The Seven Types of Power Problems

White Paper 18

Revision 1

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> Executive summary

Many of the mysteries of equipment failure, downtime, software and data corruption, are the result of a problematic supply of power. There is also a common problem with describing power problems in a standard way. This white paper will describe the most common types of power disturbances, what can cause them, what they can do to your critical equipment, and how to safeguard your equipment, using the IEEE standards for describing power quality problems.

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Introduction

Our technological world has become deeply dependent upon the continuous availability of electrical power. In most countries, commercial power is made available via nationwide grids, interconnecting numerous generating stations to the loads. The grid must supply basic national needs of residential, lighting, heating, refrigeration, air conditioning, and transportation as well as critical supply to governmental, industrial, financial, commercial, medical and communications communities. Commercial power literally enables today's modern world to function at its busy pace. Sophisticated technology has reached deeply into our homes and careers, and with the advent of e-commerce is continually changing the way we interact with the rest of the world.

Intelligent technology demands power that is free of interruption or disturbance. The consequences of large-scale power incidents are well documented. A recent study in the USA has shown that industrial and digital business firms are losing $45.7 billion per year due to power interruptions.[1] Across all business sectors, an estimated $104 billion to $164 billion is lost due to interruptions with another $15 billion to $24 billion due to all other power quality problems. In industrial automatic processing, whole production lines can go out of control, creating hazardous situations for onsite personnel and expensive material waste. Loss of processing in a large financial corporation can cost thousands of unrecoverable dollars per minute of downtime, as well as many hours of recovery time to follow. Program and data corruption caused by a power interruption can create problems for software recovery operations that may take weeks to resolve.

Many power problems originate in the commercial power grid, which, with its thousands of miles of transmission lines, is subject to weather conditions such as hurricanes, lightning storms, snow, ice, and flooding along with equipment failure, traffic accidents and major switching operations. Also, power problems affecting today's technological equipment are often generated locally within a facility from any number of situations, such as local construction, heavy startup loads, faulty distribution components, and even typical background electrical noise.

Agreeing on common terms is a first step in dealing with power disturbances

Widespread use of electronics in everything from home electronics to the control of massive and costly industrial processes has raised the awareness of power quality. Power quality, or more specifically, a power quality disturbance, is generally defined as any change in power (voltage, current, or frequency) that interferes with the normal operation of electrical equipment.

The study of power quality, and ways to control it, is a concern for electric utilities, large industrial companies, businesses, and even home users. The study has intensified as equipment has become increasingly sensitive to even minute changes in the power supply voltage, current, and frequency. Unfortunately, different terminology has been used to describe many of the existing power disturbances, which creates confusion and makes it more difficult to effectively discuss, study, and make changes to today's power quality problems. The Institute of Electrical and Electronics Engineers (IEEE) has attempted to address this problem by developing a standard that includes definitions of power disturbances. The standard (IEEE Standard 1159-1995, "IEEE Recommended Practice for Monitoring Electrical Power Quality") describes many power quality problems, of which this paper will discuss the most common.

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[1] Electric Power Research Institute, *The Cost of Power Disturbances to Industrial & Digital Economy Companies,* copyright 2001

How do we look at power?

Electricity at the wall outlet is an electromagnetic phenomenon. Commercial power is provided as alternating current (AC), a silent, seemingly limitless source of energy that can be generated at power stations, boosted by transformers, and delivered over hundreds of miles to any location in the region. Seeing what this energy is doing in small slices of time can provide an understanding of how important simple, smooth ac power is to reliable operation of the sophisticated systems that we are dependent upon. An oscilloscope allows us to see what this energy looks like. In a perfect world, commercial ac power appears as a smooth, symmetrical sine wave, varying at either 50 or 60 cycles every second (Hertz – Hz) depending on which part of the world you're in. **Figure 1** shows what an average AC sine wave would appear like on an oscilloscope.

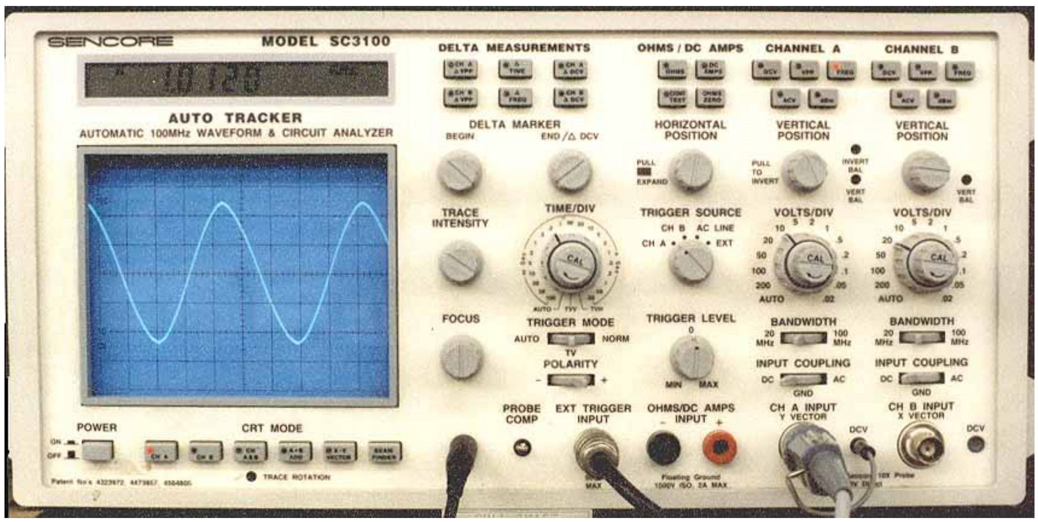


Figure 1

Oscilloscope image of a sine wave

The sinusoidal wave shape shown above represents a voltage changing from a positive value to a negative value, 60 times per second. When this flowing wave shape changes size, shape, symmetry, frequency, or develops notches, impulses, ringing, or drops to zero (however briefly), there is a power disturbance. Simple drawings representative of changes in the above ideal sine wave shape will be shown throughout this paper for the seven categories of power quality disturbances that will be discussed.

