POWER QUALITY – MONITORING AND TROUBLESHOOTING

The following is an excerpt from *The Basics of Power Quality* and is provided by Ideal Industries.

POWER QUALITY: AN INTRODUCTION

The Basics of Power Quality is a convenient guide to monitor and troubleshoot power quality. Its easy-to-read format provides you with a reference point on how to deal with the three key issues that make up power quality: power factor, harmonics and those voltage disturbances called power quality events.

Just like our complete line of recorders, testers, and meters, this guide represents the IDEAL Test & Measurement commitment to helping the professional electrician.

WHAT IS POWER QUALITY?

Power Quality is a determination of the quality of the voltage in a circuit. To measure power quality requires a set of standards with which you can establish the quality of the incoming supply. Different loads may require different standards; so many Power Quality standards exist. Power Quality examines the voltage quality by defining power quality events. Though the ANSI standard is common in utility monitoring and the ITI standard is common in electronic testing, every standard is similar in that voltage events are defined in terms of their magnitude and their duration in time. Incomplete quality information comes from instantaneous measurements as changing load factors influence quality as they vary over time. Therefore time must be included as a key part of the quality analysis. Electronic devices and most non-linear loads are most sensitive to power quality events. These non-linear loads can also impact Power Quality themselves. Poor power quality can result in lost productivity, lost and corrupt data, damaged equipment and early failure of equipment.

When added up, U.S. companies waste an estimated $26 billion on electrical power-related issues each year. In more broad interpretations, Power Quality can also include load profiling. Power Quality can provide tools to measure everything from voltage quality to power factor and energy consumption and also provide a way to analyze the benefits of alternative energy options like solar and wind.

"Power Quality" is a broad term used to describe the measurement of electrical power performance. It can be broken down into three key areas. Each will be discussed in the following pages.

THREE KEY ASPECTS OF POWER QUALITY

• Power Factor • Harmonics • Disturbances

SOURCES OF POOR POWER QUALITY

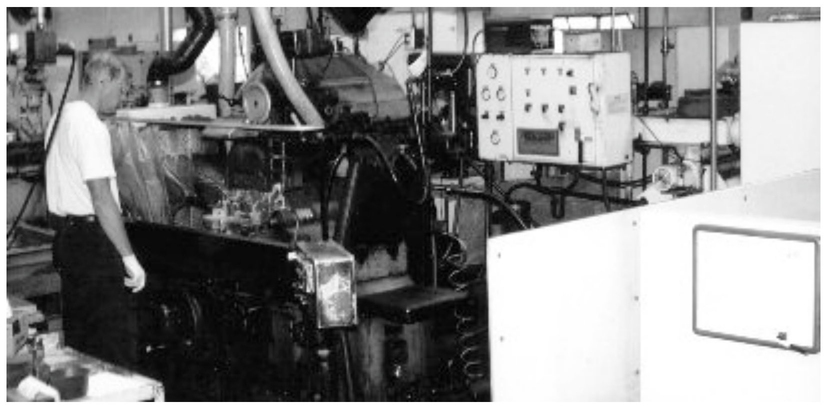
Power Quality problems can be traced to three origins – Upstream supply, internal distribution, or internal loads.

Supply
This is the initial source of power from the utility company such as the main transformer of a commercial building. It's where power coming into the facility can be monitored. But it also of course covers the production and large scale distribution of electrical power.

As shown at the right, a facility's incoming power is typically monitored at the main transformer, referred to as the supply.

Internal Distribution
80% of all power quality problems occur in a company's distribution and grounding/bonding systems. Corroded connections, defective conduit, defective electrical devices, improper wiring, overloading circuits and improper bonding are just some of the elements involved.

Internal Loads
Everything from variable speed drives, microprocessor based devices, and loads such as lighting and battery chargers contribute to the resulting quality of electrical power in a circuit. Internal loads can cause poor power factor, harmonics and power quality events such as sags, swells, and transients.



As shown above, industrial machines containing variable speed drives can cause a variety of costly power quality problems.

