

**Report on the Super Bowl Power and Lighting Issue
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On February 3rd, 2013, near the beginning of the third quarter of the NFL Super Bowl, the New Orleans Superdome experienced a power outage which affected half of the stadium. This event resulted in the lighting within the affected half of the stadium remaining off for over 30 minutes—although power was restored to the stadium relatively soon after the outage occurred. Events such as this have happened several times recently at high profile sporting events, including two outages occurring within the same game.

The following paper provides an analysis of some of the possible causes of above events, a discussing related to the provided explanation of the outage in New Orleans, a discussion of the type of lighting most commonly used in stadiums, analysis of other lighting technologies, and a conclusion related to how such events may be avoided in the future via changes and improvements to existing technologies.

Though utilities typically deliver power at dependable and reliability levels, events occur within the power distribution system which may cause abnormalities in the quality of the power delivered. The study of these disturbances falls within the area of power quality (PQ) research. Power quality research can include the investigation of a range of events, but IEEE Standard 1159 does provide a guide for dealing with certain power quality events.

The latest version of IEEE 1159 was published in 2009. On page 4 of this standard, a table is provided for the reader that covers the types of problem-causing events that may occur in a variety of locations, applications, and situations.

Group	Examples
Conducted low-frequency phenomena	Harmonics, interharmonics
	Signal systems (power line carrier)
	Voltage fluctuations
	Voltage dips and interruptions
	Voltage imbalance
	Power-frequency variations
	Induced low-frequency voltages
	DC in AC networks
Radiated low-frequency phenomena	Magnetic fields
	Electric fields
Conducted high-frequency phenomena	Induced continuous wave (CW) voltages or currents
	Unidirectional transients
	Oscillatory transients
Radiated high-frequency phenomena	Magnetic fields
	Electric fields
	Electromagnetic fields
	Continuous waves
	Transients
Electrostatic discharge phenomena (ESD)	—
Nuclear electromagnetic pulse (NEMP)	—

Table 1 – Principal phenomena causing electromagnetic disturbances as classified by the IEC - IEEE STD 1159-2009

As one may see from the table above, several events may lead to power failures within buildings. The events most commonly researched in power system failures include harmonics, undervoltage, overvoltage, voltage sags, voltage swells, ring-wave surges, and combination-wave surges. A brief description of each of these events may be found in the appendix of this document.

Though the above events can cause lighting systems to fail, the failure at the 2013 Super Bowl is currently attributed to a circuit breaker faulting opened due to an abnormality being detected. The event remains under investigation at the time of this writing; however, the result was the loss of power to half of the stadium. It should be noted that the Super Dome is fed from multiple sources to help reduce the likelihood of such events. Additionally, it has been reported that the Super dome had a backup generator to deal with the loss of power. It has also been reported that this system functioned correctly¹, and that the local power provider and the facility management company subsequently began the orderly repowering of the complex. A deeper discussion of generator and backup power system will occur later in this article.

¹ <http://www.fox8live.com/story/20953653/the-following-is-a-joint-statement-from-entergy-and-smg-management-company-of-the-mercedes-benz-superdome-regarding-the-partial-power-loss-during-the>

HID (High Intensity Discharge) lighting is the most common form of lighting used within the United States due to its high lumen output, long lamp life and low maintenance cost, the easy availability of replacement lamps, an established installation, service and maintenance base, and relatively low cost of initial acquisition. HID lamps come in several varieties, but the two primary HID technologies in use today are HPS (High Pressure Sodium), and MH (Metal Halide). Light from HPS lamps is more yellowish in tint, where light from MH lamps is more blue-white in tint. Both of these lamp technologies are available in a range of wattages to deliver solutions to a variety of lighting applications.

In discussing HID lamps and HID-based lighting systems, one should note that HID lamps contain mercury. This means that any special storage and handling requirements, as well as the cost of disposal at end of life, must be considered as part of the cost of using HID based lighting. One important characteristic of HID lamps is their warm-up time. The effect is that when they strike, or re-strike, they require a few minutes to reach full brightness. In fact, some HID systems are so sensitive to power conditions that the lamps will switch off if power drops for even one cycle. This susceptibility to power issues may have led to the long re-strike time seen in New Orleans.