As stated, there has been some ambiguity throughout the electrical industry and businesses community in the use of terminology to describe various power disturbances. For example, the term "surge" is seen by one sector of the industry to mean a momentary increase in voltage as would be typically caused by a large load being switched off. On the other hand, usage of the term "surge" can also be seen as a transient voltage lasting from microseconds to only a few milliseconds with very high peak values. These latter are usually associated with lightning strikes and switching events creating sparks or arcing between contacts.

The IEEE Standard 1100-1999 has addressed the problem of ambiguity in terminology, and has recommended that many terms in common usage not be used in professional reports and references because of their inability to accurately describe the nature of the problem. IEEE Standard 1159-1995 also addresses this problem with the goal of providing consistent terminology for power quality reporting from the professional community. Some of these ambiguous terms are as follows:

Blackout	Brownout	Bump	Power surge
Clean power	Surge	Outage	Blink

Dirty power	Frequency shift	Glitch	Spike
Power surge	Raw power	Raw utility power	Wink

Being able to talk effectively about power, such as knowing the difference between an interruption, and an oscillatory transient, could make a huge difference when making purchase decisions for power correction devices. A communication mistake can have expensive consequences when the wrong power correction device is purchased for your needs, which includes downtime, lost wages, or even equipment damage.

This IEEE defined power quality disturbances shown in this paper have been organized into seven categories based on wave shape:

1. Transients
2. Interruptions
3. Sag / Undervoltage
4. Swell / Overvoltage
5. Waveform distortion
6. Voltage fluctuations
7. Frequency variations

This paper will conform to these categories and include graphics, which should clarify the differences between individual power quality disturbances.

1. Transients

Potentially the most damaging type of power disturbance, transients fall into two subcategories:

1. Impulsive
2. Oscillatory

Impulsive

Impulsive transients are sudden high peak events that raise the voltage and/or current levels in either a positive or a negative direction. These types of events can be categorized further by the speed at which they occur (fast, medium, and slow). Impulsive transients can be very fast events (5 nanoseconds [ns] rise time from steady state to the peak of the impulse) of short-term duration (less than 50 ns).
Note: [1000 ns = 1 μs] [1000 μs = 1 ms] [1000 ms = 1 second]

One example of a positive impulsive transient caused by electrostatic discharge (ESD) event is illustrated in **Figure 2**.

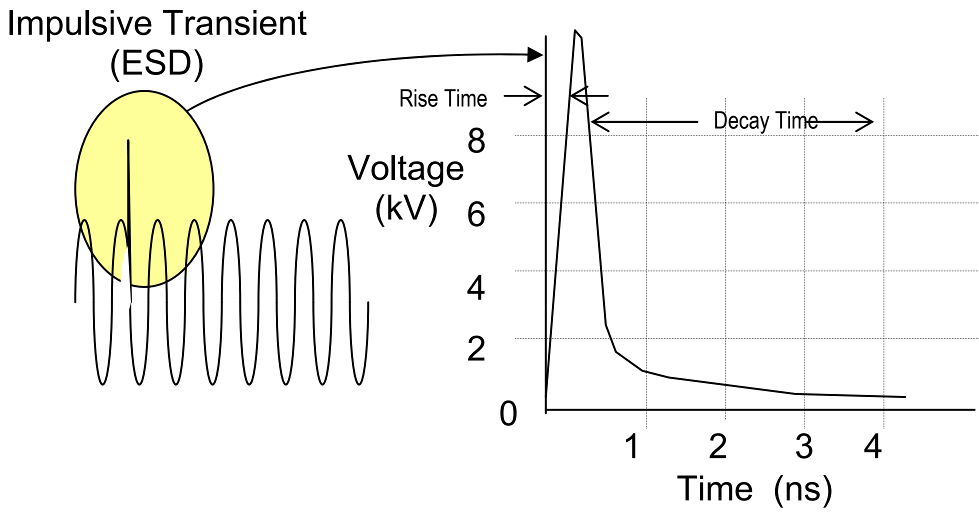


Figure 2

Positive impulsive transient

The impulsive transient is what most people are referring to when they say they have experienced a surge or a spike. Many different terms, such as bump, glitch, power surge, and spike have been used to describe impulsive transients.

Causes of impulsive transients include lightning, poor grounding, the switching of inductive loads, utility fault clearing, and Electrostatic Discharge (ESD). The results can range from the loss (or corruption) of data, to physical damage of equipment. Of these causes, lightning is probably the most damaging.

The problem with lightning is easily recognized after witnessing an electrical storm. The amount of energy that it takes to light up the night sky can certainly destroy sensitive equipment. Moreover, it doesn't take a direct lightning strike to cause damage. The electro-magnetic fields, **Figure 3**, created by lightning can cause much of the potential damage by inducing current onto nearby conductive structures.

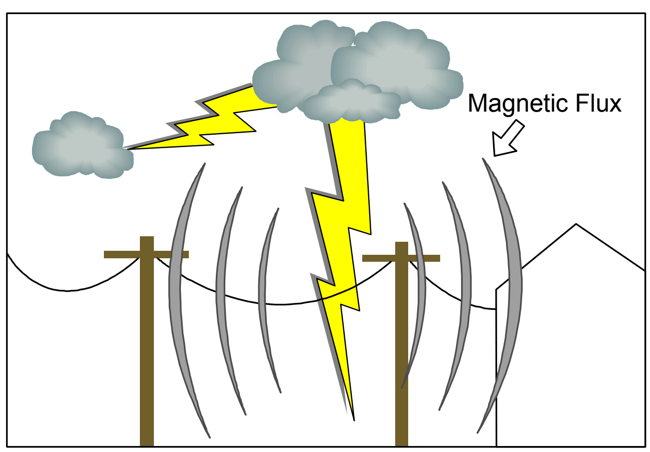


Figure 3

Magnetic field created by lightning strike

Two of the most viable protection methods when it comes to impulsive transients pertain to the elimination of potential ESD, and the use of surge suppression devices (popularly referred to as transient voltage surge suppressors: TVSS, or surge protective device: SPD).