Power Factor

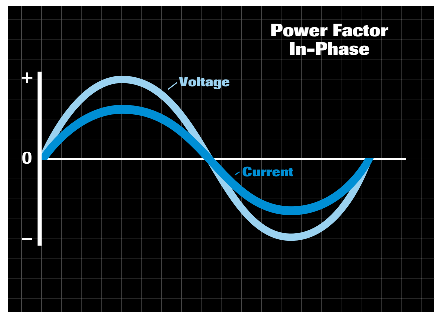
Power Factor is the ratio of true power to apparent power in a circuit; it is expressed as a ratio by using the equation below.

$$PF = \frac{W}{VA}$$

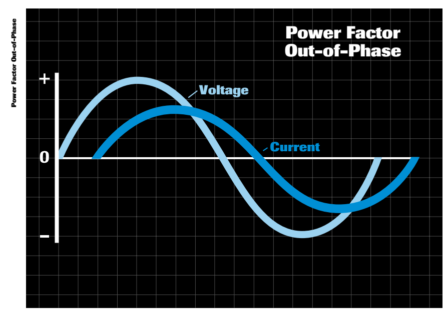
$$\text{Power Factor} = \frac{\text{Watts}}{\text{Volts} \times \text{Amps}}$$

To determine power factor, divide true power (watts) by apparent power (volt amps). If true power and apparent power were equal, the result would be a power ratio of 1.00.

The most common reason to measure power factor is to determine the amount of Energy (Volt-Amperes) in a commercial or industrial environment that is supplied but not converted to useful work. When the power factor ratio is 1.00 it means that every watt of power arriving from the utility company produces work. When displacement power factor is unity (1.00) then the zero crossing of the voltage and current waveform are synchronous.



Motors and transformers and modern computers do not have perfect power factor. Windings are inductive, and cause lagging power factor. Capacitors store charge and can cause leading power factor. Combined, a large motor load can cause current to lag behind voltage and a properly sized capacitor with its opposing capacity can correct the problem. To balance power factor requires a high quality recording power meter that records true power factor and kVar readings directly over a period of time.

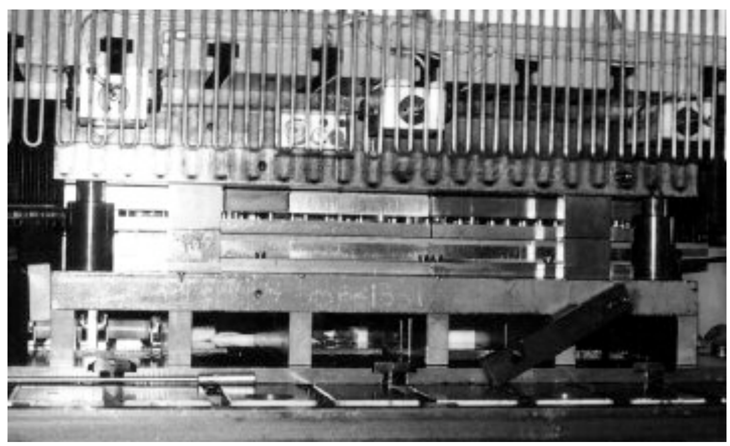


A power factor of less than 0.90 costs you plenty, both in terms of lost circuit capacity as well as power factor penalties on your electric bill. The worse the power factor, the more Apparent Power is wasted in your process. To make matters worse, utility companies apply a penalty charge when power factor drops to low levels. Maintaining a healthy power factor is an important part of controlling your energy costs. You are not billed directly for VA or VARS, but the more current your switchgear carries, the more heat is lost as resistive heating BTUs, and that is a real contributor to cost. Reducing current flow by means of reducing Apparent Power also lowers the current that your conductors and switchgear have to carry.

Troubleshooting Power Factor
In nearly all cases, it is more cost-efficient to take steps toward improving power factor than it is to live with penalty charges. Capacitors are inexpensive, and payback is immediate. (But they must be sized correctly with the help of recorded data.) While power should not be corrected to unity, power factor can certainly be controlled and costs will be reduced substantially. Often unbalanced power factor can be a sign of more serious circuit problems, and by studying power factor, you can prevent catastrophic failures in the future.

