



Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability

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Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability

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Preface

The importance of emergency power in keeping critical facilities operational during and after a major natural disaster was apparent with Hurricane Sandy in 2012. FEMA P-942, *Mitigation Assessment Team Report, Hurricane Sandy in New Jersey and New York* (FEMA, 2013a), contains observations and recommendations that should be considered in planning for emergency power in the event of a disaster. In addition, hazard-specific guidance documents developed over the years, including FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide* (FEMA, 2012b) have addressed various aspects of protecting emergency power systems from the damaging effects of natural hazards.

In September 2013, the Federal Emergency Management Agency (FEMA) awarded the Applied Technology Council (ATC) a task entitled “Emergency Power for Critical Facilities Guidance” under its “Seismic Technical Guidance Development and Support” contract (HSFE60-12-D-0242). Funding for this task was made available under the Hurricane Sandy Federal Disaster Declaration (DR-4085). Designated the ATC-118 Project, the primary objective of this work was to create a unified guidance document on emergency power vulnerabilities faced by critical facilities during natural disasters, along with associated mitigation strategies and code requirements intended to minimize these vulnerabilities.

ATC is indebted to the leadership of Bob Bachman, Project Technical Director, and to the members of the ATC-118 Project Team for their efforts in the development of this report. Work was performed and guided by the Project Technical Committee, consisting of Don Bliss, Phil Caldwell, David Low, Derek Wilson, and Steve Winkel. Technical review and comment at key stages of the project were provided by the Project Review Panel consisting of Chad Beebe, Bob Berninger, Jim Carlson, Bill Coulbourne, Mark Early, Terri McAllister, and Steve Sappington. Material forming the basis of this publication was developed under a prior contract, and David Low deserves special recognition for his efforts in developing the initial draft report and recommendations under that contract. The names and affiliations of all who contributed to this report are provided in the list of Project Participants.

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There is a significant likelihood that utility power will not be available for an extended period of time during severe natural hazard events. Thus, it is necessary for critical facilities to have reliable sources of sustained electrical power to achieve continued operation. This document provides guidance on the design and operation of emergency power systems in critical facilities so that they will be able to remain operational for extended periods, as needed.

Most critical facilities rely on a public utility grid, where power is typically transmitted and distributed by way of networked systems over long distances between where the power is generated and where it is consumed. The long-distance transmission and distribution of electricity leaves emergency power supplies vulnerable to a variety of natural hazards, even for sophisticated redundant networks. Both aboveground and belowground power lines are susceptible to damage from winter storms, high-wind events, flooding, earthquakes and tsunamis. In addition, while not specifically addressed in this document, utility electrical power systems are also vulnerable to other types of hazards including terrorist physical attacks, cyber attacks, accidental man-made hazards and large sunspot events (space weather). Regardless of the cause, the resulting loss of power to critical facilities providing much-needed services during such events can be particularly devastating to communities, unless a reliable and sustained source of emergency power is provided. The continued operation of critical facilities is a key element of community resiliency.

For purposes of this document, critical facilities are buildings that contain the following functions:

- Hospitals and emergency medical treatment,
- Fire, rescue, ambulance and police stations, and emergency vehicle garages,
- Buildings designated by the community as earthquake, hurricane, or other emergency shelters, and
- Emergency preparedness, communications systems, and operations centers and other facilities and sites required for emergency response command and control.

The term *critical facility* defines a building that is intended to remain operational in the event of extreme environmental loading from flood, wind, snow, earthquakes, or tsunamis. In model building codes, they are often referred to as essential buildings.

Disruption of health care, fire, and police services can impair search and rescue, emergency medical care, and even access to damaged areas. Critical facilities must be prepared for a loss of utility power, and their ability to function without interruption during and in the aftermath of hazard events deserves special attention.

The definition of critical facilities can be expanded to also include other types of facilities, including those that contain significant quantities of hazardous materials and those buildings that serve functions that are critical to ongoing operations of business or government. Although not covered in the scope of this guidance document, the information provided can be applied to any of these facilities.

1.1 Purpose

Modern building codes and standards acknowledge the vulnerability of electrical power supplied by utilities, and therefore require that most buildings have at least some emergency power to supply select loads when normal electrical power is interrupted. The level of emergency power required by code does not allow critical facilities to operate indefinitely when power is lost. For many buildings subjected to most natural hazards, code-required emergency power is limited and focused on supplying the minimum amount of power to allow occupants to safely leave a building.

This document examines the vulnerability of electrical power systems to natural hazards, describes what equipment in critical facilities should be supplied by emergency power sources, how long the emergency power may be needed, the specific equipment needs of different types of critical facilities, and how emergency power can be supplied. It provides guidance on how to assess the risks and vulnerabilities to the electrical power system, identifying performance goals for an emergency power system, and the importance of having realistic emergency management policies that address emergency power. It also discusses the advantages and limitations of redundant systems, the need for advanced planning of emergency power systems, potential pitfalls when sizing system components, such as fuel storage tanks, and provides examples of simple and complex installations. It emphasizes the need to apply a holistic approach to the design of a new emergency power system. In this document, a holistic approach means all elements of the design and operation of the emergency power system and the equipment using the power need to be considered, so that the facility will perform as intended under extreme design events, all in a cost effective manner. The report also provides summaries of relevant building code provisions that influence the design of emergency power systems.

In this document, the terms emergency power, alternate power, and standby power systems are used. These include:

- Systems required by building codes and standards to supply life-safety equipment, equipment that reduces hazards, and equipment that helps rescue or fire-fighting operations.
- Systems not required by code, but are desirable for preventing serious interruptions, discomfort, or damage when power is lost.

The guidance provided in this document is limited to traditional emergency power systems. There other power systems, such as co-generation facilities and micro-grids, that also can supply emergency power. These are typically considered in very large facilities where design professionals with experience in these systems provide guidance to clients on the reliability of systems when subjected to natural and other hazards.

1.2 Emergency Power from a Code Perspective

The term “emergency power” has specific meanings for code application in building codes and standards. NFPA 70, *National Electrical Code*, (NFPA, 2014), which has been adopted into law throughout the United States, uses varying terminology. It is important to understand all of the distinctions in terminology because the authority having jurisdiction (AHJ) or code official will expect systems called “emergency systems” to meet all the code requirements for emergency systems as defined in the *National Electrical Code*.

1.2.1 Emergency System

Section 700.2 of NFPA 70 defines an emergency system as follows:

“Those systems legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distribute, and control power and illumination essential for safety to human life.”

There are a number of requirements in NFPA 70 for emergency systems, including the need for an automatic transfer switch that transfers the load within 10 seconds of loss of normal power and the need for separation from the normal power supply. Emergency systems require permanent power supplies. Emergency systems are typically required in places of assembly and other large buildings that may be occupied by a large number of people.

1.2.2 Legally Required Standby System

Section 701.2 of NFPA 70 defines legally required standby systems as follows:

“Those systems required and so classed as legally required standby by municipal, state, federal, or other codes or by any governmental

agency having jurisdiction. These systems are intended to automatically supply power to selected loads (other than those classed as emergency systems) in the event of failure of the normal source.”

Legally required standby systems also require an automatic transfer switch. However, the load must be transferred within 60 seconds of loss of normal power. Legally required standby systems require permanent power supplies. These systems typically serve loads such as heating and air conditioning systems. They may also supply sewage disposal systems, lighting, and some industrial machinery.

1.2.3 Optional Standby System

These systems are defined in Section 702.2 of NFPA 70 as follows:

“Those systems intended to supply power to public or private facilities or property where life safety does not depend on the performance of the system. These systems are intended to supply on-site generated power to selected loads either automatically or manually.”

There are no requirements for a timed transfer of load for these systems, but a transfer switch is required. Optional systems do not require permanent power supplies; they may be supplied by portable or mobile equipment.

1.2.4 Critical Operations Power System

Some facilities designated as critical facilities must operate continuously. An example is an emergency operations center of a police department. Many of these facilities are supplied through a critical operations power system (COPS). These systems are defined in Section 708.2 of NFPA 70 as follows:

“Power systems for facilities or parts of facilities that require continuous operation for the reasons of public safety, emergency management, national security, or business continuity.”

1.3 Planning for Facility Resilience

The concept of resilience, when applied to a critical facility, calls for consideration of how the facility will function during and after a disaster. What systems will need to remain operational for the facility to function? Basic building code requirements for emergency or standby power systems in almost all buildings are intended to sustain a number of functions for short term needs, such as evacuating building occupants safely. Code-mandated emergency power systems are not required to operate key functions in a

facility. These systems are not designed to operate for long durations of power outage. Therefore, it is necessary to understand and provide additional emergency power for operational needs and the duration of these needs if a critical facility is to remain operational following a severe hazard event.

A key component in any consideration of emergency power systems is a disaster management plan, which establishes the desired level of function and performance of the building after a natural hazard event. The disaster management plan defines the role of the building in the post-disaster environment, and fits the purpose and role of the building in the overall framework of the post-disaster response mission. Once critical functions are identified, the building systems required to support the critical functions can be identified, along with their electrical power requirements. The plan should take into account the changes in normal operational procedures that will be implemented in the event of a disaster, which may serve to reduce the electrical power demands. The potential for outside assistance, in the form of portable emergency generating equipment, for example, should be considered along with any necessary building infrastructure that is needed to accept outside power sources. The disaster management plan should also consider the length of time before fuel and other supplies, such as lubricating oil and filter stocks, will need to be replenished.

Careful disaster management planning will help ensure that the emergency power system is adequately sized to provide the required level of electrical service, and that this power can be reliably maintained for the necessary period of time. Chapter 3 of this report provides guidance for consideration of emergency power needs in the disaster management plan.

1.4 Target Audience

The objective of this report is to assist a wide range of people associated with the design, construction, management, operation and maintenance of critical facilities in understanding the needs for emergency power. The list of interested parties includes (but is not limited to):

- Facility owners
- Facility managers
- Facility emergency managers
- Facility operating engineers
- Architects
- Structural engineers

- Electrical engineers
- Mechanical engineers
- Fire protection engineers
- First responders – fire
- First responders – other than fire
- Public sector emergency managers
- Contractors
- Subcontractors
- Equipment manufacturers
- Equipment suppliers
- Maintenance contractors

Each of these different groups will likely focus in detail on different aspects of this publication, but all of parties will benefit from examining the entire document. This knowledge will aid them in implementing sound measures that will decrease the vulnerability of critical facilities to power disruptions caused by natural hazard events. The intent of the document is to identify potential vulnerabilities that may be faced by critical facilities when preparing for the loss of utility power, as well as the best ways to provide emergency power.

1.5 Report Organization

This report is organized to guide the reader through concepts required to assess the vulnerabilities of the electrical power system of a facility.

Chapter 2 provides an overview of the electrical transmission system and the vulnerability of utility provided power and building systems to natural hazards.

Chapter 3 provides guidance on disaster risk management planning for critical facilities including defining critical facility, deciding where the facility fits into the overall framework of local and regional emergency response.

Chapter 4 provides guidance on specific critical facility needs for emergency power, including determining what functions are deemed critical and which equipment and systems that support those functions are needed, and the length of time emergency power is required.

Chapter 5 provides an overview of the elements of common emergency power generation systems.

Chapter 6 provides design considerations and best practices for emergency power systems in new critical facilities, including how to decide on what functions in a critical facility require emergency power, design decisions that affect the demand load for emergency power systems, and strategic decisions on the layout and locations of emergency power systems.

Chapter 7 provides guidance for providing more reliable emergency power systems in existing critical facilities that will function as needed following severe natural hazard events.

Appendix A provides an overview of current code requirements for emergency power systems.

Appendix B provides an overview of utility power systems and redundancy strategies.

Appendix C provides guidance on the design and selection of generators including load requirements, peak and continuous loads, along with how power quality basics, such as voltage and phase stability, frequency dip, harmonics, and transients, impact system reliability.

Appendix D provides checklists for emergency power systems to be used as helpful aids before, during, and after disaster events.

Appendix E presents examples on how to utilize this document for some typical situations.

A list of the references used in this document is included at the end of the report.

1.6 How to Use this Document

This document is intended as an introduction to the fundamental principles of providing emergency power for critical facilities. It is not intended to be a comprehensive design manual for developing actual plans and specifications. The information presented is intended to help readers understand broad risk reduction approaches and how to integrate them into facility planning and design. An example flowchart that one might use in a decision making process to evaluate emergency power generation needs using this document is provided in Figure 1-1.

While emergency power systems are highly engineered systems, without well-defined requirements for extreme natural hazard events to guide their

EMERGENCY POWER FLOWCHART

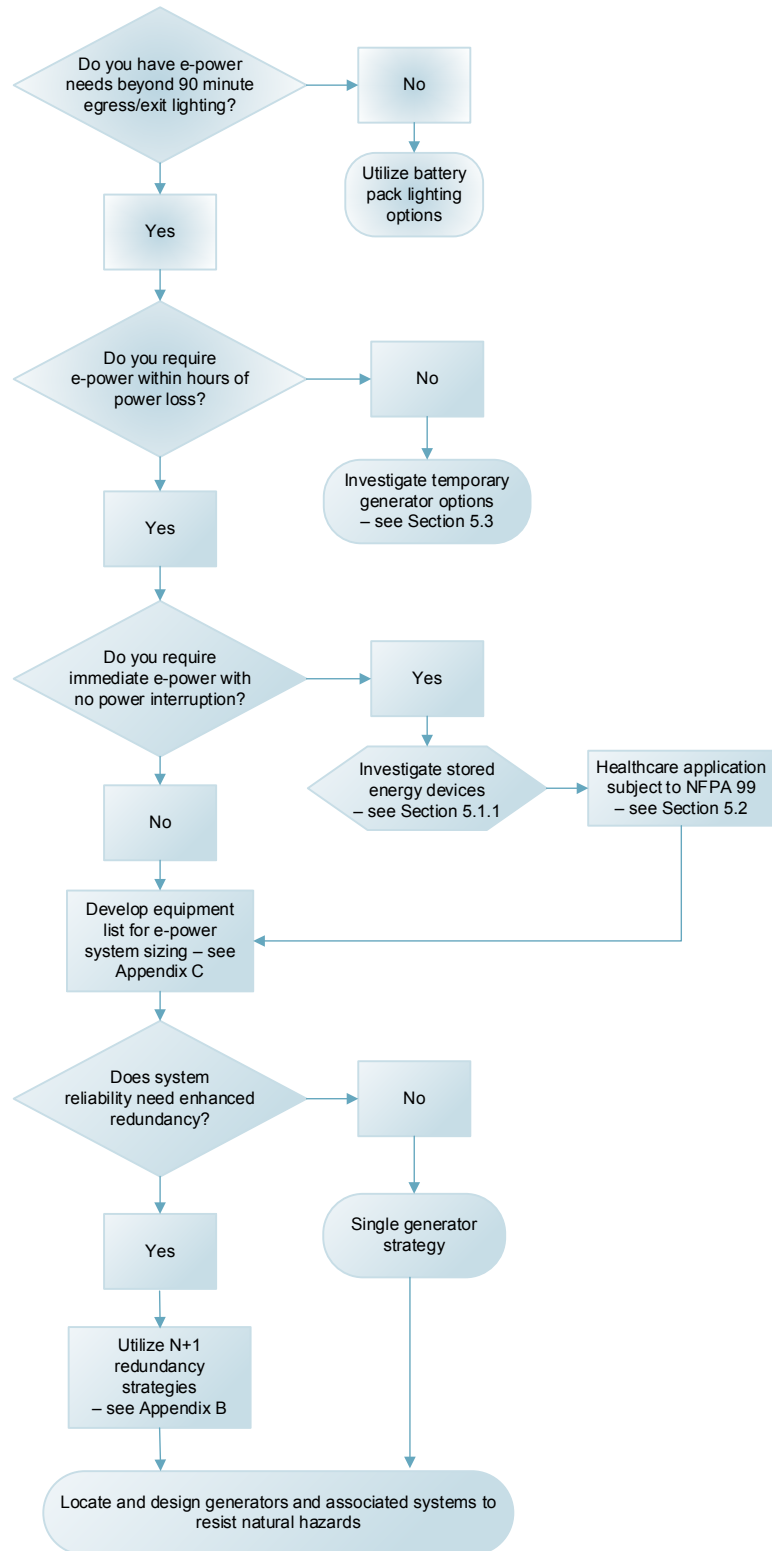


Figure 1-1 Flowchart illustrating example logic for determining emergency power needs and generator selection.

design, installation and operation, it is quite possible they may not operate as needed when such events occur. Note that the building codes, consensus standards, and design guides referenced in this document are the current editions of these nationally recognized publications. These publications are updated on regular publication cycles, which may occur after the publication date of this document. Thus, there may be newer editions than those noted in this document. Also, not all local authorities having jurisdiction over critical facilities adopt the latest standards. It is essential for detailed design of specific facilities that the currently applicable requirements be determined in consultation with the authorities having jurisdiction over the specific project.

Chapter 2

Natural Hazard Effects on Utilities and Building Systems

In this section, utility power transmission and distribution systems are described along with their observed vulnerabilities to natural hazards. The vulnerabilities of emergency power systems to natural hazards are also discussed.

Natural hazards addressed in this section include winter storms (freezing rain, snow and ice), high-wind events (hurricanes, tornadoes, and nor'easters), flooding (riverine and coastal), and earthquakes. Each of these hazards presents a unique set of design challenges for electrical transmission and distribution power systems.

2.1 Overview of Utility Power Transmission and Distribution Systems

Electrical power supplied by utilities is carried from the point of generation to the end user over two basic systems referred to as transmission and distribution (Figure 2-1). The transmission system is the backbone of the utility grid and carries power at the wholesale level. Utility power plants connect directly to this backbone to transport power to local distribution systems, and then on to the user. Transmission lines, which operate at very high voltages that range between 69,000 and 765,000 volts (69 to 765 kV), carry electricity to distribution sub-stations where it is dispersed to commercial, industrial, and residential customers. At boundaries of utility coverage areas the transmission lines connect to transmission systems of adjoining utilities.

When it is necessary to transport large blocks of electrical power over long distances, a highly specialized high voltage direct current (HVDC) transmission system is used. For example, HVDC transmission systems are used to transport bulk power from a large but remote power station, such as a hydro-electric plant at a dam, to a city.

2.1.1 Failures of Transmission Systems

Just like the inertia of a very large ocean going vessel moving at top speed, the collective inertial energy of the generators and turbines at each power

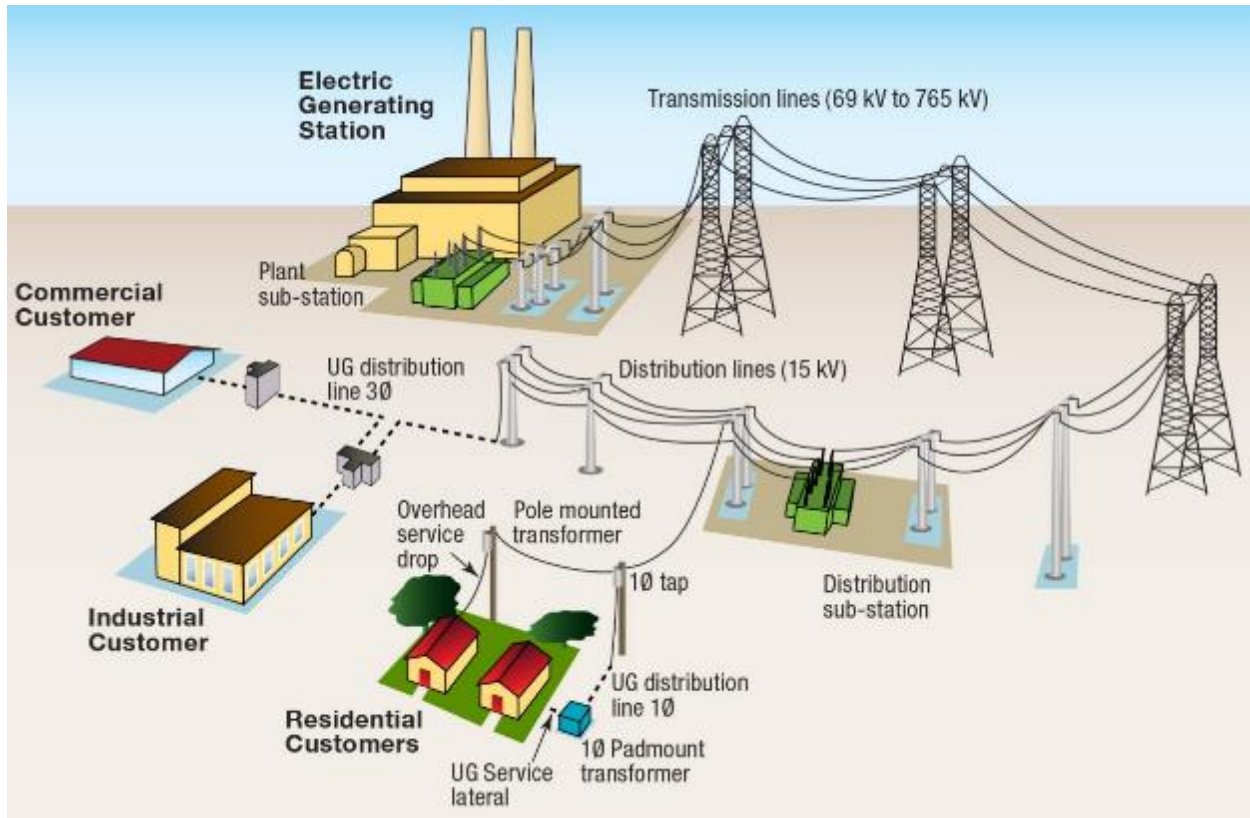


Figure 2-1 Illustration of a simplified utility transmission and distribution system. UG indicates underground; 3Ø indicates three-phase (typical for industrial customers); 1Ø indicates one-phase (typical for residential customers).

plant on the utility grid stabilizes the transmission system, due to the enormous net inertial energy of all the connected sources. As a result, the transmission system is able to absorb minor disturbances from either individual power plants or retail distribution load points within the utilities system with almost no impact to the overall system. Utilities also design levels of redundancy into their systems to allow for loss of major elements in their system due to failures or essential maintenance. Sub-station equipment at the transmission level typically costs millions of dollars and is available from a very small number of suppliers globally, and has long acquisition times. Therefore, utilities design their transmission systems for maximum reliability.

Failures of the transmission systems are unlikely, but have occurred. Rare natural hazard events that spread damage over a wide geographical area have caused failures to transmission systems. When a sufficient amount of damage accumulates, the overall transmission system goes down, taking with it neighboring utilities in a cascading sequence of failures. Automatic protective systems may trip generating stations offline and isolate ties to neighboring utilities as network operators race to protect their systems.

Recovering from such a massive outage takes days as power plants restart, reconnect the major system elements, and pick up loads from the local distribution systems.

When natural hazard damage to transmission systems occur over a multistate area, weeks may pass before power is completely restored. In some cases, the restoration of service may involve a substantial rebuilding of the utilities distribution systems over large areas. Since HVDC systems lack the redundancy of major utility transmission systems and usually span large distances, they are more vulnerable to extended outages due to natural disasters. Owners and facility managers of critical facilities that are dependent on HVDC transmission systems for power should carefully determine if these systems are sufficiently reliable during severe natural hazard effects or if alternate sources of onsite power are needed.

2.2 Winter Storms

Winter storms can bring freezing rain, sleet, snow, or a combination of the three. Snow and ice accumulation during winter storms places greater loads on structures, power lines, and trees. Winter storms can include any one or more of the following hazardous weather events:

- *Heavy Snowstorm*: Generally considered to include events with accumulations of 4 inches of snow or more in a 6-hour period, or 6 inches or more in a 12-hour period.
- *Sleet Storm*: Significant accumulations of solid pellets, which form from the freezing of raindrops or partially melted snowflakes, causing slippery surfaces that create hazards to pedestrians and motorists.
- *Ice Storm*: Significant accumulations of rain or drizzle freezing on objects, such as trees, power lines, and roadways, as it strikes them, causing slippery surfaces and damage from the weight of ice accumulation (Figure 2-2) and increased area exposed to wind loads.
- *Blizzard*: Wind velocity of 35 miles per hour (mph) or more, temperatures below freezing, and considerable blowing snow with visibility frequently below 1/4 mile prevailing over an extended period of time.
- *Severe Blizzard*: Wind velocity of 45 mph or higher, temperatures of 10 degrees Fahrenheit or lower, and a high density of blowing snow, with visibility frequently measured in feet, prevailing over an extended period time.



Figure 2-2 Damage to overhead distribution line caused by weight of ice accumulation (Nyether, 2014).

2.2.1 Effects of Winter Storms on Power Lines

Overhead Power Lines: Overhead power lines are directly affected by winter storms when snow or ice accumulate on them and the lines fail under the weight and when ice accretion (as shown in Figure 2-2), coupled with high winds, stress the conductors and their supports to their breaking point. The following modes of failure have been observed:

- Conductors, guys, and guy connectors fail when applied loads exceed their tensile strengths;
- Wooden structures supporting the lines typically fail when applied moments exceed their bending strengths; and
- Guy anchors (typically called foundation helical anchors) fail when loads exceed the amount of forces that the soils can resist and the guy anchors are pulled through the soils. Figure 2-3 depicts typical failure modes.

Overhead power lines can also be damaged when trees or tree limbs fail under the weight of snow or ice and take down sections of overhead lines when they fall. Generally, overhead power lines are designed only for wind and ice loading, not for the loads caused by fallen trees or limbs.

Repairs to damaged lines in adverse weather conditions are difficult, particularly when damage is widespread, utility crews have numerous repairs to complete, and when damage is in areas that are difficult to access. After a

severe event, customers may be without power for some time. With severe storms, outages that last two weeks or more are not uncommon.

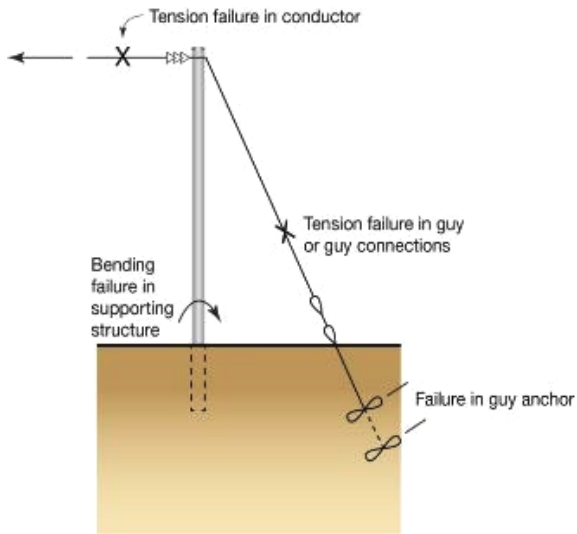


Figure 2-3 Typical failure modes of overhead power lines.

Underground Power Lines: Given the nature of winter storms, a power distribution system comprised primarily of underground power lines is usually not directly affected by winter storms. However, most underground lines are fed from overhead lines at some point, and because the overhead lines remain vulnerable to winter storms, underground systems typically experience some outages. Figure 2-4 shows a riser pole that supplies underground electrical distribution from an overhead line.



Figure 2-4 Riser pole of an underground electrical line supplied from an overhead line.

2.2.2 *Effects of Winter Storms on Building Systems*

Some mechanical, electrical, and plumbing (MEP) components, such as chillers, cooling towers, roof-mounted HVAC units, and pad-mounted transformers, are often placed outside of a building and exposed to the elements. Those components can be damaged by wind and ice loads or by falling ice or sliding snow. Wet piping systems can freeze during extremely cold periods, particularly those installed in temperate climates when exterior temperatures drop below design temperatures. Snow falling from roof levels can damage equipment. In addition, if communication towers, utility poles, or light standards are located within lay-down range and fail when exposed to ice and wind loading, they can damage equipment.

Lay-down hazards refer to hazards caused by toppling trees and structures, such as communication towers, antennas, and lighting poles.

Some components of MEP systems are placed within buildings that have structures and envelopes designed to resist code specified loads, offering protection from winter storms. However, even when placed within a building, winter storms and winter temperatures can adversely affect the operation of building systems. For example, maintaining indoor air quality requires introducing fresh outside air into a building. When exterior temperatures are extremely low, the cold outside air can freeze HVAC equipment like pre-heat coils when the cold outside air is brought into the building. Modern HVAC equipment employs thermostatic freeze protection for air intakes. However, the functionality of even protected units can be interrupted when exterior temperature drops below design temperatures and force HVAC equipment to function beyond its design parameters.