While ESD can arc off of your finger with no damage to you, beyond a slight surprise, it is more than enough to cause an entire computer motherboard to stop dead and to never function again. In data centers, printed circuit board manufacturing facilities or any similar environment where PCBs are exposed to human handling, it is important to dissipate the potential for ESD. For example, almost any proper data center environment involves conditioning of the air in the room. Conditioning the air does not just cool the air to help remove heat from data center equipment, but also adjusts the amount of moisture in the air. Keeping the humidity in the air between 40 - 55% humidity will decrease the potential for ESD to occur. You've probably experienced how humidity affects ESD potential if you've ever been through a winter (when the air is very dry) when a few drags of your socks across the carpet cause a tremendous arc to jump from your finger unexpectedly to the doorknob you were reaching for, or expectedly if you were aiming for someone's ear. Another thing you will see in PCB environments, such as you would see in any small computer repair business, is equipment to keep the human body grounded. This equipment includes wrist straps, antistatic mats and desktops, and antistatic footwear. Most of this equipment is connected to a wire, which leads to the ground of the facility, which keeps people safe from electric shock and also dissipates possible ESD to ground.

SPDs have been used for many years. These devices are still in use today on utility systems, as well as devices for large facilities and data centers, as well as everyday small business and home use; their performance improving with advances in metal oxide varistor (MOV) technology. MOVs allow for a consistent suppression of impulsive transients, swells, and other high voltage conditions, and can be combined with thermal tripping devices such as circuit breakers, thermistors, as well as other components such as gas tubes and thyristors. In some cases SPD circuits are built into the electrical devices themselves, such as computer power supplies with built in suppression abilities. More commonly, they are used in stand-alone surge suppression devices, or included with UPSs to provide surge suppression and emergency battery power should in interruption occur (or when power levels are outside the boundaries of nominal, or safe, power conditions).

Cascading SPDs and UPS devices, is the most effective method of protection against power disturbances, for electronic equipment. Using this technique, an SPD device is placed at the service entrance and is sized to dissipate much of the energy from any incoming transient. Subsequent devices at the electrical sub-panel and at the sensitive equipment itself clamp the voltage to a level that doesn't damage or disturb the equipment. Particular attention must be paid to sizing both the voltage rating and the energy dissipation rating of these devices and coordinating the devices for effective operation. Also, attention should be paid to how effective the surge suppression device is in the event that the MOV reaches the point of failure. While an MOV is consistent in its surge suppression abilities over time, it does still degrade with usage, or can fail if its rate of effective suppression ability is exceeded. It is important that if the MOV does reach the point where it is no longer useful, that the SPD have the ability to break the circuit, and prevent any damaging power anomaly from reaching the equipment it is protecting. For more information on this topic see White Paper 85, *Data Line Transient Protection*.

Related resource
White Paper 85
Data Line Transient Protection

Oscillatory

An oscillatory transient is a sudden change in the steady-state condition of a signal's voltage, current, or both, at both the positive and negative signal limits, oscillating at the natural system frequency. In simple terms, the transient causes the power signal to alternately swell and then shrink, very rapidly. Oscillatory transients usually decay to zero within a cycle (a decaying oscillation).

These transients occur when you turn off an inductive or capacitive load, such as a motor or capacitor bank. An oscillatory transient results because the load resists the change. This is similar to what happens when you suddenly turn off a rapidly flowing faucet and hear a hammering noise in the pipes. The flowing water resists the change, and the fluid equivalent of an oscillatory transient occurs.

For example, upon turning off a spinning motor, it acts briefly as a generator as it powers down, thereby producing electricity and sending it through the electrical distribution. A long electrical distribution system can act like an oscillator when power is switched on or off, because all circuits have some inherent inductance and distributed capacitance that briefly energizes in a decaying form.

When oscillatory transients appear on an energized circuit, usually because of utility switching operations (especially when capacitor banks are automatically switched into the system), they can be quite disruptive to electronic equipment. **Figure 4** shows a typical low frequency Oscillatory Transient attributable to capacitor banks being energized.

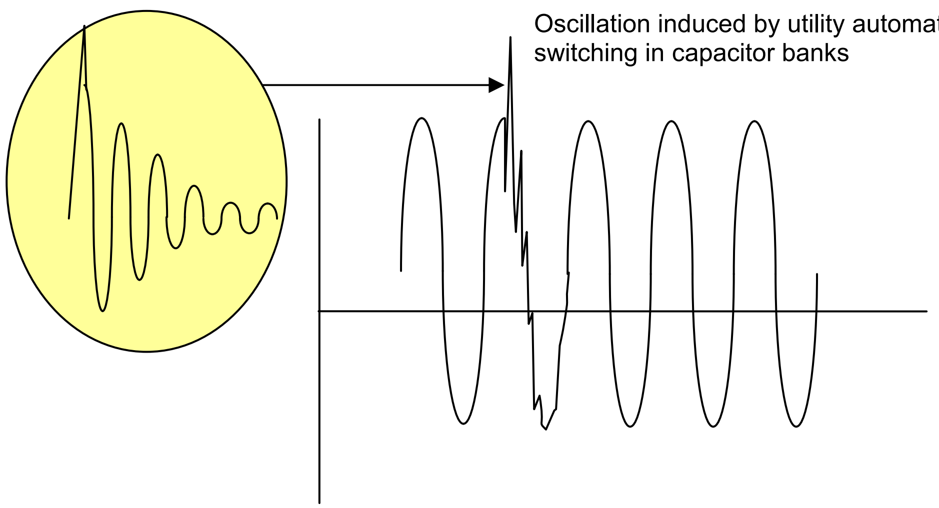


Figure 4

Oscillatory transient

The most recognized problem associated with capacitor switching and its oscillatory transient is the tripping of adjustable speed drives (ASDs). The relatively slow transient causes a rise in the dc link voltage (the voltage that controls the activation of the ASD), which causes the drive to trip off-line with an indication of overvoltage.

A common solution to capacitor tripping is the installation of line reactors or chokes that dampen the oscillatory transient to a manageable level. These reactors can be installed ahead of the drive or on the dc link and are available as a standard feature or as an option on most ASDs. (Note - ASD devices will be discussed further in the interruptions section below.)