A portable recording power meter like the IDEAL 61-807 pictured at the right is the best way to monitor a circuit's power factor. With a single measuring point directly at the transformer, the analyzer can measure true power, apparent power and power factor.

Identify the Problem
The first step in resolving a power factor issue is to identify the origin and extent of the problem with a portable recording power analyzer. A healthy power factor is in the mid to upper 0.90s. Poor power factor usually results from motors, lighting, or microprocessor loads. Once the power factor is measured, and the motors, drives, or transformers are identified, correcting the problem is a fairly simple process.



Large motors make industrial operations especially susceptible to a poor power factor. The largest loads should be corrected right at the load itself, rather than at the service entrance.

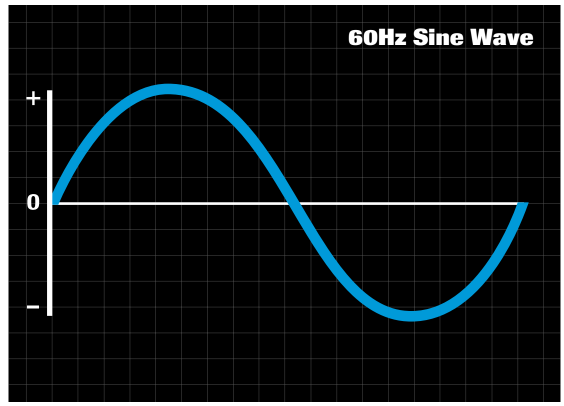
Implement a Solution
The most common means of correcting a low power factor is to compensate the circuit with additional components. Most often, this compensation comes in the form of capacitor banks to correct lagging inductive loads like motors. While capacitor banks are a permanent solution, it is wise to continue monitoring the circuit for any new problems as loads may in fact change over time. You cannot just randomly add capacitors. If a motor has a drive installed, the drive itself may be contributing to the poor power factor, but it is not because of lagging displacement. The drive may be so distorted that the return current waveform is causing poor power factor. This is only corrected by use of a reactor, which can smooth out the current waveform and lower distortion and improve power factor. A portable recording power meter like the IDEAL

61-807 provides true power factor and harmonic distortion analysis so you will never accidentally damage or destroy electronics by applying the wrong mitigating device.

Harmonic Distortions

Widespread use of electronic equipment in today's commercial and industrial environments make harmonic distortion an important but complicated power quality issue.

Simple electric devices like ac motors and incandescent lighting are a linear load, which means their impedance is constant whenever ac voltage is applied. The current waveform is the same as the voltage waveform, because linear loads do not switch on and off during one period of the voltage cycle. All of the energy provided by the ac supply is consumed. The resulting waveform of the load is a mirror of the voltage waveform. It is almost all 60Hz fundamental AC sine wave, and there is no visible distortion, on either the current or voltage.



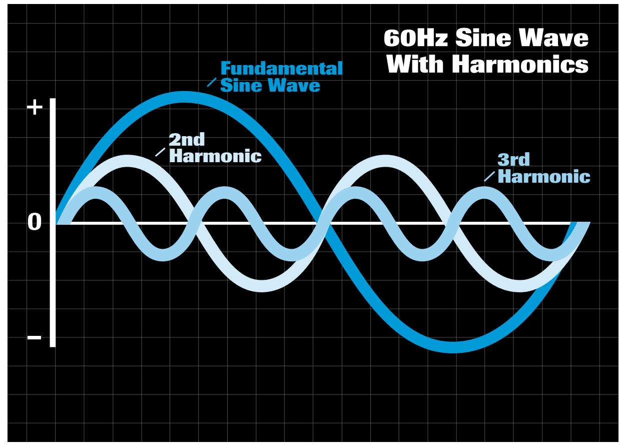
In the United States, the fundamental frequency of electricity is 60Hz. This illustration shows one cycle of that frequency.