Two key advantages contributing to the popularity of HID-based lighting system are their lifespan and efficiency. High Intensity Discharge lamps claim life spans of 12,000 to 40,000 hours (depending on brand, technology, and features), and lumen output of approximately 100 lumens per watt. Thus, an average 200W HID MH lamp is designed to produce approximately 20,000 lumens with approximately 20,000 hours of operational life. Assuming 12 hours of operation per day, then about 4.5 years of operation may occur before a lamp must be replaced. Additionally, HID lamps are capable of operating in a range of environmental conditions; thus, they work well in interior and exterior applications.

Typical HID lighting applications include sporting venues, sports fields, parking lot lighting, street lighting, facade or building lighting, signage and billboard lighting, high bay or warehouse lighting, big box retail lighting, manufacturing or assembly line lighting, and loading dock lighting. Other technologies—which will be discussed below—are useful in those applications as well; however, the HID lamp is the predominant technology used in high output/high lumen and long life applications within the United States due to the characteristics of these lamps and lighting systems.

HID lamps may be driven by either magnetic ballasts (low cost, inefficient, iron core-based, available in a wide range of wattages up to 2500W), or electronic ballasts (higher cost, more efficient, driven by integrated circuits, currently limited to around 1000W). Electronic ballasts typically offer a power savings of over 30% or more over magnetic ballasts, and also offer greater reliability and efficiency due to the power electronics and the solid state components used within them. Typically, a 400W magnetically-ballasted HID fixture is replaced with a 250W electronically-ballasted fixture. Additionally, some electronic ballasts offer the ability to dim the lamps without fully shutting them off—a critical feature in some applications.

Though HID lamps have many advantages, they require the lamp to cool before being re-struck. The amount of time necessary for the lamp to cool sufficiently before re-strike varies within HID-based technologies; however, in general, the larger the wattage, the longer the time required for the lamp to

cool before re-strike may occur. Electronically-ballasted HID lamps will typically re-strike sooner than magnetically-ballasted HID lamps of equal wattage due to the difference in lamp performance and the ballast technology.

This strike/re-strike characteristic is typically not a significant problem for HID-based systems since the vast majority that are deployed are in lower wattages (which cool quickly), or in applications where instant or fast re-strike is not required. Typical HID applications include street lights—where the lamps come on at dusk and turn off at dawn, high bay, warehouse, big box retail, or manufacturing lighting—where the lights are turned on and left on for hours at a time—and exterior lighting such as building façade or billboard lighting—again, where the lamps come on and stay on for hours at a time.

In all of these applications, the re-strike or start time of the lamp is rarely an issue—when one of these lights goes out it is off sufficiently long enough to cool and re-strike when needed. Even in the event of a power outage of just a few cycles, or a few seconds, typical street lights are able to cool and restart in just a few minutes after power is returned due to their relative low wattages (typically 400W and below).

As stated above, HID-based lighting is the primary form of lighting used in sports venues and sports fields within the United States. These venues can be found in almost every community, city, and town within the US. The vast majorities of these venues are relatively small in comparison to large sports venues, and are designed to accommodate only a few hundred to a few thousand people. These venues typically take the form of multi-use community centers, community fields, and school gyms or fields. Most of these venues use fairly low wattage HID-based lighting systems (400W or below), due to the design and size factors listed above. In fact, most of these venues employ similar fixtures to those which are used in high bay warehouses, street lighting, or façade lighting in other parts of the community and can use a range of lamp types to meet the individual needs of the application. Due to the nature of the use of these facilities, the re-strike or start time characteristic of these lamps is not an issue as the lamps are typically turned on prior to the start of the events and left on until the events are complete.

Though far less in number than the local and community facilities described above, the large stadiums and venues which dominate high-profile college and professional athletics typically use high-wattage HID lamps when distances of more than 70 feet or so are required. However, a lighting system within a large athletic venue must deliver light a greater distance—due to the physical size of the stadium—and at a higher level and intensity—due to the nature of the event, the fan base, and the unique needs of broadcast television—than that required in typical sports arenas.