Another rising solution to capacitor switching transient problems is the zero crossing switch. When a sine wave's arc descends and reaches the zero level (before it becomes negative), this is known as the zero crossing as shown in **Figure 5**. A transient caused by capacitor switching will have a greater magnitude the farther the switching occurs away from the zero crossing timing of the sine wave. A zero crossing switch solves this problem by monitoring the sine wave to make sure that capacitor switching occurs as close as possible to the zero crossing timing of the sine wave.

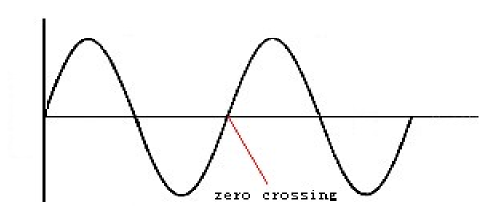


Figure 5

Zero crossing

Of course UPS and SPD systems are also very effective at reducing the harm that oscillatory transients can do, especially between common data processing equipment such as computers in a network. However, SPD and UPS devices can sometimes not prevent the intersystem occurrences of oscillatory transients that a zero crossing switch and/or choke type device can prevent on specialized equipment, such as manufacturing floor machinery and their control systems.

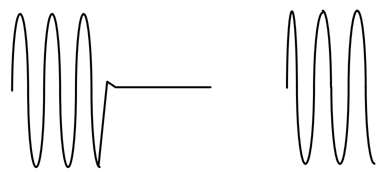
2. Interruptions

An interruption (**Figure 6**) is defined as the complete loss of supply voltage or load current. Depending on its duration, an interruption is categorized as instantaneous, momentary, temporary, or sustained. Duration range for interruption types are as follows:

Instantaneous	0.5 to 30 cycles
Momentary	30 cycles to 2 seconds
Temporary	2 seconds to 2 minutes
Sustained	greater than 2 minutes

Figure 6

Momentary interruption



The causes of interruptions can vary, but are usually the result of some type of electrical supply grid damage, such as lightning strikes, animals, trees, vehicle accidents, destructive weather (high winds, heavy snow or ice on lines, etc.), equipment failure, or a basic circuit breaker tripping. While the utility infrastructure is designed to automatically compensate for many of these problems, it is not infallible.

One of the more common examples of what can cause an interruption in commercial power systems are utility protective devices, such as automatic circuit reclosers. Reclosers determine the length of time of most interruptions, depending on the nature of the fault. Reclosers are devices used by utility companies to sense the rise in current from a short circuit in the utility infrastructure, and to shut off the supply power when this occurs. The recloser will, after a set time bring power back on line, in an attempt to burn off the material creating the short circuit (This material is often a tree limb, or small animal trapped between the line and ground).

You've probably experienced an interruption if you have ever seen all the power in your house go out (all lights and electronics), just to have everything come back on a few minutes later while you're breaking out the candles. Of course, having the power go out in your house, even if it lasts all night, may be only an inconvenience, but for businesses it can also cause great expense.

An interruption, whether it is instantaneous, momentary, temporary, or sustained, can cause disruption, damage, and downtime, from the home user up to the industrial user. A home, or small business computer user, could lose valuable data when information is corrupted from loss of power to their equipment. Probably more detrimental is the loss that the industrial customer can sustain because of interruptions. Many Industrial processes count on the constant motion of certain mechanical components. When these components shutdown suddenly from an interruption, it can cause equipment damage, ruination of product, as well as the cost associated with downtime, cleanup, and restart. For example, when an Industrial customer, producing yarn, experiences a momentary interruption, it can cause the yarn extrusion process to "break out," resulting in excessive waste and downtime. Yarn must be extruded at a certain speed and consistency for the end product to be of the quality and type expected. The off-spec yarn must be cleaned out of the spinning machine and the thread lines re-strung. As you can imagine this takes a great effort, and creates huge downtime. Also, there is waste due to a certain amount of ruined yarn.

Solutions to help against interruptions vary, both in effectiveness and cost. The first effort should go into eliminating or reducing the likelihood of potential problems. Good design and maintenance of utility systems are, of course, essential. This also applies to the industrial customer's system design, which is often as extensive and vulnerable as the utility system.

Once the potential for problems is reduced, additional equipment or design methods are needed to allow the customer's equipment or process to ride-through (remain at constant operation during power quality disturbances), or to restart after (and during) unavoidable interruptions. The most common mitigating devices employed are the uninterruptible power supply (UPS), motor generator, and the use of system design techniques that take advantage of redundant systems and energy storage. When the power goes out, these forms of alternative power can take over. Anyone who has owned a laptop has seen an example of this. When the laptop is plugged in it is powered from the wall receptacle and a trickle of energy is passed to the laptops internal battery to charge it. When the laptop is unplugged the battery instantly takes over providing continued power to the laptop. Recent advances in switch technology have allowed for standby energy storage systems to be utilized in less than a half cycle.

The term “sustained interruption,” describes a situation in a commercial utility system where automatic protective devices, because of the nature of the fault, cannot bring power back online, and manual intervention is required. This terminology more accurately describes the situation, rather than the commonly used term “outage”. The term “outage” actually refers to the state of a component in the system that has failed to function as expected (IEEE Std 100-1992).

It’s probably safe to say that you are experiencing a sustained interruption if the power has been off for more than two minutes, and you see utility trucks appear shortly after to repair utility lines outside.

3. Sag / undervoltage

A sag (**Figure 7**) is a reduction of AC voltage at a given frequency for the duration of 0.5 cycles to 1 minute’s time. Sags are usually caused by system faults, and are also often the result of switching on loads with heavy startup currents.

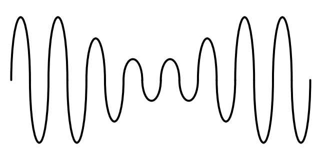


Figure 7

Sag

Common causes of sags include starting large loads (such as one might see when they first start up a large air conditioning unit) and remote fault clearing performed by utility equipment. Similarly, the starting of large motors inside an industrial facility can result in significant voltage drop (sag). A motor can draw six times its normal running current, or more, while starting. Creating a large and sudden electrical load such as this will likely cause a significant voltage drop to the rest of the circuit it resides on. Imagine someone turning on all the water in your house while you’re in the shower. The water would probably run cold and the water pressure would drop. Of course, to solve this problem, you might have a second water heater that is dedicated to the shower. The same holds true for circuits with large startup loads that create a large inrush current draw.

