, vulnerability analysis, inspection, testing, maintenance, operation, and failure procedures all work together to prevent that occurrence. Whether a duplex fuel pump skid has a single source of power or is located in an area where it is subject to the same event that takes out the utility power source, the result is potentially the same—a full power outage. Pieces of equipment on an upper floor can be rendered unusable if their power feeders are located in an area—say the floor below—that is subject to flooding or damage from other common-mode causes.

One effective approach when analyzing for potential vulnerabilities related to possible common-mode failures is to:

- Consider each component that must operate
- Determine what scenarios will cause it to fail, including all "what if?" scenarios that could damage the control systems, power sources or feeders that keep it running
- Compare those scenarios with others that may take out other redundant components, redundant power sources, or redundant feeders
- Investigate the different possible causes of those scenarios, including commonalities in power sources, feeders, or controls
- Address the resulting common-mode failure modes that have been identified

Now let us consider the common-mode failure potential for automatic transfer switches. ATSs are major components of most hospital emergency power systems. Normal power flows through them to critical equipment when normal power is available. When normal power is not available, the ATS signals generators to start, and then the ATS transfers to generator power when the generator power reaches the ATS terminals. An ATS is a potential common-mode failure point because both normal power and emergency power flow through the same piece of equipment to the critical equipment. A transfer switch failure is likely to cause an outage of the critical equipment that it feeds. The impact of any single common-mode failure of this type with a smaller ATS will probably be limited to a smaller area or smaller grouping of equipment. Larger transfer switches, however, will feed more equipment and larger spaces. A larger ATS failure will likely have a greater impact.

An ATS that doesn't receive sufficient maintenance is more likely to fail than one that does. The necessity of maintainability is very important since it is more difficult to maintain ATSs that are not designed to support maintainability. Maintenance should be performed to minimize the potential for wear-out based failures due to component aging and use. Many hospitals still have ATSs lacking a bypass isolation feature. This ATS bypass isolation feature is not typically a requirement in hospitals, but it is a best practice because it enables safe transfer switch maintenance without shutting off the critical equipment that the transfer switch feeds. A review of the recommended maintenance in consensus industry standards and manufacturers' operating and maintenance manuals indicates that certain tasks (typically included in recommended annual maintenance) should only be performed with the transfer switch removed from service or in the bypass mode. If a hospital wishes to perform maintenance on a transfer switch that does not have the bypass isolation feature, it will probably be necessary to take the transfer switch out of service and turn off its loads. This is an unacceptable condition in many hospitals. As a result, many hospitals do not perform full recommended maintenance on these devices because they are unwilling to turn off the critical equipment. Review your detailed ATS testing company reports—they may show that certain recommended annual maintenance tasks were simply not performed if your organization did not allow the power to be removed from the transfer switch.[54]

Discussion with Electrical Utility

The utility discussion recommendation that follows is an important part of an emergency power vulnerability assessment. A more reliable normal power supply might reduce the need for emergency power at any instant and therefore might be taken into account when considering other emergency power vulnerability mitigation factors.

The Joint Commission's Sentinel Event Alert 37 suggested that health care organizations have a discussion with the electrical utility serving their facilities to probe areas of power supply vulnerability. Some of the questions in the following list were excerpted and modified from a comprehensive list of questions developed for the financial community and published in an excellent resource guide by Securities Industry and Financial Markets Association (SIFMA), formerly the Securities Industry Association (SIA). It can be a good starting point for a health care organization developing its own list of discussion points.[55]

- How close is my electrical service to your utility station?
- Are other customers connected to my supply line(s)?
- Is there anticipated development or construction that could affect my supply line(s)?
- Are there common manholes and/or duct lines that contain more than one of my supply lines?
- Are there common electrical poles that contain more than one of my supply lines?
- What are your storm season precautions to minimize weather-related outages?
- Can you run alternate/additional supply lines?
- Can these alternate lines come into another service entrance point?
- Can these alternate lines come from different stations or different directions?
- What built-in redundancies do you have?
- How do you advise of service disruptions?
- How comprehensive are your contingency plans?
- What are your restoration time objectives?
- What are your public utilities commission restoration time commitments?
- Does my electrical service originate from a single source?
- What generation/distribution backups are there?
- What partnerships do you have with other utilities?
- What restoration priority is my facility? What is a higher priority than my facility?
- Will you pass along information regarding scope and expected duration of service interruptions?

- What is the contact information for your system dispatch center?
- What is the maintenance history on the supply line(s) serving my facility?
- What is the maintenance history on the switches and transformers serving my facility?

Other Power Failure Vulnerability Analysis Activities

Timothy Adams's 2007 ASHE Management Monograph contains an excellent approach to conducting an emergency power vulnerability analysis.[56] This approach can be used to conduct a normal power failure vulnerability analysis as well. The spreadsheets provided with that monograph are not included within this document. Readers are urged to read that monograph in its entirety.

Before a vulnerability analysis is conducted, it is necessary to fully understand and classify facility areas, loads, and infrastructure systems as to their criticality to patient safety and the health care organization's needs for business continuity. The critical load lists in NFPA 99, Article 517 of NFPA 70, and the Joint Commission's Sentinel Event Alert 37 provide a good starting point, but any hospital FM who has conducted scheduled power shutdowns realizes that there can be a number of areas, loads, and infrastructure systems not listed in those documents that the organization considers essential to its business continuity and that require backup power supply. Risk assessments and gap analyses will be useful in this effort.

The ASHE vulnerability analysis approach is highly recommended, and includes consideration of the following attributes and their contribution to power failure vulnerability:

- **Infrastructure.** This category considers infrastructure system features, components, condition, locations, operating flexibility, spares, and maintenance histories.
    - It should consider the vulnerabilities to disruption of electrical utility services, normal power distribution to the transfer switches, the transfer switches themselves, and their load feeders (essential system branches) and distribution.
    - Additional analysis includes the EP system documentation, labeling, failure procedures, test results, and training.

- **Power Sources.** Once the mechanical systems, facility areas, and clinical services have been identified in a spreadsheet with both their normal and emergency power sources, the data should be sorted by each power train (each generator, each switchboard, each transfer switch, etc.)
  - This type of data sorting will highlight mechanical systems, groups of facility areas, and groups of clinical services where single equipment failures or single wiring/feeder failures can take down redundant mechanical systems, intended backup facility areas, or intended backup clinical services.
  - This analysis is a form of common mode power failure vulnerability analysis.