The distance that the light must travel between the fixture and the lit surface is critical to choice of technology, or variant within a technology, to be deployed. A high-wattage high-bay fixture similar to that found in many warehouses may be used to light surfaces in basketball, hockey, and similar venues where the light may be delivered from directly above the surface and from a height of 70 feet and below. Should the distance of the light throw exceed about 70 feet, however, then specialized high-wattage HID lighting is typically chosen as it is able to address the unique requirements of these venues. It should be noted that—even in large stadiums and venues with their unique constraints—the initial

start up time of HID-based lighting may not become an issue as the venue lighting is typically activated hours prior to the beginning of the event.

Due to the special circumstances and conditions described above, the majority of these large sports venues depend on magnetically-ballasted, HID Metal Halide-based lamp systems to deliver light to the field, floor, or venue. Metal Halide lamps are chosen typically due to their color temperature and the nature of the light produced. As discussed previously, the technology behind these systems may be considered dated, and consists of large iron-core ballasts capable of producing enough power (although not efficiently) to drive high lumen output lamps. Typically, the wattage for these lamps exceeds 1200 Watts and may be as high as 2500 Watts. Since these lamps typically deliver over 100 lumens per watt, a 1500W MH lamp may deliver 150,000 or more lumens of bright, white light over the hundred or more feet required in these large venues.

As seen with the power outage during the 2013 Super Bowl, and as noted above in this report, these lights—although bright—prove to be sensitive to power interruptions and are not capable of quickly restarting once they go offline. The long re-strike time results from the large amount of heat generated by the lamp's core or capsule: before re-striking, these lamps must be cold, or must cool significantly. As mentioned previously, the amount of time required for these lamps to cool varies with wattage, technology, and design, but typically, the higher the wattage, the longer the time required for the lamps to cool. This design characteristic of high-wattage HID lamps may be what led to the 30-plus minute delay before the affected lamps restarted at the Super Dome.

In large sports stadiums, the cool down/re-strike time of these magnetically-ballasted high-wattage HID lamps can impact the event, the fans, and other involved parties. Unfortunately, the high-lumen output of high-wattage HID lamp—when paired with their ability to deliver a long-throw distance—is difficult to duplicate with other technologies due to the special circumstances presented by these environments.

Events such as that which occurred at the Super Bowl can lead some to wonder why other lighting technologies offering faster re-strike/cool down times are not installed. Below are a few overviews of some other high-lumen output lighting technologies and why they have not been found to be suitable replacements for magnetically-ballasted HID lamps up to this point. A chart illustrating the re-strike/warm-up times for these and HID lighting technologies is shown in Figure 1.

- **EHID (Electronically-ballasted HID) systems** –These HID ballasts offer high efficiency, high lumens per watt values, and improved reliability over magnetically-ballasted HID systems. Additionally, EHID ballasts offer a faster re-strike time over magnetically-ballasted HID systems. However, these re-strike times vary depending on wattages. Unfortunately, EHID ballasts are currently not available in high enough wattage/lumen output packages to serve as adequate replacements for the magnetically-ballasted HID systems currently in use in large sports stadiums. As this technology progresses, and as larger wattage systems become available, this technology may offer a viable solution for these applications.
- **Induction Lighting** – Induction lighting is a fluorescent-like technology which uses a magnetic field to excite the gases within the tube. These systems offer long life (claimed 100,000-hour

lifespan), are vibration resistant, and offer a high lumen-to-watt output. As with conventional fluorescent technologies, induction lamps contain mercury. The strike/re-strike operation of these lamps is similar to that of a fluorescent or CFL lamp in that they are temperature sensitive. In a warm environment or should the lamp be warm, they strike easily and reach full brightness very quickly, but in colder environments, or with a cold lamp, a few minutes may be necessary for the lamp to reach full brightness. Unfortunately, the shape of induction lamps (either a circle or D shape), the relative size of the lamp compared to other lamp technologies, and the current limit of 500 Watts and below serve to limit the maximum lumen output of induction lamps to a level well below that of high-wattage HID lamps. This limitation prevents this technology from being a viable replacement option for magnetically-ballasted HID systems at this time.