On the other hand, nonlinear loads such as personal computers, motor drives, electronic ballasts and office equipment switch on and off faster than the fundamental frequency of the supply voltage. Any power supply that converts AC to DC power will have a very distorted waveform at the supply. The current waveform is always a picture of the way a load reacts to the AC supply. When the return current from a distorted load reacts with the impedance of the switchgear back to the panel, an ohms law relationship exists. The distorted voltage created by the return current through the impedance of the cable and switchgear can cause the voltage waveform to distort. This voltage distortion will affect every device connected to the corrupted circuit.

By definition, a harmonic is an integer multiple of the fundamental frequency of the supply. In the USA the fundamental frequency is 60 cycles per second, or 60Hz. For example, the second harmonic of the fundamental frequency is 120Hz; the third harmonic is 180Hz and so on.

Notice that the second harmonic is half the length (or duration) of the fundamental and the third harmonic is one-third the length. The fundamental frequency is half the speed of the second harmonic and one-third the speed of the third harmonic.

Distortion of the current waveform is normal for non-linear loads. As more non-linear loads are added, distortion of the voltage waveform will result. The impact to the electrical system depends on the total amount of distortion present, the size of the distribution system, and the impedance of the connecting cables and switchgear. In general, lower frequency harmonics are more serious than higher frequency, because there is more energy in the lower frequencies. However, high frequency harmonic distortion can cause problems with communication and control equipment.



Total harmonic distortion (THD) is the percentage of distortion to the fundamental frequency. As a general rule, THD should not exceed 5% of voltage or 20% of current. More strict limits (3%) apply to hospitals and airports. Industrial circuits can withstand higher levels (8%) without problems.

Harmonic Content

Breaking down the total harmonic distortion into individual harmonics requires a mathematical tool called a Fast Fourier Transform, or FFT. Sometimes only the odd-numbered harmonics are analyzed, but since high levels of even distortion can be problematic, it is good to use a portable analyzer that checks both, like the IDEAL 61-807. Odd number distortion is caused mostly by nonlinear loads. Odd number distortion can have a great impact on an electrical system. Odd-numbered distortion is further organized into three groups, by those harmonics that are positive sequence, negative sequence, and zero sequence.

Positive sequence harmonics all provide a rotational sequence in the same direction as the fundamental. These would be the harmonics in the series 1,7,13,19,etc.

Negative sequence harmonics provide a rotational sequence to the reverse of the fundamental. Negative sequence harmonics are the 5^{th}, 11^{th}, 17^{th}, etc.

A special case exists in which there are harmonics that are not in phase with either, and these are called zero sequence harmonics. These harmonics are all odd and divisible by the number 3. Sometimes called the triplen harmonics, these are the 3^{rd}, 9^{th}, 15^{th}, etc.

These are all important to residential, commercial, and industrial applications, and some of the harmonics are more common than others. Single-phase devices often have very high third harmonic distortion. Six-pulse drives will commonly show harmonic distortion in the series 5,7,11,13,17,19, etc. The most common sources of 3^{rd} harmonic (Triplen) harmonics are caused by 120 volt hot to neutral wired computers, dimmers, and just about every socket powered electronic device. Negative sequence harmonics are commonly found in industrial environments and big contributors are chargers and variable speed drives and any other six-pulse converters.

Commercial Environments

In the 3-phase, 4-wire electrical system commonly found in commercial buildings, current flows through each phase conductor and returns in a common neutral conductor. In a balanced system, the neutral currents from each phase will mathematically cancel each other out. Any imbalance in phase current will return on the neutral at the fundamental frequency (60Hz). As this return current is typically small, it is generally not considered a problem. The characteristics of the triplen harmonics (3rd, 9th, 15th, etc.) disrupt this balance. Rather than canceling each other out on the neutral, the triplen harmonics from all three phases are mathematically added together in the neutral conductor. This can result in a higher than expected current which can cause excessive heat in the neutral conductor and transformer.