- **Areas** – For each of the functional areas investigated, look for higher power failure vulnerabilities from the infrastructure analysis, such as with less reliable equipment, poorer documentation, lack of power failure procedures or training, or a poor shutdown and electrical equipment maintenance history.
- **Clinical** – The degree of clinical preparation was well addressed by the referenced monograph and also by the Joint Commission's Sentinel Event Alert 37. Clinical analyses and the training of clinical personnel should consider each of the following types of failures:
  - Extended loss of normal power with EP available
  - Extended loss of EP in specific areas [see area analysis earlier in this list] with normal power available
  - Loss of both normal power and EP

Emergency Power Risk Assessments

Although it is not the only viable risk assessment method, the Joint Commission's seven-step risk assessment process is used to illustrate this topic. It includes the seven steps outlined in the following list, along with commentary as to how they can be applied to power system failure risks.

1. Identify the issue.

   a. The issue being considered might be that a single generator with a radial distribution system is adequate to provide EP to a clinical area.

2. Develop arguments for that issue. Examples of arguments that support the postulated issue are:
    a. The normal power system serving the area has an excellent operational history.
    b. The normal power system has regular shutdowns for maintenance.
    c. Clinical and facility management action plans developed in support of those shutdowns work well.
    d. There are backup areas served by another building's normal power system and generator.
3. Develop arguments against that issue. Arguments that *do not* support the postulated issue are:
    a. The emergency power system (such as the critical branch serving the wing that houses the area being assessed) has never been shut down for full maintenance.
    b. The ongoing thermographic scanning in recent years has shown an increasing incidence of hot spots requiring quickly scheduled localized outages for tightening of cable lugs.
4. Objectively evaluate both sets of arguments. This is perhaps the most difficult part of the risk assessment, but also the most important part. Leave preconceptions at the door.
5. Reach a conclusion. Examples of conclusion that might have been reached by this risk assessment are:
    a. More comprehensive system failure procedures and training are warranted.
    b. The critical branch with the more frequently occurring cable lug overheating must be scheduled for annual shutdowns and maintenance before other actions are taken.
6. Document the process. The risk assessment must be reviewed and approved by the organization's environment-of-care committee.

7. Monitor and reassess the conclusion to ensure it is the best decision. This step requires good follow-up to make sure that the actions taken did indeed have positive results.

Only one issue was discussed in the preceding example, but the discussion on each point can provide a starting point for the FM who needs to do his or her own power failure risk assessments. Another issue often faced by health care organizations would be whether a single normal power distribution path is adequate for an existing mechanical system, as opposed to providing EP to it.

Power system risk assessments help to determine how robust the power system infrastructure is.[57] It is helpful for the health care community to look at the huge amount of work that has already been done by the financial services community, which has been looking in detail at power system failure risks and power system reliability for many years.

Other risk assessment considerations include:

- Transfer switches maintenance history—are the transfer switches bypass isolation or not? What maintenance has been done and what has not been done?
- Normal power operational history—has any portion of the normal power system had failures, either internal or external?
- Normal power maintenance shutdowns—has the organization been conducting shutdowns for maintenance of the normal power system?
- User and facility management action plans—how robust are the facility's action plans for power outages? How robust are the clinical department action plans for power failures?
- EP system maintenance shutdowns—has there been maintenance of the EP system equipment? Specifically what equipment has been maintained and what equipment has not been maintained?
- Thermographic scanning results—How often are you doing thermographic scanning of your normal and EP systems? The author recommends annual scanning.
- Infrastructure conditions—What are the ages and physical conditions of elements of your EP systems?

Emergency Management Tracer-Type Questions for Power Failures

The following emergency management tracer-type questions are offered to enable health care organizations to test their own readiness for power failures.

- During shift with monthly testing
    - Find personnel recently transferred from another shift. Ask about their understanding of EP tests.
    - How does this equipment react to a power outage? How do you know that?
    - Do these makes of equipment react differently to power outages? Explain.
- Uninterruptible power supplies (UPSs)
    - What maintenance is performed on this UPS?
    - How often are batteries (checked) (changed)?
    - Has UPS failure occurred in the past ___ months? Why?
- Do you have normal power maintenance shutdowns?
    - Is there temporary wiring during shutdowns?
    - Where is this documented?
    - Is this included in an EP gap analysis?
- If no, how/when is power system maintained?
    - How do you know that all required equipment is on EP?
- What is your EP loading during a weather event that also causes a working fire in ___?
    - How do you know that?
    - When was your EP loading last measured?
    - What time of day is your peak EP loading?

- What happens in this area if the normal utility power fails?
    - What is on emergency power?
    - What is not on emergency power?
    - What did your EP gap analysis find?
    - What will you do about that?
- What happens in this (critical care) area if the EP critical branch fails?
    - How do you know that?
    - What is hard-wired to EP?
    - What will you do about that?
    - How long will that take?
- What will you do if this generator fails?
    - Is there a procedure for this?
    - How long will that take?
    - Where will portable generator be connected?
    - How will portable generator be tied into the existing ATS engine start circuit?
    - How will the the portable generator get fuel oil for the needed time?
    - Does the portable generator location have exhaust issues with existing air intakes?
- What happens if this equipment system (motor control center) (distribution panel) (feeder) fails?
    - What will you do about it?
    - Do affected clinical personnel know what to do?
    - Have you practiced this scenario? When?
    - Do you have a procedure for that?

- When the (cooling) (ventilation) (medical vacuum) (pressurization) in this area fails, what do you do?
- What will you do if this ATS fails?
    - Is there a procedure for this failure?
    - How long will that take?
- What will you do if this paralleling switchgear fails?
    - Is there a procedure for this failure?
    - How long will that take?
- What ATS and feeder provide power to the (telecom switch) (patient data server)?
    - What will you do if it fails?
    - How long will that take?

Best Practice Means and Methods for Mitigating EP System Vulnerabilities

When researching vulnerabilities, consider the following approach:

- Recognize that things break. Equipment that worked well yesterday may not work well tomorrow.
- Do not just expect a situation to be acceptable. Inspect what you expect. Ask critical questions. Remember that without information you have only opinions. When obtaining information, sweat the small stuff. Pay attention to the details—often those details can result in unexpected occurrences.
- Analyze the impact of the "what if" scenarios previously discussed and other scenarios you develop for your own facility.
- Do not underestimate the importance of rigorous inspection, testing, and maintenance protocols. Emphasize to your personnel that they are the eyes and ears of the organization, that they are responsible for finding potential problems before those problems occur.

- Look at different utility failure incidents to see if there are any commonalities that suggest system issues rather than just single failures.
- Look for common-mode failures using the concepts from this monograph.
- Understand that you can't control what you can't control, so you have to plan for the unwanted. Have rigorous failure procedures that can be understood and followed by those who may need to respond.