- **LED Lighting** – LED lighting is an area of interest to many at this time. The technology offers long life (typically 50,000 hours in high bay or exterior applications) instant-on capability with full light, no re-strike time, dimmability, good efficiency, and reduced issues related to environmental concerns over mercury-based lamps. Use of LED lighting allows many buildings to reach the highest levels LEED certification. LED's produce directional light and may be considered point sources. Thus, the light they produce is delivered in the direction they are pointed. Lenses within LED systems are used to diffuse the produced light to provide a broader light distribution pattern. By contrast, omni-directional light produced by a lamp (as with HID) depends on a reflector to direct the produced light in a single direction. Some LED-based architectural lighting systems are capable of delivering light several hundred feet in a tight band as may be seen on numerous building facades, many of these installations also demonstrate the color changing characteristics of some LED's. However, it should be noted that the delivery of LED-based light over several hundred feet is accomplished in dark or night applications. At this time, LED's have not demonstrated the capability of delivering light in great density over great distances in lit environments, although large advances in the light delivery capacity of LED's occur annually and some manufacturers claim to be on the brink of resolving this issue. Therefore, though LED's offer many features which would show them to be viable replacements for high wattage magnetically-ballasted HID systems, current LED technology—LED chips of sufficient size, proper lens techniques, even with grouped or ganged configurations—cannot deliver a sufficient amount of light the distance required in bright environments to fully light the playing field of a large sporting arena.
- **Plasma Lighting** – Plasma lighting a hybrid technology of HID and Induction technology where light is produced within a miniaturized HID capsule via a microwave field. This technology is capable of producing large amounts of light, is dimmable, and can be customized to deliver a range of color temperatures. This technology offers approximately 50,000 hours of life between capsule and driver retrofits, and offers approximately 30% power savings over traditional HID technologies. Plasma light sources do not include mercury. Like HID lamps, plasma-based lighting systems depend on reflectors to direct light to the surface being illuminated. Plasma light sources also require a warm-up time to full brightness—typically about one to two minutes—and a re-strike time after being turned off. This re-strike time is typically less than two minutes. Currently, plasma lighting is being offered as an alternative to traditional HID lighting in applications like high bay, parking, and some street lighting applications. Unfortunately at this

time, plasma-based lighting does not offer sufficient lumen output, packaging or ganging options, or lens options capable of delivering the amount of light over the necessary distances to replace the high-wattage, magnetically-ballasted lamps typically installed in stadium applications.

- **Other lighting technologies – incandescent, CFL, etc** – lighting technologies other than the ones listed previously already exist. Unfortunately, these technologies are typically not available in configurations that produce the necessary lumens, and do not offer viable replacement options for HID lamps. Additionally, these other technologies typically do not offer the lifespan and durability required for the environment found in stadium and large sporting venues.

