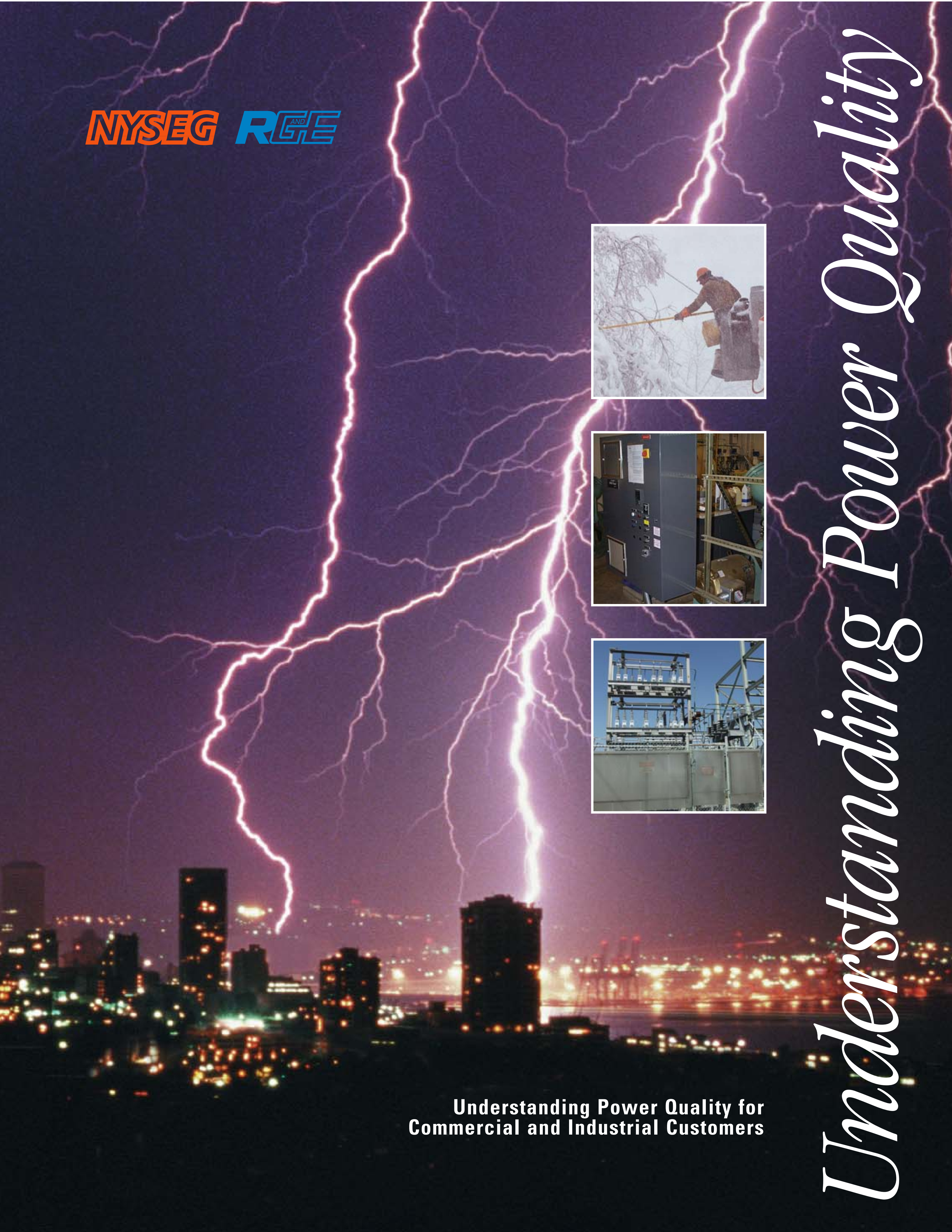
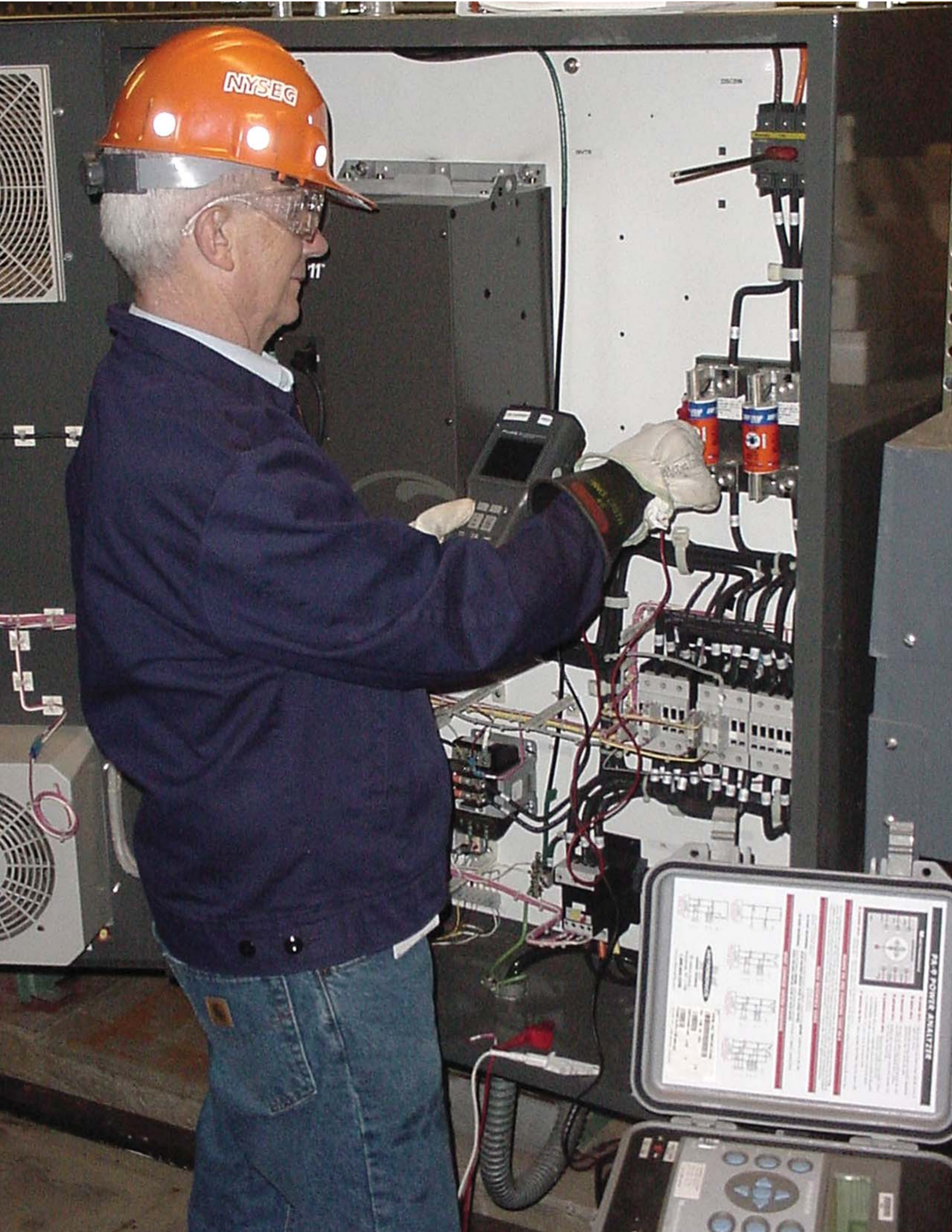
NYSEG RG&E