While it may be the most effective solution, adding a dedicated circuit for large startup loads may not always be practical or economical, especially if a whole facility has a myriad of large startup loads. Other solutions to large starting loads include alternative power starting sources that do not load the rest of the electrical infrastructure at motor startup such as, reduced-voltage starters, with either autotransformers, or star-delta configurations. A solid-state type of soft starter is also available and is effective at reducing the voltage sag at motor start-up. Most recently, adjustable speed drives (ASDs), which vary the speed of a motor in accordance with the load (along with other uses), have been used to control the industrial process more efficiently and economically, and as an additional benefit, addresses the problem of large motor starting.

As mentioned in the Interruptions section, the attempt of the utility infrastructure to clear remote faults can cause problems for end users. When this problem is more evident it is seen as an interruption. However, it can also manifest itself as a sag for problems that are cleared more quickly or that are momentarily recurring. Some of the same techniques that were used to address interruptions can be utilized to address voltage sags: UPS equipment, motor generators, and system design techniques. However, sometimes the damage being caused by sags is not apparent until the results are seen over time (damaged equipment, data corruption, errors in industrial processing).

While still in its infant stage, some utilities now provide sag analysis of industrial processes as a value-added service to their customers. A sag analysis can now be performed to determine at what sag levels equipment can and cannot operate. As studies are conducted and these weak points are identified, information is being collected, analyzed, and reported to equipment manufacturers so that they can improve the ride-through capability of their equipment.

Undervoltage

Undervoltages (**Figure 8**) are the result of long-term problems that create sags. The term “brownout” has been commonly used to describe this problem, and has been superseded by the term undervoltage. Brownout is ambiguous in that it also refers to commercial power delivery strategy during periods of extended high demand. Undervoltages can create overheating in motors, and can lead to the failure of non-linear loads such as computer power supplies. The solution for sags also applies to undervoltages. However, a UPS with the ability to adjust voltage using an inverter first before using battery power will prevent the need to replace UPS batteries as often. More importantly, if an undervoltage remains constant, it may be a sign of a serious equipment fault, configuration problem, or that the utility supply needs to be addressed.

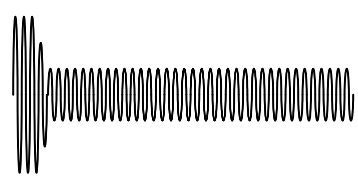


Figure 8

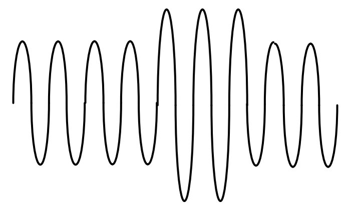
Undervoltage

4. Swell / overvoltage

A swell (**Figure 9**) is the reverse form of a sag, having an increase in AC voltage for a duration of 0.5 cycles to 1 minute’s time. For swells, high-impedance neutral connections, sudden (especially large) load reductions, and a single-phase fault on a three-phase system are common sources.

Figure 9

Swell



The result can be data errors, flickering of lights, degradation of electrical contacts, semiconductor damage in electronics, and insulation degradation. Power line conditioners, UPS systems, and ferroresonant "control" transformers are common solutions.

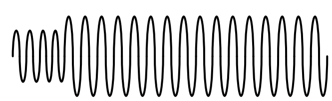
Much like sags, swells may not be apparent until their results are seen. Having UPS and/or power conditioning devices that also monitor and log incoming power events will help to measure when, and how often, these events occur.

Overvoltage

Overvoltages (**Figure 10**) can be the result of long-term problems that create swells. An overvoltage can be thought of as an extended swell. Overvoltages are also common in areas where supply transformer tap settings are set incorrectly and loads have been reduced. This is common in seasonal regions where communities reduce in power usage during off-season and the output set for the high usage part of the season is still being supplied even though the power need is much smaller. It's like putting your thumb over the end of a garden hose. The pressure increases because the hole where the water comes out has been made smaller, even though the amount of water coming out of the hose remains the same. Overvoltage conditions can create high current draw and cause the unnecessary tripping of downstream circuit breakers, as well as overheating and putting stress on equipment.

Figure 10

Overvoltage



Since an overvoltage is really just a constant swell, the same UPS or conditioning equipment that works for swells will work for overvoltages. However, if the incoming power is constantly in an overvoltage condition, then the utility power to your facility may need correction as well. The same symptoms for swells also apply to overvoltages. Since overvoltages can be more constant, excess heat may be an outward indication of an overvoltage. Equipment (under normal environmental conditions and usage), which normally produces a certain amount of heat, may suddenly increase in heat output because of the stress caused by an overvoltage. This may be detrimental in a tightly packed data center environment. Heat and its effect on today's data centers, with their many tightly packed blade server type environments, is of great concern to the IT community.

5. Waveform distortion

There are five primary types of waveform distortion:

1. DC offset
2. Harmonics
3. Interharmonics
4. Notching

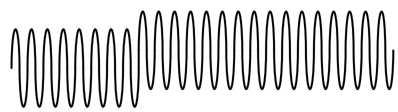
5. Noise

DC offset

Direct current (DC) can be induced into an AC distribution system, often due to failure of rectifiers within the many AC to DC conversion technologies that have proliferated modern equipment. DC can traverse the ac power system and add unwanted current to devices already operating at their rated level. Overheating and saturation of transformers can be the result of circulating DC currents. When a transformer saturates, it not only gets hot, but also is unable to deliver full power to the load, and the subsequent waveform distortion can create further instability in electronic load equipment. A DC offset is illustrated in **Figure 11**.

Figure 11

DC offset



The solution to DC offset problems is to replace the faulty equipment that is the source of the problem. Having very modular, user replaceable, equipment can greatly increase the ease to resolve DC offset problems caused by faulty equipment, with less costs than may usually be needed for specialized repair labor.

Harmonics

Harmonic distortion (**Figure 12**) is the corruption of the fundamental sine wave at frequencies that are multiples of the fundamental. (e.g., 180 Hz is the third harmonic of a 60 Hz fundamental frequency; 3 X 60 = 180).