Industrial Environments

The electrical loads within an industrial plant are affected by the negative sequence harmonics (5th, 11th, 17th, etc.). These harmonics rotate opposite (counter clockwise) to the fundamental rotational energy created by the electrical power system. For example, if you run a three-phase 60Hz motor on the fifth harmonic alone, the motor will run 5 times faster, backwards. The impact to the rotation of the motor depends on the content of the harmonic distortion. A level of 20% distortion on the fifth harmonic means 20% of the energy is working against the motor. This has a serious impact both to the torque produced by the motor and the heat given off. This affects both production being run on the machine and the life of the motor, not to mention energy cost as the harmonic energy is wasted as heat.

Troubleshooting Harmonics

Preventing damage to electrical circuits and expensive equipment means measuring the distortion levels on every circuit in a facility. To effectively troubleshoot the problem, the total harmonic distortion and harmonic content should be analyzed. Knowing the amount and characteristics of the harmonic distortion will aid in identifying a solution.

The IDEAL Power Analyzer can collect data concerning harmonic distortion as well as power quality issues like disturbances.

In commercial and industrial applications, harmonic distortion may not necessarily need to be mitigated or removed. Reactors can smooth out a lot of the current distortion on large motor drive loads, and filters and traps can further reduce the distortion on the voltage waveforms. Depending on the sensitivity of the devices powered and the general stiffness of the voltage, mitigation is not always necessary or cost-efficient. You cannot make a decision without measuring over time.

One alternative to improving harmonic distortion is to minimize the effect the distortion has on the system. If heat is the only problem, then over-sizing the neutral conductor or de-rating the existing transformers are possible solutions for a 3-phase, 4-wire system affected by triplen harmonics. Zigzag transformers also can be used to handle distorted currents.

Power Quality Events: Disturbances

The term "disturbances" is used to describe any kind of fluctuation in power. The most common types of disturbances are sags, swells, over-voltages, under-voltages, transients and interruptions.

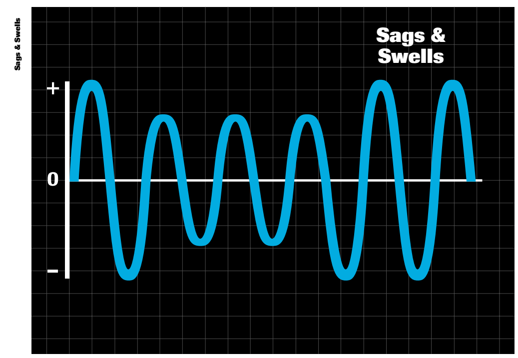
Sags, Under-voltages and Interruptions.

Sags are momentary decreases in voltage. This decrease is typically 10 to 90% of the nominal voltage with duration between 0.5 cycles and 60 cycles. A sag in voltage lasting longer than a period of one minute is called an under-voltage and a complete loss of power is called an interruption. Sags occur commonly, and may be caused by any possible source including service failure, motor starts, or cycling machinery.

Swells and Over-voltages

Swells are the opposite of sags. They are momentary increases in voltage up to 110% of nominal lasting between 0.5 cycles and 60 cycles. This increase in voltage is more unusual than a sag, but it is far more damaging. An increase in voltage lasting longer than a period of one minute is called an over-voltage.

Though they are caused by different factors, sags and swells often follow each other as the system attempts to compensate. This further increases their potential to cause damage.

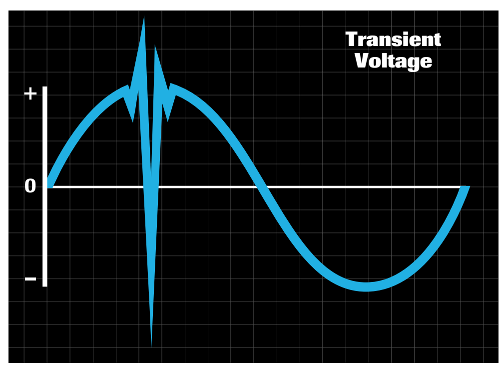


Transients

Transients are short-duration, high-amplitude pulses superimposed on a normal voltage waveform. They can vary widely from twice the normal voltage to several thousand volts and last from less than a microsecond up to a few hundredths of a second.