Another possible failure stems from the need for outside air for combustion and ventilation of emergency generators. Section 6.4 of NFPA 99, *Health Care Facilities Code* (NFPA, 2012a), requires fresh air intake louvers to be placed in generator rooms to provide unrestricted airflow to the generator. These louvers are required to fail in the open position to ensure that airflow is not restricted. However, louvers open to extremely low exterior temperatures can rapidly introduce large volumes of cold air into the building that can cause piping systems, domestic water systems, and fire suppression systems to freeze and fail.

Also, other systems, such as battery systems for starting emergency generators and controlling medium voltage electrical switchgear, are also susceptible to failing at extremely cold conditions.

2.2.3 *Case Study – Winter Storms of 2007*

In January 2007, a severe ice storm hit several states from Texas to New England, as well as some areas of southeastern Canada. The storm arrived in

three waves (Tulsa Tornado Tribune, 2007): The first wave hit Oklahoma on January 11 and was followed by a second wave in the southern United States that extended from Texas to the Carolinas from January 16 through January 18. A third wave from January 19 through January 24 hit the southern plains and Mid-Atlantic regions of the United States, as well as the Canadian provinces of Newfoundland and Labrador. This long-lasting and widespread event resulted in widespread power outages. The impacts in several areas are described below.

- *Oklahoma*: More than 100,000 customers without power, 63,000 of which were without power for more than one week (CNN, 2007). Overall damage in the State totaled approximately \$40 million.
- *Missouri and Illinois*: 330,000 customers in Missouri were without power at the peak of the storm, including 70,000 in Springfield, Missouri, alone. In east Missouri and central Illinois, over 110,000 customers were without power. Overall damage in Missouri totaled approximately \$353 million (Spellman, 2007).
- *Texas*: Approximately 60,000 customers were without power across the State between January 12 and 18 (USA Today, 2007).

2.3 High Winds

High winds occur in several types of storms, including hurricanes and tropical storms, tornadoes, and nor'easters. Each storm produces a unique set of weather conditions, but all have the potential for winds that exceed design wind speeds, particularly for overhead lines less than 60 feet tall designed to resist minimum loading requirements according to *National Electrical Safety Code* (IEEE, 2012).

- *Hurricane*: A system of spiraling winds converging with increasing speed toward the storm's center (the "eye" of the hurricane). These storms originate over warm ocean waters and can vary in diameter from 50 to 600 miles. A hurricane's forward movement (translational speed) can vary from approximately 5 mph to more than 25 mph. In addition to delivering extremely strong winds for several hours and moderately strong winds for a day or more, many hurricanes also bring very heavy rainfall and may occasionally spawn tornadoes. The Saffir-Simpson Hurricane Wind Scale is used to categorize hurricanes based on wind speed (See Table 2-1). Of all the storm types, hurricanes have the greatest potential to devastate a large geographical area and, hence, affect the largest sections of electrical lines and the greatest number of people.

Table 2-1 Saffir-Simpson Hurricane Wind Scale (NOAA, 2014a)

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 kt 119-153 km/h	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph 96-112 kt 178-208 km/h	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 kt 209-251 km/h	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Enhanced Fujita Scale
 The Enhanced Fujita Scale classifies tornado damage using ratings of EF0–EF5. The EF Scale is calibrated by engineers and meteorologist and is based on 28 different types of buildings and structures (called “damage indicators”) that are observed for different types of damage after a tornado event (roof removed, broken windows). The resulting EF ranking is based on detailed observations of tornado damage.

- *Tornado:* A rapidly rotating funnel of air extending toward the ground from a cumulonimbus cloud. Other hazards that accompany tornadoes include rainstorms, windstorms, large hail, and lightning. Tornadoes can occur at any time during the day or night, but are most frequent during late afternoon into early evening, the warmest hours of the day. The width of a tornado varies greatly, ranging from less than 100 feet to a mile. Some tornadoes never touch the ground and are short-lived, while others may touch the ground several times and cross several states. Nationwide, approximately 1,000 tornadoes are produced annually by severe thunderstorms. The intensity of a tornado is determined by the damage it causes according to the Enhanced Fujita (EF) scale (See Figure 2-5).
- *Northeaster (or nor’easter):* A cyclonic storm occurring off the east coast of North America. These winter weather events produce heavy snow and rain, high waves, and strong winds. A nor’easter gets its name from its general path along the Atlantic Coast toward the northeast and from the continuously strong northeasterly winds it creates ahead of the storm. Nor’easters can last for several days.

EF Rating	Wind Speeds	Expected Damage
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled. 
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged. 
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed. 
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark. 
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse. 
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped. 

Figure 2-5 Illustrated Enhanced Fujita scale (NOAA, 2014b).

2.3.1 Effects of High Winds on Power Lines

Overhead Power Lines: Overhead power lines are particularly vulnerable to high-wind events, and the damage can be acute and widespread because of the fragility of overhead components. Specifically, lines can be damaged by wind loading, fallen tree limbs and trees or other lay-down hazards, and failure of supporting power structures (e.g., poles, towers). Sub-station equipment can be damaged from wind loads, debris impact, and lay-down hazards. Figure 2-6 shows transmission lines that were damaged by tornadoes that struck Tuscaloosa, Alabama, in April 2011.

Underground Power Lines: A power distribution system comprising primarily underground power lines is not directly affected by high winds. However, because underground lines are fed from overhead lines at some point, and overhead sections are vulnerable to wind damage, underground systems often experience outages caused by high winds.

2.3.2 Effects of High Winds on Building Systems

Similar to the protection offered from winter storms, a properly designed building can also protect interior systems from high winds, particularly when the wind speeds do not exceed those that the building was designed to resist.



Figure 2-6 Tornado damage to transmission lines, Tuscaloosa, Alabama, April 2011 (FEMA, 2012a).

Building envelope refers to the exterior walls and roof of a structure.

Wind speeds that exceed design levels can penetrate the building envelope, damaging the critical interior system components, and may also weaken structural elements.

In properly designed and constructed buildings, envelope failures are more common than structural failures. Failures can result when wind loads exceed the ability of the envelope to resist those loads. Wall sheathing, roof sheathing, and the roof membrane can be torn, particularly near the edges and corners of a building where wind pressures are at their highest. Building envelope failures can also result from wind-borne debris. Wind-borne debris can be particularly damaging to glazing but can also damage non-glazed portions of the envelope. Damage can also result from water intrusion from wind-driven rain. Exterior equipment can also be damaged from lay-down hazards. FEMA 543 report, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings* (FEMA, 2007a), provides additional information on the effects of winds on buildings.

2.3.3 Case Study – 2011 Tornadoes in the Southeastern United States

From April 25 to 28, 2011, widespread and destructive tornadoes in the southeastern United States left many homeless, and many more without power or water service. This tornado outbreak produced approximately four tornadoes rated EF5 (FEMA, 2012a). For comparison, typically only one EF5-rated tornado occurs per year.

The tornados destroyed 300 transmission towers in northern Alabama. As a result, all incoming transmission 161 kV and 500 kV lines were lost and power was not fully restored for two weeks. A nuclear power plant in the area lost all offsite power briefly and was only able to regain one incoming circuit, forcing the plant to operate its onsite backup diesel generators for four days.

Nearly 260,000 customers lost service in the Tuscaloosa, Alabama, area as a result of the tornadoes (Robertson and Severson, 2011). Emergency operations centers (EOCs) in three of the counties and one 9-1-1 dispatch system in one county affected by this storm were without power. EOCs and 9-1-1 dispatch systems are in the greatest demand immediately following an event. When power is lost and no emergency power systems are in place, those systems and facilities can offer only limited functionality.

Figures 2-7 and 2-8 show the remains of a building housing the switchgear and emergency generator for a critical facility in Joplin, Missouri, that was struck by tornado winds during the outbreak and collapsed. The building utilized steel deck/steel roof structures and unreinforced masonry block walls, which were designed for normal (non-tornadic) design winds speeds.



Figure 2-7 Collapsed building housing switchgear and emergency generator after the Joplin, Missouri Tornado (FEMA, 2012a).

In addition to the customers in Alabama affected by the storms, the Tennessee Valley Authority lost more than 200 towers and other structures in the events, leaving nearly 700,000 customers across several states without power. For approximately 150,000 of these customers, power was restored

shortly after the storm. For the remaining, power was not restored for more than one week.



Figure 2-8 Steel deck/steel joist URM building housing the emergency generator and switchgear destroyed in the Joplin, Missouri Tornado (FEMA, 2012a).

2.3.4 Case Study – Derecho Winds – June 2012

The June 2012 “Derecho” winds damaged subtransmission and distribution systems over an 800-mile long path from Indiana to Virginia and Maryland with winds up to 100 mph. Damage was so extensive that it took up to ten days to restore power over this wide multi-state area.

2.3.5 Case Study – 2012 Superstorm Sandy in Long Island

Superstorm Sandy made landfall on October 29, 2012 near Brigantine, New Jersey. Sandy had been originally classified as a hurricane but the classification was revised to a post-tropical cyclone at landfall. Sandy impacted a 1,000 mile section of the United States with maximum sustained wind speeds estimated at 80 mph (FEMA, 2013a).

Damages from Sandy interrupted power to over 90% (1.1 million customers) of Long Island Power Authority’s customer base. In some areas power outages lasted 14 days. While damage occurred to some transmission lines, distribution line damages, particularly damages to the main three-phase feeder lines, accounted for most of the customer service interruptions.

2.4 Flooding

Flooding is the most common natural hazard in the United States, affecting more than 20,000 local jurisdictions and representing more than 70 percent of Presidential disaster declarations. Several evaluations have estimated that 7 to 10 percent of the Nation’s land area is subject to flooding. Some communities have very little flood risk, while others lie entirely within areas designated by FEMA as Special Flood Hazard Areas (SFHAs) on National Flood Insurance Program (NFIP) Flood Insurance Rate Maps (FIRMs) (Figure 2-9). The SFHA designate the land area covered by the floodwaters of the base flood. The SFHA is the area where the NFIP’s floodplain management regulations must be enforced and where the mandatory purchase of flood insurance applies.

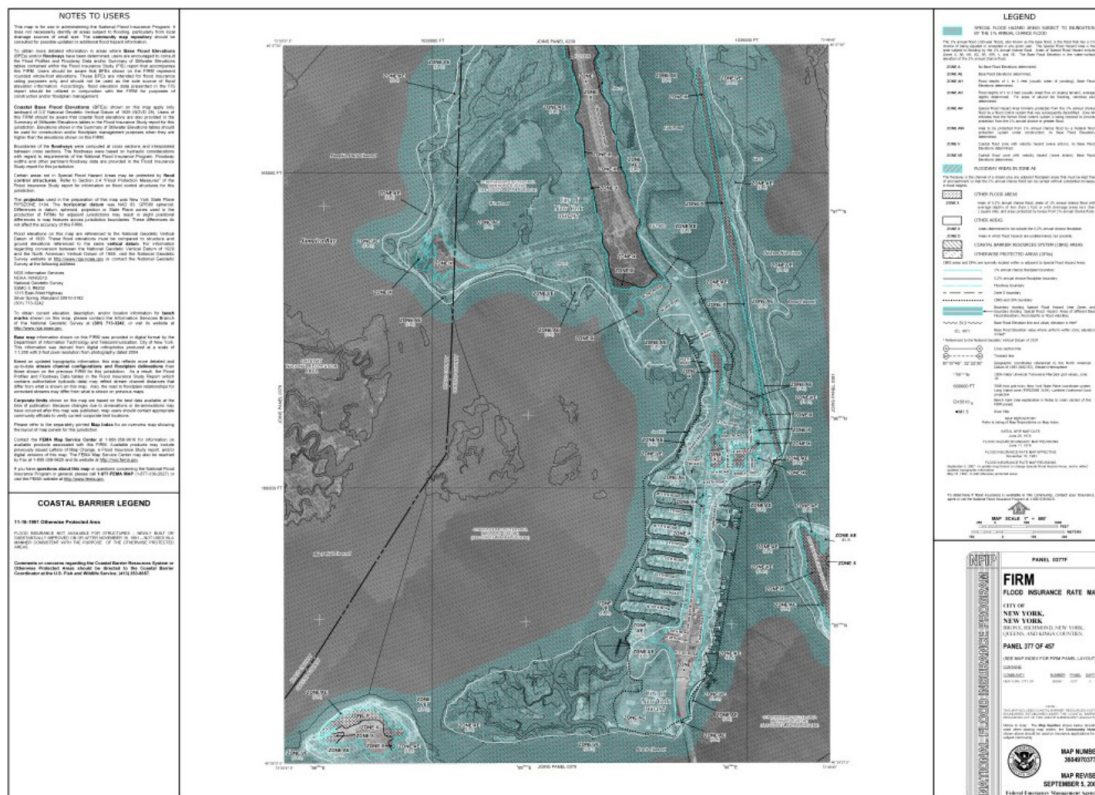


Figure 2-9 Example for map from FEMA Flood Map Service Center (MSC), the official public source for flood hazard information produced in support of the National Flood Insurance Program (NFIP). Available at <https://msc.fema.gov/portal> for panel number 3604970377F.

Flooding events are generally subcategorized as either riverine or coastal. Riverine flooding results when the volume of rainfall or runoff exceeds the capacity of waterway channels and spreads out over the adjacent land. Flooding depth, duration, and velocity are functions of many factors, including watershed size and slope, degree of upstream development, soil

types and nature of vegetation, topography, and characteristics of storms (or depth of snowpack and rate of melting).

Coastal flooding occurs along the Atlantic, Gulf, and Pacific coasts, and along the shores of the Great Lakes. Coastal flooding is influenced by storm surges associated with tropical cyclonic weather systems (hurricanes, tropical storms, tropical depressions, typhoons), extratropical systems (nor'easters and other large low-pressure systems), and tsunamis (surges induced by seismic activity). Coastal flooding is characterized by wind-driven waves.

The intensity of both riverine and coastal flooding events is measured by the depth and velocity of flood waters, the duration for which the waters remain above normal levels, and whether any debris damage, wave action, and erosion or scour occurred.

Another type of flooding that must be considered is flash flooding, which can occur in both coastal and inland areas. Flash flooding results when there is an extremely intense rainfall for a relatively short period of time that causes rapid rises in water levels and flooding.

2.4.1 Effects of Flooding on Power Lines

Overhead Power Lines: Overhead lines are generally not at a significant risk for flood damage. Energized power lines are elevated to prevent people from accidentally coming into contact with them, and the elevation protects much of an overhead electrical system from flood inundation damage. However, some portions of an overhead electrical system, most notably sub-stations, are not elevated. Such portions of an overhead system may be vulnerable to inundation, particularly when located in low-lying areas or in SFHAs.

Further, structures that support overhead lines can be damaged by moving floodwaters from scour, erosion, and hydrodynamic loads. They can also be damaged if they are struck by flood-borne debris. These risks are more common when overhead lines are routed along waterways or floodways.

Flooding can also damage overhead lines by saturating soils, which reduces the soil strength. When soils are saturated, structures like poles and ground anchors, which rely on soil strength to resist loads imposed on the overhead lines, can fail (Figure 2-10).

Even when not directly damaged by flooding, overhead electrical systems can be affected when floodwaters impede normal maintenance and operation activities. This is particularly true when electrical lines are routed through areas where long-duration floodwaters are slow to recede. If floodwaters are particularly deep (approximately 2 feet or so), equipment needed to repair

overhead electrical lines may not be able to access damaged sections. In those instances, outages may persist until all floodwaters recede and the lines can be accessed and repaired.



Figure 2-10 Overhead line damaged when flooding saturated soils and reduced strength of guy anchors (Deleon, 2014). Hydrodynamic loads from moving floodwaters may have contributed to failure.

Underground Power Lines: Underground portions of power lines are generally resistant to damage from freshwater flooding. Most underground equipment can resist immersion in freshwater, particularly for short durations. Immersion in saltwater is more problematic because of the electrical conductivity of saltwater.

However, aboveground components of underground power line systems, such as pad-mounted transformers, medium-voltage sectionalizing switches, and pad-mounted switchgear, are vulnerable to floods. Like the supporting structures for overhead lines, pad-mounted equipment can be damaged by hydrostatic forces, hydrodynamic forces, flood-borne debris impact, scour, and erosion. Submersion can also short-circuit energized pad-mounted equipment, particularly the older style live-front equipment.

2.4.2 Effects of Flooding on Building Systems

For many facilities, flood is the natural hazard that poses the greatest risk of damage to building systems that can prevent a facility from functioning. This is because major components of buildings systems, such as boilers, electrical service and distribution equipment, fuel tanks and fuel pumps, other pumps, and IT servers, are often located in the lowest level of a building, which is the level most vulnerable to flooding.

The risk of flood damage is particularly high for buildings that were constructed before flood risks were quantified. Some buildings constructed after flood risks were quantified but before 2006 when the *International Building Code* (IBC) first referenced ASCE 24-05, *Flood Resistant Design and Construction* (ASCE, 2005), are also at risk. ASCE 24-05 requires that building systems (referred to as “utilities” in that standard) either be elevated above design flood elevations or dry floodproofed.

Flooding can have disastrous effects on emergency power systems. Floodwater can damage or inundate fuel tanks that supply diesel generators, fuel oil pumping equipment, and emergency power distribution equipment, such as transfer switches, panels, and feeders. Many post-flood event investigations have shown that components of the emergency power and distribution system are often placed at lower elevations than components of the normal power distribution system and therefore are more vulnerable to flooding.

2.4.3 Case Studies

During Hurricane Katrina in 2005, generators serving one hospital were elevated but automatic transfer switches that transfer critical loads from normal (utility) power to emergency power when utility power is lost, were not elevated. The floodwaters rendered the transfer switches inoperable. Thus, even though the generators themselves could still function, they could not provide power to critical equipment.

During Hurricane Ike in 2008, many buildings on a large hospital campus flooded and could no longer provide critical services. In one building, however, the emergency generators and all their associated equipment were located on the second floor. While the storm surge flooded the first floor, the floodwaters did not reach the critical equipment so it remained operable during and after the flood.

During the floods in the mid-western United States in 2008, emergency generators for several law enforcement facilities were destroyed by flooding.

Figures 2-11 and 2-12 show one of those facilities, where the floodwaters fully inundated the generator and submerged two thirds of the diesel engine prime mover.



Figure 2-11 Emergency generator in an exterior enclosure in Cedar Rapid, Iowa, inundated during the 2010 Midwest floods.

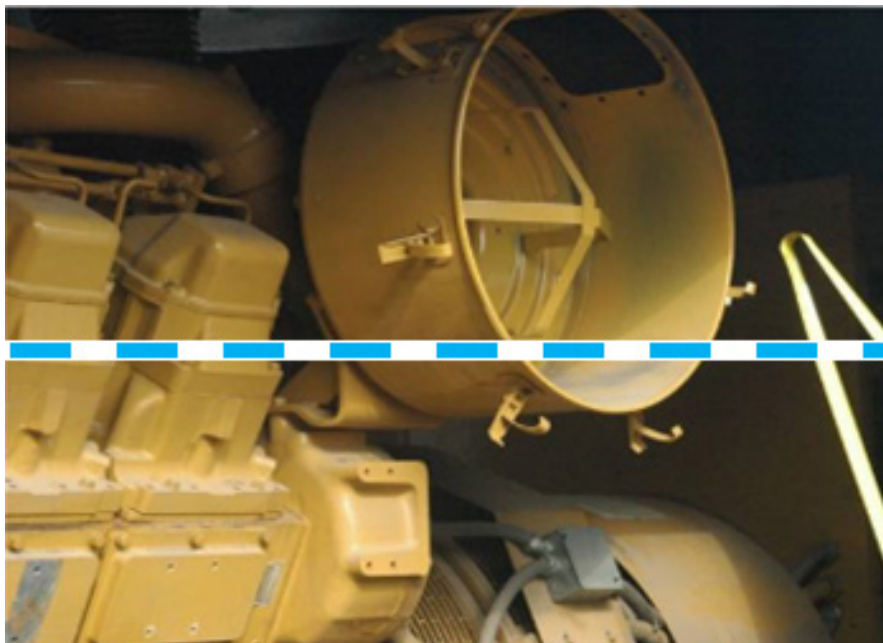


Figure 2-12 Interior view of the flooded emergency generator shown in Figure 2-11. The blue dashed horizontal line denotes the high watermark.

During Superstorm Sandy in 2012, a large hospital lost emergency power because the fuel pumps were immersed. Without emergency power, they were unable to operate the pumps used to fill storage tanks with potable

water. When the storage tanks drained, the hospital lost potable water and the patients and staff had to be evacuated.

2.5 Earthquakes

Earthquake ground motions are the result of sudden movements or fractures within the earth's crust. The earthquake generates waves that travel through the rocks and soil outward from the epicenter of the earthquake, the source of the shaking. Most earthquakes occur on known faults, weakened planes in the earth's crust that have generated earthquakes in the past, although not all earthquakes are associated with faulting. The propagation of waves through the earth's crust produces shaking of the earth's surface that can result in motions ranging from barely perceptible to violent shaking. The shaking effect or seismic ground motion diminishes with distance from the epicenter. The intensity of the ground motion at a given site is a function of the magnitude of the earthquake, the distance of from the earthquake source and site soil conditions. The magnitude of earthquake (most commonly referred to as the Richter Magnitude although other magnitudes are often used) provides an indication of the energy released. If the intensity of shaking is high, most structures will sustain some damage and some may collapse. The most commonly used shaking intensity scale is the Modified Mercalli Earthquake Intensity scale, which rates the level of ground motion at a site based on perceptions and observed damage (See Table 2-2).

The criteria used to evaluate the effects of ground motion on the built environment include displacement demands, i.e., deformations of the ground and structures, and acceleration demands, i.e., inertial forces generated by the shaking motion. For building code purposes, nonstructural components are considered tolerant of these damaging demands when they have a seismic capacity greater than the seismic demand.

In addition to the ground shaking, earthquakes can cause geological hazards, including surface fault ruptures, soil liquefaction, landslides, tsunamis, and seiches. Soil liquefaction occurs when ground shaking temporarily changes saturated loose granular soils and sands from a solid to a liquid. Liquefaction occurs mainly at sites with high water tables near rivers, lakes, and bays. Earthquake shaking can trigger landslides on slopes that otherwise appear stable, and generate large waves in both oceans (tsunamis) and lakes (seiches). Both the ground shaking and subsequent geological hazards have the potential to disrupt or destroy power distribution lines and building systems.

Table 2-2 Description of Modified Mercalli Intensity Levels (USGS, 2014)

Level	Description
I	Not felt except by a very few under especially favorable conditions.
II	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

2.5.1 Effects of Earthquakes on Power Lines and Sub-stations

Overhead Power Lines: Many structures supporting overhead transmission lines, such as poles and towers, are cantilevered (fixed to the soil at the base and free to translate at the top). If seismic loads are not considered during design, overhead power lines can be damaged or destroyed during an earthquake, particularly when they are near the epicenter and subjected to intense shaking. Even if designed to withstand seismic motion, overhead electrical lines may suffer outages when energized conductors experience excessive movement and come into contact with grounded surfaces or other energized conductors. Ground faults and phase-to-phase faults can cause protective devices, such as circuit breakers, fuses, or reclosers, to trigger and de-energize the line. Fortunately, when structures are not damaged, the outages are usually of short duration.

Underground Power Lines: Widespread damage to belowground components of electrical systems due to earthquakes are not common, however, duct banks and their connections to manholes and hand holes, can

Extensive loss of belowground utilities was experienced in the second Christchurch, New Zealand, earthquake due to liquefaction.

be damaged when they cross fault lines or are located in areas that suffer ground failures due to geologic hazards, such as liquefaction. Since failures in underground systems take much longer to locate and repair than failures in overhead systems, extended outages can result unless power can be re-routed around damaged sections.

Sub-stations: Postearthquake assessment reports, particularly those gathered following the 1971 San Fernando, California, earthquake, indicate that most of the damage to electrical transmission systems is to above ground equipment. Equipment in sub-stations, such as transformers, insulating bushings, surge arrestors, and switching equipment, are particularly vulnerable. Of particular significance was the loss of the Sylmar high voltage direct current converter station (See Figure 2-13), which impacted utility power capacity for months. Many sub-station components require long lead times to replace, and although most utilities maintain spare parts, a seismic event can cause damage so widespread that available spares are depleted, resulting in extended power outages.



Figure 2-13 Sylmar high voltage direct current converter station damaged in the 1971 San Fernando earthquake (NOAA/NGDC, E.V. Leyendecker, U.S. Geological Survey).

2.5.2 Effects of Earthquakes on Building Systems

Buildings respond dynamically to earthquake ground motion. The shaking intensity may increase by a factor of up to three at the roof level of a multistory building, compared to the shaking intensity at the ground level. In order to keep the cost of the structure within reason, building codes have long taken advantage of the ability of structural elements to deform

inelastically without breaking in response to the earthquake, which dissipates enormous amounts of energy. The advantage of this approach is that even in seismically active areas the increase in cost of the structure is to provide earthquake resistance to only a small fraction of the overall structural system. The disadvantage is that many elements of the structure will sustain damage. If the structure were to be designed to remain elastic for earthquake loads (elements of the structure remain undamaged) the cost of the structural system would be impractical for many buildings.

Everything permanently anchored to the structure of a building but not part of the building structural system is referred to as a nonstructural component. These items must be able to tolerate the combined demands of the earthquake-induced accelerations and building displacements. This means that nonstructural elements, such as cladding and windows, that are more likely to be damaged by the relative displacements of support points must be able to tolerate the displacements experienced by the building. Meanwhile, nonstructural elements that are more likely to be damaged by seismic inertial forces must be able to withstand the seismic acceleration demands.

Components mounted on vibration isolation springs or elastic mounts, such as generators and chillers, will experience significantly higher acceleration demands, and must be designed accordingly. Where flexible components, such as piping systems, are connected to relatively rigid components, the connections must be able to accommodate the relative displacements between the components (see Figure 2-14 for an example connection detail). Electrical and mechanical equipment that is vulnerable to acceleration demands should be well anchored (see example in Figure 2-15) and may require shake table testing to establish that they have the capacity to resist seismic shaking and remain operable.

Observations after earthquakes consistently demonstrate that when nonstructural elements are properly attached to the building structure they perform well. Experience has also shown that if the entire MEP system is to survive, all of the interconnecting electrical raceways, process piping, and ductwork must be properly braced and installed.

Earthquakes commonly damage architectural building elements, such as unreinforced masonry parapets, which can result in falling debris that can destroy exposed utilities and MEP equipment (See Figure 2-16), rendering the facility incapable of being quickly restored to operation. It is highly recommended that a rapid visual screening of an entire facility be conducted by qualified experts to identify vulnerable building components that threaten the seismic performance of essential MEP systems and, provide recommended actions to mitigate the hazards. The methodology set forth in

FEMA P-154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* (FEMA, 2014a), can be used for this screening.

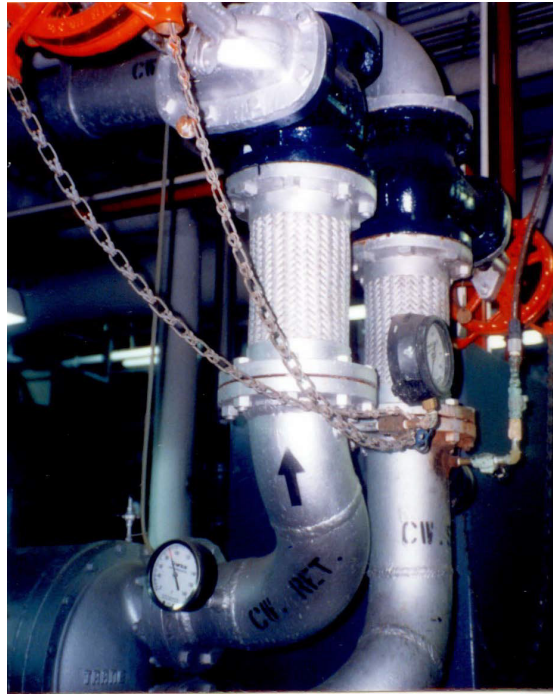


Figure 2-14 Example of a connection which accommodates relative displacements (FEMA, 2012b).



Figure 2-15 Well-anchored equipment (FEMA, 2012b).



Figure 2-16 Falling debris from security wall and parapet damaged cooling equipment for servers resulting in the data center going off line in the 2011 Haiti earthquake.