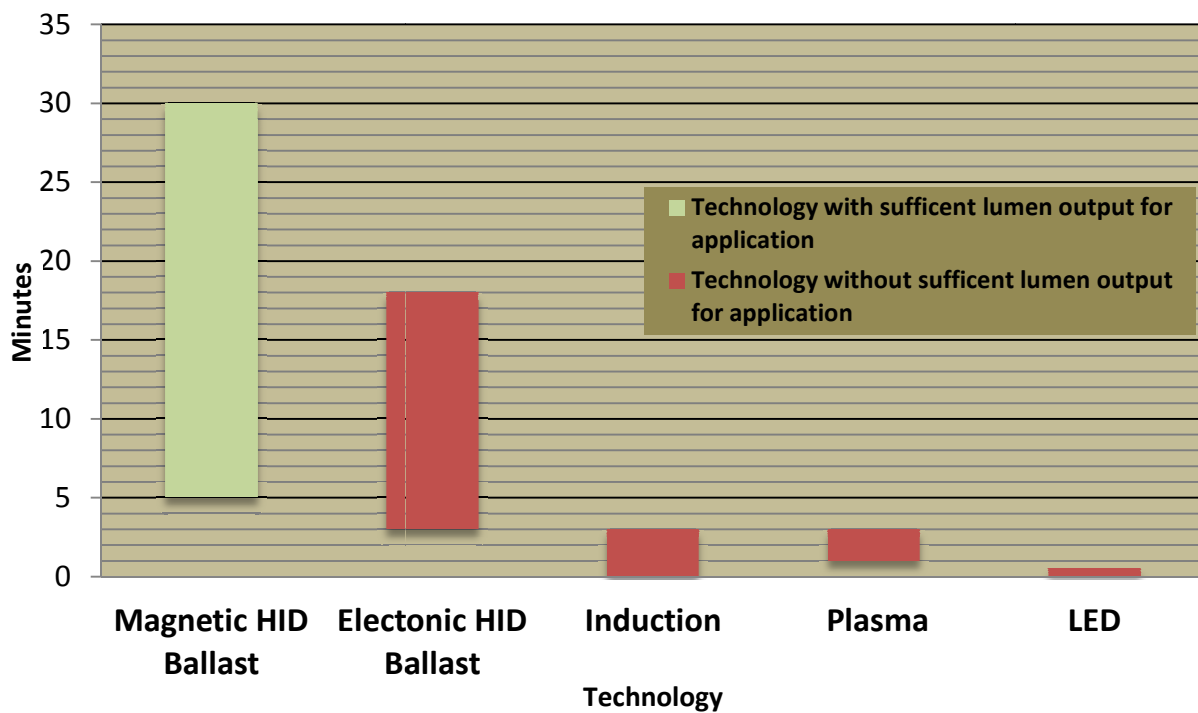


Figure 1
Approximate Re-strike/Warm-up Time of Lighting Technologies – In Minutes

Therefore, with magnetically-ballasted, HID-based systems being the primary and best existing technology to deliver high-lumen packages required for the large distances in stadium applications, the question arises: what may be done, or what may be used help reduce or mitigate events such as that which occurred in New Orleans on February 3rd? Two approaches may prove to be effective.

The first approach to consider would involve further improvements in lighting technologies. These improvements could take a number of directions, but the goal would be similar: high-lumen output, faster strike/re-strike lighting capable of delivering the necessary lumens at stadium distances. This goal may be achieved, for instance, with further improvements in HID lamp technologies, which would offer faster re-strike times in large wattage lamps. Another method, the development of multi-head HID fixtures, could combine numerous HID lamps of 500W or less into one fixture. This would allow for the

delivery of an equal amount of light, but the re-strike time would be reduced because the individual HID lamps, being smaller, would cool and re-strike sooner than the single, large-wattage lamps they are designed to replace. This method may result in larger physical fixtures with equal or great power consumption of each fixture as each lamp would require its own ballast. However, were these issues known, they could be included in the stadium design. Yet another method may involve the enhancement of EHID ballasts which would allow them to become viable replacements for high-wattage applications, as EHID ballasts typically allow for faster re-strike times than comparable magnetic HID ballasts. A fourth method could be the continued improvement of competitive, high-output technologies such as LED, induction, and plasma lighting sources to allow them to deliver sufficiently high lumens over the distances required for stadium environments. All of these methods may be possible at this point due to the innovative nature of the lighting industry. Moreover, the suggestions described above, and others as well, may be undertaken to deliver solutions to situations such as power outages or power events at large sporting good venues and other unique lighting applications.

The second approach to consider would require the analysis and study of power quality events so that effective bridge power systems may be specified to provide temporary power to the lighting system until the diesel generators may activate and come on-line to carry the load. Typical diesel generators are installed with an Automatic Transfer Switch (ATS). The switch automatically disconnects from the power source when power is lost and connects to the generator once it activates and is ready to come on-line—which can take about 10 seconds or more. It has been reported that the New Orleans Super Dome uses generators and backup power systems to mitigate power interruptions during events should they occur. These systems have been reported to have operated properly in some articles. Had these technologies operated flawlessly and automatically transferred from the faulted power source to generator power, the lighting loads would have seen a power outage for as much as a 10 to 20 seconds—no power would have been provided to these critical loads. Therefore, the re-strike time delay would still have been an issue. Regardless of the exact nature of the operation of the Super Dome's generators, several viable bridge-power options currently exist to help mitigate the effects of power quality events or outages in large venues such as the Superdome. These solutions take the form of flywheel or battery-based UPS systems as illustrated in Figure-2.