Understand the vulnerability management life cycle

- Finding: Take the time (using the approach recommended above) to find those vulnerabilities.
- Prioritizing: Determine which vulnerabilities have the biggest potential impact on your operations or are the most likely.
- Assessing: Assess the full impact of the vulnerability and determine which actions might be undertaken to mitigate it. Consider using the gap analysis recommendations from this document if appropriate.
- Reporting: Tell others about the vulnerability and what you intend to do about it.
- Mitigating: Take action to mitigate the vulnerability, short term if needed and long term if possible.
- Verifying: Verify that the actions taken really did mitigate the vulnerability.

Consider using leak detection in high-value electrical rooms. This equipment warns of water-based vulnerabilities when relocation is not practical. Be sure to monitor this equipment if you install it and have it subject to inspection, testing, and maintenance processes. Electrical rooms can be vulnerable to water ingress because they are co-located near mechanical rooms containing systems with pressurized fluids (domestic water, fire water, chilled water, steam systems, etc.). Electrical rooms may be at low elevations and subject to water from other elevations. They may also be subject to water from natural causes, such as weather, or from internal causes, such as broken or leaking pipes. And even when sump pumps are present, have the sump pumps themselves been looked at as a potential vulnerability upon failure?

Planning for Power Failures[58]

Without power, health care facilities are extremely vulnerable, especially if they are without power for an extended period of time. Every health care facility needs to have a plan in place since there is rarely a warning before loss of power, except in cases where a slow-moving hurricane or similar natural disaster is approaching.

The purpose of this section is to offer recommendations and examples of effective power failure planning concepts, including gap analyses, emergency power risk assessments, commentary and recommendations on power failure vulnerability analyses, and other tools to improve readiness for power failures. Many of these actions are recommended by the Joint Commission's Sentinel Event Alert Issue 37.[59]

This section also offers several dozen emergency management tracer-type questions on power failures to enable a health care organization to test its own readiness. These sample tracer-type questions address the issues discussed in this monograph and in the following statement.

> Reliability and facility infrastructure health are not guaranteed simply by investing in and installing new equipment. Unexpected failures can compromise even the most robust facility infrastructure if appropriate testing, maintenance, and due diligence techniques are not employed.[60]

This section also contains references to three excellent documents from the financial business continuity sector. Readers interested in business continuity and power system reliability should review these documents in their entirety. All three are readily available via the listed websites.

Power System Failure Contingency Planning

Electrical system failures occur for many reasons. The causes can be as varied as aging of the equipment and wiring, human error, core drilling by construction/renovation projects, deferred maintenance, overloading of circuits, lack of preventive maintenance, hospital unwillingness to accept planned shutdowns, and the combination of concrete dust with high humidity. Many hospitals already have basic electrical utility failure procedures—procedures perhaps prepared many years ago. However, the ongoing enhancement of computerization in modern OR suites and other acute care areas may well require regular reviews and updates to these earlier utility failure procedure versions.

The accreditation requirement for proactive risk assessment means that hospitals should recognize that these internal failures do happen and plan appropriate responses ahead of time. Most hospitals conduct power system failure analyses, but often such analyses consider only the failure of the incoming utility service (normal power.) In these analyses, the emergency power system is assumed to be available, and hospital business continues with the essential services on emergency power as designed. However, internal failures, both normal and emergency power, can occur at any point in the power system. It is important to consider different failure points, not just at the mains. The responses will be different for each type of failure, and it is too late to formulate a response after the failure has occurred.

Consider this:

> *Your power fails, and you implement your utility failure response plan. No problem. But what if power to the hospital fails, and one of your two emergency generators fails as well?"*
>
> —Joint Commission[61]

Some generators have failed to start, and some generators that did start have tripped offline. Hospitals that postulate a generator failure may have backup generators already tied into a paralleling system, which is becoming a more commonplace design feature in larger facilities. Others may have a spare generator available, or may have procedures to bring in a rental generator. Those hospitals would also need procedures to connect the rental generator to the existing EPSS and ensure that the hospital's existing transfer switches will start it and there is sufficient fuel oil available to run it.

Paralleling switchgear represents the potential for an EPSS common-mode failure because all generator outputs are connected and flow through it to the EP system loads. Control power failure is a possibility, as is an internal short circuit. These potential failures are very rare, but the downside potential if they do occur is so great that facilities would be wise to consider them and create response procedures. The short circuit, of course, would be noticed immediately, but a control power failure may become apparent only when the EPSS is called upon next to operate.

Critical branch feeders and risers often provide emergency power to the critical branch power panels on several floors of an acute care wing. One simple cause of a critical branch riser failure, discussed in Table 10, is a critical branch dry type transformer primary circuit breaker tripping on a hot-to-hot

Table 10: Sample Issues That Can Be Found During Emergency Power Testing

General Topic	Detailed Examples
Starting	Test switch does not start generator. Battery has insufficient cranking or starting power. Battery cables fail or are loose. Generator fails to start.
Elevator control systems	Elevator recall function does not work. Some cars do not work when selected while on emergency power. Car station indicator lights do not work. Cars do not run automatically on emergency power, but will run when selected manually. Older motor generators all run when on emergency power, even though only one car in bank is running at a time. Elevator entrapment occurs due to test (many cars in use on starting test, then only one at a time during test). A member of the public panics due to a misleading elevator voice announcement at start of test. Many complaints occur when elevators recall then go into emergency operation during high traffic periods.
Lamp problems	Normal power available lamp is burned out; emergency position lamp is burned out. Normal power and emergency power lamp jewels are wrong colors (switched).
Breaker issues	EPSS circuit breaker found open before test. Circuit breaker trips due to (1) motor starting inrush, (2) transformer energizing current*, (3) ground fault relay sensing imbalance during transfer.
ATS issues	Return to normal power circuit fails when emergency breaker tripped. ATS does not operate properly after modification. Return to normal power takes too long (adding a "bypass time delay button" for faster returns after testing can solve this problem). Time delay relay fails, causing failure to transfer to emergency power.
Pretest issues	Emergency power breaker found open before test starts.
Operator and training errors	Incorrect control switch is operated. Bypass switch is operated instead of ATS test switch.
Communications issues	Clinical equipment resets itself during a procedure, requiring reboot and reconfiguration. Personnel claim that they did not know the test was to occur. Clinical personnel who are transferred from off-hours shift with no testing into a shift with testing, not familiar with equipment reactions to testing. Equipment from one area (with one type of reaction) is moved into a new area where personnel do not know how it reacts to testing. Different brands (makes) of clinical equipment react differently to power transfers, confusing caregivers.
UPS issues	UPS switches to battery power when on generator power, then works fine on AC when on normal power (can indicate that UPS voltage or frequency tolerances are set too tightly.) UPS fails due to bad battery or poor maintenance.
Reset/Restart issues	Fire doors or smoke doors close during each power transfer and must be reopened to fire alarm magnets after each transfer. Some automatic doors must be manually reset after power transfers. Adjustable speed drive trips off due to transfer of power.