For critical facilities where the tolerance for loss of operation and extended downtime is very low, base isolation of the entire building may provide a solution. Base isolated buildings are constructed on top of special bearings (see Figure 2-17) that isolate the structure from earthquake ground motions, greatly reducing the intensity of shaking above the isolators. Flexible connections for all building utilities (see Figure 2-18) allow the isolators to laterally displace several feet without damage. Base isolation is not limited to buildings, and is beginning to be used to protect sub-station equipment. In recent large earthquakes in Chile and Japan, there are many examples of base isolated structures surviving the shaking with little or no damage.

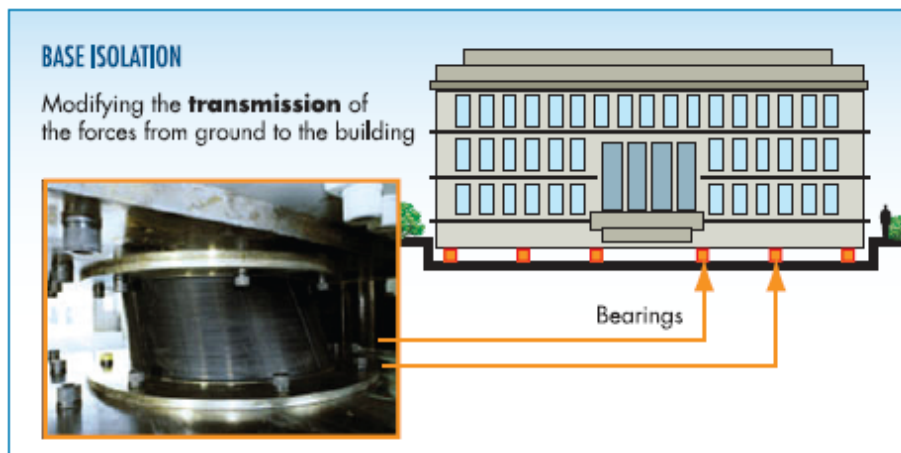


Figure 2-17 Example of seismic isolation bearings and typical installation location (FEMA, 2007b).



Figure 2-18 Typical flexible utility connections in base isolated building.

2.5.3 Case Study – 1994 Northridge Earthquake

The magnitude-6.7 Northridge earthquake occurred at 4:31 a.m. PST on January 17, 1994, near Los Angeles, California. It generated one of the highest ground accelerations recorded in a North American city (1.8 g) and shaking was felt as far away as Las Vegas, Nevada. The earthquake resulted in 60 deaths and over 7,000 injuries and produced an estimated \$20 billion in damages.

The Northridge earthquake induced soil liquefaction that damaged high-voltage transformers and the foundations of transmission-line towers. The resulting outage affected much of the greater Los Angeles area. Power was 93% restored in 24 hours, and 99.5% restored in 72 hours. Total direct losses suffered by utilities include \$138 million for the Los Angeles Department of Water and Power and \$45 million for Southern California Edison (ASCE, 1995).

The Northridge earthquake also triggered power outages as far away as British Columbia, Montana, Wyoming, Idaho, Oregon, and Washington. The longest disruption in those areas as a result of the earthquake was three hours. This event demonstrates that earthquakes can cause interruptions in electrical networks well outside of the geographical location of the actual event, with implications for regions hundreds of miles away.

Emergency power systems in hospitals and emergency operations centers located in the affected area generally performed well following the Northridge earthquake. Many hospitals were forced to function for a week on emergency power because of the intermittent interruptions of utility power. However, 26 healthcare facilities did report issues with their emergency generators. Common problems documented by Office of Statewide Health Planning and Development are listed in Table 2-3.

Table 2-3 Summary of Problems Related to Emergency Generators in the 1994 Northridge Earthquake (Office of Statewide Health Planning and Development, 1995)

Problem	Number of Facilities
Generator failed to operate	6
Damaged generator anchors	2
Generator equipment damaged	1
Generator anchors missing	7
Unanchored batteries	8
Unanchored fuel tank	5
Unbraced exhaust stack	2

The following are specific reasons some emergency generators in healthcare facilities failed to operate following the Northridge earthquake (Office of Statewide Health Planning and Development, 1995):

- Berkeley West Convalescent Hospital, Santa Monica: Offsite natural gas fuel supply was interrupted
- Chandler Convalescent Hospital, North Hollywood: Underground fuel tank was damaged
- Crescent Bay Convalescent Hospital, Santa Monica: Generator could not be started due to battery failure

2.6 Other Events

In addition to natural hazards listed above, there are other events that have recently resulted in loss of power.

2.6.1 Case Study – Solar Storms of 1989 and 2012

In March of 1989 a solar storm (also called a geomagnetic disturbance (GMD) or solar flare) led to the collapse of the Hydro-Quebec transmission systems. Six million customers were without power for nine hours before the system could be restored to normal operation (Hadhazy, 2009).

A much larger solar storm developed in 2012 but narrowly missed the earth (Liu et al., 2014). This event was estimated to have been twice the sized of the largest known solar storm to strike the earth in 1859 that disrupted telegraph operation over the entire earth. If this event had occurred nine days earlier, it would have struck earth and the damage to earth-orbiting satellites, ground-based communications, and bulk power transmission systems could have taken as long as four years to fully restore.

2.6.2 Case Study – Northeast Blackout of 2003

On August 14, 2003, the largest blackout to affect North America occurred. At its peak, over 50 million customers were without power for up to two days. Large sections of the northeast and Canada were affected, including New York City, which lost power (NERC, 2004). The event has been extensively studied and many conclusions and recommendations have been developed to help prevent its recurrence.

The problem originated when a generating unit in Northern Ohio went offline. This occurred at 1:31 PM while an operator was making voltage adjustments. This relatively common occurrence would typically be easily remedied by drawing additional power from other online sources to make up for the production loss of a single generator. However, 45 minutes after the generating unit tripped offline, the alarm and logging system that monitored a large portion of the network failed. Over the next two hours, the operators, without the help of an alarm and logging system, were not able to detect actual conditions in the grid and were unable to take appropriate actions to manage it. As loads shifted to account for loss of generating units or the loss of transmission lines, portions of the network became overloaded; heated electrical lines sagged and came in contact with inadequately trimmed trees; circuit breakers protecting those transmission lines tripped and the rapid reduction in electrical demand that resulted when transmission lines tripped offline caused generators to overspeed and automatically trip offline in an attempt at self-preservation.

At its peak, 531 generating units at 263 plants shut down, interrupting about 65,000 MW of load. The event resulted from no natural hazard and few, if any, physical damages affecting the grid.

Chapter 3

Disaster Management and Operations Continuity

A strategy must be developed to protect assets, limit damage and injuries, restore operations, and coordinate the resources that are needed to effectively respond to a disaster event. Without effective and continuous planning, the impact of a disaster on a business, a community, or a region will be truly catastrophic. The goal of this chapter is to provide guidance on instituting a disaster planning process.

In the United States, the foundation for planning for disasters is the National Preparedness Goal (FEMA, 2014b):

“A secure and resilient nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk.”

The goal can be applied at the federal, state and local government levels, and within the private sector. Without the commitment of the business and industrial sectors to effective disaster planning, the “whole community” as described in the National Preparedness Goal will never be secure and resilient. Disaster preparedness is not the sole responsibility of government; facility owners and operators have an obligation as part of the “whole community” to plan and prepare for catastrophic events. The social needs of a community are supported by buildings and utilities that also need to remain functional. In particular, critical facilities need to define performance goals for desired levels of functionality for immediate, short term, and long term recovery plans.

Consequences from natural catastrophes continue to be on the rise primarily because of increased development in vulnerable areas. Furthermore, the dependence on technology increases a facility’s vulnerability to power-supply interruptions, loss of data, and the loss of ability to manage operations with internet-dependent remote stations. Supply chains (including energy resources) are especially vulnerable to disasters which means that the event could be thousands of miles away. Without a disaster plan in place, a facility could suffer irreversible harm from events both near and far.

The failure to be able to react effectively to a disaster will have a significant negative impact on the financial performance and reputation of a company.

3.1 Critical Facilities

All organizations should have disaster plans, but it is essential for the owners and operators of critical facilities and infrastructure to plan for catastrophic events. Performance goals for recovery plans should address the role of a critical facility within the community.

NIPP 2013: Partnering for Critical Infrastructure Security and Resilience (Department of Homeland Security, 2013) defines critical infrastructure as “systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.” While this definition focuses on critical infrastructure of national importance, state and local governments have identified assets in their respective jurisdictions that they consider to be critical infrastructure. A critical facility can be defined as a facility that is essential for the delivery of vital services or protection of a community. Critical facilities include, but are not limited to, hospitals, emergency operations centers, fire and police stations, schools, and primary utility and transportation facilities (FEMA, 2013).

Approximately 85% of all critical infrastructure in the United States is privately owned (Department of Homeland Security, 2014). Accordingly, the private sector plays a key role in planning efforts to protect and increase the resilience of critical infrastructure.

Table 1604.5 in Section 1604.5 of the 2012 *International Building Code* (ICC, 2012) provides Risk Category classifications for buildings and other structures that address minimum design criteria based on the facility type and their role in many communities (Table 3-1). These Risk Category classifications are aligned with ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), which provides specific design criteria for each Risk Category type. While previous editions of ASCE/SEI 7 contained a detailed list of what facilities were to be included in each Risk Category, the 2010 edition of ASCE/SEI 7 moved the descriptions of Risk Categories to the commentary and removed specific occupancy requirements. This was because it was felt that specific population number thresholds, such as more than 250 students in schools for younger children, may lead to incomplete consideration of all the factors that a decision maker must consider. The ASCE/SEI 7-10 approach supports the identification of the appropriate risk category for a facility based on the guidance that considers the impact of facility failure on the community. However, as a minimum, the facilities must at least satisfy IBC Section 1604.5.

Table 3-1 Risk Category of Buildings and Other Structures (IBC 2012, Table 1604.5)

Risk Category	Nature of Occupancy
I	<p>Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to:</p> <ul style="list-style-type: none"> • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	<p>Buildings and other structures except those listed in Risk Categories I, III, and IV.</p>
III	<p>Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to:</p> <ul style="list-style-type: none"> • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing elementary school, secondary school or day care facilities with an occupant load greater than 250. • Buildings and other structures containing adult education facilities, such as colleges and universities, with an occupant load greater than 500. • Group I-2 occupancies with an occupant load of 50 or more resident care recipients but not having surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load great than 5,000¹. • Power-generating stations, water treatment facilities for potable water, waste water treatment facilities, and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: <ul style="list-style-type: none"> ○ Exceed maximum allowable quantities per control area as given in [2012 IBC] Table 307.1 (1) or 307.1 (2) or per outdoor control area in accordance with the <i>International Fire Code</i>; and ○ Are sufficient to pose a threat to the public if released².
IV	<p>Buildings and other structures designated as essential facilities, including but not limited to:</p> <ul style="list-style-type: none"> • Group I-2 occupancies having surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations, and emergency vehicle garages. • Designated earthquake, hurricane, or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities requires for emergency response. • Power-generating stations and other public utility facilities requires as emergency backup facilities for Risk Category IV structures. • Building and other structures containing quantities of highly toxic materials that: <ul style="list-style-type: none"> ○ Exceed maximum allowable quantities per control area as given in [2012 IBC] Table 307.1 (2) or per outdoor control area in accordance with the <i>International Fire Code</i>; and ○ Are sufficient to pose a threat to the public if released². • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

¹ For purposes of occupant load calculation, occupancies required by [2012 IBC] Table 1004.1.2 to use gross floor area calculations shall be permitted to use net floor areas to determine the total occupant load.

² Where approved by the building officials, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic, or explosive materials is permitted to be reduced to Risk Category II, provided it can be demonstrated by a hazard assessment in accordance with Section 1.5.3 of ASCE 7 that release of the toxic, highly toxic, or explosive materials is not sufficient to pose a threat to the public.

Selection of a risk category implies specific minimum design load levels and associated design criteria that are to be used for design. Risk Categories III and IV address critical facilities and in their definitions, note the emphasis on the intended use of the facility and exposed population. For instance, a school is often classified as a Risk Category III facility but if it will be used as a shelter, as a minimum, that section of the facility should be classified as a Risk Category IV facility.

3.1.1 Determining if a Facility is Critical

The process to determine whether your facility is critical is straightforward.

- Has a federal, state, or local government agency sent a notification that the facility has been classified as critical?
- Does the facility fit Risk Categories III or IV as defined in Section 1604.5 of the IBC?

It is important to note that the definitions of “critical infrastructure” and “critical facilities” will vary depending on who is asking the question. The federal government focuses on critical infrastructure that will have a national impact. At the local level, however, even small facilities or structures can be considered critical. For example, the local gas station that provides fuel for volunteer firefighters and health care workers could be defined as “critical.” A local school or college facility could be used for evacuation sheltering, and nursing homes and assisted living facilities are often included in disaster surge capacity planning for acute care hospitals.

3.2 Emergency Preparedness and Business Continuity Planning

Planning that is based on an effective risk assessment process is the most effective way to mitigate the impact of a crisis on the financial health, reputation and long-term recovery of an organization. Fortunately, it is not necessary to re-invent the wheel; a great deal of reliable guidance is available to guide facility owners/operators in the development of disaster management and business continuity programs and plans.

3.2.1 PS-Prep

The U.S. Department of Homeland Security (DHS) has established a voluntary private sector preparedness accreditation and certification program known as PS-Prep. The program provides free, on-line resources that are designed to improve the preparedness of private-sector and not-for-profit organizations to consensus-based preparedness standards and best practices. The program focuses on the ability of organizations to identify and

implement steps to address business continuity, organizational resilience, and emergency and disaster management. DHS provides recognition for those entities that certify to the adopted preparedness standards.

As a voluntary program, PS-Prep serves as a resource for private and non-profit entities interested in instituting a comprehensive business continuity management system. PS-Prep offers organizations the opportunity to develop and maintain certification to nationally recognized and respected approaches to resilience and preparedness. See <http://www.fema.gov/about-ps-preptm>.

Three standards have been adopted by DHS under the PS-Prep Program:

- NFPA 1600, *Standard on Disaster/Emergency Management Continuity Programs* (NFPA, 2013b);
- ASIS SPC. 1-2009, *Organizational Resilience: Security, Preparedness, and Continuity Management Systems - Requirements with Guidance for Use* (ASIS, 2009); and
- ISO 22301:2012, *Societal Security—Business Continuity Management Systems—Requirements* (ISO, 2012).

Of these, the mostly commonly used is NFPA 1600, which establishes a common set of criteria for “all hazards” disaster/emergency management and business continuity programs. The standard provides the fundamental criteria to develop, implement, assess, and maintain activities for prevention, mitigation, preparedness, continuity, and recovery. The standard applies to private entities as well as public, not-for-profit, and nongovernmental organizations.

Because there is no one size fits all emergency plan, NFPA 1600 enables an organization to customize a disaster management and business continuity program to its own specific needs and circumstances. The key elements of a program established in accordance with NFPA 1600 include the following:

- **Program Management.** In order to be successful, a disaster management/business continuity program must have the full commitment of the leadership of the organization. Commitment is demonstrated by a willingness to provide the necessary resources and by ensuring that the program is reviewed, evaluated and updated as necessary. A program coordinator is responsible for overall development, implementation and administration, with support from a program committee selected from key functional areas within the organization as well as external representatives, such as the local



Chapter 12 of NFPA 99, *Health Care Facilities Code* (NFPA, 2012a), establishes the criteria for developing emergency management programs in new and existing health care facilities. NFPA 1600 is the foundation for this chapter.

emergency management agency, fire service, or hospital.

Documentation of program activities is essential, including the establishment of an executive policy that specifies the vision, mission statement, roles, responsibilities, and enabling authority. In addition, the costs and resources needed for the program should be clearly established.

- **Planning.** The planning and design process establishes the basis for the implementation of a plan that is customized to meet the specific risks and threats that are faced by the organization. During the planning process, three important evaluations should be performed:
 - *Risk Assessment:* This is a process that identifies the natural hazards, human-caused events, and technology-caused events that are likely to be encountered. The vulnerability of people, property, operations, the environment and the entity itself should be assessed. In addition, the impact of the identified hazards should be evaluated. Risk assessment also examines the potential cascading effects of regional, national, or international incidents.
 - *Business Impact Analysis.* This is an evaluation of the potential impact resulting from the interruption or disruption of individual functions, processes, and applications. This analysis includes a review of critical functions, processes, infrastructure, systems and applications and is used in the development of recovery strategies.
 - *Resource Needs Assessment.* This is based on the findings of the risk assessment and the business impact analysis. This assessment determines what human resources, equipment, training, facilities, funding, expert knowledge, materials, technology, information and intelligence will be needed to plan for, respond to, and recover from an event.
- **Implementation.** The implementation phase of NFPA 1600 describes the various plans and support functions that should be developed.
 - *Prevention:* Development of a strategy that prevents an incident that could threaten life, property or the environment.
 - *Mitigation:* Development of a strategy that includes measures to be taken to limit or control the consequences, extent or severity of an incident that cannot be prevented.
 - *Crisis Communications and Public Information:* Development of a plan and procedures to disseminate information and establish a crisis communications capability.

- *Warning, Notifications, and Communications*: Development of a reliable, redundant, and interoperable warning, notification, and communications capability.
- *Operational Procedures*: Development of operational procedures to support the program, including response, recovery, continuity, and mitigation.
- *Incident Management*: Development of an incident management system (IMS) to direct, coordinate, and control response, continuity and recovery operations.
- *Emergency Operations Centers (EOCs)*: Establishment of a primary and alternate EOC, either physical or virtual, to manage response, continuity and recovery operations.
- *Emergency Operations/Response Plan*: Development of a plan that defines responsibilities for carrying out specific actions during an emergency.
- *Business Continuity and Recovery*: Development of a plan that includes recovery strategies to maintain critical or time-sensitive functions and processes.
- *Employee Assistance and Support*: Development of a strategy to support employees and their families during an emergency.
- **Training and Education.** A training and education curriculum should be developed with the goal of creating awareness and enhancing the knowledge, skills, and abilities required to implement, support, and maintain the program. The program should include training on the incident management system (IMS) that is used by the organization during an event.
- **Testing and Exercises.** Testing and exercises are a critical component of any disaster preparedness and business continuity program. Exercises are designed to evaluate program plans, procedures and capabilities, and they provide a standardized methodology to practice procedures and interact with other entities in a controlled setting. They should be conducted on a regular basis so that required preparedness and response capabilities can be established and maintained. The FEMA Emergency Management Institute offers a free, on-line self-study course, IS-139 *Exercise Design*. This course is designed as an introduction to the fundamentals of exercise design and to help design and conduct a small functional exercise for at the attendee's organization. See <http://training.fema.gov/IS/>

- **Program Maintenance and Improvement.** The program should be evaluated on a regularly scheduled basis to ensure that the policies, performance objectives, and program implementation continue to be effective. Reviews should also be conducted based on post-incident analyses, lessons learned, and operational performance, or when internal or external conditions change that might impact the effectiveness of the program. Corrective action should be taken whenever deficiencies have been identified.

3.2.2 Issues to be Considered in the Disaster Preparedness Plan

The after-action reports and lessons-learned from Hurricane Sandy and other recent catastrophic events have identified a number of common deficiencies related to the loss of emergency power that should be addressed in the disaster preparedness and business continuity plan. Some examples of areas that should be included are as follows:

- Fuel delivery/fuel availability for standby power sources. A risk assessment study should determine the expected length of time needed to continue the operation of emergency generators. The plan should address such issues as:
 - Reliable on-site storage of fuel. It is important to note that there are requirements in codes and standards that must be complied with in order to ensure that the fuel storage system is not an undue fire or explosion hazard,
 - Contracts with fuel suppliers, including delivery,
 - Alternative fuel sources,
 - Capabilities and authorization to deliver fuel and critical maintenance supplies (e.g., filters) within restricted disaster zones, and
 - Generator maintenance, testing, and repair (both preventive and during the event).
- Coordination/input from government agencies (state and local emergency management, fire service, law enforcement). The organization should establish a working relationship with local, regional or state emergency response authorities. The authorities can provide guidance and input during the development and implementation of the planning process and will be a critical resource during the disaster event. Emergency managers and first responders should be invited to participate in the development of the facility's emergency operations and business

continuity plan. They can also be a valuable resource during drills and exercises that test the effectiveness of the plan. The facility plan should embrace key elements of the local emergency response plan to ensure proper coordination of critical activities, such as warnings, notifications, incident management, and evacuation. Authorizations for personnel to remain within or re-enter evacuation zones because of critical facility needs should be determined as part of the pre-event planning process.

- Situational awareness is critical to the success of response and recovery operations. The organization should utilize technologies to monitor on-site conditions, alerts and advisories from government agencies, weather conditions and other potential threats, the status of employees and their families, and the condition of supply chains and other resources. An internal and external communication plan is critically important and should include the ability to monitor social media and control rumors.
- Redundancy of operational facilities, data systems, remote operation (SCADA) systems and supply chains may be the most cost-effective strategy for emergency preparedness and business continuity.
- Food and water supplies are a critical aspect of emergency planning. Supermarkets typically have only a two- to three-day supply of food in stock and their resources are quickly depleted by the general population. Critical facility operators should plan for alternative sources for food and water.
- The delivery of fuel and essential maintenance supplies (such as filters) within restricted disaster zones should be pre-approved by public safety officials in order to ensure access to the facility.
- A system must be developed that provides important operational information to key officials (up the chain of command).
- Staffing needs must be part of the operational plan, including the need for relief personnel for an extended incident.
- Implementation timing. Some equipment or personnel may not be immediately in place for an emergency. Plans must consider the timing necessary to place important elements into operation.

Chapter 4

Identifying Emergency Power Needs in Critical Facilities

A key element in the design of an emergency power system in a critical facility is to understand and determine the appropriate power needs in the event of a loss of utility power. The emergency power needs must be identified and assessed based on code requirements and on the essential services that must be maintained in order for the facility to maintain its critical functions. Emergency power needs in critical facilities fall into two broad categories:

- *Emergency power needs established by building code and standards.*
The three primary sets of such requirements for the purposes of this document are contained in the 2012 *International Building Code* (IBC; ICC, 2012), NFPA 101, *Life Safety Code* (NFPA, 2012b), and NFPA 99, *Health Care Facility Code* (NFPA, 2012a).
- *Emergency power needs required to support the functionality of the critical facility.* Following a hazardous event, critical facilities must continue to operate albeit at some reduced level of operations and select equipment must be powered to support those operations. The operation of non-essential systems and equipment often constitutes a desired use that can only be met when cost effective emergency power is available. Emergency power should be limited to that required for essential services that must be maintained for the facility to function as required or as expected following a loss of utility power.

After code requirements and emergency power needs for functionality have been identified and demands have been limited to essential systems only, a detailed analysis of electrical power needs beyond code minimums should be conducted.

The following sections describe the identification of emergency power needs for each of the categories and needed duration of emergency power, where applicable. Section 4.3 provides a comparison of the emergency power requirements and needs along with a discussion of how needs must be limited in order to keep the critical functions of the facility operational.

4.1 Requirements for Emergency Power Specified by Building Codes and Standards

A critical facility that is fully compliant with the minimum building code requirements may not be able to operate as needed or provide the expected services when power is lost.

Building codes and their referenced engineering and technical standards govern the design and construction of most new buildings. They also often apply to major renovations, repairs, or substantial improvements to existing buildings. The purpose of a building code is to establish the minimum acceptable design and construction requirements necessary for protecting the public's health, safety, and welfare. Structural integrity (for both gravity loads and loads imposed by external hazards, such as wind, earthquake, and flooding), building envelope integrity, fire and smoke resistance, life-safety considerations, sanitation, and recently, energy efficiency, are some of the issues addressed by contemporary building codes and engineering standards.

Some portions of the building code consider the importance of critical facilities performing their essential functions after extreme natural hazards by adding significantly greater requirements for resistance to some natural hazards. However, code requirements for emergency power are generally not directed at continued operation of the facility. They generally focus on emergency power required to allow people to evacuate a building quickly and safely. Appendix A provides a detailed description of requirements in widely adopted codes and referenced standards for emergency power in critical facilities.

While the intent of the *International Building Code* includes "other hazards," emergency power requirements for most buildings are based on fire as the primary hazard with additional requirements in areas where flooding, high winds, or earthquakes are to be expected. Fire and life-safety requirements are generally based on a 90-minute to two-hour window of time to provide egress of building occupants and protection of first-responders for expected durations of fire-fighting or evacuation taking place.

The code generally does not require provision of enough emergency power to allow buildings to remain functional during a power outage except for systems such as elevators in high-rise buildings or large assembly spaces where the conveying systems may be used by first responders to fight a fire or evacuate building occupants. The code-required 90-minutes of emergency power (excluding elevator power) can be supplied by batteries or other stored energy devices; in most cases, emergency generators are not required to satisfy code duration requirements. For the small percentage of facilities where onsite generators are needed to satisfy code requirements, the generators typically only supply the minimum loads required for life safety. Life-safety loads include fire alarm and annunciation systems, smoke control

systems, emergency and egress lighting, and conveyance systems that are required for egress. In most cases, onsite generators required by code have neither the power generation capacity nor the fuel supply that a facility needs to remain functional during prolonged power outages.

4.2 Emergency Power Requirements

This section discusses the conduct of a needs assessment to identify how long a critical facility must remain functional while using emergency power and what equipment needs to be operational to allow the facility to function.

An example of the type of planning that is necessary based on anticipated need and use is that for Emergency Operations Centers. These facilities, which are designed for disaster response, are often provided with emergency power sufficient for 100% operation of the entire facility with onsite fuel capacity, allowing full-scale operations for a week or more. This duration is not code mandated, but the result of a careful review of when the center will be most needed and for how long.

The functional duration identified affects both what loads are supplied and how they are supplied. Typically, the most significant effect on the emergency power requirements of a facility is its location in relation to climatic conditions and whether air conditioning equipment needs to be supplied from an emergency power system. Additionally, the purpose of the critical facility plays a significant role in determining emergency power needs. For example, if the facility only needs to remain functional for several hours (as in a tornado safe room), equipment required for heating or food preparation does not need to be powered. In contrast, heating or food preparation equipment would need a power supply in a host shelter facility used after an ice storm, major flood event or a hurricane expected to operate for several days or weeks.

The duration that a facility must remain functional depends on the use of the facility, which is typically easy to identify, and on the length of time utility power will be out, which is difficult to quantify in advance of an event. The duration of a power outage can range from a few minutes to several weeks (though it is rare for utility power to be unavailable for longer than one month since mutual assistance allows most utilities to rebuild damaged utilities as soon as practical).

There are no hard and fast guidelines for assessing the emergency power needs of a critical facility. The following approach identifies four levels of operation, each with a different duration and need for supply of emergency power:

- Level IA operations are based on the minimum code requirements from the *International Building Code*. These operations include electrical loads that are required for short-duration use only, such as fire alarm equipment, exit and egress lighting, and starting and operating fire pumps (when present), as well as the minimum lighting equipment required to allow occupants to move throughout the facility. The expected duration of these operations is typically 90 minutes. The purpose of these requirements is to allow safe egress or occupant relocation from a building in an emergency and to provide a minimal level of illumination or equipment operations for first-responders to assist in evacuation of the building. With only a few limited exceptions for certain building uses or types, minimum requirements of the IBC are not intended to provide operational levels of illumination or power to allow continued use of the facility. For the code required 90-minute duration, power supplies are sized for the code-mandated loads and will likely not allow anywhere near normal operations of the facility. Therefore, significant additional emergency power provisions are likely necessary for continued operation of facilities beyond those provided for Level IA operations.
- Level IB operations are defined as those required for critical health care facilities per NFPA 99, *Health Care Facilities Code*. Appendix A provides a detailed discussion of these requirements. These requirements are meant to apply in conjunction with the requirements of Level IA and do not supplant Level IA requirements. Although written specifically to apply to health care facilities, the principles of power distribution and requirements for selection of systems to be operated on emergency power provide good guidance for all types of critical facilities. Note that even when the criteria of Level IB are met, there may be unpowered operations based on facility-specific needs. Significant additional emergency power provisions are still likely to be necessary for continued operation of facilities beyond those provided for Level IB operations.
- Level II operations are defined as facilities that must remain operational for more than just the duration of emergency occupant evacuation, but do not require air conditioning. Level II operations include electrical loads for Level IA (and Level IB for healthcare facilities) in addition to powering heating and ventilation systems and food preparation and preservation equipment. Additionally, operational systems, such as computers and other radios, may need to be accommodated in this level as well, since the power demands of these systems will likely exceed the capacity of the battery or rechargeable (UPS) systems based on anticipated duration of operations. Longer term Level II operations may

come into play when a facility needs to be used for longer than 12 hours or when the facility provides food for occupants. Loads supplied under Level II operations may not be adequate under extreme weather conditions, particularly during periods of extreme high exterior temperatures or high humidity. In addition, it is important that limits be assessed for areas that may not need heating, ventilation, food service, or other operational support such as computing or communications. During the planning process, it is imperative to ascertain the anticipated duration of operations and to identify which operations can be curtailed during an emergency to reduce demand on the critical facility support mechanisms.