Symptoms of harmonic problems include overheated transformers, neutral conductors, and other electrical distribution equipment, as well as the tripping of circuit breakers and loss of synchronization on timing circuits that are dependent upon a clean sine wave trigger at the zero crossover point.

Harmonic distortion has been a significant problem with IT equipment in the past, due to the nature of switch-mode power supplies (SMPS). These non-linear loads, and many other capacitive designs, instead of drawing current over each full half cycle, “sip” power at each positive and negative peak of the voltage wave. The return current, because it is only short-term, (approximately 1/3 of a cycle) combines on the neutral with all other returns from SMPS using each of the three phases in the typical distribution system. Instead of subtracting, the pulsed neutral currents add together, creating very high neutral currents, at a theoretical maximum of 1.73 times the maximum phase current. An overloaded neutral can lead to extremely high voltages on the legs of the distribution power, leading to heavy damage to attached equipment. At the same time, the load for these multiple SMPS is drawn at the very peaks of each voltage half-cycle, which has often led to transformer saturation and consequent overheating. Other loads contributing to this problem are variable speed motor drives, lighting ballasts and large legacy UPS systems. Methods used to mitigate this problem have included over-sizing the neutral conductors, installing K-rated transformers, and harmonic filters.

Spurred on by the remarkable expansion of the IT industry over the last decade, power supply design for IT equipment has been upgraded via international standards. One major change compensates for electrical infrastructure stresses caused, in the recent past, by large clusters of IT equipment power supplies contributing to excessive harmonic currents within a facility. Many new IT equipment power supplies have been designed with power-factor corrected power supplies operating as linear, non-harmonic loads. These power supplies do not produce the waste current of harmonics.

Figure 12

Typical harmonic waveform distortion

Interharmonics

Interharmonics (**Figure 13**) are a type of waveform distortion that are usually the result of a signal imposed on the supply voltage by electrical equipment such as static frequency converters, induction motors and arcing devices. Cycloconverters (which control large linear motors used in rolling mill, cement, and mining equipment), create some of the most significant interharmonic supply power problems. These devices transform the supply voltage into an AC voltage of a frequency lower or higher than that of the supply frequency.

The most noticeable effect of interharmonics is visual flickering of displays and incandescent lights, as well as causing possible heat and communication interference.

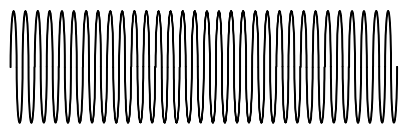


Figure 13

Interharmonic waveform distortion

Solutions to interharmonics include filters, UPS systems, and line conditioners.

Notching

Notching (**Figure 14**) is a periodic voltage disturbance caused by electronic devices, such as variable speed drives, light dimmers and arc welders under normal operation. This problem could be described as a transient impulse problem, but because the notches are periodic over each ½ cycle, notching is considered a waveform distortion problem. The usual consequences of notching are system halts, data loss, and data transmission problems.

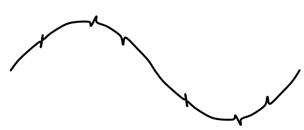


Figure 14

Notching

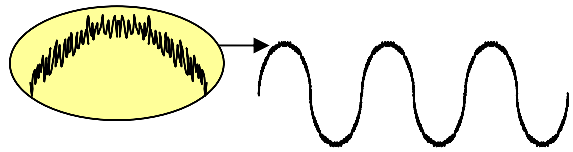
One solution to notching is to move the load away from the equipment causing the problem (if possible). UPSs and filter equipment are also viable solutions to notching if equipment cannot be relocated.

Noise

Noise (**Figure 15**) is unwanted voltage or current superimposed on the power system voltage or current waveform. Noise can be generated by power electronic devices, control circuits, arc welders, switching power supplies, radio transmitters and so on. Poorly grounded sites make the system more susceptible to noise. Noise can cause technical equipment problems such as data errors, equipment malfunction, long-term component failure, hard disk failure, and distorted video displays.

Figure 15

Noise



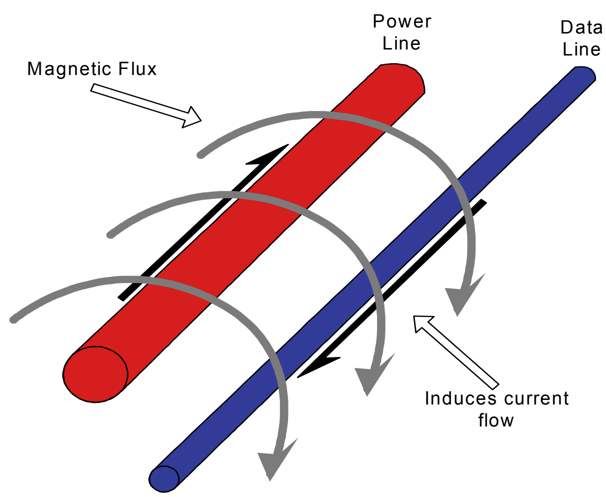
There are many different approaches to controlling noise and sometimes it is necessary to use several different techniques together to achieve the required result. Some methods are:

- Isolate the load via a UPS
- Install a grounded, shielded isolation transformer
- Relocate the load away from the interference source
- Install noise filters
- Cable shielding

Data corruption is one of the most common results of noise. EMI (Electromagnetic Interference) and RFI (Radio Frequency Interference) can create inductance (induced current and voltage) on systems that carry data as shown in **Figure 16**. Since the data is traveling in digital format (ones and zeros that are represented by a voltage, or lack of voltage), excess voltage above data operating levels can make the appearance of data that does not belong or the opposite. A classic example of noise created by inductance is when network cabling is run through a drop ceiling past fluorescent lighting. Fluorescent lighting produces significant EMI, which if in close proximity to network cabling can cause erroneous data. This can also commonly happen when network cabling is run in close proximity to high capacity power lines. Bundles of power lines often end up running in tandem with network cabling in raised floor data centers, and this increases the chances of noise.