**Note that the standard NEC® transformer primary overcurrent protection requirements (150% with no secondary O/C protection, 250% with secondary O/C protection) may be too low for dry type transformers on EP systems. Inrushes on power transfers can exceed these values under certain conditions.*

transfer. These feeders and risers are on the load side of the critical branch transfer switch, so there may be no backup source of power except for the normal power in the same clinical unit. Since it is likely that all critical care equipment will already be plugged into those 'red' critical branch outlets, the clinical personnel need to be trained on the correct response to that situation before the failure occurs. A smaller and less serious version of this same event would be the failure of a single critical branch circuit.

When power failures occur, it is advisable to prepare utility failure incident reports as soon as possible after the failure has been dealt with. Facilities personnel will always fix the immediate failure as soon as possible, but these reports can assist management in reviewing all utility failures to determine their generic relevance. More than one failure might have the same root cause. Once the root cause of the failure is determined, systems, policies, and procedures can be improved, allowing the facility a greater likelihood of avoiding similar future failures and thereby improving overall utility reliability. Lessons learned in dealing with the specific failure can sometimes also be used in emergency management planning.

Hospitals need to keep spare parts on hand to support their maintenance programs. Due diligence for utility management consideration of internal electrical failures also requires that an adequate inventory of manufacturer-recommended replacement parts be kept in stock to minimize the duration of outages caused by equipment failures.

It is also possible to quantify EP system reliability through probabilistic risk assessment[62] (PRA), and an industry standard is available for guidance.[63] Some of the issues PRA will quantify are the probability of failure, failure rates, annual downtime vs. availability, mean time to failure, mean time to repair, and mean time between failures.

Utility failure contingency planning that considers just the failure of the main electrical utility service is probably not sufficient in medium-sized and larger facilities. In those cases, the facility should consider preparing failure procedures as part of its utility management plan for each item in the list that follows. Creating sample utility failure procedures is beyond the scope of this monograph, but a hospital facility manager who considers the diversity in the following list should easily see the need for different responses to each scenario.

- Failure of a generator
- Failure of paralleling switchgear

- Failure of a transfer switch
- Failure of a critical branch riser
- Failure of a life safety riser
- Failure of a main transformer
- Failure of a main switchgear section
- Failure of a main switchboard
- Failure of a major power distribution riser
- Failure of an electrical switchgear or switchboard room
- Failure of a generator room
- Failure of a transfer switch room

All these scenarios should also be included in the ongoing competency training for hospital operations and maintenance personnel.

Utility Management Documents for Training Clinical and Support Staff

Drilling down from the major electrical distribution equipment to the local patient care units, the following two tables are examples of approaches to power outage planning that might be found in a typical hospital utility management document.

Many health care facilities are familiar with the single page that summarizes building utility failures and the basic staff response that is expected for those events. A quick review might show that this document, if used as part of an organization emergency management plan or utility management plan, includes a power failure entry similar to the one that follows. Although the entry does not stipulate that it only considers normal power failure, that fact is evident from a review of the detailed responses.

Emergency Conditions and Basic Staff Response

Building Utility Failures	What to Expect	What to Do	Other Responses
Electrical power failure	Power only to corridor lights and RED plug outlets.	• Open disaster bin for flashlight, extension cords, etc. • Know areas on emergency power.	• Ensure that life support systems are attached to RED plugs; be prepared to hand-ventilate. List other clinical interventions. • Report to supervisor.

The Joint Commission's Sentinel Event Alert 37 suggests that health care organizations consider the failure of emergency power as well. These additional considerations could lead to the addition of a new emergency power failure entry to supplement the existing normal power failure entry, as illustrated in the following table. Clinical staff should be aware of this eventuality and the possibility that under that condition normal power could still be available to them.

Emergency Conditions and Basic Staff Response

Building Utility Failures	What to Expect	What to Do	Other Responses
Normal electrical power failure	Power only to corridor lights and RED plug outlets.	• Open disaster bin for flashlight, extension cords, batteries, etc. • Know areas on emergency power.	• Ensure that life support systems are attached to RED plugs; be prepared to hand-ventilate. List other clinical interventions • Report to supervisor.
Emergency electrical power failure (only)	Power only to "normal" lighting and gray or white plug outlets	• Open disaster bin for flashlight, extension cords, batteries, etc. • Check all patient care equipment and patient task lighting.	• Ensure that life support systems are attached to gray/white plugs or to BACKUP red plugs if available; be prepared to hand-ventilate. List other clinical interventions. • Report to supervisor.

Some clinical personnel and many others expect that emergency power is or should be uninterruptible. They believe it should never fail. Some articles published in medical journals include phrases such as "uninterrupted power supply," "uninterrupted electrical power," and "red outlets are supposed to be the reliable uninterruptible ones." And one wonders if a medical journal article that mentions a "usually less than 1 second" outage duration upon loss of commercial power in that author's hospital is actually incorrectly referring to the very short hot-to-hot power source transfer times during monthly emergency power tests. Despite best efforts, sometimes emergency power systems fail, even when they are needed. The challenge—an important one—for hospital facilities personnel is to educate clinical staff that power failures unfortunately can occur and that they need to be prepared for that eventuality.[64]

Emergency Management for EP Systems

Hospital emergency management programs should be in compliance with applicable AHJ requirements. Emergency management phases fall into four categories: mitigation, preparedness, response, and recovery. Mitigation activities are those undertaken to reduce the severity and impact of a potential emergency. Preparedness activities build capacity and identify resources to be used in an emergency. Response activities execute the utility failure plans created in the preparedness phase. Finally, the recovery activities get the organization back to normal and use lessons learned to improve future emergency plans.

An example of mitigation activities as applied to EP system management is minimizing the potential for common-mode failures in designs for facility renovations. A variation on this approach is reducing the many eggs in one basket approach. Clinical area designs could augment backup outlet capacity, thus reducing, or mitigating, the impact of the next normal power outage. Another example is installing backup feeders between switchboard rooms on the same hospital campus. These backup feeders are only for use during emergencies, shutdowns, and maintenance, and would allow larger facilities to respond to local outages by moving power from unaffected locations into the affected locations. A more comprehensive mitigation activity would be an infrastructure upgrade that relocates existing generators and transfer switches above the flood plain.