- Level III operations are defined as facilities that must remain operational and must provide air conditioning in at least some areas. Level III operations include electrical loads required for both Levels I and II in addition to equipment required for air conditioning. Level III capacities are appropriate for long-duration use during periods of high exterior temperatures or high humidity levels when air conditioning is needed for a facility to remain functional. It is important that limits be assessed for areas that may not need air conditioning or other mechanical systems, food service, or other support systems. It may be possible to curtail certain operations during an emergency to reduce demand on the critical facility support mechanisms and achieve Level II operations.

4.3 Assessing Emergency Power Needs in Detail

Assessing emergency power needs requires determining what equipment must operate for a facility to function during a power outage. The design and construction and the mechanical and electrical layouts of critical facilities vary greatly, so it is not possible to provide specific guidance and requirements for all facilities. However, the following general discussion will help facility managers identify which equipment should have backup emergency power.

While detailed code requirements are based on the occupancy classification (e.g., a hospital) and size (e.g., a high-rise) of the facility, the basic requirements for each system are fairly consistent. Table 4-1 presents a simplified checklist of systems that should be considered, in the general order as the levels of operation discussed in the previous section. Many of the items noted in Table 4-1 may not be required by the code, but must be considered in the design of the emergency electrical systems for critical facilities. Some items in the table may have varying requirements for different occupancies or building types. Examples of these are elevators, lighting, ventilation, water supply, sanitary sewer pumps, sump pumps, and

air conditioning. In addition, Table 4-1 does not take into account that engineering requirements for certain life-safety systems and structural systems will vary by location. Thus, design requirements for earthquake-prone areas may vary from those in high-wind areas or in flood zones.

Table 4-1 is intended to give guidance on options for providing emergency power over the range of levels that facility operators may elect to pursue. Column for Level IA describes the basic code requirements from the *International Building Code*. The third column (Level IB) describes the requirements from NFPA 99 *Health Care Facilities Code*. NFPA 99 *Health Care Facilities Code* defines three branches within an emergency distribution system: (1) equipment branch; (2) critical branch; and (3) life-safety branch. Of these, the life-safety branch is the most important and given the highest priority. Each of the systems with code mandates can be presumed to have the phrase “where required by the code for the intended use” appended to them. Appendix A provides further discussion of the requirements contained in various codes and referenced standards.

It is assumed here that the basic code-mandated functions in both parts of Level I will continue to be maintained for whatever duration the facility remains in operation. The fourth column lists the requirements for Level II operations. The fifth column shows Level III operations that are discretionary uses, including the other levels, but with the addition of air conditioning loads.

The following subsections provide guidance on the emergency power needs of life-safety equipment, fire pumps, lighting, mechanical equipment (heating, ventilation, plumbing, and air conditioning), food preparation facilities, and other items that are commonly found in critical facilities.

4.3.1 Life-Safety Equipment

Although life-safety equipment is designed primarily to allow occupants to safely exit a building, it is just as important when people must stay in a building during an extended power outage. Code-required fire and smoke alarm systems, exit signage, and egress lighting must remain powered while the facility is in use. Figure 4-1 depicts life-safety equipment required by the *International Building Code* for several occupancy classifications.

Table 4-1 Elements Potentially Requiring Emergency Power

Duration of Operation	Level IA Basic IBC Requirements	Level IB NFPA 99 Requirement for Critical Healthcare Facilities	Level II Discretionary Uses Without Air Conditioning	Level III Discretionary Uses With Air Conditioning
	90-Minute Minimum Duration	Per NFPA 99	As Needed	As Needed
Exit signs	●	● Life-Safety Branch	○	○
Means of egress illumination	● (code minimum is for emergency egress only)	● Life-Safety Branch	○ ■ (if continued use is desired, requires discretionary increase)	○ (same scope as Level II)
Elevator car lighting and communications	●	● Life-Safety Branch	○	○
Emergency alarm systems	●	● Life-Safety Branch	○	○
Emergency communications systems	●	● Life-Safety Branch	○	○
Electrically powered fire pumps and jockey pumps	● (if required)	● Life-Safety Branch	○	○
Power operated doors and locks	● (if required for occupant security or egress)	● Life-Safety Branch	○	○
Generator set location lighting and local power	●	● Life-Safety Branch	○	○
Ventilation of smokeproof enclosures	● (if ventilation is required by code)	● Equipment Branch	○ (if code requirement, continue operations)	○ (if code requirement, continue operations)

Legend:

- Required for code minimum durations
- Discretionary increase if continued operation of system is required for continued occupancy
- Discretionary increase, added at the indicated level
- Air conditioning systems to be provided with emergency power

Table 4-1 Elements Potentially Requiring Emergency Power (Continued)

	Level IA Basic IBC Requirements	Level IB NFPA99 Requirement for Critical Healthcare Facilities	Level II Discretionary Uses Without Air Conditioning	Level III Discretionary Uses With Air Conditioning
Duration of Operation	90-Minute Minimum Duration	Per NFPA 99	As Needed	As Needed
Smoke control system	● (if smoke control is required by code)	● Equipment Branch	○ (if code requirement, continue operations)	○ (if code requirement, continue operations)
Horizontally sliding electric doors	● (if doors are used for egress)	● Life-Safety Branch	○ (if code requirement, continue operations)	○ (if code requirement, continue operations)
Elevator operations	● (only in occupancies requiring fire service use for elevators, e.g., high-rise, atrium)	● Equipment Branch	○ (if code requirement, continue operations) ■ (emergency power will be required for short term operational uses)	○ (if code requirement, continue operations) ■ (same scope as Level II)
Platform lifts	● (if used for accessibility)		○ (if code requirement, continue operations) ■ (if provided for operational reasons, verify number of lifts to be powered)	○ (if code requirement, continue operations) ■ (same scope as Level II)
Task lighting outside of egress paths		● Critical Branch	■ (extent as required outside of egress paths for short term critical operations)	■ (same scope as Level II)

Legend:

- Required for code minimum durations
- Discretionary increase if continued operation of system is required for continued occupancy
- Discretionary increase, added at the indicated level
- Air conditioning systems to be provided with emergency power

Table 4-1 Elements Potentially Requiring Emergency Power (Continued)

	Level IA Basic IBC Requirements	Level IB NFPA 99 Requirement for Critical Healthcare Facilities	Level II Discretionary Uses Without Air Conditioning	Level III Discretionary Uses With Air Conditioning
Duration of Operation	90-Minute Minimum Duration	Per NFPA 99	As Needed	As Needed
Sump pumps		● Equipment Branch	□ (if required to prevent damaging water accumulation)	□ (same scope as Level II)
Ventilation for identified operational areas		● Equipment Branch	□ (for minimum number of ventilation fans at areas required for critical operations)	□ (same scope as Level II)
Telephone equipment		● Critical Branch	□ (Can use short term UPS for charging, mobile phone charging systems or central switchboard)	□ (same scope as Level II)
Sewage lift pumps			□	□ (same scope as Level II)
Water system booster pumps			□ (if required for adequate system pressure in critical areas)	□ (same scope as Level II)
Domestic hot water circulator pumps			□ (if low power use and serving areas required for critical operations)	□ (same scope as Level II)

Legend:

- Required for code minimum durations
- Discretionary increase if continued operation of system is required for continued occupancy
- Discretionary increase, added at the indicated level
- Air conditioning systems to be provided with emergency power

Table 4-1 Elements Potentially Requiring Emergency Power (Continued)

	Level IA Basic IBC Requirements	Level IB NFPA 99 Requirement for Critical Healthcare Facilities	Level II Discretionary Uses Without Air Conditioning	Level III Discretionary Uses With Air Conditioning
Duration of Operation	90-Minute Minimum Duration	Per NFPA 99	As Needed	As Needed
Heating equipment (eg. boilers, fans, air handling units, pumps and controls)		● Equipment Branch (select areas)	○ ■ (applies to all equipment serving critical areas and operations)	■ (same scope as Level II)
EMCS (Environmental Management and Control Systems)			■ (as required for long term operations)	■ (same scope as Level II)
Computer equipment			■ (provide UPS to supply critical systems during generator start up)	■ (same scope as Level II)
Network servers and routers			■ (provide UPS to supply critical systems during generator start up)	■ (same scope as Level II)
Food preservation equipment refrigeration			■ (if required to maintain critical functions for on-site personnel)	■ (same scope as Level II)
Food preparation and service equipment			■ (if required to maintain critical functions for on-site personnel)	■ (same scope as Level II)
Intercom systems			mobile phones should suffice for short term	■ (same scope as Level II)

Legend:

- Required for code minimum durations
- Discretionary increase if continued operation of system is required for continued occupancy
- Discretionary increase, added at the indicated level
- Air conditioning systems to be provided with emergency power

Table 4-1 Elements Potentially Requiring Emergency Power (Continued)

	Level IA Basic IBC Requirements	Level IB NFPA 99 Requirement for Critical Healthcare Facilities	Level II Discretionary Uses Without Air Conditioning	Level III Discretionary Uses With Air Conditioning
Duration of Operation	90-Minute Minimum Duration	Per NFPA 99	As Needed	As Needed
Central clock systems			□ (if critical to facility function)	□ (same scope as Level II)
Radio communication equipment			□ (if critical to facility function)	□ (same scope as Level II)
Air conditioning systems				■ (if required for long-term operations. Determine extent of facility to be air- conditioned. See Section 4.3 for discussion of system choices)

Legend:

- Required for code minimum durations
- Discretionary increase if continued operation of system is required for continued occupancy
- Discretionary increase, added at the indicated level
- Air conditioning systems to be provided with emergency power



Figure 4-1 Life-safety equipment: fire alarm control panel (top) and exit signage (bottom).

4.3.2 Fire Pumps

Fire pumps or sprinkler system pumps boost water system pressures and ensure adequate water flow to sprinklers for fire suppression. Unlike most other electrical equipment, fire pumps, including the motors, electrical feeders, and pump controls, are exempted by NFPA 70, *National Electrical Code* (NFPA, 2014), from many of the code requirements protecting electrical equipment from damage. The assumption is that, in the event of a fire, a fire pump must continue to operate until the fire is suppressed, even if it damages or destroys the pump and associated equipment. Having a fire pump shut down to protect itself may save the pump, but would increase risks to the occupants and the facility. Figure 4-2 shows a typical fire pump controller.



Figure 4-2 Typical fire pump controller.

4.3.2.1 Emergency Power Recommendations for Fire Pumps

Although fire pumps are critical for protecting occupants, they are only rarely powered from emergency generators. A common arrangement is to power the fire pump “upstream of the main.” That is, the fire pump is connected to the electrical service equipment on the distribution line side of the main electrical service disconnect. This allows fire fighters to shut off power to a building in order to reduce potential for injury during manual fire suppression without sacrificing the fire suppression provided by the sprinkler system. When connected upstream of the main, fire pumps receive power from the electrical utility. If normal utility power is not available, the fire pumps cannot operate and the occupants are not fully protected. Because of this, fire pumps should be provided with emergency power.

NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection* (NFPA, 2013d), only requires auxiliary power for the following two circumstances: (1) when the primary power supply is deemed unreliable; and (2) when pumps are located in high-rise buildings where the height of the building is above the pumping capabilities of the fire department apparatus. Although NFPA 20 does not require auxiliary power for every fire pump installation, it does require auxiliary power for fire pumps in critical facilities that must remain operational when the primary power supply is not reliable (i.e., not available when needed).

Another component of a fire suppression system is a jockey pump (Figure 4-3). Jockey pumps maintain sprinkler system pressures. In fire suppression

systems that contain fire pumps, jockey pumps can prevent inadvertent operation of the fire pump itself. Jockey pumps are typically much smaller than fire pumps, often operating at only a fraction of a horsepower. Jockey pumps are only required to have backup power if they are installed in a healthcare facility. In other facilities, they are not usually supplied by the emergency system.



Figure 4-3 A typical jockey pump.

4.3.3 Lighting

Code-required emergency lighting ensures that egress paths have the minimum amount of illumination needed to exit a building. Most codes specify an average initial illumination of 1 foot-candle (fc) with a minimum illumination of 0.1 fc at the end of the 90-minute duration. By comparison, office areas are typically illuminated to 50 to 100 fc and corridors at 15 fc. Egress lighting must be provided for more than 90 minutes if the facility is to be occupied. The level of lighting in the egress system may be fairly low, but that level will not be adequate for operational spaces.

4.3.3.1 Emergency Power Recommendations for Lighting

For most facilities, lighting egress paths with a relatively low level of illumination is not adequate for operations during prolonged power outages.

Illumination levels of 30 percent to 50 percent of the normal lighting levels are more likely to be appropriate for most areas to function at a base level. For areas where visual tasks are demanding, full lighting levels should be provided.

4.3.4 Mechanical Equipment

Mechanical equipment heats and cools a building's interior and also provides fresh air for ventilation. Nearly all heating and cooling equipment requires electrical power to operate, so an emergency power supply must be provided if heating and cooling may be needed during a prolonged utility power outage. Mechanical equipment described in this section includes heating, air conditioning, and electrical components of plumbing systems that provide water service and sanitary waste removal.

4.3.4.1 Heating

In cold climates, heating is required for both occupant comfort and freeze protection. For occupant comfort, only critical areas need to be heated but for freeze protection, all areas vulnerable to freezing need to be heated. Minimum temperatures may also need to be maintained for piping systems that contain condensable gases.

Emergency Power Recommendations for Heating

Emergency power should be provided to all heating equipment serving critical areas and operations whenever the heating equipment is needed to maintain adequate interior temperatures for occupant comfort or freeze protection. The following is a list of major heating system components that may need to be supplied from emergency power sources.

- *Forced air systems:* With forced air systems, emergency power needs to be supplied to the furnaces, distribution system, and where in use, supply and exhaust fans and the heating, ventilation, and air conditioning (HVAC) controls.
- *Hydronic systems:* With hydronic systems, emergency power needs to be supplied to the boilers, circulating pumps, HVAC controls and, where used, supply and exhaust fans. Power may also need to be provided for fuel oil pumps and for equipment that chemically treats boiler make-up water.
- *Combined systems:* With combined hydronic and force air systems, emergency power is needed for the boilers, circulating pumps, air handling units, and HVAC controls. Emergency power to ventilation systems and make-up water systems may also be needed.

4.3.4.2 Air Conditioning

Air conditioning systems mechanically cool the interiors of buildings. Most air conditioning systems also dehumidify because when air is cooled below its dew point, condensation forms on cooling coils and removes water vapor from the conditioned air.

Air conditioning is provided by forced air systems where supply air is cooled and distributed to the conditioned areas and warmer air is returned to the air conditioning units to be re-cooled and dehumidified. There are two common systems, described below.

DX systems consist of two components: (1) an interior evaporator coil and fan unit; and (2) an exterior compressor and condensing unit. In DX systems, refrigerants undergo a reversible phase change (condensation and evaporation) and the heat required for evaporation is drawn from the interior of a building and released to the exterior when the refrigerant condenses. Figure 4-4 shows roof mounted DX units that provide air-conditioning to a school.

In chilled water systems, water is cooled and circulated through air handling units where it absorbs heat from interior spaces. Slightly warmer chilled water often is returned to be re-chilled. Several styles of chillers exist. Most contain compressors and condensers and use a refrigerant cycle (like DX units) where the refrigerant goes through a phase change between vapor and liquid, and in doing so transfers heat to the refrigerant from the chilled water. Heat is removed from the chiller condensers by air cooling or by evaporating water in cooling towers. Pumps circulate chilled water from the chiller unit to the air handlers and returns the warmer water for re-cooling.

Figure 4-5 shows two major components of a chilled water air conditioning system that uses a cooling tower. Figure 4-6 shows an integral air-cooled chiller unit that does not require a cooling tower.

Emergency Power Recommendations for Air Conditioning

Air conditioning systems require a lot of electricity to operate, and when added to emergency power systems, these loads significantly increase the required generator capacity. Because of this, adding air conditioning loads to an emergency power system should be done judiciously. No more air conditioning loads than what are truly needed for operations should be connected to an emergency power source.

Air conditioning may be required for occupant comfort, humidity control, and equipment protection, particularly temperature sensitive electronic

equipment. Air conditioning may also be needed to protect stored temperature sensitive materials like many pharmaceuticals.



Figure 4-4 Roof-top mounted DX HVAC units.



Figure 4-5 Water-cooled chiller (left) with cooling tower (right).

For a DX system to function, power is required to supply the interior evaporator coil and fan unit, the exterior compressor and condensing unit, and all control equipment. In a DX system, the exterior unit draws the majority of the system's total electrical load. The interior unit, which contains distribution fan(s), draws much less power.



Figure 4-6 Air-cooled chiller.

For a chilled water system to function, the power is required to supply the interior air handling units, chilled water circulating pumps, chillers, control equipment, and where used, evaporative cooling tower pumps and fans.

4.3.4.3 Plumbing Systems

The electrical load requirements for plumbing systems are generally less than other mechanical systems. However, if emergency power is not provided, plumbing systems may not operate during a prolonged power outage.

Many facilities that are built below grade have sump pumps to prevent site water from seeping into below-grade areas. Those pumps can range from only a fraction of a horsepower to about 5 horsepower. Figure 4-7 shows a below-grade sump. The sump pump is located within the sump.

Sanitary lift pumps are needed when the municipal sanitary sewer lines are at a higher elevation than the building's sanitary sewer piping. While lift pumps are normally placed in sumps that have some storage capacity, the storage capacity is usually limited.

For taller buildings where water service pressure is not sufficient to lift water to upper floors, domestic water booster pumps are often used. Figure 4-8 shows a typical domestic water booster pump station.

Commercial domestic hot water systems often have a circulator pump to prevent hot water from cooling in the piping when hot water usage is low. Those pumps are typically driven by small motors that do not add significant

loads. The blue pumps in Figure 4-9 are circulator pumps for a domestic hot water system.



Figure 4-7 Sump cover; pump is within the sump.



Figure 4-8 Domestic water booster pumps.

Emergency Power Recommendations for Plumbing Systems

Pumps associated with plumbing systems do not typically add significant loads to an emergency power source, but not providing emergency power to them can reduce the functionality of a critical facility that is without power for a significant period of time.



Figure 4-9 Domestic hot water circulator pumps.

Sump pumps do not add significant loads to an emergency power source and should be supplied with emergency power to prevent flooding in below-grade areas.

Since the storage capacity associated with sanitary lift pumps is usually limited, the pumps must receive emergency power if a facility needs to operate during power outages that extend a few hours or more.

If upper floors will be occupied during extended power outages, booster pumps should be supplied by emergency sources to retain water pressure on upper floors. Water pressures on lower floors are less vulnerable to pressure loss than are fixtures on higher floors.

Although domestic water systems will still operate during power outages, hot water may be wasted while users of the system wait for cooled water to work its way through hot water piping unless the circulator pumps are supplied with emergency power. Circulator pumps require relatively little power to operate and should be supplied when emergency power is provided.

4.3.4.4 Food Preparation and Preservation

For critical facilities that must prepare food for occupants, food preparation equipment must be provided with emergency power. Unless the power outages are of short duration, food preservation equipment must also be provided with emergency power. Figures 4-10 and 4-11 show food preparation and preservation equipment for a typical commercial kitchen.



Figure 4-10 Commercial kitchen for critical facility that provides food for occupants.

Emergency Power Recommendations for Food Preparation and Preservation

Electrical requirements for food preparation vary greatly. “All electric” kitchens require more electrical power than kitchens where cooking equipment operates on natural gas or liquid propane. Even with gas-fired kitchens, power is needed for igniters, gas solenoid valves, and controls.

Food preservation equipment, such as walk-in freezers, walk-in refrigerators, and smaller chest or upright refrigerators and freezers need emergency power to maintain temperatures during a prolonged power outage.

Even with all-electric kitchens, the total power requirements for food preparation and preservation are typically a lot less than power requirements for building heat and certainly less than for air conditioning. Power requirements for kitchens are typically easy to accommodate by using generators sized to supply mechanical systems.

4.3.5 Other Building Systems

The following list identifies other building systems that may need to operate if the facility is to be used during a prolonged power outage:

- ECMS (Environmental Control and Management Systems)
- Telephone equipment
- Network servers and routers
- Computer equipment



Figure 4-11 Large commercial refrigerator and freezer in commercial kitchen.

- Intercom systems
- Central clock systems
- Radio and telephone communication equipment
- Mechanical alarm systems (like sump or lift pump monitoring equipment)
- Elevators and conveyance systems
- Medical equipment in health care facilities (detailed information is provided in Appendix A)

Chapter 5

Emergency Power Sources and Systems

This chapter provides an overview of the elements of common emergency power generation systems. Power sources are devices that create (or store) electricity and ancillary equipment needed for power production or storage. The sources include generators, fuel supplies, stored energy devices, and controls for operating them. Power distribution systems deliver power from the power source to the critical equipment. The distribution system consists of switchgear or switchboards, feeders, distribution panels, panelboards, protective devices, and transfer switches. Many aspects of an emergency power distribution system are similar to normal power distribution systems. The difference is that emergency power distribution systems can receive power from either the normal power source or from an emergency power source.

Many factors come into play for an emergency power system to function for a sustained periods. Therefore, a holistic approach, as discussed in Chapter 6 to the entire system is needed to ensure emergency power is functional and reliably available when needed.

5.1 Emergency Power Sources

In general, critical facilities employ two common methods of providing emergency power: (1) stored energy devices, such as battery and inverter systems; and (2) standby/emergency generators. Nearly all non-residential facilities possess some stored energy devices (typically those for emergency and egress lighting) and many facilities have both stored energy devices and emergency generators.

Both methods of supplying emergency power must be properly sized, properly installed, and properly maintained to be reliable and effective. Fuel-fired generators must be supplied with appropriate fuel from a reliable source.

5.1.1 *Stored Energy Devices*

Stored energy devices are frequently used to provide short-duration emergency power. When used alone, they often are sized to supply loads for

90 minutes, the duration required by NFPA 101, *Life Safety Code* (NFPA, 2012b), which allows safe egress from the facility for many occupancies. When used in conjunction with standby or emergency generators, stored energy systems are often used to supply power only during the time required to start an emergency or standby generator, stabilize its operation, and transfer critical load to the generator.

5.1.1.1 Battery-Powered Systems

Battery systems are the most common short-duration emergency power supply systems. They typically provide emergency power for approximately 5 minutes (when used with standby generators) to 2 hours when required to supply life-safety loads without a generator. However, some facilities, such as telephone company central offices and data centers, have battery systems designed to power communications equipment for longer periods, often 24 hours or more. The most common type of battery-powered emergency systems is the uninterruptible power supply (UPS) system.

UPS systems provide continuous (uninterruptible) power and are typically used to supply critical equipment that can be adversely affected by even momentary power outages. UPS systems are typically used in computer rooms, data centers, mission-critical medical centers, emergency operation centers (EOC), and similar facilities. They are generally sized to provide power long enough either to allow an orderly shut-down of electronic equipment or for an onsite emergency generator to sense the loss of utility power, start the generator's prime mover, allow the prime mover to achieve operating speed, and allow the generator's automatic controls to transfer critical loads to the generator. For medical facilities, NFPA 99, *Health Care Facilities Code* (NFPA, 2012a), specifies the maximum allowable time to transfer power to an emergency power supply and UPS systems are often designed to provide power for that duration.

UPS systems contain batteries, a battery charger, and an inverter that converts the direct current (DC) supplied by batteries into alternating current (AC). UPS systems may also have by-pass features that allow them to be tested and maintained without taking them out of service. While utility power is supplied to the building, the UPS battery charger maintains the UPS battery in a fully charged state. When utility power is lost, the UPS draws power from the batteries to supply the critical loads. Figure 5-1 shows typical equipment found in a medium-sized UPS system.



Figure 5-1 UPS system containing an inverter (left) and battery rack (right) located in a low seismic area.

5.1.1.2 Flywheel Systems

Flywheel systems are short-duration power supplies that provide emergency power for a duration of 1 minute or less, sufficient to allow emergency generators to start, stabilize, and transfer loads (typically 10 seconds).

Flywheel systems are good alternatives to battery systems because of their simple design, small size, and limited maintenance requirements. Figure 5-2 shows one type of flywheel system.

The flywheel system stores energy in the inertia of a rotating mass. The major system components are a motor that can function as a generator directly attached to a heavy flywheel and the flywheel itself. While power is supplied to the system, the motor drives the heavy flywheel. When power is lost, the inertia forces allow the flywheel to continue to rotate and the motor instantaneously begins to function as a generator. The inertia of the heavy flywheel keeps the generator spinning at nearly the same speed for 20 seconds or more.

5.1.2 Emergency and Standby Generators

Emergency and standby generators serve a wide range of applications. Small facilities with immediate but infrequent generation needs may employ a single generator with manual start and manual power transfer control scheme. Larger critical facilities may employ complex systems utilizing

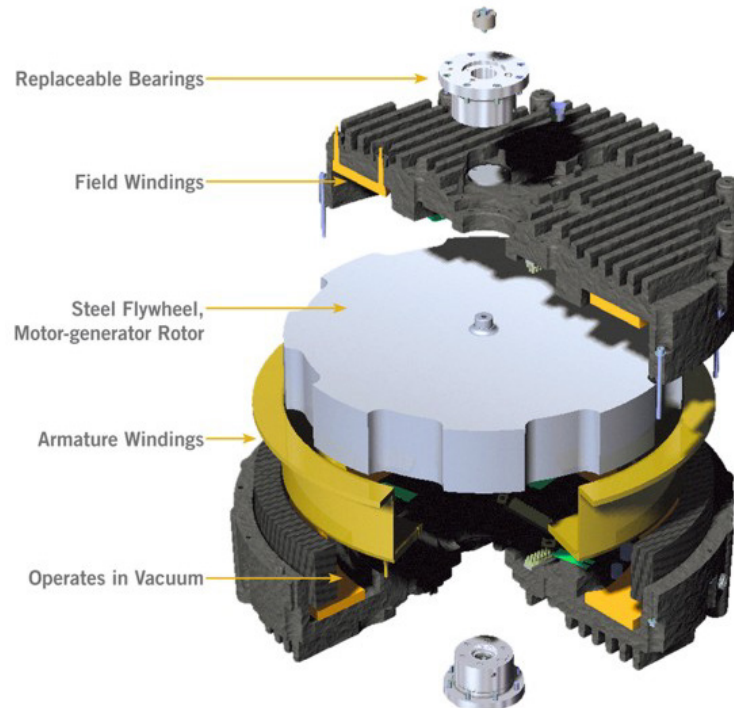


Figure 5-2 Rendering of flywheel system.

parallel generator installations, complex generator control, automatic transfer switches, and sophisticated power monitoring.

Generators are available in a wide range of sizes, with ratings from 1 kilowatt to several megawatts. They can operate almost indefinitely when properly sized, installed, maintained, and supplied from reliable fuel sources.

5.1.2.1 Generators and Engines

Emergency generators consist of an engine (often called a prime mover), a synchronous generator, monitoring equipment, and controls. The prime mover provides mechanical power to the generator; for units 1 megawatt and below they are typically piston driven; larger units may be turbines. The synchronous generator converts the mechanical power into alternating current; the monitoring equipment senses the state of the generator (primarily its speed); and the controls adjust fuel flow to match the prime mover power output with the power drawn from the generator. The generator also senses generator output voltage and adjusts the generator's output for voltage control.

Generators require cooling to remove heat created by the prime mover and the generator and ventilation for the combustion air required by the prime mover. Usually, the combustion air also helps cool the equipment. In

addition, emergency generators require equipment (typically lead-cell batteries) to start the prime mover. Battery chargers are integral to the total system to ensure starting capability is maintained.

Generators can be installed either within the facility or in exterior enclosures (Figure 5-3). When placed outside, generators are more exposed to damage from natural hazards. The natural hazards (wind, flood, and earthquake) that most often damage generators are described in Chapter 2. Chapters 6 and 7 contain guidance on how to protect generators from those hazards in new and existing facilities.



Figure 5-3 Emergency generator installed on the interior (left) and exterior (right).