Transients are caused by a rapid release of energy stored in an inductive or capacitive source in the electrical system, or from an external source such as lightning.

While the duration of transients is unnoticeable to a human observer, their effect on power quality is still considerable. A single lightning strike can result in a transient large enough to destroy electronic devices.



Troubleshooting Power Quality Events

Voltage events tend to be periodic and they do repeat, but certain conditions may be required to see them. That means that a series of recordings will be needed, or perhaps you might want to leave a recorder on a circuit to record continuously until a failure occurs. Recording over time is the only way to successfully find a problem and diagnose it. The nature of disturbances in industrial settings can be irregular. By tracking a circuit over an extended period of time with the IDEAL Power Analyzer, data can be saved and analyzed later on a computer. This makes disturbances easier to pinpoint.

Server power quality events that are causing complaints or failures need to be located and fixed quickly. The good news is that voltage events or disturbances are fairly easy to eliminate once they've been properly identified. The bigger the problem, the easier it is to track down, once you have a reliable recording power meter.

IDEAL 61-830 VPM

When testing power quality on single-phase circuits, all you need is the IDEAL VPM. Plug it in, select the appropriate standard, or use the default ITIC standard, and away you go. Sag, Swell, Impulse, THD events are all measured, categorized, and listed for your review. The magnitude and duration along with the exact time of the event are all saved for later review. This quickly allows you to correlate that the voltage is the cause of the problem, or that some other issue exists. High accuracy, reliable, easy to use, no computer required, the IDEAL VPM is your first line of recording for power quality problems.

Branch Circuit Analyzer

In the past, measuring total harmonic distortion (THD) was a task for bulky and expensive equipment, but when you have both the IDEAL VPM and the IDEAL SureTest Circuit Analyzer 61-165 you have changed that equation! The SureTest is designed to troubleshoot an electrical distribution system, analyzing both common circuit and power quality problems. It is the first handheld circuit analyzer capable of applying a full 15-amp load without causing interruption to equipment on the circuit. It identifies and locates loose connections, bad splices or receptacles, loose ground connections and high-resistance grounds.

The SureTest Circuit Analyzer is used for a multitude of power measurements

The SureTest model 165 is specifically designed for residential commercial and industrial environments where electronic lighting and electronic equipment are present. The SureTest captures True RMS measurements, analyzes the integrity of branch circuits, measures voltage drop, provides available short circuit current values, and resistance of each wire, hot, neutral, and ground on a live circuit.

The versatility of the IDEAL Power Analyzer means simultaneous recording of all parameters for extended periods of time.

IDEAL Power Analyzer
This is a unique instrument designed for in-depth examination of commercial and industrial power issues like kilo-watt/hour consumption, power quality, energy, and harmonics. What sets the IDEAL Power Analyzer apart from the rest is its versatility and ease-of-use. Built-in memory enables the long-term recordings of all parameters simultaneously. Information can then be downloaded to the included powerful windows software for analysis. The Power Analyzer can be used for all power issues discussed in this guide. The Power Vision analysis software creates a variety of tables and graphs to make in-depth analysis of power quality problems easier. It all adds up to the most complete, versatile and easy-to-use power measurement tool anywhere.

TECHNICAL DEFINITIONS

Ampere - A unit of measure for the rate of current flow.
Ohms law: One ampere of current flows through One Ohm of resistance at One Volt of pressure. This unit if measure is named for Andre-Marie Ampere. Current is the measured presence of an inductive field (alternating magnetic field in AC circuits.)

Apparent Power – The total energy supplied to a device or circuit. This is not the same as power. Apparent Power is measured in Volt-amperes (VA).
Formula: TRMS Amperes multiplied by TRMS Voltage equals apparent power in an AC circuit.

Frequency - The period of a sine wave measured in terms of the number of cycles per second. The frequency of alternating current in the USA is 60 cycles per second. This unit of measurement is named for Heinrich Hertz, abbreviated as Hz.

Harmonics - An integer (multiple) of the fundamental source frequency. Harmonic distortion is measured up to the 50^{th} Harmonic, which is 3000 Hz. Harmonics can be odd or even. The return current of non-linear loads can cause harmonic distortion of the voltage waveform.