Figure 16

Induction



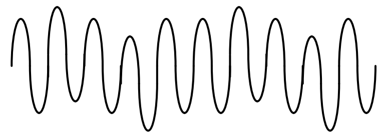
The solution to this particular problem involves moving data carrying devices and/or cabling away from the source of EMI/RFI, or to provide additional shielding for the data devices and/or their cabling to reduce, or nullify, the effects of the EMI/RFI.

6. Voltage fluctuations

Since voltage fluctuations are fundamentally different from the rest of the waveform anomalies, they are placed in their own category. A voltage fluctuation (**Figure 17**) is a systematic variation of the voltage waveform or a series of random voltage changes, of small dimensions, namely 95 to 105% of nominal at a low frequency, generally below 25 Hz.

Figure 17

Voltage fluctuations



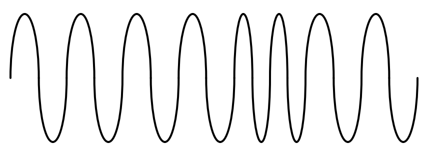
Any load exhibiting significant current variations can cause voltage fluctuations. Arc furnaces are the most common cause of voltage fluctuation on the transmission and distribution system. One symptom of this problem is flickering of incandescent lamps. Removing the offending load, relocating the sensitive equipment, or installing power line conditioning or UPS devices, are methods to resolve this problem.

7. Frequency variations

Frequency variation (**Figure 18**) is extremely rare in stable utility power systems, especially systems interconnected via a power grid. Where sites have dedicated standby generators or poor power infrastructure, frequency variation is more common especially if the generator is heavily loaded. IT equipment is frequency tolerant, and generally not affected by minor shifts in local generator frequency. What would be affected would be any motor device or sensitive device that relies on steady regular cycling of power over time. Frequency variations may cause a motor to run faster or slower to match the frequency of the input power. This would cause the motor to run inefficiently and/or lead to added heat and degradation of the motor through increased motor speed and/or additional current draw.

Figure 18

Frequency variations



To correct this problem, all generated power sources and other power sources causing the frequency variation should be assessed, then repaired, corrected, or replaced.

Voltage imbalance

A voltage imbalance is not a type of waveform distortion. However, because it is essential to be aware of voltage imbalances when assessing power quality problems, it merits discussion in this paper.

Simply put, a voltage imbalance (as the name implies) is when supplied voltages are not equal. While these problems can be caused by external utility supply, the common source of voltage imbalances is internal, and caused by facility loads. More specifically, this is known to occur in three phase power distribution systems where one of the legs is supplying power to single phase equipment, while the system is also supplying power to three phase loads.

In general these imbalances show as heating, especially with solid state motors. Greater imbalances may cause excessive heat to motor components, and the intermittent failure of motor controllers.

A quick way to assess the state of voltage imbalance is to take the difference between the highest and the lowest voltages of the three supply voltages. This number should not exceed 4% of the lowest supply voltage. Below is an example of this quick way to get a simple assessment of the voltage imbalance in a system.

Example:

First supply voltage:	220 V
Second supply voltage:	225 V
Third supply voltage:	230 V
Lowest voltage:	220 V

4% of 220 V = **8.8 V**

Difference between highest and lowest voltage: **10 V**

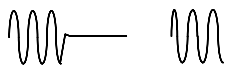
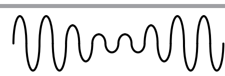
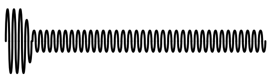
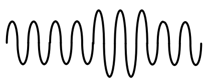
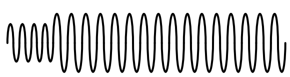
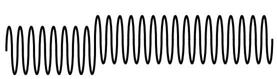
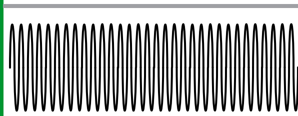
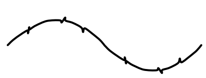
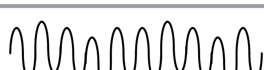
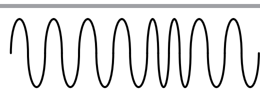
10 V > 8.8 V – imbalance is too great!

Correcting voltage imbalances involves reconfiguring loads, or having utility changes made to the incoming voltages (if the imbalance is not being caused by internal loads).

Table 1 summarizes the power disturbances discussed and provides possible solutions to mitigate the effects that these problems can have on business operations.

Table 1

Summary of disturbances with solutions

Disturbance category	Wave form	Effects	Possible causes	Possible solutions
1. Transient				
Impulsive		Loss of data, possible damage, system halts	Lightning, ESD, switching impulses, utility fault clearing	TVSS, maintain humidity between 35 – 50%
Oscillatory		Loss of data, possible damage	Switching of inductive/capacitive loads	TVSS, UPS, reactors/ chokes, zero crossing switch
2. Interruptions				
Interruption		Loss of data possible, damage shutdown	Switching, utility faults, circuit breaker tripping, component failures	UPS
3. Sag / undervoltage				
Sag		System halts, loss of data, shutdown	Startup loads, faults	Power conditioner, UPS
Undervoltage		System halts, loss of data, shutdown	Utility faults, load changes	Power conditioner, UPS
4. Swell / overvoltage				
Swell		Nuisance tripping, equipment damage/reduced life	Load changes, utility faults	Power conditioner, UPS, ferroresonant "control" transformers
Overvoltage		Equipment damage/reduced life	Load changes, utility faults	Power conditioner, UPS, ferroresonant "control" transformers
5. Waveform distortion				
DC offset		Transformers heated, ground fault current, nuisance tripping	Faulty rectifiers, power supplies	Troubleshoot and replace defective equipment
Harmonics		Transformers heated, system halts	Electronic loads (non-linear loads)	Reconfigure distribution, install k-factor transformers, use PFC power supplies
Interharmonics		Light flicker, heating, communication interference	Control signals, faulty equipment, cycloconverters, frequency converters, induction motors, arcing devices	Power conditioner, filters, UPS
Notching		System halts, data loss	Variable speed drives, arc welders, light dimmers	Reconfigure distribution, relocate sensitive loads, install filters, UPS
Noise		System halts, data loss	Transmitters (radio), faulty equipment, ineffective grounding, proximity to EMI/RFI source	Remove transmitters, reconfigure grounding, moving away from EMI/RFI source, increase shielding filters, isolation transformer
Voltage fluctuations		System halts, data loss	Transmitters (radio), faulty equipment, ineffective grounding, proximity to EMI/RFI source	Reconfigure distribution, relocate sensitive loads, power conditioner, UPS
Power frequency variations		System halts, light flicker	Intermittent operation of load equipment	Reconfigure distribution, relocate sensitive loads, power conditioner, UPS