When generators are located outside, they are typically placed in an enclosure to protect the generator and its controls from weather. Some enclosures allow generators to be heated; this feature improves the ability of the fuel-fired unit to start in cold weather. Some enclosures also provide sound attenuation to reduce the noise emitted from an operating generator (Figure 5-4). Facility operators should also be cognizant of restrictions on diesel exhaust emissions when planning generator locations in urban areas. Local ordinances sometimes require up blast fans or other exhaust disbursement mitigation.

5.1.2.2 Fuel Selection and Delivery

The vast majority of emergency and standby generators operate on fossil fuels. Fuel delivery systems are critical to the reliability of fuel-fired generators. Selecting the proper fuel source is important, and many factors play into that decision, including generator consumption rates, the availability of fuels and the ability to replenish the fuel supply after a natural hazard that blocks roads or disrupts infrastructure. Fuel sources for generators are either liquid (gasoline or diesel) or gas (propane or natural gas). Most generators under 15 kW are fueled by gasoline, propane, or



Figure 5-4 Exterior emergency generator placed in a sound-attenuating enclosure.

natural gas. Generators over 15 kW can also be fueled by diesel while those over 300 kW are almost exclusively fueled by diesel.

Fuel can be either stored onsite or delivered from offsite. Onsite fuels include gasoline, diesel fuel, No. 2 fuel, and propane. For onsite storage, provisions for refueling are critical, particularly immediately after an event. It is also critical that the fuel tanks, fuel pumps, and fuel lines be protected from natural hazards. Guidance for protection is provided in Chapter 6. Fuel sources must be reliable to ensure they are available when generators need to operate. Municipal or utility fuel sources are commonly shut off in preparation for an oncoming hazard event (most notably floods or hurricanes) to reduce the risk of fire and explosion. If a generator receives fuel only from a source that may be interrupted, the fuel source is not considered reliable. For generators used for life-safety protection, NFPA 110, *Standard for Emergency and Standby Power Systems* (NFPA, 2013c), requires an onsite fuel supply that is not solely dependent on a public utility. NFPA 110 requires enough onsite fuel to operate the emergency power systems at full load for between 5 minutes and 48 hours depending on the facility's use, location, and the equipment served; a minimum of 90 minutes is typically required for most installations to support emergency egress. In high seismicity areas for critical facilities, NFPA 110 requires 96 hours of onsite fuel storage to address the risk of widespread damage to infrastructure. FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings* (FEMA, 2007), and *Guidelines for Design and Construction of Healthcare Facilities* (FGI, 2014) also recommend that generators be able to run 96 hours without refueling.

Diesel

Diesel, nearly the same as fuel No. 2, with its low vapor pressure and high ignition temperature, is less volatile than gasoline and propane, and it can be stored longer than gasoline without deteriorating. Diesel fuel also has a high energy content (approximately 145,000 BTUs/gallon) and is readily available in most areas. However, diesel fuel eventually degrades over time, and this degradation can severely affect generator operation and reliability. If too much fuel is stored onsite, fuel inventories can become stagnant and degrade if not used.

Fuel degradation is a complex problem, and providing comprehensive recommendations on preventing degradation is beyond the scope of this document. However, the following are general recommendations for owners and operators:

- Supply emergency generators from fuel tanks that serve other fuel burning devices (like boilers) to benefit from more constant fuel use.
- Test fuel frequently to identify fuel quality, and replace fuel when the quality degrades to unacceptable levels.
- Provide parallel fuel filters that will allow clogged filters to be quickly by-passed while maintaining constant fuel filtration.
- Provide polishing systems to circulate and clean fuel of biologic growth that can foul filters.
- Avoid oversizing fuel tanks, particularly those that supply only generators that run occasionally.
- Be aware of the problems with fuel degradation and maintain vigilance to prevent fuel degradation from affecting system reliability.

Supplying diesel generators from shared fuel tanks is a good method to reduce the risk of fuel degradation because heating fuels are cycled more frequently. Diesel engines can operate on No. 2 fuel oil, which is a common fuel for many boilers. When emergency generators are supplied from shared fuel tanks, provisions must be put into place to ensure fuel inventories do not fall below critical levels. Figure 5-5 shows a large shared fuel oil storage tank.

Propane

Propane can be stored indefinitely, but is highly volatile. The risks associated with its volatility can be reduced with proper installation and routine testing and maintenance. Unless site limitations prevent placing

sufficiently large tanks onsite, adequate quantities of fuel can generally be stored onsite.



Figure 5-5 Fuel oil storage tank used for heating equipment that can supply an emergency diesel generator.

Natural Gas

Natural gas, unlike propane and diesel, is not stored on site but rather piped to a site from a local utility. Natural gas supplies can be interrupted during high-wind, flood, or earthquake events. Also, natural gas services are often intentionally shut down prior to a storm event to reduce the risk of fires and explosions. Because of this, natural gas should not be used as a fuel for providing emergency power to critical facilities unless the facility can confirm that natural gas service will not be interrupted.

5.1.2.3 Generator Synchronizing

When multiple generators are employed in a system, each generator must be synchronized before it is connected to the power system. The frequency, phase angle, and voltage of the generator being brought on-line must be closely matched to the system before closing the generator breaker.

Generator synchronizing boards (GSBs) automatically control the starting, stopping and synchronizing of generators. Modern GSBs are often equipped with data acquisition features as well as programmable parameters that allow demand control, load shedding, and alarm notifications. Strategies on

redundancy of systems can be supported with modern synchronization board controls. Appendix B discusses redundancy strategies. Figure 5-6 shows multiple generators supplying emergency or standby power. Figure 5-7 shows the GSB that synchronizes the generators and provides load shedding and demand control.



Figure 5-6 Multiple generators in parallel.

5.1.2.4 Load Shedding

Load shedding is a controlled response to excessive electrical demand, that ensures that the most critical equipment receive emergency power. Loads supplied from the emergency power system are assigned a priority and shed based on that priority. Lower priority loads (e.g., mechanical cooling) are shed first and then more critical loads (e.g., specialty equipment) are shed only if needed. Life-safety loads are given the highest priority and are not available to be shed. With sophisticated controls, the GSB monitors total generator production capacity and automatically sheds least critical loads to match generator output. In this way, the loss or curtailment of any generator only impacts the least critical loads.

5.1.2.5 Battery Starting Systems

Battery starting system for a generator is an often overlooked but critical component of the total system. The single most frequent reason for generator failure to start is its battery system. Battery systems should be installed in conditioned space to avoid extreme temperatures. Proper design and



Figure 5-7 Generator synchronizing board.

installation of interconnecting cables can compensate for voltage drop. Routine maintenance should verify proper charging and that cable connections remain tight and corrosion free. Frequently battery failure is due to an inoperable charger caused by an open breaker left off during routine maintenance. Care should be taken by maintenance personnel to check all automatic settings and connections after each preventive maintenance check.

5.2 Emergency Power Distribution

The emergency power distribution system includes all wiring and equipment between the emergency or alternate power sources and the critical equipment the sources supply. Similar to the normal power distribution system, emergency distribution systems consist of switchboards or distribution panels, feeders, branch circuit panelboards, and branch circuits and devices downstream of overcurrent protection. Unlike normal power distribution systems, emergency power systems are fed from both normal and emergency power sources. The transfer from normal to emergency power system is completed through transfer switches, which may be automatic or manual.

Upon sensing normal power loss, an automatic transfer switch (ATS) automatically sends a start signal to the generator and monitors power quality. When the generator produces power within acceptable voltage and frequency limits (i.e., the generator has stabilized enough to accept electrical loads), the ATS automatically switches from the normal to the emergency

power source. The ATS then continuously monitors normal power and automatically re-transfers back to the normal source when utility power has been restored and stabilized. Typically, the transfer back to normal power is delayed to help prevent nuisance or premature transfers.

Manual transfer switches (MTS) are similar but need to be operated manually. Also, manual transfer switches lack the generator start controls of an ATS.

NFPA 99 *Health Care Facilities Code* defines three branches within an emergency distribution system: (1) equipment branch; (2) critical branch; and (3) life-safety branch. The life-safety branch is the most important and given the highest priority. As the name implies, the life-safety branch is reserved for loads, such as exit lights and emergency lights required by NFPA 101 *Life Safety Code*. Fire detection and signaling devices complying with NFPA 72 *National Fire Alarm and Signaling Code* (NFPA, 2013a) can also be supplied from the life-safety branch as can hospital communication systems, systems that support the generator and elevator controls and elevator cab illumination. No other loads can be supplied from the life safety branch. NFPA requires the generator to start, stabilize, and transfer to energize loads on the life-safety branch in less than 10 seconds.

NFPA 99 *Health Care Facilities Code* requirements for the critical branch and the equipment branch are less restrictive than those for the life-safety branch. Manual control and load shedding are allowed on selected equipment branches and more time is allowed for energizing those branches.

NFPA 70 *National Electrical Code* also contains requirements for emergency systems. Article 700, *Emergency Systems*, defines three distinct classifications of emergency power systems: (1) emergency systems; (2) legally required standby systems; and (3) optional standby systems. Of these, emergency systems are for “the safety of human life” and are consistent with the loads specified by the NFPA 101 *Life Safety Code* and the life safety branch of NFPA 99 *Health Care Facilities Code*. The second classification, legally required standby system, supplies loads other than life safety loads that are required by municipal, state, federal, or other codes, or by governmental agencies having jurisdiction. The informational note of NFPA 70 states that legally required standby systems could create hazards or hamper rescue or firefighting operations if their functionality is interrupted. One example of a legally required standby system is a smoke control system. Optional standby systems are systems that provide power to equipment that, if interrupted, could cause discomfort, serious process interruptions, or product damage. Many of the systems required for a critical facility to

At the time of this writing, pending updates to NFPA 99, 2015 edition, NFPA 101, 2015 edition, and regulations from Centers for Medicare / Medicaid Services (CMS) are under consideration that may increase best practice recommendations for the health care environment.

function following an event fall into the category of optional standby systems.

NFPA 70 *National Electrical Code* requires wiring within emergency systems to be separate from all other wiring and prohibits (with listed specific exceptions) emergency system wiring from sharing raceways, cables, boxes, and cabinets with general wiring. NFPA 70 also limits what loads can be placed on emergency systems. In addition, recent editions of the NFPA 70 also require emergency system wiring to be routed through areas that are fully protected by sprinkler systems or provided with 2-hour fire protection. Article 700 of NFPA 70 also requires protective devices in emergency systems be coordinated to ensure that the minimum amount of equipment is affected when overcurrent devices, such as circuit breakers operate to isolate electrical faults.

Wiring for legally required standby systems and optional standby systems can share raceways, cables, boxes, and cabinets with general wiring.

5.3 Optional Standby Generators

Many smaller critical facilities find the capital cost of permanently installed generator redundancy prohibitive. An alternative to providing full redundancy for emergency power is to install means for rapidly connecting a temporary generator. Installing these connections, often called quick connects, and using temporary generators offer several advantages over permanently installed redundant systems. Temporary generators do not require large capital expenditures and do not require facility owners to continually maintain and test the units. Routine maintenance requirements can be shifted to unit supplier or contract vendor. However, temporary generators require significant advance planning to ensure that they will be available when needed and provisions that allow them to be safely connected to the facility's electrical system.

The following sections describe the preparations that must be made before a temporary generator can power a critical facility.

5.3.1 Providing Reliable Vehicle Access

In order to place a temporary generator into service, vehicular access to the temporary generator location must be available. If the generator is delivered after the event, at least one access route must be clear of fallen trees, not blocked by debris or other obstructions, and not rendered inaccessible by floodwaters. Temporary generators are heavy (for example a 100 kW unit weighs approximately 10,000 pounds), and paved roads or gravel road beds

may need to be constructed to support the heavy equipment used to transport generators to the site and to support trailer-mounted generators after they are delivered to the site.

5.3.2 *Creating a Location*

The generator location is usually controlled by the need to access the electrical service and distribution equipment. The temporary generator must be located reasonably close to where it will be electrically connected to the facility. Cables are used to connect the generator to the facility, and long cable runs create an undesirable voltage drop that can damage equipment. For long runs, oversized cables can be used or additional cables can be installed to reduce voltage drop, but those options are relatively expensive.

Concrete slabs can be placed to support generators, or designated parking areas can be assigned to site the trailers. When siting a temporary generator, facilities should make sure the temporary unit can be refueled while on site. In addition, when possible, temporary generators should be placed where their operating noise will not be objectionable.

5.3.3 *Installing Connections*

When preparing to connect the generator, the types of cables that will be used for the connection, as well as where it will be electrically connected, should be connected.

Flexible cables are normally used to connect the temporary generator to a facility. For smaller installations (approximately 15 kW single-phase or 25 kW three-phase), a multi-conductor cable that terminates in a twist-lock receptacle is often used. The receptacle can connect to a mating plug mounted on the building. Figure 5-8 shows two styles of building-mounted twist-lock plugs for connecting temporary generators. For larger generators, single conductor cables that terminate in slip-fit plugs and matching receptacles are typically used. Conductors can be installed in parallel to meet the amount of current drawn by the building. Figure 5-9 shows two installations of slip-fit devices. To prevent injury or death, the method used to connect the must prevent any power from being back-fed onto utility lines.



Figure 5-8 Building-mounted twist-lock plugs for connecting temporary generator cables.



Figure 5-9 Electrical connection point for temporary generator using slip-fit connectors (left), and cables at building connection (right).

5.3.4 Ensuring Availability

To ensure generators are available when needed, facility operators should establish contracts with equipment rental agencies before an event strikes. Agreements may also be developed between neighboring municipalities or State agencies. For larger municipalities that have several similar facilities (such as fire stations, police stations, or water or wastewater pumping stations), a single generator could be purchased and used to serve standby power for several sites provided concurrent use is not required.

5.4 Electrical Control and Coordination

When electrical systems are properly designed, properly installed, and free from failures or damages, they can safely distribute large amounts of power. That power can range from 1,000 watts for an individual branch circuit supplying a piece of electrical equipment to 100 kilowatts for an electrical

feeder in a commercial building or industrial plant to 1 megawatt for a distribution line circuit supplying a small community to several 100 megawatts for transmission lines supplying an entire city or a large geographic area. However, the beneficial power that electrical systems can distribute can rapidly become destructive when failures occur either within those systems or when they are damaged by external forces.

5.4.1 System Protection and Control

Electricity is distributed at essentially the speed of light and therefore the power systems that distribute potentially damaging energy must include automatic protective devices fully integrated into the system. Those protective devices must detect anomalies within the system often in fractions of a microsecond and initiate automatic protective actions in order to: (1) eliminate or minimize damage to both the power source and the downstream equipment; and (2) isolate the damaged elements of the system to minimize the loss of electrical power.

Power system controls can be automatic or manual and are custom designed for each facility to configure the power system to accommodate the code requirements and specific performance goals of the owner. Control systems can monitor the actions of protective systems but are not allowed to interfere with the protective actions. The actions of the protective systems are then incorporated into how the control system may respond. A code required example is the automatic detection of the loss of utility power by the emergency generator controls. The protective system initiates the isolation of the facility power system from the utility, starts the generator(s) and transfers the source of facility power to the generator(s).

Significantly more complex power control systems may be capable of connecting a facility's generators to its power system for parallel connection to the utility source. In this co-generation mode, facility power is supplied by both the facility generators and outside utility. The seamless transfer is made possible by custom generator controls continuously sensing utility and generator parameters, such as voltage, frequency, and power factor, to automatically adjust the generator output to be synchronized with the utility before connection is allowed. If the proper control action cannot be achieved, the protective functions of the generator switchgear act to prohibit the paralleling of the generator to the utility source.

Each facility may employ one or more protection schemes with varying degrees of complexity to meet the goals of functionality for the institution as

a whole. These emergency power and normal power protection controls must be carefully coordinated to ensure proper operation.

5.4.2 Selectivity and Coordination

The term selective coordination refers to the selection and setting of protective devices in an electric power system in such a manner to ensure the smallest possible portion of the system is deenergized by an abnormal condition.

If faulty equipment with an internal short circuit in its internal power wiring is plugged into an outlet in a critical facility, the expectation would be that the branch circuit breaker feeding the outlet would immediately trip and prevent the building wiring to the outlet from overheating and failing. If instead, the main circuit breaker controlling the power for the entire facility opens before the individual branch circuit, all power downstream of the main circuit breaker would be lost and the entire facility could go dark. In a properly designed, installed, and maintained building electrical power system, the protective circuit breaker closest to the fault, or short circuit, senses the problem and acts to open the power circuit at the lowest possible level. When this outcome is achieved, the power system is providing the maximum possible selectivity and coordination.

Modern electrical codes contain requirements for selectivity and coordination of normal power systems that should also be applied to emergency power systems. Design decisions made during the collaborative process between facility owners and the engineering team should not sacrifice selectivity and coordination.

Chapter 6

Design Considerations for Emergency Power Systems in New Facilities

Appropriate planning during the design of a new facility can greatly improve the ability to provide emergency power for that facility following severe natural hazard events when the facility is needed most. If proper considerations are made, what may be extremely difficult to achieve in existing construction can readily be achieved with a new facility. The keys to a successful design are the following: (1) getting all design professionals and the building owners and operators to take a holistic approach to the design process; and (2) having the design team work closely with the owner or operator of the facility to identify all critical operations that must remain functional when utility power is lost.

In this chapter, considerations and best practices for design of emergency power systems in new critical facilities are provided. These include determination of functions that require emergency power, decisions that affect the demand load for emergency power systems, and strategic decisions on the layout and locations of emergency power systems. Although it is easier to implement these recommendations in new facilities, the procedures discussed in this chapter are also applicable to the design of emergency and standby power systems in existing buildings. Finally, specific minimum code requirements applicable to emergency power systems are discussed along with best practices that go beyond those code minimums so that critical facilities will be better able to resist severe natural hazards and keep functioning when needed.

Best practices are presented to aid architects and engineers in developing effective designs for electrical systems in facilities that must remain operational during a prolonged power outage, when the facility site and surrounding area are subjected to severe natural events. While best practices aim to create cost-effective electrical designs, the recommendations also influence architectural, civil, electrical, and mechanical engineering disciplines. Involvement from all design professionals is critical.

6.1 Holistic Approach to Design

Whether designing a new building's emergency power system, adding capacity to an existing system, or simply analyzing an existing system, a holistic approach considers all aspects of the emergency power system design, installation and operation, along with the essential building systems it will be serving. This means a systems point of view must be taken at the start of the design and carried all the way through construction.

The functionality of an emergency power system (and thus the critical facility) will only be as strong and reliable as its weakest link. If a holistic approach is taken, the system will be properly sized, designed, constructed and maintained. It has been observed that too often, each component supplier in the job optimizes each of their individual subtotals at the expense of an optimized total. Many mistakes can be avoided by having one engineering firm or project manager oversee the entire endeavor. A comprehensive view of the total system will generally provide improved results.

6.1.1 Determining Emergency Power Load Requirements

When planning or analyzing the needs of an emergency power system, one of the most difficult engineering tasks is to properly identify the required loads that must be powered when normal power fails. Facility managers should not underestimate the planning required to thoroughly identify equipment and their associated controls to be supplied by the emergency power system. Most codes simply mandate life-safety components only. NFPA 99, *Health Care Facilities Code* (NFPA, 2012a), provides additional requirements for health care critical facilities beyond the basic requirements of the 2012 *International Building Code* (IBC; ICC, 2012), listing specific equipment that must be on emergency power, as well as required branch circuitry. NFPA 99 mandates emergency power for "selected" HVAC equipment only, e.g., in the emergency, intensive care unit, labor and delivery departments.

Care must be taken in utilizing these documents to create the intended result, as code minimums will generally not achieve institutional goals. For example, an institution may choose to operate a catheterization lab on the emergency power equipment branch in accordance with NFPA 99; however, without proper cooling for patients and control rooms, the emergency powered catheterization lab may be rendered non-functional.

A second example is a pharmacy. NFPA 99 specifies that in hospitals pharmacy task illumination and selected receptacles should receive emergency power from the critical branch. However, the code is silent on HVAC for pharmacy locations. Many pharmaceuticals must be stored within

narrow temperature limits that may not be maintained when only code-minimum emergency power is provided. Accordingly, health care institutions should evaluate the pharmacology operations expected and the temperature ranges required for the pharmaceuticals to determine if HVAC in pharmacies should actually be required to meet the overall planned mission of the institution, regardless of what is specified by codes and standards.

6.1.2 Emergency Power System Design

After the emergency power load requirements have been determined, the entire system must be planned with the overall institutional goals in mind.

Individual mechanical, electrical, and plumbing equipment, conveyance equipment (e.g., elevators, escalators, and lifts), and other critical equipment should be considered as individual components in a heavily interconnected system. The vulnerability of any one piece of critical equipment can affect the performance of the entire system and the adverse effects of that system can affect other systems. For a critical system to function, often all components of that system must function, as well as those of other interconnected systems.

Emergency power systems are a prime example of the interdependence of the overall system to its components and to other systems. For an emergency power system to operate and supply power to essential equipment, all components of the emergency power system must be undamaged and able to function. This includes: the emergency power source and all of its ancillary equipment (equipment to start and regulate the prime mover, lubrication and cooling equipment); the emergency power distribution system (distribution panels or switchboards, branch circuit panel boards and the feeders and branch circuits that interconnect them), and the transfer switches that supply critical loads from either normal or emergency power sources.

Protected locations are imperative for the entire emergency power system and the equipment it serves, which take into account local conditions of the facility. Each component of the system should be evaluated in conjunction with expected hazards and by understanding how each interrelated component impacts another. For example, fresh air intakes should not impinge on sprinklers or any freeze-sensitive components. Although a generator installation may be acceptable when considered in isolation, if its operation creates unacceptable ambient conditions, the generator will not provide satisfactory performance or life cycle expectations. Generator

exhaust should be directed to a proper location away from facility air intakes to avoid reentry into buildings and occupied spaces.

A holistically planned electrical distribution system is as important as power generation. Dedicated and protected emergency power wiring is recommended to reduce the potential that failures of non-critical equipment and wiring disrupt critical equipment. A study of the electrical system performed by a competent design professional will highlight additional areas of interrelated functionality and help broaden the design view, thus strengthening the holistic approach.

6.1.3 Holistic Design Tools and Culture

In order to foster holistic design and implementation on any project starts with assembling a diverse team early in the schematic design phase. Contracting methods that bring together multiple disciplines of engineering to the project early in the design process have the advantage of breaking down silos of work product, driving a holistic collaborative effort. Often, trade subcontractors can provide significant project-wide input when employed to provide design phase services. Contracting methods which foster this holistic design approach during the programming phase can pay dividends far in excess of upfront consulting costs.

Recent technological advances in design also promote a holistic approach. Building Information Modeling (BIM) is widely being used to create three-dimensional architectural drawings with component information embedded in the file structure. BIM can produce integrated multi-disciplinary design documents that can be analyzed and reviewed by a diverse engineering design team allowing for simultaneous input, as well as better collaboration throughout the design and construction process.

6.2 Identification of Emergency Power Needs and Emergency Power Sources

Early in the design process, the critical functions of a facility need to be identified. For example, for a high school design, will the school's gymnasium be used as a secondary shelter? For a fire station, will the entire facility need to remain functional after a hazard event or will just the dispatch and communication center within the building be sufficient? For a hospital, what departments or critical functions are needed to provide expected services when utility power is lost and what functions can possibly be postponed or diverted to other facilities? Chapter 3 provides guidance on whether a facility should be considered a critical facility and Chapter 4 provides guidance on selecting building systems to be considered essential

for purposes of needing emergency power and the duration, assuming these functions cannot be postponed or diverted.

The decision of whether to power the facility from permanently installed or temporary generators also needs to be made. If alternate power is not needed immediately following a loss of utility power, temporary generators may be adequate. However, if power is needed before temporary generators can be delivered to the site and connected to the facility, on-site generation will need to be installed. Both permanently installed and temporary generators require reliable fuel sources. Chapter 5 contains discussions on selecting the fuel source for emergency generators.

6.3 Fire Protection, Mechanical, and Electrical Design Considerations that Affect Emergency Power Systems

The design team for a new critical facility can have a significant impact on design requirements and engineering of the emergency power system. In this section, guidance to these professionals from a holistic perspective is provided.

6.3.1 Fire Protection and Mechanical Engineering

Fire pumps and air conditioning are two of the heaviest loads to serve from emergency generators. Accordingly, fire protection engineering and mechanical engineering can have a significant impact on emergency power demand loads.

6.3.1.1 Fire Suppression

Fire pumps are required by code in high-rise structures, or when the available water flow or water pressure is inadequate to operate the fire sprinkler system. Often, the amount of water available for suppression is outside of the designer's control. When facilities are constructed remote from water sources or are placed on elevated sites, fire pumps are needed to boost water pressures and flows to acceptable levels. In those instances, generators must be sized to accommodate electrically driven fire pumps or separate diesel fire pumps need to be installed. It should be noted that use of diesel fire pumps would reduce emergency power requirements (Figure 6-1). However, there are instances where water sources can provide acceptable flow rates if larger sprinkler piping is used. In those cases, fire suppression systems should be designed to function without fire pumps or with the smallest fire pump required. If fire pumps are needed to provide adequate water flow for fire suppression, past analyses show that generator capacity requirements may increase ten-fold over emergency power requirements for loads not related to fire pumps.

If fire pumps are required, either diesel-driven fire pumps or electric fire pumps with separate emergency generators should be considered. This is to avoid oversizing an emergency or standby generator, sized to provide power to essential equipment.



Figure 6-1 Diesel-driven fire pumps.

6.3.1.2 Heating and Ventilation

Most commercial facilities are heated by fossil fuels, such as No. 2 fuel oil, natural gas, and occasionally propane. No. 2 fuel oil is heating oil nearly identical to off-road diesel fuel.

The electrical requirements for operating fossil fuel heating systems generally include:

- Power to operate furnaces, air distribution equipment, and controls (hot air systems)
- Power to operate boilers, hot water circulation pumps, air distribution equipment, and controls (hydronic systems)

Compared to all-electric heating systems (also called electric resistance systems), fossil fuel-fired heating systems place relatively low loads on emergency power sources. Most of the energy required to heat a space is not provided by the generator but rather is obtained from fuel combustion. Therefore, if the option is available, heating for critical facilities that must be supplied by emergency power systems should be provided by fossil fuels rather than by electric resistance.

Besides selecting which fossil fuel will be used to heat the building, other design decisions can further reduce generator requirements, including:

- Air handling equipment that uses the smallest distribution fans practical should be selected. For larger fans, motor controls and starters that reduce starting currents should be selected.
- For hydronic systems, hot water distribution pumps should be controlled to reduce starting currents.
- For hydronic systems requiring multiple pumps to operate, control systems should be developed that allow the largest pump motor to operate continuously and smaller pump motors to operate cyclically when additional flow is needed. With this control approach, the generator will not be exposed to the starting load of a large cyclically operated motor.

Another option that is becoming more prevalent is geothermal systems. In these systems, heat pumps are typically used to draw heat out of an earth loop while heating the building or rejecting heat to an earth loop while air conditioning. Geothermal loops can use large motors (50 horsepower or greater) to circulate water through the facility. When used with conventional across-the-line starters, those large motors place great demands on a generator when they are started. For all large motors like geothermal pumps, starters like wye-delta starters, or other “soft” starters should be used when those motors must be supplied from an emergency power source. Appendix C provides additional discussion on starter options.

6.3.1.3 Air Conditioning

The selection of air conditioning equipment can have a profound effect on generator requirements for facilities where air conditioning is considered critical.

In general, direct expansion (DX) units place lower demands on an emergency power source than central chilled water systems. Also, they more readily allow selection of specific areas of a facility to be mechanically cooled. Central chilled-water systems, on the other hand, require operating the chiller (which requires a large generator to start and run) whenever any space needs to be air conditioned. However, the decision to select DX units or central systems usually is dictated by the day-to-day use of the facility and not on its occasional use as an emergency facility.

For DX units, the following are recommended:

- Configure controls to allow individual areas to be operated separately. Allow units that serve areas not used for sheltering or other critical functions to be turned off when normal power is not available.
- As far as practical, control large fan motors with variable frequency drives (VFD) or use starters that limit motor-starting currents. Avoid across-the-line starters for all large motors.
- Supply operating and control power from single feeders.

For central systems, the following are recommended:

- Select chiller units to operate in stages and base load the larger compressors within the chillers.
- Control chilled water pumps with VFDs that limit starting currents.
- As much as practical, control large fan motors with VFDs or use starters that limit motor-starting currents. Avoid across-the-line starters for all large fan motors. See Section 6.3.2.2 for additional discussion.