Examples of preparedness activities as applied to EP system management are installing additional onsite generation capacity or analyzing the failure of each major element of the EP system when considering failure scenarios. Utility failure procedures are then prepared that can be followed if that failure occurs. Other examples are considering common-mode failures of different utility systems, such as the broad infrastructure failures that occurred in the New Orleans area after Hurricane Katrina. It is too late to plan for a failure if the failure has already occurred.

> *Being prepared means realizing what could go wrong before it does.*
>
> —Joint Commission[65]

All hospital facility departments know about emergency response activities—they diagnose and then repair the causes of outages in the EP system and the normal power system. They also support the clinical emergency response, say with extension cords or portable coolers.

What if the outage is a critical branch outage instead of a normal power outage? Since this type of failure is the opposite of the problem addressed in nearly all previous training, do the clinicians still know what to do? Clinical personnel need to be taught to switch critical patient care equipment from the red critical branch outlets back to the normal power outlets in this case. Are there still enough normal power outlets, or were too many of them rewired to emergency power in preparation for Y2K? Are the normal power outlets accessible? Items to be dealt with may include ventilators, monitors, computers, fax machines used for medication management, printers, and so on. What about hard-wired critical branch equipment, such as X-ray view boxes and medication dispensing machines? Do facility and clinical personnel know what to do so that patient care is not compromised? Are sufficient approved extension cords available? Are enough electricians available to rewire this equipment within the time frames required by patient care needs?

This may be an area for a vulnerability analysis.

Another potential area for a vulnerability analysis is common-mode failures, particularly when redundant systems are in close proximity and the same event causes the failure of the redundant systems. An excellent article in *Critical Care Nurse* described such an event and the issues that it raised.[66]

The last element of emergency management covers recovery activities. Recovery means returning to normal functioning. In the case of internal power failures, recovery usually means that temporary extension cords and back-feeds must be removed. Hospitals should have detailed procedures for switching back to normal operation to minimize the potential for accidents from back-feeds. A small part of one such procedure might be the requirement to shut off de-energized equipment to minimize damage to sensitive electronics from power surges during initial power-up.

Disasters and Lessons Learned[67]

It goes without saying that hospitals need to plan for external electrical utility failures regardless of locality. Decades of emergency events have shown how widespread such failures can be, such as during the 1993 Mississippi River flooding (affecting nine states); the 1996 Northwest Blackout (affecting nine states); the September 2001 attacks; the July 2003 Memphis straight line windstorm; the August 2003 Northeast/Midwest Blackout (affecting 50 million people); the East Coast's Hurricane Isabel in September 2003; California's Northridge earthquake; rotating blackouts and wildfires; the numerous 2004 and 2005 Gulf Coast hurricanes and tropical storms (Charley, Ivan, Katrina, Rita, Wilma, etc.); numerous tornados, ice storms, and blizzards since then, including the 2012 Super Storm Sandy; and more. Many of the events listed demonstrate clearly how prolonged such utility failures can be.

Reports of some EP failures surfaced after each event. For example, one article stated that during the 2003 Northeast/Midwest Blackout, “about 1.5 percent of the EPSSs failed to deliver power to the essential loads for various reasons.”[68] Reasons for EPSS failures range from fuel quality problems and fuel pumps that break to overheating and aged batteries. Sometimes even a required generator auxiliary system is miswired to normal power.

EP system failures have many causes, including installation error and lack of acceptance testing (such as a cooling fan or fuel oil transfer pump on normal power), generator overloads, circuit breakers and fuses, paralleling system load shed controls that malfunction and cause multiple generators to fail, a lightning-caused voltage power surge that negatively affects generator controls, a thrown engine rod, generators that run out of fuel, and other mechanical or electrical failures. Sometimes a downstream short circuit causes a more widespread EP system outage due to lack of protective coordination in the power system. If the facility is fortunate, these sorts of failures will occur during the routine testing rather than during a power outage.

The failures make the news. The successes do not. But the fact is that some hospital emergency generators ran for weeks after Hurricane Katrina. Survivors of the other disasters listed and other events can all report similar successes. So what is the difference? The difference between success and failure can usually be traced to a well-designed and well-constructed EP system that is subject to a comprehensive, diligently executed maintenance and testing program.[69, 70] If any of these pieces are missing from the equation, the EP system’s reliability will be diminished.

Much of what hospitals learned from the 2005 Gulf Coast disasters reinforced lessons from the terrorist attacks of September 11, 2001.[71] And some of what they learned (relearned) during Super Storm Sandy in 2012 unfortunately reinforced lessons of 2001, 2005, and other years when disasters affected utility power. Among these lessons were the impact of common-mode failures, extended utility failures, simultaneous failures of multiple utilities, and high patient surge levels. The surge levels were aggravated by the quantity of citizens seeking shelter. Many hospitals also housed employees’ families, causing an additional strain on resources.

An example of a common-mode failure lesson learned is normal power and EP system distribution equipment or wiring both being located in the same hospital basement. The rising floodwaters during the major Gulf Coast hurricanes caused both normal and emergency power failures in some hospitals, with shared elevation (even though the equipment might have been in different rooms) being the common-mode failure mechanism.

Many of the recommendations in this document are based on lessons learned from numerous EP system failures over a substantial period. Other lessons learned by hospitals in disaster areas included the following:

- Make sure equipment intended to be connected to the EP system is really connected to that system. Often this is most effectively done by turning off the normal power, if possible.
- Fuel deliveries into nearly empty fuel storage tanks can stir up sediment in the bottom of the tanks. This sediment can then clog fuel filters, resulting in diesel generator failure. This potential failure mechanism is a very strong argument for multiple fuel filter assemblies with isolating valves serving all emergency generators, with procedures to verify fuel filter cleanliness after all fuel deliveries.
- Monthly testing workarounds, such as shutting down sensitive equipment during the test periods, can come back to haunt a facility during real extended outages.

Many hospitals are arranging for temporary backup generator sets, some for additional backup power capacity and others to have replacements on hand in case their permanent units fail during a power outage. Regardless of the reason, hospitals that arrange for temporary backup generators should have a predetermined safe location for the generators out of harm's way, protected from the impact of local flooding and high winds if their HVA considers those hazards. The pre-event emergency planning should also consider the means to connect the temporary generators safely into appropriate parts of the existing wiring systems, and then to disconnect them when they are no longer needed. Accidents can occur when the planning for such temporary wiring is not detailed enough and personnel are forced to make decisions under emergency conditions.