Harmonic Analysis – Fast Fourier Transform or FFT – Mathematical Analysis used to break Total Harmonic Distortion into its basic integer components.

Linear Loads – The current waveform mirrors the sinusoidal voltage waveform with a Linear Load. The load uses the voltage exactly as it is presented in the circuit. Examples of linear loads are synchronous motors and incandescent lighting.

Negative Sequence Harmonics – These Odd-numbered harmonics starting with the 5^{th} harmonic (5th, 11th, 17th, etc.) produce rotational sequence opposite to the fundamental frequency.

Nonlinear Loads – When a load switches faster than the frequency of the line voltage, the load impedance is not constant within the period of the voltage waveform. The current waveform does not mirror the voltage waveform, but does demonstrate the way the load switches on and off during the period of the voltage. Current distortion is a signature of the type of non-linear load; for instance a 6-pulse drive looks quite different than an 18-pulse drive. Examples of nonlinear loads are computers and variable speed machines.

Odd Harmonics - Odd-numbered integer of the fundamental frequency (60Hz). The 3rd harmonic of the fundamental frequency is 180Hz; the 5th is 300Hz, etc. Odd numbered harmonics are caused by nonlinear loads and cause non-symmetrical waveform distortion.

Outage - An extended interruption of AC power is called an outage. A very brief outage is called an interruption.

Power Factor - The ratio of work performed (active power or watts) to the energy supplied by a system (apparent power or volt-amperes). It is not a measure of efficiency. It is a measurement of electro-magnetic losses.

Power Quality – The measurement of the quality of electrical power. Voltage quality is categorized by power quality events: sags, swells, under and over voltage, as well as wave-shape distortion. Voltage transients can also be considered to be Power Quality events. The description of the sags and swells are different depending upon the standard used, but all power quality events include both magnitude and duration of the event.

Sag - A very brief period of reduced voltage, from sub-cycle to 60 cycles in length.

Swell – a very brief period of increased voltage, from sub-cycle to 60 cycles in length.

Transient - A sub-cycle release of positive or negative energy superimposed on an AC voltage waveform. The transient can be either impulsive or oscillatory. The transient can be a single event, or multiple events.

Total Harmonic Distortion (THD) - The percentage of all integer distortion up to the 50th harmonic compared to the fundamental waveform frequency.

Triplen Harmonics – Odd numbered harmonics divisible by 3. Also, see zero sequence harmonics.

True Power – Also known as True Active Power. This is the active power resulting when True Power Factor (both displacement power factor and harmonic distortion) are considered in the calculation.

Volt - A unit of measure of the electrical pressure in an electrical system measured in Volts. Also considered to be electro-motive force, and is the measured presence of an electric field. Named for Alessandro Volta. One volt is determined to be the voltage at which 1 ampere of current produces 1 watt of power.

Volt-Amperes – Apparent Power. Apparent Power is the sum of active power (watts) plus reactive power (kVarL and KvarC) this is the energy supplied to a load or electrical system.

Watt – Active Power. See true power. It is the power expended when one ampere of current flows through a resistance of one ohm. It is the work performed by the load or circuit, as opposed to the energy consumed by the load or circuit.

Zero Sequence Harmonics - Also called triplen harmonics, these are odd harmonics divisible by 3 (3rd, 9th, 15th, etc.). Zero sequence harmonics cause problems on 3 phase 4 wire circuits because they are not in phase with anything but themselves. They are additive as they flow on the neutral and can cause overheating as a result. In the past when it was common to de-rate the neutral conductor, zero sequence harmonic distortion caused overloaded neutral conditions in severely distorted circuits because zero sequence harmonics from all 3 phases return on the single neutral.