6.3.2 Electrical Engineering

Historically, much of a building's electrical design is in response to the mechanical engineering design. The electrical engineer typically designs power delivery to equipment selected by the mechanical engineer. However, since the electrical engineer will need to design the critical power system and that system is greatly affected by the mechanical design, a collaborative approach is needed, making electrical engineering input on the selection of mechanical equipment appropriate. Also, HVAC controls can be programmed to reduce peak electrical demand. Peak demand reduction may reduce the size of the generator required.

Emergency power and distribution systems, particularly power and distribution systems that operate over 600 volts, can be vulnerable to transient voltage surges. Transient voltage surges can result from lightning, from the switching of heavily loaded circuits, from the operation of vacuum switches, and from the operation of non-linear power supplies. Standards developed by the Institute for Electrical and Electronics Engineers (IEEE 1990 and 1993) contain discussions and recommendations on reducing the effects of transient voltage surges.

6.3.2.1 Lighting

Compared to the generator capacity required to operate mechanical systems, the generator capacity needed for lighting systems is relatively low.

However, efficient lighting design is still important. Lighting systems in commercial facilities generally consist of fluorescent luminaires or high intensity discharge (HID) fixtures, such as high pressure sodium or metal halide or more recently light emitting diodes (LEDs). These light sources have efficiencies of around 100 lumens per watt. Few light sources are commercially available that exceed that level. Incandescent light sources should be avoided since their efficiency is greatly less than that of fluorescent, HID, or LED sources.

Metal halide HID fixtures have a prolonged restrike (restart) period where lamps within metal halide fixtures need to cool off following even a momentary power interruption before they can restart and illuminate the space. Auxiliary lighting systems using quartz or fluorescent lamps are often required to provide illumination during that restrike period.

6.3.2.2 Controls

Where possible, large motors should be designed to be started in sequence (i.e., stagger-started or delay-started) to reduce peak loads placed on emergency generators. All large motors that need to be supplied from emergency power systems should be provided with soft-start features to reduce motor starting loads.

Control for HVAC loads should be provided from the electrical feeders that power those loads. This approach simplifies providing emergency power to select equipment since energizing the feeders that power those loads from a generator will also provide emergency power to their control devices. Where possible, HVAC equipment should be controlled to reduce fluctuations in demand when operated by the emergency power source.

6.4 Design Considerations Regarding the Layout, Location, and Protection of Emergency Power Systems

Once the critical functions are identified, mechanical and electrical needs can be identified. Critical functions should be grouped together where possible to enable the portions of the facility that house these functions to be made more structurally robust and less vulnerable to natural hazards than other portions of the structure. Where and how these functions and emergency power systems are located are dependent upon the natural hazard of concern. It should be noted that sometimes recommendations for one hazard may conflict with those of another. For such situations, the final placement of the system should be taken under careful consideration by the design team.

6.4.1 Design Considerations for Reducing Flood Risks

For an emergency power system to be effective, the entire system must be above the flood level or otherwise protected from flood waters. This includes the generator and all electrical distribution equipment that is part of the emergency system, transfer switches, feeders, panel boards, fuel tanks, and controls. In addition, all critical equipment that the emergency power system supplies must be elevated. Flood risk considerations should not be limited to the emergency power systems. Electrical conduits, even those that are not part of the emergency power system, can provide pathways that allow floodwaters to enter a building when they are located below the flood levels. Sanitary sewer lines can allow floodwaters to enter a building if not provided with backflow devices or other methods of flood protection. Below grade utility trenches can be particularly problematic. When utility trenches are required to be placed in flood hazard areas, they should be provided with barriers to prevent floodwater entry.

For an emergency power system to serve a critical facility, it must, as a minimum, be provided with the same level of flood protection as that provided for the facility itself. However, due to the importance of emergency power systems and the essential equipment they serve, it is prudent to provide more flood protection than what is provided for the facility. Figures 6-2 and 6-3 show an elevated generator and associated switchgear that withstood Hurricane Ike with no flood damage.

Codes and standards, such as the 2012 IBC and ASCE 24-05, *Flood Resistant Design and Construction* (ASCE, 2005), contain criteria that are based on the base flood, i.e., the flood event that has a 1% chance of being equaled or exceeded in any given year, or the design flood when adopted locally. The minimum flood protection is tied to the base flood elevation (BFE) (the elevation of floodwaters including wave height associated with the base flood) or the design flood elevation (DFE) (the flood elevation associated with the design flood). For example, ASCE 24-05 requires flood protection a height of 1, 2, or 3 feet in addition to the DFE or the BFE levels, depending on the importance of the facility and its orientation to approaching waves.

Other more stringent criteria may apply. For example, following a major flood event, Interim Recovery Maps that depict Advisory Base Flood Elevations (ABFEs) are often developed to help communities benefit from the best available data during rebuilding and some federal funding requires protection to the 0.2% annual chance flood. Also, FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*:



Figure 6-2 Example of an elevated generator; photograph shows the intake louver in Galveston, Texas, 2010.



Figure 6-3 Switchgear, normal, and emergency power feeds, and associated equipment elevated to the same level as the emergency generator at UTMB, Galveston, Texas in 2010.

Providing Protection to People and Buildings (FEMA, 2007a), recommends critical equipment be elevated as required by ASCE 24-05 or the 500-year flood level (the level of the flood event that has a 0.2% chance of being equaled or exceeded in any given year) whichever is greater. It should be noted that the minimum flood provisions and design flood elevations of

contemporary codes and standards continue to be revised as more information is gathered following flood events.

Regardless of the criteria, it is recommended that minimum flood provisions specified by codes and standards apply to all systems within a facility. For emergency power systems and the equipment they supply in critical facilities, it is recommended that more stringent criteria be applied. After Superstorm Sandy destroyed emergency power systems and critical equipment in many critical facilities, FEMA P-942 report, *Mitigation Assessment Team Report, Hurricane Sandy in New Jersey and New York* (FEMA, 2013a), recommended building systems in Risk Category IV structures and certain Risk Category III structures be provided with one additional foot of flood protection above that specified for other structures.

In summary, it is recommended that critical facilities be protected to the greatest of the following flood elevations:

- Base Flood Elevation (BFE) plus 2 feet,
- Locally adopted Design Flood Elevation (DFE), and
- 500-year flood elevation (flood event having a 0.2% chance of being met or exceeded annually).

Emergency power systems within critical facilities and the equipment they supply should be protected to the greatest of the following flood elevations:

- Base Flood Elevation (BFE) plus 3 feet,
- Locally adopted Design Flood Elevation (DFE) plus 1 foot, and
- 500-year flood elevation (flood event having a 0.2% chance of being met or exceeded annually) plus 1 foot.

Whenever possible, flood protection should be provided by locating critical systems and equipment above predicted flood levels. When that is not possible, critical systems and equipment can be protected by dry-floodproofing to the elevation of predicted flood levels. However, the elevating critical systems and equipment is greatly preferred over dry-floodproofing since once floodwaters overtop dry-floodproofing provisions, equipment will be rapidly inundated and potentially destroyed.

It is also recommended that fuel tanks for emergency generation systems be placed above the DFE and the recommended flood elevations for critical facilities. If exposed to floodwaters, the tanks should be anchored to resist buoyant forces and the crushing forces of hydrostatic loads. ASCE 24-05 requires buoyancy to be calculated on an empty tank and that anchorage be

provided to resist 150% of the buoyant forces. ASCE 24-05 also requires fill and vent pipes to extend above the DFE to ensure floodwaters do not enter tanks and displace fuel during a design flood.

6.4.2 Design Considerations for Reducing Risks from High Wind Events

High winds generated by hurricanes, tropical storms, and tornadoes can damage both exterior equipment and equipment installed within a building if the building's structure or its envelope cannot withstand wind forces or is damaged by wind-borne debris.

In all installations where an emergency power system serves a critical facility, the entire emergency power system and its components should be protected from natural hazards. When an emergency power system is required by ICC 500-2008, *Standard for the Design and Construction of Storm Shelters* (ICC, 2008), the system must be protected from design event conditions.

6.4.2.1 Protecting Interior Installations

To protect equipment from high winds, it should be placed in areas that will resist wind pressures, will not be penetrated by wind-borne debris, will not allow wind-driven rain to affect equipment operation, and will not be exposed to lay-down hazards (Figure 6-4).

To resist wind pressures, the walls and roof of the generator room must be structurally robust and possess load path continuity that transfers all wind loads to the foundation. The total weight of the building, including its foundation, must be sufficient to resist overturning or sliding, or anchorage must be provided to secure the building in place. Because even small generators require large penetrations in the building envelope for ventilation (for combustion air) and cooling, a generator room should be designed as a partially enclosed building per ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010). Any interior walls shared with the rest of the building should be designed to resist at least the wind pressure associated with the internal pressures of a partially enclosed building. It may be prudent to design the internal walls of the generator room to resist external wind pressures to counteract failure of ventilation grills and louvers.

To be effective, grills and louvers for combustion air and cooling must be strong enough to resist wind-borne missiles. If missile-resistant grills and louvers are not readily available, baffles or alcoves can be constructed to



Figure 6-4 Interior generator protected from the effects of wind and wind-borne debris.

prevent direct missile impact. ICC 500-2008 provides criteria for baffles and alcoves. This national standard bases its criteria on a much more energetic missile than an Type E missile, as defined by ASTM E-1996-14, *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes* (ASTM, 2014), so an alcove and baffle design based on ICC 500-2008 will likely be conservative. In addition, having a secondary roof membrane reduces the potential for water entry when the primary membrane is punctured or penetrated. FEMA 543 provides guidance on secondary membranes.

To prevent damage, emergency power systems and associated equipment should be placed in areas that are not vulnerable to lay-down hazards. If the equipment cannot be installed away from lay-down hazards, the lay-down hazards themselves should be removed or relocated.

Another benefit of interior installation is that it allows staff to operate the generator without being exposed to injury.

6.4.2.2 Protecting Exterior Installations

While exterior enclosures offer some protection from the elements, few can offer the same protection from high-energy wind-borne missiles and lay-down hazards as a properly designed interior location. Where possible, exterior enclosures should be designed to resist wind pressures for Category IV buildings, as defined by ASCE/SEI 7-10 and resist at least a Type D, or

preferably a Type E missile, as defined in ASTM E1996-14. Generators should be located where they cannot be damaged by lay-down hazards or by wind-borne debris. If site restrictions require placing a generator in an area where lay-down hazards exist, the hazards should be removed or relocated.

Structural fencing can be constructed around generator enclosures for additional protection, particularly from horizontal missiles. The fencing, which typically consists of reinforced masonry or reinforced concrete walls, must be designed so as not to impede airflow required for generator cooling. Structural fencing does not protect against vertical missiles.

6.4.3 Recommendations for Placement where Earthquake Hazards are Present

Buildings typically respond to an earthquake such that the accelerations at the top of a building can be two or three times stronger than those at the base. Therefore, if flood or storm surge hazards are not present, it is recommended that emergency power equipment and ancillary systems be located at grade since seismic demands will be lower. It is generally not good practice to locate emergency power systems in the basement, since they may be flooded by seismic failure of piping systems.

Where both seismic and flood risks exist, critical functions and the equipment needed to support those functions should be located on floor(s) with elevations above Design Flood Elevation and these functions and equipment should also be protected from wind forces, wind-borne debris and seismic effects. All critical equipment and interconnecting piping, wiring, and ducts should be elevated or protected as recommended in Sections 6.4.1 and Section 6.4.2. ASCE /SEI 7-10 provides requirements for designing buildings (including mechanical and electrical equipment) to resist seismic loads and FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide* (FEMA, 2012b), provides guidance for designing and seismically qualifying MEP systems to perform as expected following Design Earthquake events.

It is advisable that the structural engineer of the project work with the project architect, MEP and HVAC design team members to ensure they are fully aware of seismic design, equipment qualification and seismic certification requirements at the proposal stage of the project and that the design documents fully define and document design requirements, including anchorage bracing. Where the design and qualification of these items are being deferred until construction, a clear plan should be developed on how these requirements will be handled by the construction manager. It is likely that these additional engineering services will entail additional fees and these

should be included in proposals and the initial project costs. If the project involves consideration of seismic requirements for MEP and HVAC systems, it is imperative that a structural engineer with practical design experience in seismic design of nonstructural systems be selected for the team.

6.5 Code Design Requirements for Emergency Power Systems to Resist Severe Natural Hazards

In the United States, buildings and other structures and their architectural, mechanical, electrical systems are designed for natural hazards to satisfy the requirements of the *International Building Code* (IBC). The current version of the IBC was published in 2012. In Chapter 16 of the 2012 IBC, structures are classified depending on their level of importance with higher requirements mandated for those structures with higher importance. Most critical facilities are identified as essential facilities in Chapter 16 and classified as Risk Category IV. Other important, but less critical structures will be classified as Risk Category III. The 2012 IBC references ASCE/SEI 7-10 for natural hazard loading and design requirements. Design maps are provided in the ASCE/SEI 7-10 for natural hazards that vary by location in the United States, depending upon the risk of that hazard occurring at individual site.

In ASCE/SEI 7-10, higher risk categories have higher importance factors for seismic and snow loads. These importance factors amplify the design loading, and may trigger special design and detailing provisions. On the other hand, wind design requirements assign different wind speeds to be used for design depending on Risk Category. Risk Category III and IV structures are to be designed for a wind speed with a 1700-year mean return interval as compared to normal structures (Risk Category II) which are to be designed for a 700-year mean return interval. On the other hand, seismic loads are based on Design Earthquake ground motions with a mean return period range between 500 and 1,000 years. For Risk Category IV structures, seismic loads are increased by an importance factor of 1.5 and by an importance factor of 1.25 for Risk Category III structures. No increase is applied to Risk Category II structures. Therefore, considering the importance factor, Risk Category IV facilities are effectively being designed for design ground motions that have a return period that ranges between 1,000 years and 2,500 years. In ASCE/SEI 7-10, wind loads are adjusted depending on their height above grade, the local topography and the wind exposure while seismic loads are adjusted based on soil conditions and several other factors including the level of seismic detailing. Certain types of structural systems are not permitted in areas of high seismic activity.

Because critical facility structures require special expertise, it is advisable that the project team include a structural engineer with experience in design of critical facilities for natural hazards that are significant to the site. Critical facility structures designed to satisfy the requirements of the 2012 IBC and ASCE/SEI 7-10 should have a high likelihood of performing well structurally when subjected to most severe natural hazards. It should be noted that ASCE/SEI 7-10 does not have design provisions for tornados or tsunami waves. The next version of the document, ASCE/SEI 7-16, still under development is scheduled to address tsunami hazards. Also, ASCE/SEI 7-10 only considers a 100-year return period for flooding, which is very low considering the much higher return periods required for design for wind and seismic loadings. Therefore, for design of critical facilities for flooding, the recommendations of Section 6.4.1 of this document should be utilized.

Chapter 13 of ASCE/SEI 7-10 provides seismic design requirements for nonstructural components. Nonstructural components are defined as architectural, mechanical, and electrical equipment and systems associated with structures. The primary focus of Chapter 13 is the design of anchorage and bracing of nonstructural components. Procedures for determining seismic design forces are specified and are a function of building ground motion values, relative height of the component within the structure, type of nonstructural component, and the importance of the component. Nonstructural components in Risk Category IV structures have the highest importance and design forces. For important nonstructural components in higher seismic areas, not only does the anchorage bracing need to be designed for seismic forces but also the nonstructural components themselves need to be designed or seismically qualified. This means that piping systems, HVAC ducting, and cable trays all need to be designed for seismic forces. Furthermore, active mechanical and electrical equipment (including those associated with emergency power systems), including the emergency generators and engines, need to be shake table tested to demonstrate they will function following design earthquake hazard events. FEMA E-74 provides guidance for designing, detailing, and seismically qualifying MEP systems to perform as expected following Design Earthquake events in a manner that would satisfy ASCE/SEI 7-10. An example of an emergency generator with seismically rated vibration isolators is shown in Figure 6-5.

ASCE/SEI 7-10 does not currently provide specific requirements for nonstructural components for natural hazards other than earthquakes. However, it is prudent that MEP components and systems that are part of the emergency power system and the MEP systems and components considered

essential for functionality of the critical facility be designed to resist the other natural hazards. MEP systems and components with direct wind or snow load exposure should be designed for the same wind speeds and snow loadings as Risk Category IV building structures. In addition, the IBC requires that structures supporting MEP systems or utilities be elevated and protected in accordance with ASCE 24-05. Finally, MEP systems that have direct wind or snow load exposure should be designed for the same wind speeds and snow loadings of Risk Category IV building structures.



Figure 6-5 Emergency generator supported by seismically-rated vibration isolators.

Chapter 7

Design Considerations for Optional Standby Power Systems in Existing Facilities

This chapter provides guidance for providing reliable emergency or optional standby power systems in existing facilities. It is intended for use in cases where optional standby power beyond the code-minimum level is needed following severe natural hazard events. This chapter covers two situations in the event utility power is not available. The first is where an evaluation made of an existing facility as suggested in Chapter 4 determines that optional standby power is needed where none currently exists. The second situation is where an emergency or optional standby power system exists but may have vulnerabilities or limitations that will make it less likely to function as desired following severe natural hazard events.

As noted in Chapter 1, NFPA 70, *National Electrical Code* (NFPA, 2014), classifies standby power systems as emergency systems, legally required standby systems, optional standby systems, or critical operation power systems with specific requirements for each type of system. In this chapter, it is presumed that the standby power system addition or modification is being done as a voluntary upgrade and is not associated with a code mandate. However, if the addition is being done to satisfy mandated requirements, all current code requirements must be followed.

When contemplating adding optional standby power to such a facility, the local authority having jurisdiction should be consulted, since the addition of a new optional standby power system may need to include upgrades to meet the minimum emergency power requirements of current code, as well as fulfill the operational goals of the owner. There are several options for providing sources of emergency or optional standby power in existing critical facilities where none currently exist. These include providing alternate power sources, moving the critical function to a backup facility or providing a new emergency power system.

It is important to understand the potential total scope of the project early in the planning process. For example, if there are changes in the use or building code “occupancy” classification of a building that place it into Risk Category

III or IV in Table 1604.4.5 of the *International Building Code* (ICC, 2012) the authority having jurisdiction may impose the code requirements for new buildings on the facility. The requirements for new buildings are discussed in Chapter 6 of this report.

For existing systems with identified vulnerabilities or limitations, there are several options for improving performance and reliability. However, as indicated in Chapter 6, what can be readily achieved with a new facility is much more difficult to achieve in an existing facility because of physical limitations and constraints. These physical limitations and constraints, as well as budget considerations, mean that an incremental or phased approach to adding or upgrading the emergency power system is a more feasible approach. Again, the local authority having jurisdiction should be consulted, regarding potential upgrades that may be required to meet the minimum emergency power requirements of current code.

Incremental and phased upgrades will involve compromise – what can be done within the time and budget constraints? In order to determine this, an assessment of the desired operational performance is needed, as well as an assessment of the existing electrical systems and physical plant. Work may be spread out over a number of years, as components are replaced and upgraded over time for operational reasons, as well as improvement of disaster response. Many successful phased upgrades to emergency or optional standby power systems have been tied to mechanical and electrical system upgrades that are driven by the replacement of obsolete or inefficient MEP systems. Replacement equipment components that draw less power and have special certification for seismic loads (if needed) can be selected. It may be possible to reconfigure some systems during an equipment replacement or upgrade project to reduce the number of components that must be on optional standby power.

7.1 Considerations for Determining Optional Standby and Emergency Power Demands in Existing Facilities

The first step is to define the critical electrical loads that must be powered by emergency or optional standby power systems. This means all equipment related to building critical functions and their associated electrical circuits, along with their peak and steady-state electrical loads, should be considered in determining the critical electrical loads. Once everything about the mechanical, electrical, and plumbing systems is known and documented, and the critical functional equipment and systems are identified, the most practical approach to providing standby power system capacity can be determined.

The preferred method of operating a facility on emergency or standby power is to energize only those loads required to operate the facility. Energizing more equipment than what is necessary requires a larger generator than necessary and more importantly, energizing non-critical loads reduces overall system reliability since the failure of any non-critical equipment or faults in any portion of the electrical system that supplies non-critical equipment can interrupt power to critical equipment. It should be noted that there are some critical facilities, such as dedicated emergency operation centers (EOCs), where all portions of the facilities are deemed critical.

An alternative, but a much less desirable method of operating a facility (other than an EOC type of facility) on emergency or optional standby power, is to energize the facility's main electric service. Theoretically, energizing the main service allows an optional standby generator to deliver power to any electrical load within the facility and provided the generator is large enough, any load can be run from that source. However, since it is rarely practical to supply a generator large enough to power all electrical loads (except for a dedicated EOC type facility), energizing a facility's electrical service equipment can create a risk that more power is drawn from a generator than it can be reliably or safely supplied.

When properly connected and operated, energizing a facility's electrical service can be an acceptable option until the facility can be modified to allow generators to only power equipment that is needed. In addition, Section 5.3 provides some considerations that should be made if optional standby generators are used as the alternate power.

7.1.1 Identifying Electrical Sources that Supply Critical Loads

All critical loads are supplied from a building's electrical service and distribution system but, because of insufficient documentation, it is often not known how the loads are supplied. This is particularly true in older facilities that have legacy wiring and equipment intermingled with newer wiring and equipment. Older facilities may have had modifications that were not fully documented and newer facilities may lack documentation of the original construction.

Construction drawings, when available, should be investigated first. Electrical one-line diagrams that show the entire service and distribution system, or riser diagrams that are one-line diagrams that also depict the physical layout of the service and distribution systems are particularly informative. One-line and riser diagrams also can identify logical connection points for introducing emergency power into a facility.

Some construction drawings contain circuit lists, which list individual branch circuits or feeders and what equipment is supplied by those circuits and feeders. That documentation can be invaluable at identifying power distribution within the facility. Mechanical equipment schedules should also be investigated for additional information.

Critical loads that draw large amounts of power are often supplied by electrical feeders which can have capacities of 100, 200 or even 1,000 amperes (often shortened to amps). Small critical loads may draw very little current and can be supplied by 15 or 20 ampere branch circuits. For reference, a 120 volt hair dryer typically draws about 10 amperes; a typical desktop computer draws around 2 amperes, whereas a 150 ton water cooled chiller, large enough to air condition a 40,000 square foot office building, draws the equivalent of 1,200 amps.

If electrical system documentation is incomplete, system information can be gathered by electrical circuit tracing where electrical signals are applied to individual circuits or feeders and then traced through the distribution system with sensing devices. This method can identify the branch circuits, branch circuit panelboards, and feeders that supply individual pieces of critical equipment. Once circuits, feeders, and panelboards that supply critical equipment are identified, additional investigation should be conducted to identify non-critical loads.

Information can also be developed by selectively de-energizing portions of the electrical service and distribution system and observing what equipment is affected. This can be done by opening circuit breakers, service disconnects, and overcurrent devices. This method should only be used when loss of power does not pose unacceptable risks to equipment or occupants. One benefit of selective de-energizing circuits and feeders is that doing so readily identifies both the critical and non-critical loads supplied by portions of the electrical system.

7.1.2 Reconfiguring Electrical Distribution

Once all pieces of critical equipment and the circuits, feeders, and panelboards that supply them are identified, methods of providing power from an emergency or optional standby source can be developed. In most cases, it will likely be more practical to construct new power distribution (i.e., new feeders, new distribution panelboards, new branch circuit panelboards, possibly new motor control centers) within the building and then transfer the individual circuits or feeders that supply critical loads to the new power distribution system.

The new power distribution system will require transfer switches, either manual or automatic, to transfer the critical loads from the normal power system when utility power is available to the emergency or alternate power source when utility power is lost. Transfer switches, or other methods, are required to prevent power from the optional standby power supply from back feeding through the building's electrical service onto utility lines. Back feeding can kill or injure utility workers trying to repair damaged lines and restore power.

Figure 7-1 is a schematic diagram that shows changes to an existing distribution system that allows selected loads to be supplied from an emergency or optional standby power system. The existing feeder and branch circuit that supply the critical equipment (labeled CE) are shown as dashed lines. Those must be disconnected when the critical loads are transferred to the new emergency or optional standby system. The diagram shows a new circuit breaker installed in the existing main service switchboard, a generator (labeled GEN), an automatic transfer switch (labeled ATS) that receives power from either the main service or from the generator and supplies the new optional standby power distribution system, a new emergency or optional standby distribution panel (labeled EDP) and a new branch circuit panelboard (labeled EP).

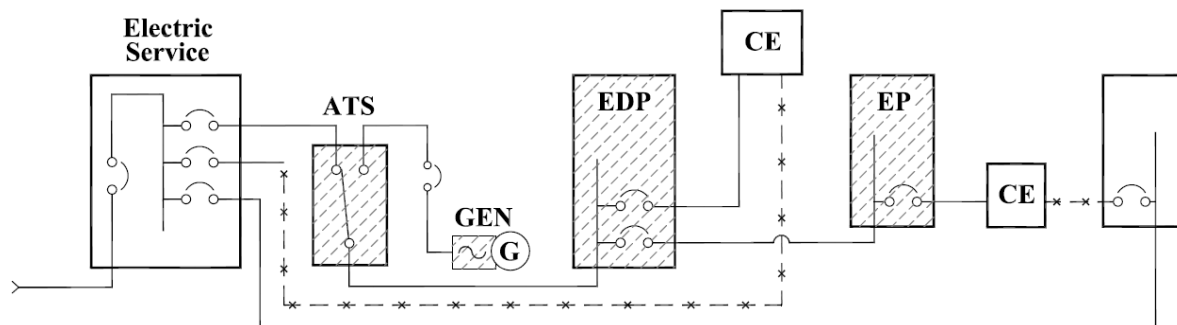


Figure 7-1 Schematic diagram showing changes to a facility that allows critical loads to be supplied from an optional standby generator.

The schematic also shows two pieces of critical equipment (CE) that need to operate to allow the facility to function. One piece of critical equipment is assumed to draw little power (e.g., a computer for HVAC controls) and can be supplied from the emergency branch circuit panelboard; the other critical equipment is assumed to draw more power (e.g., a sanitary sewer lift pump) and is fed from the higher capacity emergency distribution panel. In this schematic, since the transfer switch receives power from either the main service or the generator, it prevents power from the generator from back feeding into the main service equipment and the upstream utility system.

If the existing electrical distribution system that supplies critical equipment only supplies critical equipment or if it supplies some non-critical equipment but the non-critical equipment does not add significant power demands on the optional standby power source, then entire portions of the existing electrical distribution may be reconfigured to be supplied from the optional standby power source and the reconfiguration need not be done on an individual feeder/branch circuit level.

When reconfiguring the electrical system, code requirements must be considered. For example, to ensure reliability of the portion of the electrical system that supplies code-required critical loads, both the NFPA 70, *National Electrical Code* (NFPA, 2014) and NFPA 99, *Health Care Facilities Code* (NFPA, 2012a), limit what equipment can be supplied from critical sources or placed on feeders or circuits that supply code required critical loads. Code required loads, like emergency lighting, exit signage, and fire detection and alarms systems must be powered from dedicated circuits or feeders that do not supply other non-critical equipment. Equipment that is essential for a facility to function but that is not considered critical by those codes, must be fed separately.

7.1.3 Providing Optional Standby Power through the Electrical Service

When possible, providing optional standby power by energizing the entire electrical service should be avoided except for EOC type critical facilities. However, energizing the entire electrical service may be necessary before the electrical system can be reconfigured to supply only critical loads from optional standby sources.

The most critical aspect of energizing the building's service equipment from optional standby power sources is ensuring that power cannot be back fed onto the utility system. The preferred method is to install a transfer switch upstream of the building's service. The transfer switch allows the facility to be fed from either the utility or the optional standby power source but never simultaneously. Other methods of preventing back feeding onto utility lines may be acceptable. Alternate methods need to be acceptable to the electrical utility serving the facility.

Of the types of standby power systems defined by NFPA 70, the only one where a manual transfer switch is permitted is the optional standby systems. Each of the other systems requires an automatic transfer switch in order to meet the transfer time requirements. Therefore, if an onsite generator is present as the optional standby power source, the transfer switch could be either manual or automatic. If only a pre-wired connection for a portable

generator is installed, the transfer switch should be manual. However, the transfer switch would need to be automatic (and the generator would need to be sufficiently sized to power the entire building) if code required loads rely on that generator for emergency power.

Figure 7-2 is a schematic diagram of a transfer switch installed to supply service equipment from either the utility or from an optional standby power source.