The 2004 and 2005 Gulf Coast hurricane seasons heightened all industries' (including health care's) awareness of potential flooding scenarios. Unfortunately flooding is not just a problem along the coastlines. The 1993 Mississippi River flood that inundated four hundred counties in nine states is one example. Facilities located on high ground are also not safe from flooding. Something as simple as a broken water main in a location high above sea level, say from nearby construction, can (and has) also flood infrastructure systems that are located in adjacent basements. Even internal failures, such as broken sprinkler lines or water supply pipes, can cause interior flooding and result in electrical power failures.

It has been common practice for many decades to locate generator sets out of sight in facility basements. The heightened awareness of the devastating effects of flooding (disaster-related or not) is likely to result in more generator sets being located above any potential flood plains. Readers are urged not to forget the emergency power system feeders as well—generators located above floodwaters are useless if the EP distribution conduit systems and junction boxes are flooded and the EP wiring sustains a short circuit. This situation has occurred during at least one recent natural disaster.

Hospitals are required to complete an HVA as a condition of accreditation. They analyze the most likely hazards they might face and develop emergency management plans to deal with those hazards. These facilities should consider sharing their HVA results with the professionals who design their new buildings and infrastructure upgrades to make sure that the design protects EP system components and wiring from the listed hazards.

Additional Backup Power Needs[72]

NFPA 99 contains a detailed list[73] of areas and types of loads that must be powered by each branch of a health care facility's essential electrical system. NFPA 99 also allows some latitude in assigning additional loads to either the critical branch or the equipment system where the hospital determines they are needed for effective facility operation. Some hospitals might decide to conduct a thorough vulnerability analysis and then use this latitude to accommodate the recent lessons learned during prolonged multiple utility outages along the Gulf Coast and in southeast Florida. Some hospitals might now decide, after performing an emergency power gap analysis, that some of the following types of loads are needed for effective facility operation.

- *Equipment required to operate during extended power outages* can include cooling for clinical labs, radiology, and other diagnostic equipment spaces to avoid equipment shutdown from overheating of the electronics; more hallway outlets with capacity to power box-type fans to move air in case the main HVAC systems are disabled; cooling in yet more areas; and kitchen ventilation and exhaust hoods not already powered by the essential electrical system.
- *Other changes to cope better with extended loss of multiple utility services* can include patient room TV sets and resurrecting

mothballed TV antenna systems in case local cable TV services fail; onsite water storage or a well with well pumps for backup water in case of municipal water failure; and local sewer lift stations and storage in case of municipal sewer disruption.

- *Additional backup lighting* might be needed in loading docks for nighttime deliveries without municipal street lighting; temporary helicopter landing spaces, including parking garage rooftops, and safe evacuation routes to them; spaces and supporting services required for high patient surge levels, citizens seeking shelter, and employees' families; additional public and employee bathrooms; temporary triage locations; temporary morgues; and other elements of an enhanced disaster plan. Backup lighting power provisions also include charging stations for large quantities of rechargeable batteries for flashlights and portable hand lanterns.
- *Backup communications capabilities* are needed in case regional communications, including 911 systems and cellular systems, are disrupted as they were during September 11, 2001; Hurricane Katrina; and even as recently as Super Storm Sandy in 2012. These could include battery chargers with plenty of extra rechargeable batteries for satellite phones, portable two-way radios, cell phones and PDAs that can communicate via text messaging; portable radios to tune in to regional emergency broadcast system radio stations; and a communications center with battery-powered amateur (ham) radio capabilities[74] and a spare radio antenna in case all other regional communications fail. A boost to employee morale in disaster situations would be spaces and backup communications capabilities for employees to contact their families.
- *Other modifications to increase operational flexibility* can include operating additional elevators when an elevator bank switches to EP; elevators in other buildings that might be needed if older, less robust elevator penthouses fall victim to the disaster; additional clinical operations beyond those stipulated in NFPA 99; repair shops and equipment used in making repairs; expanded dialysis capabilities for citizens who cannot use their usual free-standing dialysis centers; upper or interior spaces for operational flexibility if lower floors or a specific wing, for example, must be abandoned due to flooding or structural damage; and backup power to additional exterior areas that might be needed for high patient surge hazmat decontamination.

- *A large regional disaster* may also require that hospitals establish temporary MASH unit locations, temporary triage areas, temporary morgues, and corresponding support services. These services could require multiple portable generators with their flammable gasoline storage issues.

It may be necessary to plan for weeks without power and water/sewer if roads are not passable or the extent of damage exceeds the three to five days for which most hospitals plan. Longer than expected response times for government assistance can also be a challenging factor, as many hospitals found out after Hurricane Katrina. Hospitals might also consider ordering extra fuel, portable generators, and other supplies for early delivery, before the state of emergency is declared. It is advisable to work with local government to make sure the deliveries actually get to your hospital and do not get confiscated or redirected by others. Also remember that having a lot of extra fuel oil on hand increases the possibility of fuel aging and contamination before use if the need is less that anticipated. Refer to the discussion of fuel oil aging issues elsewhere in this monograph for more information.

Keeping a Handle on Growing EP System Demand[75]

How does a hospital facility manager who is facing a growing demand for backup power avoid overloading the existing EP system? The best starting point is to thoroughly understand the existing peak EP demand load. Do not rely on your monthly generator test loading, since the actual demand loading during a real power outage (lengthy or not) is likely to be greater than the peak load during the monthly test, as described previously. Refer to the discussion on determining the existing EP system loading for more information.

Essential power system allowances need to take into consideration hospital surge capacity, along with other disaster-related loading, because disaster-related surge will require that more medical devices be used. ED surge may also require that existing intermittent essential loads be used more frequently, resulting in less load diversity and increased generator load.

Some of the additional loads that may be considered for backup power are the same types of loads that are often identified when the hospital is planning for a building-wide normal power maintenance shutdown. Capture lessons learned from these shutdowns and project them into longer duration outages and multiple utility outages. Consider your latest hazard vulnerability analysis and determine the potential impact of a natural or man-made disaster coincident with the multiple utility outages.

Remember that additional equipment on backup power will release heat into a potentially non-cooled and non-ventilated space. This may have been one of the more common issues faced by hospitals that remained open after the 2005 hurricanes damaged utility power systems.

Be aware of the NFPA 99 distinction between emergency loads and other essential loads, and follow all requirements for load shedding to avoid reducing the reliability of power to the emergency loads.