Conclusion

The widespread use of electronics has raised the awareness of power quality and its affect on the critical electrical equipment that businesses use. Our world is increasingly run by small microprocessors that are sensitive to even small electrical fluctuations. These microprocessors can control blazingly fast automated robotic assembly and packaging line systems that cannot afford downtime. Economical solutions are available to limit, or eliminate, the affects of power quality disturbances. However, in order for the industry to communicate and understand power disturbances and how to prevent them, common terms and definitions are needed to describe the different phenomena. This paper has attempted to define and illustrate power quality disturbances as outlined in IEEE Standard 1159-1995, *IEEE Recommended Practice for Monitoring Electrical Power Quality*.

Reducing equipment downtime and production expense, therefore increasing profit, is the goal of any size business. Communicating by understanding the electrical environment, and equipment's susceptibility to power quality disturbances, will help in the discovery of better methods to achieve business goals and dreams.

About the author

Joseph Seymour is the lead Claim Analyst at Schneider Electric Claims Department in West Kingston, RI. He evaluates and inspects damages caused by catastrophic transient events, and adjudicates customer claims filed in accordance with the Schneider Electric Equipment Protection Policy.

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Appendix – power supply tolerance

Now that the various power disturbances have been identified and described, it is necessary to understand what modern equipment will tolerate. Not all power disturbances affect modern equipment. There is an acceptable range of ac voltage variation and disturbance that modern equipment power supplies will tolerate over short periods of time.

Most technological equipment runs on low voltage dc supplied by lightweight, tolerant Switch-Mode Power Supplies (SMPS) converting nominal ac power into positive and negative dc voltage. Power supplies provide the most effective barrier between sensitive electronic components and the raw energy of ac supply voltage with its associated background noise.

Specifications from IEC 61000-4-11, an international standard, define limits on the magnitude and duration of voltage disturbances that are acceptable to an SMPS load. Similarly, an Application Note commonly referred to throughout the industry as the CBEMA curve, originally developed by the Computer and Business Manufacturer's Association, illustrates a performance curve designed for minimal tolerance of power disturbances in single-phase IT equipment power supplies. The Information Technology Industry Council (ITIC, formerly CBEMA) has recently refined the original curve as shown in **Figure A1**. The curve and this application note are available at http://www.itic.org/clientuploads/Oct2000Curve.pdf

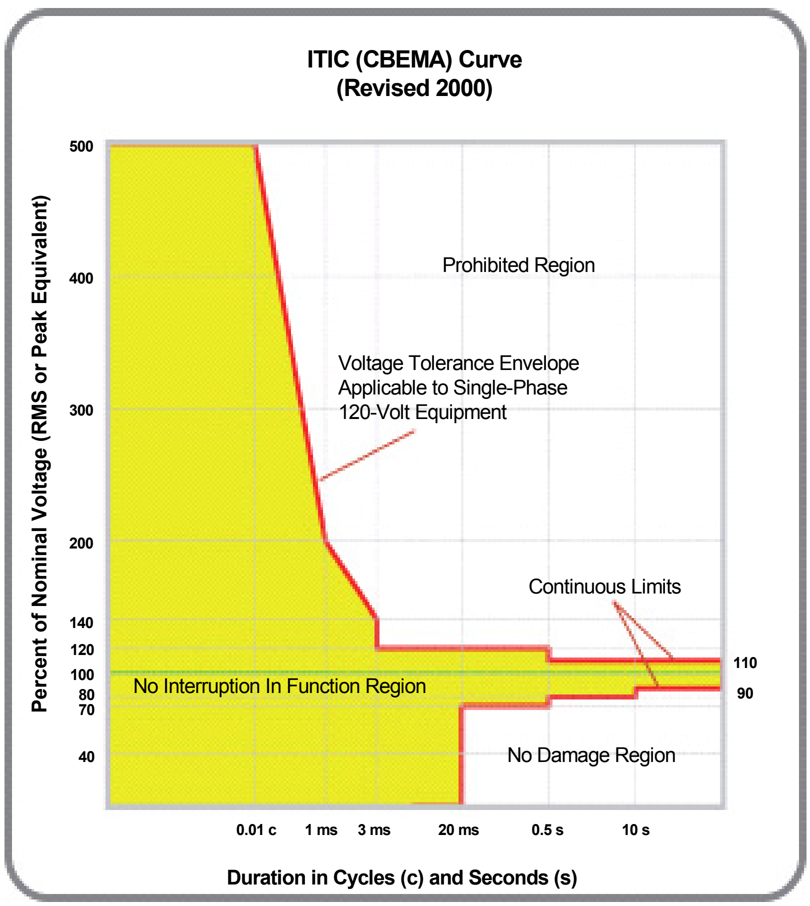

Figure A1

ITIC curve

A1 shows a time scale beginning with sub-cycle scale, expanding through to ten seconds of DC power supply operation. The vertical scale represents the nominal voltage applied to single-phase IT equipment. The most common nominal voltages for this design are 120 V AC for 60 Hz equipment, and 240 V AC for 50 Hz equipment. Following the zero volts line, it can be seen that the power supply will operate for 20 milliseconds after AC supply voltage drops to zero, meaning that the DC output will continue for 1/50th of a second after the AC supply is lost. Another feature of this curve is that if the input AC voltage should decrease to 80% of its nominal value, the DC output of the power supply will hold up the circuitry for a minimum of 10 seconds. On the positive side of the 100% line, power supplies must tolerate an increase of 200% for a period of at least 1 millisecond. At a period of 0.01 of the AC cycle (e.g., 1.6 microseconds in a 60 Hz system, and 2.0 microseconds in a 50 Hz system), the power supply will tolerate an increase of 500% without interruption to circuit operation.