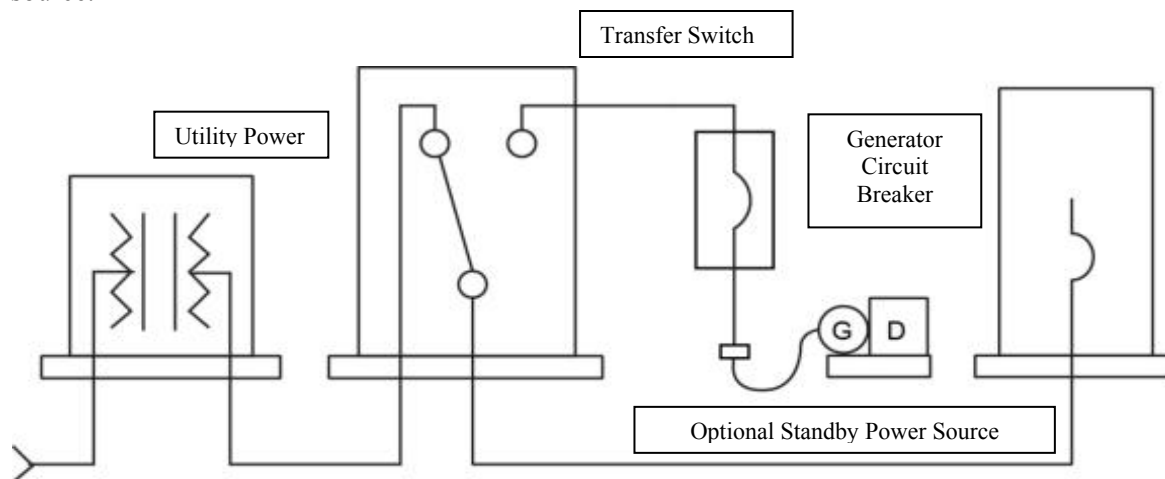


Figure 7-2 Schematic diagram showing transfer switch installed to supply an electrical service from either the utility or an optional standby power source.

Another critical aspect of energizing the electric service is ensuring that the generator is not overloaded. Energizing the electric service will allow power to be delivered to any device in the building unless it can be electrically isolated from the service. Opening all circuit breakers within the service equipment that do not supply critical equipment will prevent non-essential equipment from drawing power from and potentially overloading the emergency power supply. Identifying which circuit breakers that can be opened requires a detailed knowledge of the facility's electrical distribution system.

Often individual feeders or branch circuits supply both critical and non-critical equipment. In those instances, isolating the non-critical equipment may need to be done remote to the service equipment. NFPA 70 requires that means for disconnecting be located near equipment to allow it to be de-energized for servicing. If present, they can also be used to isolate the equipment from the optional standby power source. If service disconnects are not in place, the non-critical equipment may need to be manually turned off. If so, procedures to prevent the inadvertent operation of the equipment should be developed.

Providing emergency power through the main service requires equipment to be automatically controlled. Failure to do so and allowing equipment to be connected manually could cause an unacceptable voltage drop, or in the worst case, stall the generator or cause it trip offline.

7.2 Protecting Optional Standby Power Systems from Natural Hazards

Providing an optional standby power system to serve critical loads makes the facility much less vulnerable to loss of utility power. Making the optional standby power system resistant to floods, high winds, and seismic events can make the facility's ability to operate more reliably. In some cases, reliability of an existing facility can be improved by conducting simple steps to strengthen or harden the equipment connections and enclosures of the emergency power system.

In Section 6.4, recommendations for the layout and placement of new emergency power systems are provided to improve their resistance to withstand severe natural hazards. In Section 6.5, the code and regulatory requirements of new emergency power systems designed to withstand severe natural hazards are discussed. For situations where new optional standby power systems are being installed in existing critical facilities, it is recommended that the recommendations and code requirements of Sections 6.4 and 6.5 be followed for both the optional standby power system and the building or structure in which it is housed. If physical or financial limitations and constraints do not permit the recommendations of Sections 6.4 and 6.5 to be satisfied, it is recommended that the project design team minimize the vulnerability to the natural hazards to the maximum extent practicable to do so. This can be done in a cost effective manner, by addressing the components with the greatest vulnerabilities first. For example, unanchored optional standby power system components in regions of seismic risk are likely to displace or topple in moderate shaking. Simply anchoring the generator, battery racks and charger, day tank, exhaust system, and switchgear will significantly improve the likelihood that the optional standby power system will function after a seismic event. If the generator is in need of replacement, selecting a unit that has been seismically qualified by shake-table testing will greatly improve the odds of the generator functioning following a strong earthquake.

The project design team should also provide the facility owner a comparison of natural hazards for which the facility was designed, as compared to the recommendations of Sections 6.4 and 6.5 in the event the owner may elect to do further upgrades or replacements at a later date. It should be noted that

laws in some states mandate that critical facilities be retrofitted to function following severe natural hazards, as defined by the regulations. The project design team should check the laws and regulations that govern critical facilities for the jurisdiction for the existing critical facility for any laws and regulations that are applicable. It should be noted that if the primary goal is to have more reliable optional standby power, both the facility structure and the emergency power system should be evaluated and retrofitted as needed.

Appendix A

General Code Considerations for Emergency Power in Critical Facilities

Building codes, and their referenced architectural and engineering standards, govern the design and construction of buildings. The purpose of a building code is to establish the minimum acceptable design and construction requirements necessary for protecting the public, health, safety, and welfare. Structural integrity, building envelope integrity, fire and smoke resistance, life-safety considerations, sanitation, and recently, energy efficiency, are some of the issues addressed by contemporary building codes.

A.1 History of Building Codes

Over the last 50 years, numerous building codes have been developed. In the past, individual States, and occasionally individual cities, developed their own codes. However, because of the level of effort required to write and maintain effective building codes, private organizations were formed with the charge to write and maintain “model” building codes. Once developed, model codes are put through an extensive consensus process, which includes input from all interested parties.

Until 2000, three different model codes were widely adopted in the United States. Each of these codes was adopted in different regions of the country, and the provisions were strongly influenced by the specific concerns in each region. In the Northeast, the *National Building Code* developed by the Building Officials and Code Administrators (BOCA) was widely adopted; the *Uniform Building Code* developed by the International Council of Building Officials (ICBO) was widely adopted in the West; and the *Standard Building Code* developed by the Southern Building Code Congress International (SBCCI) was widely adopted in the Southeast. In the 1990s, BOCA, ICBO, and SBCCI elected to stop maintaining their individual codes and merged to become the International Code Council (ICC). The ICC developed a single series of building codes, commonly referred to as the I-Codes, which were intended for adoption throughout the United States. The series includes the: *International Building Code (IBC)*, *International*

This appendix is not intended to be an exhaustive discussion of emergency power requirements, but an overview of codes and standards and how they relate to emergency power, with emphasis on the emergency power requirements of the *International Building Code*.

There are other codes, engineering standards, and other requirements (like Joint Commission requirements for certifying health care facilities) that can apply to the design and construction of a building. Therefore, any discussion on code requirements for a wide range of facilities will inherently be limited.

Residential Code (IRC), International Mechanical Code, and the International Energy Code. The first editions of the I-Codes were issued in 2000.

The IBC and the IRC are the predominant building codes that have been adopted in the United States. These documents are revised every three years, but it is not unusual for the model codes to be amended by the adopting authority (state and local jurisdictions) to meet local needs. Facility owners and operators should consult with their local building and fire officials to determine what requirements are currently in effect.

The National Fire Protection Association (NFPA) also developed a model building code. NFPA 5000, *Building Construction and Safety Code* (NFPA, 2012c), was first issued in 2000 and continues to be updated and maintained. However, it is not widely adopted in the United States. Many jurisdictions have adopted NFPA 101, *Life Safety Code* (NFPA, 2012b), for new and existing occupancies. Health care facilities that are regulated by the Centers for Medicare and Medicaid Services (CMS) are required to comply with NFPA 101. NFPA 101 includes requirements for emergency power and emergency lighting systems.

Other national standards that establish requirements for electrical systems in critical facilities include NFPA 70, *National Electrical Code* (NFPA, 2014), NFPA 99, *Health Care Facilities Code* (NFPA, 2012a), and NFPA 110, *Standard for Emergency and Standby Power Systems* (NFPA, 2013c).

A.2 Emergency Power Requirements of the International Building Code

While the intent of the IBC includes language to guard against “other hazards,” emergency power requirements for most buildings are based on fire as the primary internal hazard and are included in Chapters 1-15 of IBC 2012. Structural design requirements for natural hazards are provided in Chapter 16 (See Section 6.4 of this document), but only the seismic requirements provide special requirements for provision of emergency power. However, the IBC references ASCE 24-05, *Flood Resistant Design and Construction* (ASCE, 2005), which requires utilities and equipment to either be elevated or dry floodproofed above the design flood elevation. Simply stated, Chapters 1 through 15 of the IBC requires most facilities to have enough emergency power to allow occupants to leave a building safely. It does not require emergency power to allow buildings to remain functional during a power outage.

The IBC requirements for emergency power are generally for short duration, typically 90 minutes, or about the maximum time required for occupants to exit a building. Ninety minutes of emergency power can, in most instances, be supplied by batteries or other stored energy devices. In most cases, emergency generators are not required to satisfy these code requirements.

For the small percentage of facilities where onsite generators are needed to satisfy code requirements, the generators typically only supply the minimum loads required for life safety. Life safety loads include: fire alarm and annunciation systems, smoke control systems, fire pumps where present, emergency and egress lighting, and conveyance systems that are required for egress. In most cases, onsite generators required by code have neither the capacity nor the supply that a facility needs to remain functional during prolonged power outages.

A.2.1 IBC Emergency Power Requirements by Occupancy Classification

Chapters 3 and 4 of the IBC contain provisions on the use and occupancy of buildings. How the buildings are used dictate methods of construction, egress requirements, life-safety requirements, and size requirements. Buildings are classified by Occupancy Classifications, and some occupancy classifications are further described by two or more Groups. For example, buildings with an occupancy classification of “Assembly” are used as gathering locations for civic, social, or religious functions, recreation or food consumption, or awaiting transportation. Within the “Assembly” occupancy classification, there are Groups A-1 (production or viewing of performing arts) through A-5 (participation or viewing of outdoor activities). Table A-1 lists the occupancy classifications of the 2012 IBC.

Facilities that typically house critical functions fall into the occupancy classifications shown in Table A-2. Note that building occupancies are determined by the locally adopted codes, as enforced by the authority having jurisdiction. The information in Table A-2 is provided to describe occupancies that are typically used for select critical facilities and should not be used to determine occupancy classifications.

For structural design purposes, buildings are classified in “Risk Categories” in IBC Chapter 16. Buildings considered to be critical facilities that are to be classified into Risk Category IV are listed in IBC 2012 Table 1604.5. Section 3.1 provides a description of the types of buildings included in Risk Category IV. Structural design of buildings is to be a level to avoid “unacceptable performance.” Such unacceptable performance for an essential facility in this code context would be for the building to experience

a structural failure such that it could not perform its essential functions when subjected to design level hazards. In addition, the seismic requirements of ASCE/SEI 7-10, which is referenced by 2012 IBC, also require that mechanical and electrical equipment and systems in Risk Category IV facilities that are necessary for the facility to perform its essential function be designed or seismically qualified so they will continue to function after being subjected to Design Earthquake motions.

Table A-1 Occupancy Classifications

Occupancy Classification	Groups
Assembly	A-1, A-2, A-3, A-4, A-5
Business	B
Educational	E
Factory and Industrial	F-1, F-2
High Hazard	H-1, H-2, H-3, H-4, H-5
Institutional	I-1, I-2, I-3, I-4
Mercantile	M
Residential	R-1, R-2, R-3, R-4
Storage	S-1, S-2
Utility and Miscellaneous	U

Table A-2 Critical Facilities by Occupancy

Occupancy Classification	Critical Facility
Group A – Assembly	Host shelters
	Evacuation shelters
	Community safe rooms ¹
Group B – Business	Police stations
	Emergency Operations Centers
	Fire stations (engine house/equipment bay excluded)
	Schools beyond the 12th grade
Group E – Educational	K through 12 schools
Group I – Institutional	Hospitals
	Nursing homes

¹ The 2012 IBC does not list community safe rooms in a specific occupancy classification. In the absence of a specific classification, Section 3.8 of FEMA P-361, *Design and Construction Guidance for Community Safe Rooms* (FEMA, 2008), recommends community safe rooms be designed as assembly Group A-3 when the space is used only as a safe room. For multi-use safe rooms where other occupancies apply, the requirements for the most stringent occupancy need to be met.

Emergency power requirements specified by the IBC and its referenced standards depend on the occupancy classification. Most of the emergency power requirements are to address the risk of fire as follows:

- Exit signs must identify doors that lead to the exterior to help occupants leave a building safely.
- Emergency lights to illuminate egress routes are required, particularly for corridors, which can fill with smoke.
- Fire alarm systems, either manually operated or automatically operated by smoke or heat detectors, or valves that detect water flow in sprinkler systems, must notify occupants when fire is present and may notify the local fire department.

In addition to the occupancy-based requirements, the IBC also requires emergency power for non-specific occupancy. For instance, the IBC requires emergency power for elevators, personnel lifts, and other conveyance systems when they are relied upon for building egress. The IBC also requires emergency power for smoke control systems. Table A-3 summarizes the occupancy-based IBC emergency power requirements for several occupancies.

Table A-3 Emergency Power Requirement by Occupancy

Emergency Power Requirement	IBC Reference	Occupancy Classification			
		Group A - Assembly	Group B - Business	Group E - Educational	Group I - Institutional
Exit signs	Section 1011	X	X	X	X
Emergency lighting	Section 1006	X	X	X	X
Fire alarm	Section 907	X	X	X	X
Emergency voice/alarm systems	Section 907	X	X	X	X
Smoke control/management systems	Section 909	X			
Elevators, lifts, and other conveyance systems required for egress ¹	Section 1007	X	X	X	X

¹ For high-rise buildings, some emergency power is required for elevators (e.g., car lighting) even when the elevators are not required for egress.

Some of the most stringent emergency power requirements are for Occupancy Group H (High Hazard). In those facilities, emergency power is

required to prevent the release of hazardous materials and prevent explosions that can occur when normal power is lost. The IBC also contains emergency power requirements for underground buildings, covered mall buildings, and membrane (air inflated) structures; however, because those structures are rarely used for a community's critical facilities, IBC emergency power requirements for those types of buildings are not discussed here.

Several other model codes, engineering standards, and guidance documents apply to health care facilities in the Institutional Group. This document does not provide an exhaustive list or description of applicable codes for those facilities.

A.2.2 Emergency Power Duration Requirements

The IBC has the following requirements for emergency power duration:

- *Exit Signs*: IBC 2012 Section 1011.6.3 requires that emergency power systems for exit signs provide power for a minimum of 90 minutes.
- *Emergency Lighting*: IBC 2012 Section 1006.3 requires the same 90-minute duration for emergency lighting.
- *Fire Alarm Systems*: IBC 2012 references NFPA 72, *National Fire Alarm and Signaling Code* (NFPA, 2013a), for fire alarm system requirements.

Smoke control systems, elevators, lifts, and other equipment required for egress require continuous emergency power.

A.3 Fire Pump Requirements

Many facilities use automatic sprinkler systems, which use water for fire suppression. For various reasons, sufficient water pressure and volume may not be available from a municipal water system to meet code requirements for a facility sprinkler system. In those facilities, fire pumps are required to boost municipal water pressure and volume. The specific requirements for fire pumps can be found in NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection* (NFPA, 2013d).

Fire pumps can be powered by direct-coupled diesel engines or electric motors. Fire pumps powered by electric motor have special code requirements. Fire pumps are code-mandated to have a reliable source of power. Determining the reliability of power sources, however, is subjective, and decisions are often made by the local authority having jurisdiction (plan examiners or inspectors) without the benefit of specific reliability criteria. To ensure this important device has reliable power, plan examiners and

inspectors often require a second power source. The second source is often an onsite stand-by generator; a feeder from the generator to provide this second source is included. NFPA 20 specifies the requirements for standby power for fire pumps. Facility owners and operators should work closely with the authority having jurisdiction to ensure compliance with the applicable code requirements. The insurance company that is providing coverage for the facility may also provide guidance that can reduce risk premiums.

Section 3-6.4 of Unified Facilities Criteria (UFC) 3-600-01, *Design Manual for Fire Protection* (Department of Defense, 2006), provides some guidance on utility system reliability. UFC 3-600-01 defines a reliable electrical source as “a power source having an average forced down time, excluding scheduled repairs, which does not exceed 8 consecutive hours for any one incident or more than 24 hours cumulatively over the last 3 years.” The goal of fire protection is the protection of life and property. To protect occupants of critical facilities that may be occupied during prolonged power outages, UFC 3-600-01 recommends that fire pumps be connected to emergency power generators (even if not required by local authorities) to provide power whenever the facility is occupied, and thereby ensure the pumps can operate when normal power is not available.

A.4 Critical Healthcare Facility Power Distribution Requirements

NFPA 99 *Healthcare Facilities Code* lists requirements for provision of emergency power in critical healthcare facilities. These requirements are subdivided into distribution branches to power various groups of medical equipment and support facilities. These are the following: (1) equipment branch; (2) critical branch; and (3) life-safety branch. The life-safety branch is the most important and given the highest priority.

These requirements are specifically designed for healthcare facilities, but they offer a good set of guidelines for other facilities to consider when determining what elements should be provided with emergency power beyond the basic code minimum requirements.

A detailed list of elements, taken from NFPA 99 is listed in Tables A-4 through A-7. Those elements which correspond to basic code requirements, generally the items on the Life Safety Branch, are included in Table 4-1.

Table A-4 Items Requiring Emergency Power in Healthcare Facilities: Life Safety Branch

Life Safety Branch	
A.	Egress lighting
B.	Exit signs and exit directional signs
C.	Hospital communications systems where used for issuing emergency related instructions
D.	Generator set location as follows
a.	Task illumination
b.	Battery charger for emergency battery-powered lighting unit(s)
c.	Select receptacles at the generator set location and essential electrical system transfer switch locations
E.	Elevator cab lighting, control, communications
F.	Electrically powered doors used for building egress
G.	Fire alarms and auxiliary functions of fire alarm systems complying with NFPA 72

Table A-5 Items Requiring Emergency Power in Healthcare Facilities: Critical Branch

Critical Branch	
A.	Task lighting and select receptacles in anesthetizing gases locations
B.	Isolated power systems in special environments
C.	Task illumination and select receptacles in patient care rooms including infant nurseries, selected acute nursing areas, psychiatric bed areas (omit receptacles), and ward treatment rooms, medication preparation areas, pharmacy dispensing areas, nurses' stations (unless adequately lighted by corridor luminaires)
D.	Additional specialized patient care task illumination and receptacles, where needed
E.	Nurse call systems
F.	Blood, bone, and tissue banks
G.	Telephone equipment rooms and closets
H.	Task illumination, select receptacles, and select power circuits for general care beds with at least one duplex receptacle per patient bedroom, and task illumination as required by the governing body of the health care facility, angiographic labs, cardiac catheterization labs, coronary care units, hemodialysis rooms or areas, emergency room treatment areas, human physiology labs, intensive care units, postoperative recovery rooms
I.	Additional task illumination, receptacles, and select power circuits needed for effective facility operation, including single-phase fractional horsepower motors, which are permitted to be connected to the critical branch

Table A-6 Items Requiring Emergency Power in Healthcare Facilities: Equipment Branch (Automatic Connection)

Equipment Branch	
A.	Central suction systems serving medical and surgical functions
B.	Sump pumps and other equipment required to operate for the safety of major apparatus, including associated control systems and alarms
C.	Compressed air systems serving medical and surgical functions
D.	Smoke control and stair pressurization systems
E.	Kitchen hood supply or exhaust systems, or both, if required to operate during a fire in or under the hood
F.	Supply, return, and exhaust ventilating systems for airborne infectious/isolation rooms, protective environment rooms, exhaust fans for laboratory fume hoods, nuclear medicine areas where radioactive material is used, ethylene oxide Evacuation, anesthetic evacuation.
G.	Where delayed automatic connection is not appropriate, ventilation system shall be permitted to be placed on the Critical Branch

Table A-7 Items Requiring Emergency Power in Healthcare Facilities: Equipment Branch (Automatic or Manual Connection)

Equipment Branch	
A.	Heating equipment used to provide heating for operating, delivery, labor, recovery, intensive care, coronary care, nurseries, infection/isolation rooms, emergency treatment spaces, and general patient rooms; and pressure maintenance (jockey or make-up) pump(s) for water-based fire protection systems
B.	Heating of general patient rooms during disruption of the normal source shall not be required under any of the following condition
a.	Outside design temperature is higher than 6.7°C (+20°F)
b.	Outside design temperature is lower than 6.7°C (+20°F), where a selected room(s) is provided for the needs of all confined patients [then only such room(s) need be heated]
C.	Elevator(s) selected to provide service to patient, surgical, obstetrical, and ground floors
D.	Supply, return, and exhaust ventilating systems for surgical and obstetrical delivery suites, intensive care, coronary care, nurseries, and emergency treatment spaces
E.	Hyperbaric facilities
F.	Hypobaric facilities
G.	Autoclaving equipment, which is permitted to be arranged for either automatic or manual connection to the alternate source
H.	Controls for equipment listed in NFPA 99, 6.4.2.2.4
I.	Other selected equipment

Redundancy of Electrical Power Systems

Redundancy is a key strategy for improving the reliability of both utility power systems and individual critical facility emergency power systems. In this Appendix, the concepts and the common implementation approaches to redundancy for these systems are described.

B.1 Redundant Utility Source Delivery

The point at which the utilities revenue metering is installed is called the “utility service entrance” point. The system upstream of that point is the utility’s responsibility; the downstream components are generally the responsibility of the end users. In order to create utility service redundancy, critical facilities, such as hospitals, large campuses, and industrial plants or complex commercial facilities, often negotiate with the utility (or occasionally with other utilities) to supply power from more than one utility source. In some cases the separate source may be supplied by the utility from dedicated sub-transmission or distribution lines. With this level of utility redundancy, a high level of reliability is attained.

The theory of redundant services is that the probability of all electrical services failing simultaneously is much less than the probability of a single-service failure. Redundant services can provide uninterrupted electric power even when one service fails or, as a minimum, redundant services can significantly reduce outage durations when an electrical failure occurs. However, having multiple incoming distribution lines can be expensive and may be cost prohibitive for many users.

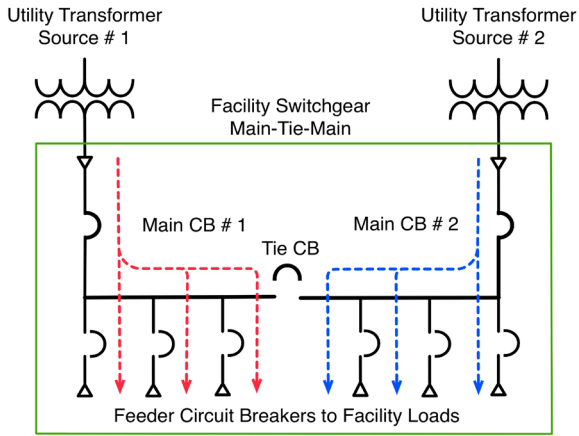
One of the more common methods of employing redundant utility feeds is shown in Figure B-1. With this method, two separate utility transformers provide power to two separate services that supply a double-ended service switchboard. The switchboard contains two main circuit breakers (one for each of the two services) and a tie circuit breaker. The facility can be operated in two possible line-ups. In the normal operation mode shown below (Figure B-1a), both main circuit breakers are kept closed and the tie breaker kept open. Operation from both utility sources is referred to as “normal” because the loading of utility equipment keeps it warm and

minimizes deterioration of condensing humidity. With the normal operation mode, both utility services supply the facility: One utility service supplies the left-hand switchgear and the other utility service supplies the right-hand switchgear with the tie breaker in open position, separating the two. With the line-up shown in Scenario #1 and Scenario #2 (Figures B-1b and B-1c, respectively), one of the main service circuit breakers and the tie breaker are kept closed, and the other main service breaker is open. With these line-ups, the entire facility is powered from one of the two services. Physically, there is no difference in the wiring configuration between the two line-ups. The difference is only in how they are typically operated and how the facility can respond to an electrical outage.

As shown in Figure B-1b (Scenario #1), the loss of Utility Source #2 will briefly shut down the left-hand section of the switchgear, but by opening the failed service circuit breaker and closing the previously open tie breaker, the facility can be re-energized quickly. In Scenario #2, the loss of Utility Source #1 will interrupt power to the right-hand switchgear of the circuit but power can be reestablished quickly by opening the failed service circuit breaker and closing the tie breaker. In critical facilities, this “main – tie – main” circuit breaker opening and closing is generally automatic.

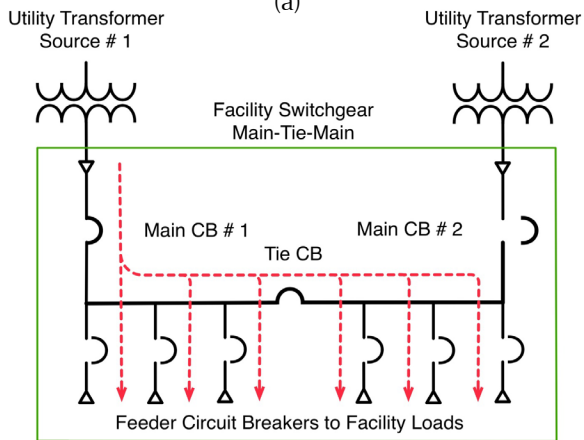
It can be observed that another option for normal operation is as follows: the entire facility could operate from one of the utility sources with one main and the tie breaker closed and the redundant utility feeder open; but in ready reserve. Failure of the normally closed utility feed could initiate a switch from one source to the other with the tie breaker remaining unchanged. The transfer from one utility to the other source would require a delay of many seconds. This delay is necessary to allow for all facility motor loads to spin down and preclude them from acting as generators. This temporary source of electrical energy would be out of synch with the utility source and result in a damaging fault if connected to the utility. It is noted that for redundant feeds to be most effective, utility sources should originate from different distribution line circuits and preferably from different distribution substations.

Other variations of redundant utility source delivery are possible with cooperation with the electrical service provider. A common example where a single point of utility power delivery is used but where some redundancy is provided would be a “spot network.” With a spot network, power is introduced into a network (also called “collector bus”) at several points. For power at the collector bus to be lost, all power connections feeding that bus would need to fail. The network is typically operated at distribution voltages



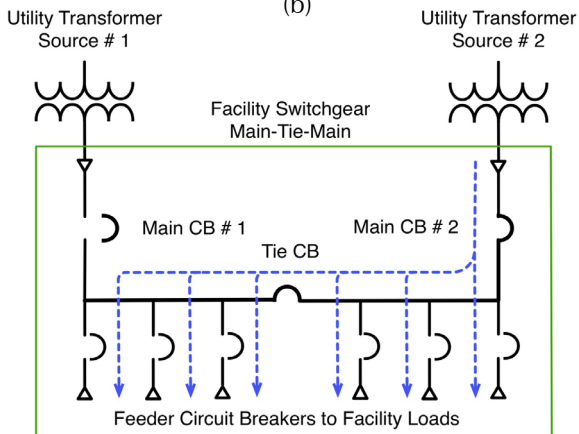
Normal Operation - Both Utility Sources Available
Close MCB's # 1 & 2 and Open Tie CB

(a)



Scenario # 1 - Utility Source # 2 Fails
Open MCB # 2 and Close Tie CB

(b)



Scenario # 2 - Utility Source # 1 Fails
Open MCB # 1 and Close Tie CB

(c)

Figure B-1 Schematic diagram for one style of redundant service illustrating circuit breaker responses if a utility source fails.

Again, for redundant feeds to be most effective, they should originate from different distribution line circuits and preferably from different distribution substations.

While there are many variations of utility-networked systems, they all have in common the ability to supply uninterrupted power to the customer's facility through some parallel redundancies should one or more of the utility's sources fail. This type of utility scheme is especially advantageous for users with large inductive motor loads where voltage sags can occur. This paralleling of utility sources requires highly specialized network equipment and redundant power feeders.

B.2 *N+1 Redundancy Strategy*

Critical facility managers often feel that the installation of an onsite emergency generator will provide uninterrupted power to the facility. However, it is important to realize that any power source, whether it is a utility service or an onsite generator, can fail. Each critical facility manager should be acutely aware that any power system employed can be called upon in the most critical time. Prudent planning dictates careful consideration be given to the potential for failure even in an emergency power system.