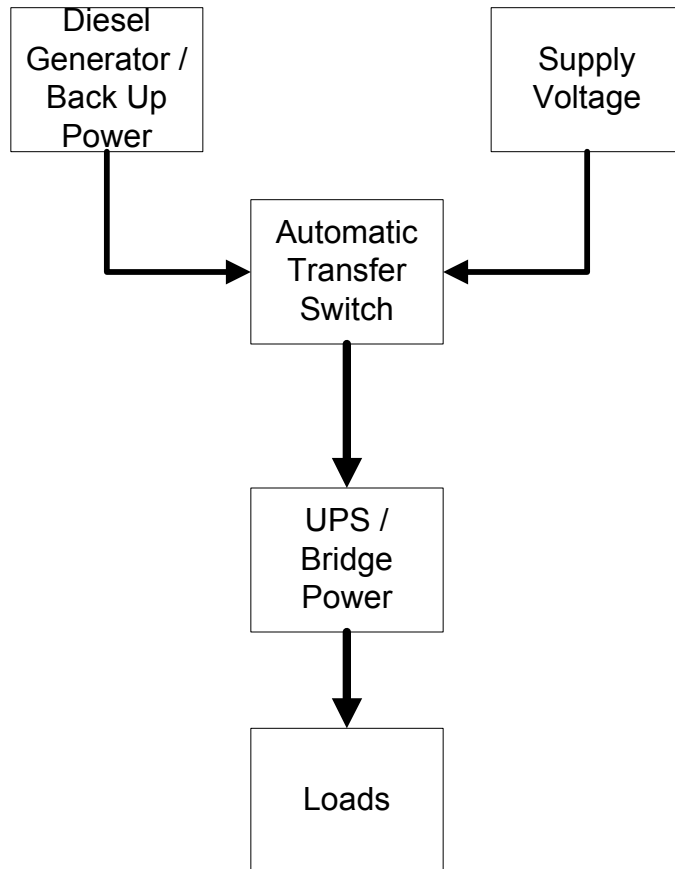


Figure-2
Typical Backup Power Configuration

Regardless of the form they take, these solutions are typically installed in series downstream of the ATS. Once power is lost on the input of the bridge power system, the system must be capable of delivering sufficient power to assure that sensitive systems such as computers, data centers, and lighting are able to operate until the ATS switches to the generator. Zero downtime applications such as data centers, hospital operating rooms, and critical industrial processes may achieve this feat through the use of either a large battery or a flywheel-based UPS bridge power system. Currently, these zero downtime solutions are expensive and somewhat large; however, these provide very effective bridge power solutions when properly designed and installed. These systems continue to improve in fast-switching power technologies, flywheel designs, and battery chemistry and such systems may see reductions of both the physical size and the response times along with increases in overall efficiency, reliability, and capacity.

As seen during the 2013 Super Bowl, the quick restoration of power to a circuit does not assure the ability to continue normal or planned operations quickly. Once sensitive systems go offline, they must be allowed sufficient time to restart, reboot, cool and re-strike, or reinitialize. As more and more end-use loads are controlled by drivers with power-sensitive components, it becomes more and more critical for power assurance/power quality devices to be fast-acting and sufficient in size to keep these loads operational during short-term power quality events.

Regardless of the solution approach taken to reduce the possibility of power interruptions, it is also critical that the deployed systems be tested regularly—ensuring that the systems are operational and have sufficient capacity to handle power quality events. Part of this testing must include regular maintenance and monitoring to assure all the components within the system are operational. The successful performance of high-end and expensive power solutions can be prevented by the failure of relatively inexpensive components which have not been maintained. No proof exists that this occurred in New Orleans, but it is critical to be sure that backup systems are tested and operating correctly.

At this time, it would appear that the best way to reduce the likelihood of events occurring in the future—such as that seen at this year’s Super Bowl—would be to focus on improvements in various components of lighting systems and lamp technologies, thus improving the performance of both existing technologies and future high-output lighting systems. Such improvements should allow for faster re-strike times or instant-on, full-brightness lighting, higher efficiency, reduced power consumption, and less sensitivity to power quality events. In addition to improvements to lamp and lighting technologies, it is important also to look at the underlying events occurring within the power deliver system to help reduce the likelihood of outages due to short-term power quality events. Once these events are understood in greater depth, it is critical to continue the design and deployment of effective devices which will allow for resilient end-user solutions. An important part of the process of assuring proper end-use resilience includes regular testing and evaluation of system components—regardless of their complexity and cost.