Maintenance

EP System Maintenance Programs[76]

Please also refer to the earlier section on weekly inspections.

Why should you maintain your emergency power system? Why should you change the oil in your car? The answer to both questions is the same: so that the equipment will continue to operate as it was designed to operate. Many hospitals do not pay enough attention to EP system electrical testing and maintenance because the power systems do not have moving parts and therefore appear more benign than they really are. The fact is that they are not benign at all. The electrical energy within most EP systems can cause damage to facilities and severe disruption to patient care.

Although most generator sets only operate when normal power fails, the critical branch, life safety branch, and equipment systems operate 24/7/365. Many hospitals never shut down these subsystems for maintenance because of the perceived risk that the scheduled shutdowns would pose to patient safety. This approach is like playing with fire. As with any other apparatus that operates continuously, failures will occur in electrical systems that are not maintained. If the life safety branch, critical branch, and equipment system are not shut off and maintained on a pre-planned basis, they will shut themselves off unexpectedly when they fail. That is the real danger to patient safety.

The purpose of an electrical testing and maintenance program is to improve operational reliability by finding and correcting incipient failures before they occur. This is not to say that a good electrical testing and maintenance program will absolutely eliminate all risk of failures. Rather, it substantially reduces the risk in the same way a prospective buyer's due diligence program will uncover most of the defects in a property. One should think of an EP system electrical testing and maintenance program as the due diligence of a smart emergency power management program. The Institute of Electrical and Electronics Engineers (IEEE) has published data indicating higher electrical component failure rates in facilities that do not maintain their electrical systems.[77]

Two of the recommended proactive approaches to EP system maintenance are predictive maintenance (PdM) and preventive maintenance (PM). PdM is condition-based, while PM is calendar-based. A third approach that is gaining new adherents is reliability-centered maintenance (RCM), which uses system analyses, logic, statistical input, and criticality of the equipment to be maintained, and has been called the optimum mix of reactive, time-interval-based, condition-based, and proactive maintenance practices.

The alternative to these proactive maintenance approaches is a high-risk sort of maintenance often known as reactive maintenance, also called run-to-failure or breakdown maintenance. Hospitals that do not regularly maintain their EP systems will instead end up trying to fix something after it fails while also recovering from the failure's effects.

Infrared Thermography

One of the first instances of PdM for electrical power systems was infrared thermography, also known as infrared testing, infrared scanning, and infra-scanning. It is a rapidly growing non-contact, nondestructive testing method that allows users to identify components that are experiencing excessive heating. This tool is important because it usually allows deteriorating components to be identified prior to catastrophic failure. This gives the facility manager time to schedule a shutdown to replace or repair the component before it fails and causes an unscheduled outage.

Facilities with infrared thermography programs should not scan only the normally energized portions of their power systems. Some facilities exclude the generator panel, generator breakers, and paralleling switchgear from their infrared thermography program simply because they are not energized when the technicians are onsite scanning. When one considers the thermal cycling an emergency power supply gets every month (43,000 minutes at room temperature followed by 30 to 45 minutes at loaded/operating temperature), one can appreciate the potential for the normally off emergency power supply lugs being worked loose. Therefore, hospitals should be sure to include infrared scanning of their normally off emergency power supply as well as the emergency lugs in transfer switches during monthly EPSS tests.

Infrared thermography programs involve comparing the current operating temperatures of electrical components with their baseline operating temperatures. These baselines are established when the electrical systems are operating under normal load and operating conditions. Facilities that have a power monitoring system installed can easily determine normal load and operating conditions. Even facilities that do not have a power monitoring system installed can obtain the load profiles described elsewhere in this document to determine these conditions.

Generator Maintenance

Be wary of applying the 2013 CMS Alternate Equipment Management Program to all or any portions of your emergency power supply system. According to the CMS Survey and Certification Letter that permits the program, the alternate equipment management program approach is not permitted if "other Federal or state law; or hospital Conditions of Participation (CoPs) require adherence to manufacturer's recommendations and/or set specific requirements" or if "new equipment without a sufficient amount of maintenance history has been acquired."[78] NFPA 110 is a mandatory reference from both NFPA 99 and NFPA 101. Hospitals should be cognizant of the following requirements from NFPA 110, which have been pretty consistent for several editions:

> 8.1.1 The routine maintenance and operational testing program shall be based on **all** of the following: *[emphasis added by author]*
>
> 1. Manufacturer's recommendations
> 2. Instruction manuals
> 3. Minimum requirements of this chapter
> 4. The authority having jurisdiction

The above statement applies to the entire EPSS. The EPSS is more than just the generator. NFPA 110 defines the EPSS as follows:

> 3.3.4 Emergency Power Supply System (EPSS). A complete functioning EPS system coupled to a system of conductors, disconnecting means and overcurrent protective devices, transfer switches, and all control, supervisory, and support devices up to and including the load

> terminals of the transfer equipment needed for the system to operate as a safe and reliable source of electric power.

Many hospitals have generator maintenance programs performed by specialist service companies or contractors. It is the hospital's responsibility to ensure that these service organizations are aware of and comply with all applicable requirements, including NFPA 110 and manufacturers' instructions. All generator maintenance programs must be in full accordance with the recommendations of the generator set manufacturer, because no entity knows what a generator needs to keep running reliably more than its manufacturer does. Most such programs involve regular inspections, oil changes, filter changes, coolant testing, and regular replacement of batteries, belts, hoses, and coolants. Every hospital does monthly generator load testing and monthly load transfer testing as a condition of accreditation. Load bank testing is also usually performed when indicated. Special attention should be paid to the fuel oil condition issues and fuel oil testing described in the following sections.

The monthly testing does not fully load most generator sets, since the generator sets usually are not fully loaded when the tests are conducted. Most hospitals conduct their monthly tests during off-peak hours to minimize the impact on hospital operations. Also, many hospitals have peak demand loads that are less than the generator set rating to provide an allowance for load growth. See the discussion on determining the peak demand load elsewhere in this document. Load bank testing may be a useful component of the generator maintenance program even if it is not required by regulations. It can be used to operate the generator set at full load, which is necessary to fully evaluate some of the diesel engine's systems according to some manufacturers.

The commonly acknowledged leading cause of emergency power supply system failures is the lack of adequate maintenance and testing of the generator set starting system (batteries, battery cables, and other starting system components.) This fact indicates that greater attention should be paid to the starting system and its components in many generator maintenance programs.