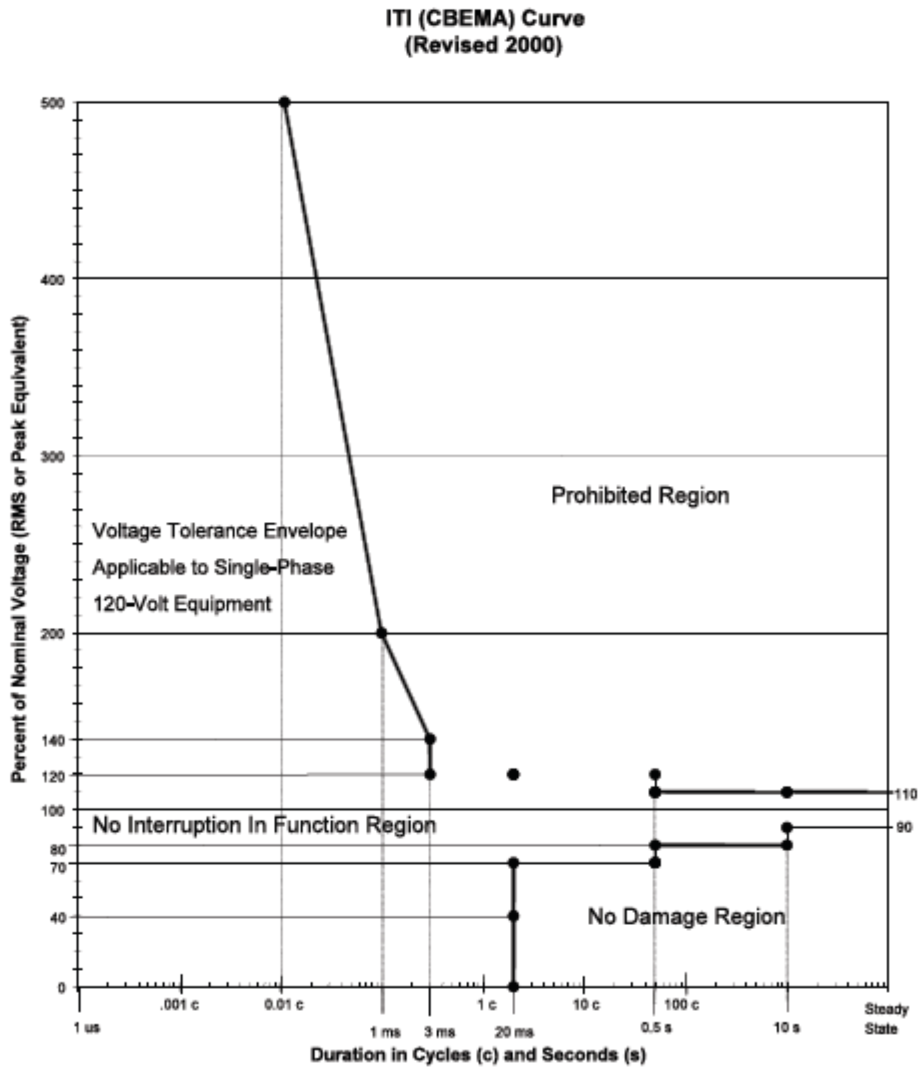
Common Power Quality Standards

ANSI

Table 3.1 ANSI C84.1 Voltage Limits (Service Voltage)
Service Voltage (1) ***Range A (2)(4) Range B (2)(6)***
Maximum +5% +5.83%
Minimum -5% -8.33%
1. **Service voltage** is measured at the point of common coupling between Customer and Company. Jurisdictional Public Service Commission's may specify other voltage limits.

Table 3.2 ANSI C84.1 Voltage Limits (Utilization Voltage)
Utilization Voltage (6) ***Range A (2)(4) Range B (2)(6)***
Maximum (equipment rated >600 V) +5% +5.83%
Maximum (equipment rated <600 V) +4.17% +5.83%
Minimum -8.33%(-10% (3)) -11.67%(-13.33%(3))
2. Voltage limits in % deviation from nominal
3. For circuits with no lighting equipment
4. **Range A** applies to normal operations
5. **Range B** applies for short duration and/or abnormal conditions on the utility system (excluding fault conditions and transients).
6. **Utilization Voltage** is measured at the equipment using the electricity.

ITI (CBEMA)



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