N+1 is a strategy providing redundancy to safeguard against a single component failure. N+1 is a term used in numerous applications including power distribution, mechanical systems, and information technology. In N+1 terminology, "N" stands for the minimum number of devices, such as modules, power sources, and pumps, required to perform the intended function. "N+1" stands for the minimum plus one redundant unit. For example, one large generator may supply critical loads in a building. But when called upon, a simple failure will prevent from operating when it is needed. Instead, a strategy involving two smaller generators to supply the load, with a third generator of equal size in parallel as a group provide N+1 redundancy. Most highly critical facilities, such as hospitals and large data centers, employ an N+1 strategy whether utilizing batteries, generator systems, or a combination of both. This strategy is also advocated by operations and maintenance considerations, allowing single units to be taken offline for preventive maintenance without sacrificing operations protection. N+1 strategy can be applied to each component of the critical system. One large fuel tank can be replaced by two smaller tanks with parallel fuel rails feeding the multiple generator system. Parallel filter sets allow a filter clog or be changed while continuing to operate. Parallel generator start battery packs with individual chargers are inexpensive options providing significant redundancy to components historically most likely to fail. Critical facilities,

such as hospitals, are required by code to maintain parallel utility feeds into the main switchgear as described above. Applying N+1 strategy, many large-scale critical facilities also use parallel emergency bus feeders to emergency panel boards.

When formulating an N+1 design strategy, it is important to consider the impact of any aspects of the design having a common failure mode that could negate the intended N+1 performance objective. An example would be the placement of the “normal power” electrical switchgear in the same room (or within the same fire barrier) as the emergency generator electrical switchgear. A fire, flood, or other hazard that causes all of the electrical switchgear to fail negates the N+1 design.

Regardless of what customer or utility supplied redundancy is determined to meet the post-event operational performance expectations of the critical facility, it is imperative that all stakeholders consider the increased space and facility requirements. The overall business performance expectations may be such that more than twice the space would be required over that of a baseline code compliant facility. This reality of design and construction requirements should not be overlooked when planning new systems or retrofitting into a completed facility. The implementation of redundancy strategies for critical equipment and systems is an integral part of emergency management contingency planning and should be carefully considered by facility operators and design professionals.

This appendix discusses the sizing of generators for emergency or alternate power systems.

C.1 Generator Load Requirements

Generators must be large enough to supply their peak electrical load while maintaining adequate voltage and frequency. The peak electrical load is generally the load required to start the largest motor (or the motor with the most extreme starting characteristics) while being base-loaded by all other equipment that may need to run concurrently.

Motors require much more current to start than to operate. Their starting characteristics depend on many factors, such as their synchronous speed, their inertia, and their electrical characteristics. When designing supplies for motors, engineers consider a motor's locked rotor current. As the name implies, the locked rotor current is the amount of current drawn when a motor's shaft is locked in place and prevented from rotating. When started, the amount of current a motor draws approaches its locked rotor current and in most installations, the locked rotor current must be provided while the generator is already operating other loads.

Motors are assigned a code letter that correlates their locked rotor current to their horsepower (hp). Table C-1, based on NFPA 70, *National Electrical Code* (NFPA, 2014), lists code letters for motors and the associated ranges of locked rotor kVA/hp. As an example, a 10 hp Code K motor would draw between 80.0 kVA ($10 \text{ hp} \times 8.0 \text{ kVA/hp}$) and 89.9 kVA ($10 \text{ hp} \times 8.99 \text{ kVA/hp}$) under a locked rotor condition.

Assuming that the generator had to supply a 35 kVA load while starting that motor, its peak load would be 35 kVA plus 89.9 kVA for a total of 125 kVA. A generator with a peak capacity of 125 kVA would be the minimum required: a 150 kVA generator would likely be chosen to provide some room for expansion. If the motor had a less severe starting characteristic (for example, a Code D motor) a smaller generator would suffice. An 80 kVA generator could start a 10 hp Code D motor ($10 \text{ hp} \times 4.49 \text{ kVA/hp}$ for a total of 45 kVA) while concurrently supplying a 35 kVA load. Again, the prudent selection of a 100 kVA unit would provide capacity for load expansion.

**Table C-1 Motor Codes and Associated Lock Rotor Apparent Power (kVA/hp)
(from NFPA 70)**

NFPA 70 Table 430-7(B) - Locked Rotor Indicating Code Letters	
Code Letter	Kilovolt-Ampere per Horsepower with Locked Rotor
A	0 - 3.14
B	3.15 - 3.54
C	3.55 - 3.99
D	4.0 - 4.49
E	4.5 - 4.99
F	5.0 - 5.59
G	5.6 - 6.29
H	6.3 - 7.09
J	7.1 - 7.99
K	8.0 - 8.99
L	9.0 - 9.99
M	10.0 - 11.19
N	11.2 - 12.49
P	12.5 - 13.99
R	14.0 - 15.99
S	16.0 - 17.99
T	18.0 - 19.99
U	20.0 - 22.39
V	22.4 and up

It should be noted that for short durations, generators can supply loads in excess of their nameplate rating. The amount of additional capacity depends on how closely the prime mover is matched to the generator, on the synchronous speed and the inertia of the generator and the prime mover and on the duration that the load must be supplied. Generator manufacturers should be consulted to determine the ability of a generator to support short duration loading.

Often several motors, all smaller than the largest motor, are connected to an electrical system in a fashion that as soon as the system is energized (either by normal or emergency power), the motors will attempt to start

simultaneously. When powered from an emergency generator, the generator recognizes the group as one large motor and that significant generator capacity is needed to successfully start those motors. Simple controls, like adding time delay relays so all of the generators do not try to start immediately after power resumes or controls that stagger-start motors can prevent the simultaneous starting of several motors. Such controls are relatively easy to obtain, can be installed relatively inexpensively, and can significantly reduce required generator capacity. When this strategy is deployed, it is common practice to start the motor with the largest surge current first. An exception to this is when larger motors are associated with cycling loads. For this case, the largest cycling motor should be started last and therefore the generator size will be increased to handle the running steady-state load of the non-cycling motors plus the starting surge current of the cycling motor(s). Strategies for progressively starting allow the smallest generator set for the overall total emergency power load.

Other improvements are available to reduce required generator capacity needed to start the largest motor(s). For example, wye-delta (or star-delta) starters allow the motor to be started with reduced voltage, which reduces the starting currents and the required generator capacity. Also, reactor starting where reactors (inductive impedance) are introduced in series with the motor can also reduce starting currents. The inductors are removed from the circuit after the motor reaches its operating speed. Digital soft starters and variable frequency drives (VFDs), used to vary the speed of motors, can also reduce starting demand and required generator capacity. Often, the savings associated with reducing generator capacity more than offset the cost of installing motor controls (particularly if sophisticated controls are only needed only on a few motors).

Most steps that reduce starting demand reduce the torque that the motor produces while starting. Before those actions are taken, it should be confirmed that reduced starting torque is acceptable.

Non-linear loads must be reviewed to determine if it will be necessary to de-rate generator capacity to compensate for heating effects of harmonic currents. If field measurements are used to determine harmonic contributions, it will be necessary to utilize specialized instrumentation to determine harmonic content. Typical non-linear loads are caused by the use of the following:

- Variable frequency drives,
- Solid-state type uninterruptible power supply units,

- Battery charger loads used to convert AC to DC and provide a controlled charge to batteries,
- Lighting loads, except incandescent, and
- In the case of a high-density environment of personal computers, it may be necessary to increase neutral capacity to carry significantly larger “third harmonic current.”

Other specialized loads which can impact generator sizing are:

- Medical imaging loads – Voltage dip limits must not be exceeded when operated with all other loads, and
- Regenerative loads, such as elevators, cranes, and hoist, where the power source absorbs power during braking when the motor is being overhauled by its dynamic load and acting as a generator.

C.2 Continuous Generator Load

Predicting the continuous load on a generator follows the same approach as estimating the continuous load on a utility power service. The total connected load on an emergency system is totaled and demand and diversity factors are applied to address the fact that all loads do not operate continuously at their maximum load. Diversification is a common term used to refer to the cyclic or non-concurrent operational characteristics of multiple loads on the entire system. The design engineer should have a good understanding of the diversity component of the total expected load early in the sizing calculation.

Predicting demand and diversity factors is never straightforward. There are several publications available to assist electrical engineers and designers estimate continuous load, many published by the Institute of Electrical and Electronics Engineers (IEEE).

Designers are cautioned not to use the same demand and diversity factors for an emergency system as used for the normal utility system. When a facility is operated under emergency power, the occupancy of the facility may be significantly different than during non-emergency operations and the equipment that is energized from the generator may be operated with different demand and diversity factors than those under normal conditions. To address this, designers need to select demand and load factors that accurately represent the system when powered from the emergency power source.

C.3 Maximum Allowable Voltage Dip

The ideal generator would provide constant voltage under any load condition. However, like utility power systems, generators are not ideal. With both types of systems, voltage dips or momentary sags occur as loads are added. Invariably, utility power systems are “stiffer” than standalone generators and experience less voltage fluctuation for a given added load.

Commercially available generators have a certain amount of voltage output variation as a function of their rated load. As load is added to a generator, the voltage output dips until the generator engine and regulator can work together and compensate for the added load (by increasing fuel flow) and return the voltage to normal. Large, instantaneous load additions contribute to larger voltage dips.

If the entire load that a generator serves is added simultaneously, the generator can experience a severe voltage dip. However, if the load is added gradually, in a step-wise fashion, the generator voltage drop will be less. For this reason, generator sizing should consider not only the maximum load but how loads in a facility will be applied. For example, consider a building that has no building automation system to control HVAC loads. If the generator for that building were required to carry the load on a hot or cold day, many of the HVAC units would likely start simultaneously when the loads were transferred to the generator, contributing to a higher-than-normal voltage drop. To limit the voltage drop to acceptable levels, a larger generator would need to be selected. Alternatively, controls must be chosen.

The allowable step voltage dip percentage must also be chosen. Some generator manufacturers list a 35% default allowable voltage dip percentage. This amount of voltage dip can be excessive for an office building with a high concentration of sensitive electronics, such as computers and data processing equipment. For such facilities, a more moderate voltage dip percentage of 20% may be preferred and included in the calculations. Reducing the allowable voltage dip will require a generator with a larger capacity.

C.4 Maximum Allowable Frequency Dip

The ideal generator power frequency output would always exactly match that of the electric utility, which in the United States is typically 60 Hz (many European countries operate on 50 Hz). However, similar to voltage dip described previously, frequency decreases as loads are added to a generator until the generator engine and regulator can compensate and return the

frequency to normal. Large, instantaneous load additions generally result in larger frequency dips.

The allowable frequency dip percentage must also be chosen. Some manufacturers list a 10% default allowable frequency dip. This may be excessive for some facilities. A more moderate dip of 6% may be preferred. Like tighter voltage control, tighter frequency control results in a need for larger generators.

C.5 Caution on Oversizing Generators

Although capacity for additional allowance should be considered for future growth, providing a diesel generator that is oversized by more than double the current load is not advised. Operating a diesel generator for extended periods under light loading conditions can lead to engine damage, reducing its reliability and significantly increasing maintenance costs. In some cases, generators have required a complete engine overhaul within only a few hundred hours of operation because of this phenomenon. Most manufacturers recommend continuous loading on the diesel generator of at least 30% of its rated capacity. This minimum continuous loading level requirement factors heavily into decisions regarding generator capacity sizing and selection.

Unlike gasoline engines utilizing spark plugs, a diesel engine utilizes hot compressed air in the cylinder to vaporize and ignite the fuel. Diesel generators operating under low load conditions burn very little fuel and as a result run cooler than their design temperature. Cooler temperatures within the cylinder create less than optimum burn conditions resulting in soot forming in the engine and exhaust system. This soot condenses in exhaust stacks creating “wet stacking.” This condition, over a prolonged period, can seriously degrade engine performance and can lead to permanent engine damage. Careful design and thorough generator test protocols should be used to eliminate potential wet stacking.

To avoid oversizing generators, yet still provide for load growth, engineers should size generators close to the required load but consider adding additional generators in the future in the design provisions. Ensuring generator rooms have space for additional units, additional switchgear, and likely synchronizing gear will allow logical and effective expansions to an emergency power system. When properly planned, installing additional units for increased system capacity can also facilitate maintenance and improve reliability.

Appendix D

Emergency Power System Operational Checklist

The following checklists are provided as a helpful aid on items that should be checked before, during and following an extreme natural hazard event. They should be tailored to the individual facility situation.

Disclaimer: The following information supplements the generator manufacturer’s application, installation, operation, and maintenance information and requirements. Always read, understand, and follow the manufacturer’s guidance. When there is conflict between the manufacturer’s and the below information, consult with qualified personnel to determine necessary methods and materials.

Table D-1 Checklist for Emergency Planning Prior to Emergency or Disaster

Checklist for Emergency Planning Prior to Emergency or Disaster			✓
1.	Combustion Air Intake and Exhaust Systems		
a.	Louvers	Operational with no restricted movement and no obstructions	
b.	Rain cap	No restricted movement	
c.	Exhaust piping	No foreign object blockage, i.e., bird and rodent nesting, condensation drained	
2.	Batteries		
a.	Batteries installed in conditioned air space to avoid temperature extremes		
b.	Interconnecting cables sized to compensate for voltage drop		
c.	Charging system operational and alarms tested		
d.	Specific gravity and voltages checked and acceptable		
e.	Cable connections corrosion free and tight on both ends		
3.	Generator set controller		
a.	All lock-out faults investigated, corrected, and cleared		
b.	AUTO start engaged		
4.	Output circuit breakers	Closed or ready and able to close if electrically operated	
5.	Load cables	Clean and terminations checked for proper spacing and torque	
6.	Engine block, generator space heaters, circulating pump(s)	Operational and circulating warm coolant and oil (if equipped with pump)	

Table D-1 Checklist for Emergency Planning Prior to Emergency or Disaster (Continued)

Checklist for Emergency Planning Prior to Emergency or Disaster		✓
7.	Fuel Delivery System	
a.	Fuel quality tested and storage vessels maintained to prevent water accumulation and bacterial growth	
b.	Storage vessels, including day tanks, topped to appropriate levels	
c.	Fuel transfer pumps powered by emergency system and periodically tested	
d.	Preferred customer agreements in place with fuel suppliers to assure delivery	
8.	Engine oil	
a.	Low run time, capable of at least 48 hours continuous run time	
b.	Level proper	
c.	Scheduled Oil Sample results reviewed and proper actions taken	
d.	Spare oil and delivery methods, i.e. funnels, pumps, drum carts, etc. nearby	
e.	Leaks	Inspect and correct
9.	Consumables	10 day supply (minimum) in on-site storage
a.	Fuel filters	
b.	Oil filters	
c.	Air filters	
d.	Oil	
e.	Coolant	
10.	Local, state, and federal authorities and service organizations	
a.	Emergency plans developed	
b.	Road maintenance crews aware and in agreement that site's public access is critical and shall be maintained and at all times to allow emergency vehicle passage	
c.	Aware and in agreement that fuel delivery and engine generator set parts and service organizations are to be considered and labeled as emergency vehicles with authorized site passage	
d.	Service organizations have developed emergency plans to assure effective support staffing is available and capable	
11.	Communications	
a.	Portable cell towers available and capable of being placed and made operational in short time	
b.	Site two-way radios and cell phones charged and fully operational	
c.	Site data reception and transmission systems inspected and proper operation tested with remote facilities and personnel	
12.	Generator	
a.	Windings clean	
b.	Space heaters operational	
c.	Bearings properly greased	
d.	Air intake and exhaust air paths cleared of dirt, debris, and obstructions	
13.	Cooling system	
a.	Proper levels	
b.	Leaks	Inspect and correct

Table D-2 Checklist for Operation During Emergency or Disaster

Checklist for Operation During Emergency or Disaster			✓
1.	Combustion air intake	Louvers open and no obstructions	
2.	Output circuit breakers	Closed or ready and able to close if electrically operated	
3.	Fuel delivery system		
	a.	Fuel quality tested and storage vessels maintained to prevent water accumulation and bacterial growth	
	b.	Storage vessels, including day tanks, topped to appropriate levels	
	c.	Fuel transfer pumps powered	
	d.	Water separators drained	
4.	Engine oil		
	a.	Level checked periodically and determined proper	
	b.	Plan oil changes on the fly if needed	
5.	Consumables	Restock to 10 day supply (minimum) in on-site storage	
	a.	Fuel filters	
	b.	Oil filters	
	c.	Air filters	
	d.	Oil	
	e.	Coolant	
6.	Local, State, and Federal Authorities and Service Organizations		
	a.	Emergency plans implemented	
	b.	Road maintenance crews maintaining site's public access	
	c.	Fuel delivery and engine generator set parts and service organizations allowed site access	
	d.	Service organizations implemented emergency plans to assure effective support staffing is available and capable	
7.	Communications		
	a.	Portable cell towers available and capable of being placed and made operational in short time	
	b.	Site two-way radios and cell phones charged and fully operational	
	c.	Site data reception and transmission systems properly operating	
8.	Generator		
	a.	Winding temperatures acceptable	
	b.	Bearings properly greased	
	c.	Air intake and exhaust air paths cleared of debris and obstructions	
	d.	Stable output voltage and frequency	
9.	Condition Monitoring		
	a.	Receiving data	
	b.	Results normal	

Table D-3 Checklist for Recovery Following Emergency or Disaster

Checklist for Recovery Following Emergency or Disaster			✓
1.	Combustion Air Intake and Exhaust Systems		
a.	Louvers	Closed and no obstructions	
b.	Rain cap	Closed	
c.	Exhaust piping	Inspect and drain condensation	
d.	Wet stacking	Inspect and develop corrective action plan	
2.	Batteries		
a.	Charging system operational and alarms tested		
b.	Specific gravity and voltages checked and acceptable		
c.	Cable connections corrosion free and tight on both ends		
3.	Generator set controller		
a.	All lock-out faults investigated, corrected, and cleared		
b.	AUTO start engaged		
4.	Output circuit breakers	Closed or ready and able to close if electrically operated	
5.	Load cables	Clean and terminations checked for proper spacing and torque	
6.	Engine block, generator space heaters, circulating pump(s)	Operational and circulating warm coolant and oil (if equipped with pump)	
7.	Fuel delivery system		
a.	Fuel quality tested and storage vessels maintained to prevent water accumulation and bacterial growth		
b.	Storage vessels, including day tanks, topped to appropriate levels		
8.	Engine oil		
a.	Change oil and filter(s) and sample as needed		
b.	Level proper		
9.	Consumables	Re-stock to 10 day supply (minimum) in on-site storage	
a.	Fuel filters		
b.	Oil filters		
c.	Air filters		
d.	Oil		
e.	Coolant		
10.	Local, state, and federal authorities and service organizations		
a.	Emergency plans reviewed and improved		
b.	Road maintenance crews remove debris and repair damage to allow site access		
c.	Service organization emergency plans reviewed and improved		
11.	Communications		
a.	Portable cell towers retracted, maintained, and properly stored		
b.	Site two-way radios and cell phones charged and fully operational		
c.	Site data reception and transmission systems inspected and proper operation tested with remote facilities and personnel		

Table D-3 Recovery Following Emergency or Disaster (Continued)

Checklist for Recovery Following Emergency or Disaster		✓
12.	Insulation system test conducted and results analyzed to detect erosion	
a.	Space heaters operational	
b.	Air intake and exhaust air paths cleared of debris and obstructions	
c.	Air gap between rotor pole and stator measured at 12:00, 3:00, 6:00, and 9:00 positions, recorded, and analyzed to detect bearing wear or misalignment	
d.	Excitation system inspected and tested	
e.	Voltage regulator connections inspected and properly torqued	
f.	Insulation system test conducted and results analyzed to detect erosion	
13.	Cooling System	
a.	Proper levels	
b.	Drain, flush, and replace coolant as needed	
c.	Leaks Inspect and correct	

Appendix E

Examples of How to Utilize this Document

This appendix provides two examples complete with descriptions of challenges and solutions as an instructional tool to better understand the use of this document to aid in decision making for emergency power systems. The flow chart provided in Chapter 1 illustrates the underlying decision making process. As stated throughout this document, facility owners and operators should collaborate with a qualified integrated design team to develop solutions.

E.1 Example 1 – New Facility

A rural town in the Midwest is planning the construction of three new schools: a new elementary school (grades K through 4), a middle school (grades 5 through 8) and a high school. Design for the first phase, the new elementary school is complete. The construction project has been awarded and site work is scheduled to begin within two months. The remaining two schools are planned to be completed within 12 years. The town is approaching its bond limit and the schedule for the final school will be dictated by final construction costs of the first two schools.

The area is vulnerable to tornadoes and winter storms. An EF-2 tornado struck the town four years ago and destroyed 20 homes; more were damaged but were repairable. Many of the overhead distribution lines were constructed in the 1940 and 1950s and are particularly vulnerable to damage when radial ice accretion levels exceed 1/4 inch. Power outages from winter storms typically last four days but can extend into two weeks.

The local planning board passed a resolution to fund construction of tornado safe rooms in each new school to provide protection for students, staff, and volunteers. The planning board also passed a resolution to support the use of schools for short-term host shelters for residents of the town.

The school board, planning board, and the design team for the middle school are collaborating to determine the feasibility of providing emergency power that will allow the gymnasium to be used as a host shelter that can house residents following winter storms. Emergency power for the tornado safe

room, estimated to be only 7.5 kW for lights and ventilation, will be part of the safe room budget. The bond limits are placing constraints on the project budget.

E.1.1 Emergency Power Functions Determination

A needs assessment is conducted, as follows.

E.1.1.1 Normal Operations

- The school will be designed for a population of 600 students and a staff of 40 teachers, administrative staff, and custodial staff.
- The single floor structure will be constructed on grade. No below grade spaces are proposed.
- The entire school will be heated and mechanically cooled by packaged natural gas fired rooftop units with integral DX units with compressors, condensers and evaporative coils.
- Sanitary sewer will be gravity fed; a potable water service and a fire suppression service will be provided. Hydrant tests confirm domestic pressures are sufficient; no fire pump or domestic water booster pump will be required. A fractional horsepower jockey pump may be installed on the sprinkler system to maintain pressure.
- Exit signage, egress lighting and a fire alarm detection and annunciation system will be provided to meet the requirements of NPFA 101, Life Safety Code (NFPA, 2012b). The emergency power source for exit and emergency lighting and for the fire alarm system will be provided by batteries integral to that equipment.
- A 100 foot by 125 foot gymnasium will be constructed on the east side of the site. Restroom and locker room facilities will be adjacent to the gymnasium.
- The gymnasium will have dedicated HVAC units.
- Gymnasium lighting will be high intensity discharge (HID) metal halide.
- A 30 foot by 70 foot kitchen and a 70 foot by 70 foot cafeteria will be constructed on the west side of the site.
- The kitchen's ovens, grills, and steam tables will be natural-gas fired and controlled electrically. A commercial walk-in freezer and walk-in refrigerator are proposed.
- The cafeteria will have movable furnishings to allow the space to function as an auditorium.

E.1.1.2 Operations as a Host Shelter

- The usable space in the gymnasium can provide space to shelter 100 people at the recommended 50 square feet per person.
- The host shelter will be made available approximately two days after an event and will remain operational for up to 14 days.
- The host shelter will be used primarily to house occupants displaced from their homes by loss of power following winter storms.
- Food service is desired.

E.1.2 Proposed Solution

Preliminary electrical load analyses based on square footage estimates predict that the total operating load for the gymnasium, kitchen, and cafeteria, while operating in the heating mode, will be 100 kW. Air conditioning would add an additional 75 kW.

At current construction pricing, a permanently installed generator is estimated at \$200,000. The additional cost required to allow the equipment serving the gymnasium, kitchen, and cafeteria to be operated as optional standby equipment is estimated at \$20,000. That includes the cost of dedicated feeders, manual transfer switches, and panelboards. The flanged connection for a permanent generator is estimated at \$12,000.

The permanent generator and its required maintenance are considered impractical with the town's projected construction projects and its bond status. The planning board considered the additional site work and infrastructure that will allow the gymnasium, kitchen, and cafeteria to be supplied from an optional standby generator acceptable.

The design team developed the following concepts to allow portions of the facility to function as a host shelter:

- Provide a concrete pad with vehicle access adjacent to the electrical service room.
- Install an emergency distribution panel in the electrical room. Distribute emergency power from a manual transfer switch that receives power from the main electrical service or from a portable generator.
- Install two dedicated panelboards in the kitchen wing and two in the gymnasium. Combining the distribution equipment for the gymnasium and kitchen is not practical due to the physical separation of the two areas. (One panelboard for HVAC loads and one for lighting and other electrical loads.)

- Select each HVAC unit for the kitchen and the gymnasium from two separate feeders. One feeder will supply heating, ventilation, and control functions; the second feeder will supply air conditioning.
- Supply the fire alarm, egress lighting, and exit signage from an emergency power panel.
- Supply other desired loads (telephone, network server, computer outlets, clock system, staff lounge) from an emergency power panel when the desired equipment improves functionality, but does not significantly increase required loads on the emergency system.
- Elevate all essential equipment to protect from flooding; install all essential equipment to resist wind damage and damage from seismic events.
- Establish contracts with local suppliers for temporary generators, fuel, and generator service.

E.2 Example 2 – Existing Facility

A medium size community hospital is planning an expansion. The current bed tower has NFPA 99, *Health Care Facilities Code* (NFPA, 2012a), compliant emergency power and distribution but would like to provide for a new 50-bed expansion wing, as well as air conditioning for the total in-patient population and expanded emergency services in radiology. The current hospital employs one 2,000 kW generator to serve the existing emergency power needs but is fully loaded by the existing building. The hospital administration is lobbying to install a second 2,000 kW generator to double generation capacity. Budgetary constraints are an issue as construction of the 50-bed addition absorbs the majority of available funding.

E.2.1 Analysis: Emergency Power Functions Determination

- It is readily understood that minimum NFPA 99 required emergency power will not satisfy the business model of sustained community health care service during a local emergency event advocated by upper management. A detailed study of the exact equipment and emergency power loads needed shows that the proposed additional 2,000 kW load is generally divided equally between NFPA 99 requirements for the new bed tower including air conditioning and the upgrades for the existing in-patient spaces and radiology equipment.
- Maintenance operations note that during a recent winter storm power outage, a small day tank pump at the generator failed. Maintenance was

able to troubleshoot and bypass this pump quickly but noted the facility was within 20 minutes of generator failure at a critical moment.

- Engineering analysis recognizes the current basement level of the hospital is below the 500-year base flood elevation.
- Budgetary constraints become evident that the entire 2,000 kW desired addition will not be immediately financially achievable.

E.2.2 Proposed Solution

- The realization of the maintenance issue concerning the day tank pump resonates with management. The value of an N+1 redundant scheme is readily apparent (see Appendix B). The addition of two 1,000 kW generators instead of the one 2,000 kW is preferred.
- The redundancy scheme is extended to distribution feeders as well. It is noted that the current emergency bus carrying the supply to the building was originally sized to handle the original 2,000 kW generator and is at capacity. Rather than up-size the current bus, a second bus can be installed parallel to the existing bus. This allows constructability of the new system while keeping the existing building emergency power capability intact, lowering the construction costs of removing the existing busway.
- Generator synchronizing board and switchgear installations are planned for an extended mechanical space on the second floor protecting the new gear from flooding.
- The fuel storage tank must also be upsized to maintain the hospital's regulatory requirement of 96-hour runtime. A second tank can be installed with cross-connect capability such that any generator's day tank can be fed from either main storage tank. Care must be taken in a re-circulating fuel rail assembly such that returning fuel cannot route to a single tank either starving one or overfilling another.
- Budgetary constraints are a major concern and a phased approach is offered.
 - Phase 1 – Install one 1,000 kW generator, second bus, and new synchronizing switchboard. This new service will primarily serve the new bed tower expansion but feeding a common board for distribution as needed. The new programmable switchgear and multiple generators will allow for loads to be categorized into priority blocks. Life-safety equipment will reside in a priority block, which will keep life safety and selected loads from the new tower and existing building operational in the event of a single generator

failure. Subsequent equipment can operate at a lower priority and be load shed in case of a single generator failure.

- Phase 2 – In a subsequent budget year, the second 1,000 kW generator can be added to the existing system, readily expanding the capabilities of equipment served by emergency power. General patient population air conditioning for the existing in-patient population, as well as select radiology services, can be added.
- Phase 3 - If the second bus is sized properly, a future third generator can be added to the set. With proper synchronizing board programming modifications, the current bus hardware can be utilized providing additional emergency power with lower installation costs.

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