The above article was authored by EPRI—the Electric Power Research Institute—via a cross-sector team of energy professionals. If you have questions regarding the contents or details of this piece please contact the following individuals:

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Appendix

Delivered Voltage will be defined for the events described below as the voltage supplied to the service entrance of the end user. Electric-supply systems are designed to maintain a steady-state service entrance voltage within ANSI-specified ranges (see ANSI/IEEE Standard 141-1999, *IEEE Recommended Practice for Electric Power Distribution for Industrial Plants* and ANSI Standard C84.1-1995, *Electric Power Systems and Equipment – Voltage Ratings (60 Hz)*).

Harmonics are signal disturbances occurring within the power cycle. These disturbances may result in distortion of the voltage or current waveform (normally a sine wave) that may appear as notches or noise. Harmonics can be generated by a range of events. Some of these events may be caused by the power generator or distributor, but many may result from devices used by end-use customers. Low-power-factor devices, or non-power-factor-corrected devices, such as electronic lighting devices, motors, pumps, power supplies, and similar devices may generate harmonics. These harmonic signals can cause other devices to malfunction, fault, or fail. They can also cause excessive wear on devices and may result in premature failure.

Undervoltages are recognized by a sustained lowering of the supply voltage over a longer period of time than is characteristic for a voltage sag. Undervoltages may occur as large customer loads are switched on or as capacitor banks are switched on to correct the power factor and maintain the stability of the power system. During peak load periods, utility companies may lower transmission line voltages to reduce the power consumption of the system.

Overvoltages (the opposite of undervoltages) indicate the extended delivery of voltage higher than the intended nominal voltage for a period of time. Overvoltages may be caused by switching on capacitor banks or switching off large customer loads. These events result in higher line voltages than normal being delivered to the end user.

Voltage sags are temporary (one cycle to one minute) and non-planned events (as opposed to some undervoltage events, which may be caused by utilities) where the delivered voltage drops below nominal voltage. These are dynamic events and do not occur periodically across the sine wave. Sags in the line voltage lasting for several cycles or longer may result from line faults in the distribution system (which may lead to system outages depending on the cause and fault location) or they may occur as heavy customer loads are switched on. These disturbances may produce unpredictable results for voltage-sensitive equipment on the line and are common causes of electronic-system upsets.

Voltage Swells are temporary and non-planned events where the delivered power increases above nominal voltage. The ANSI C84.1 document does not address voltage swell conditions, but some information on swells is included in ANSI/IEEE Standard 141-1999. Line voltage may increase up to 1.73 times nominal voltage for several cycles during power-system faults on secondary circuits or in cases where the neutral becomes ungrounded at the service. Voltage swells are dynamic events and do not occur periodically across the sine wave. These disturbances may produce unpredictable results for voltage-sensitive equipment connected to the affected line. Although not as common as voltage sags, swells may cause electronic-system upsets that may include failures of line-side protective, filtering components as well as active devices used in power factor correction (PFC) circuits.

Ring-wave surges are primarily voltage surges having very short rise times and relatively low current (200 A max in laboratory compliance testing). These surges may result from a range of events and are the most frequently observed type of transient overvoltage to occur in low-voltage power systems for

all types of service entrances. The ANSI/IEEE C62.41.2-2002, *IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits*, defines a 100-kHz ring wave as having a rise time of 0.5 μ s. A short rise time indicates that a large change in voltage occurred over a short period of time. This type of surge may damage or activate sensitive electronic components such as semiconductor devices now used in many electronic lighting systems.

Combination-wave surges, or combo-wave surges, are high energy surges such as those caused by lightning and high-voltage switching. These surges are known to exist in low-voltage systems and can cause the failure of electrical and electronic loads. These surges differ from ring-wave surges as there is a large current component (some instances call for 10 kV and 10 kA surge waveform for compliance testing). The 1.2/50- μ s, open-circuit voltage part of the Combination Wave, described in ANSI/IEEE C62.41.2-2002, *IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits*, has long been used to represent low-voltage surges caused by lightning on overhead lines. A corresponding 8/20 μ s short-circuit current waveform has also been defined with levels appropriate to the location of the ballast or lamp. These two waveforms have significant energy-deposition capability that, in combination, can cause failures of electronic lighting systems.