Generator Set Fuel Oil Stability

Concerns about the negative effect of dirty or aged fuel oil on generator set operability resulted in a tightening of fuel oil criteria in the 2002 and 2005 editions of NFPA 110.[79,80] Items that were recommendations before 2002 became requirements in the 2002 edition. The 2005 edition was even more restrictive. The 2013 revisions include numerous new recommendations in the Annex to mitigate the potential damaging effects of fuel oil contamination on emergency power availability. The 2013 edition should be reviewed to ensure that both its new requirements and its Annex recommendations, many of which are current best practices, are given due consideration in existing facilities.[81]

Those discussions and other fuel oil system maintenance recommendations in NFPA 110 guide owners toward fuel oil testing and fuel oil system maintenance programs. Fuel oil condition requirements have become more stringent because fuel contamination is considered by many to be the second leading cause of emergency power supply failures.[82]

Degradation of emergency generator fuel oil systems is not a new concern. There is ample historical literature on the subject, primarily federal publications responding to stringent testing, analysis, and reporting requirements that apply to the civilian nuclear power industry as well as federal facilities.[83, 84] Concerns and actual diesel engine failures have resulted from water and impurities in fuel oil due to system condition, maintenance error, fuel stagnation, day tank corrosion, clogged or fouled fuel oil filters, excessive fuel oil filter replacement intervals, workmanship during fuel oil system renovation, fuel oil truck operator error, day tank micro-organism contamination, inconsistent fuel oil quality from the supplier, incorrect biocide use, and even inadequate sampling techniques. Contamination can include algae, bacteria, yeast, acids, sludge, oxidation, sediment, suspended solids emulsification, and even foreign objects.[85] Even recirculated fuel oil that is too hot can result in an engine failing to meet its performance criteria.

Fuel oil must be consumed within its storage life, and stale fuel oil must be replaced. Fuel system designs must provide for a supply of clean fuel to the engine. Even the best designs should be followed through by appropriate management controls to ensure an adequate supply of fresh, clean fuel throughout the operating life of the engine and fuel oil system. Hospitals that were not previously monitoring fuel oil condition as a part of the utility management program should consider improving their programs.

Many hospitals are increasing their onsite fuel oil storage capacity as a part of their emergency management improvements, amid concerns about longer potential utility outages without adequate outside support. This increased storage capacity can make the issue of fuel aging more critical. The clean fuel criteria apply not only to the large fuel oil storage tanks but also to the local day tanks. Water and other contaminants can occur in both locations, and natural fuel degradation from aging affects fuel oil throughout the storage and piping system.

Emergency generator manufacturers have historically published recommended changing intervals for oil and for oil filters. Some manufacturers, suppliers, and service companies now provide oil analysis trending programs that are a useful predictive maintenance tool. Some manufacturers may allow regular oil analysis programs to determine oil-changing intervals, whereas others may not.[86] This issue is still being debated within the industry and bears close observation. Meanwhile, many hospitals should undertake regular fuel oil testing programs and fuel oil tank cleaning[87] programs to ensure and document that their fuel oil is fresh and clean.

Maintenance and Testing of Other EP System Components[88]

NFPA 110 requires that facilities have an ongoing annual maintenance and testing program for their transfer switches, consisting of major annual maintenance supplemented by three quarterly inspections.[89] The standard states that the manufacturer's recommendations should be followed and provides minimal procedures to follow in the absence of the manufacturer's recommendations. As with any portion of the essential electrical system, transfer switch maintenance must include special permission by facility management, notification to all potentially affected parties, and contingency planning.

Paralleling switchgear (in paralleled equipment arrangements only) is critical to the reliability of the overall EP system, and maintenance is a necessary part of the reliability equation. A strong maintenance program is particularly important for paralleling switchgear because of its complexity and its importance to the reliable operation of paralleled generator systems. NFPA 110 requires paralleling switchgear maintenance and testing. Since NFPA 110 invokes manufacturer's maintenance recommendations, the standard need not go into details on maintenance for this complex, specialized subsystem equipment. Despite this, the stipulated criteria listed in NFPA 110 presently include checking connections, inspecting or testing for evidence of overheating, or excessive contact erosion, removing dust, and replacing contacts when required. A proposed addition for the 2016 edition of NFPA 110 includes verifying during maintenance that the system controls will operate as intended. The proposed additions also include proposed Annex discussion that suggests staying on top of ATS loading changes because of their impact on ATS load block logic. Regardless of the final decision on the next NFPA

110 update, this is clearly an important element of a robust paralleling switchgear maintenance program and is highly recommended as organizational due diligence. Unfortunately not all facilities presently include this verification in their maintenance programs, and sometimes the issues that might have been found and rectified proactively during maintenance are not discovered until the paralleling switchgear does not operate as originally intended.

Electrical protective devices are the fuses, circuit breakers, and relays in a power system. Every power system will have short circuits, also known as faults. Electrical protective devices must operate as designed to mitigate the damage these short circuits cause when they occur. Circuit breakers need to be maintained regularly, or they could fail to open when needed. When circuit breakers fail to open or trip when they should, the overload or short circuit that is occurring will intensify and adversely affect a much larger part of the hospital.

The settings for adjustable circuit breakers and protective relays, and fuse types and sizes, are determined by the electrical protective coordination study, which is done in conjunction with the power system short circuit study. Both studies must use the actual as-found power system configuration, and this information will come from accurate, up-to-date electrical one-line and riser diagrams. These diagrams are also required for the electrical system maintenance process to be managed proactively and safely. Circuit breakers and protective relays must be tested regularly to ensure that they will still operate within the fault-clearing times required by the protective coordination study.

Electrical equipment maintenance is a combination of common sense and highly technical activities around and inside high energy equipment with the potential for disastrous results. Industry standards have been developed for this purpose by NFPA[90] and The InterNational Electrical Testing Association (NETA)[91] and are highly recommended. Most electrical equipment manufacturers publish recommended maintenance activities and intervals for their equipment. The manufacturers' recommendations should be factored into the overall maintenance program. The hospital's insurance company may also have specific maintenance criteria. Some insurance companies publish their own maintenance recommendations on the web, while others have them available for their customers.

In Summary

> **holistic:** *relating to or concerned with complete systems rather than individual parts*
>
> *—Merriam-Webster, 2014*

This monograph discusses a holistic approach to managing all aspects of hospital emergency power systems. The approach needs to be comprehensive because of the increasing complexity of hospital infrastructure and operational constraints combined with mounting regulatory commitments. Heavier reliance on electricity for medical treatment, emergency and otherwise, raises the stakes. Emergency power system management programs should include system load testing, utility management, finding and mitigating vulnerabilities, thorough power failure planning, emergency management, and rigorous inspection, testing, and maintenance.

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