Understanding Power Quality



Understanding Power Quality for Commercial and Industrial Customers


NYSEG
PA-9 POWER ANALYZER

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<< **Power quality problems may require an inspection of your facility, including installation of a power line disturbance analyzer.**


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Power Disturbances and Sensitive Electronic Equipment

Sensitive electronic equipment like computer-based devices require high quality, disturbance-free power to operate properly. All electrical systems, however, are subject to occasional events which result in disturbances. These disturbances can be significant enough to affect the operation of sensitive electronic equipment. In addition, electrical equipment within your facility may produce disturbances that affect other equipment in your facility or neighboring facilities.

This brochure is intended to help plant managers, facility supervisors, managers of computer services or information systems, and small-business owners identify and control power supply disturbances that can affect the operation of sensitive electronic equipment. It includes a list of the typical equipment that could be affected; the types of power disturbances that can occur; their causes; steps that can be taken and information on what NYSEG and RG&E are doing to prevent these disturbances.

Equipment That Could Be Affected

Typical equipment that could be affected by power disturbances or irregularities include:

❍ Computers
❍ Medical instruments and life support equipment
❍ Point-of-sale terminals
❍ Testing and measuring instruments
❍ Process control systems
❍ Adjustable speed drives
❍ Traffic control systems
❍ Machine tools
❍ Communication systems
❍ Security systems
❍ Digital clocks
❍ Computer peripherals (printers, modems, hard drives, etc.)

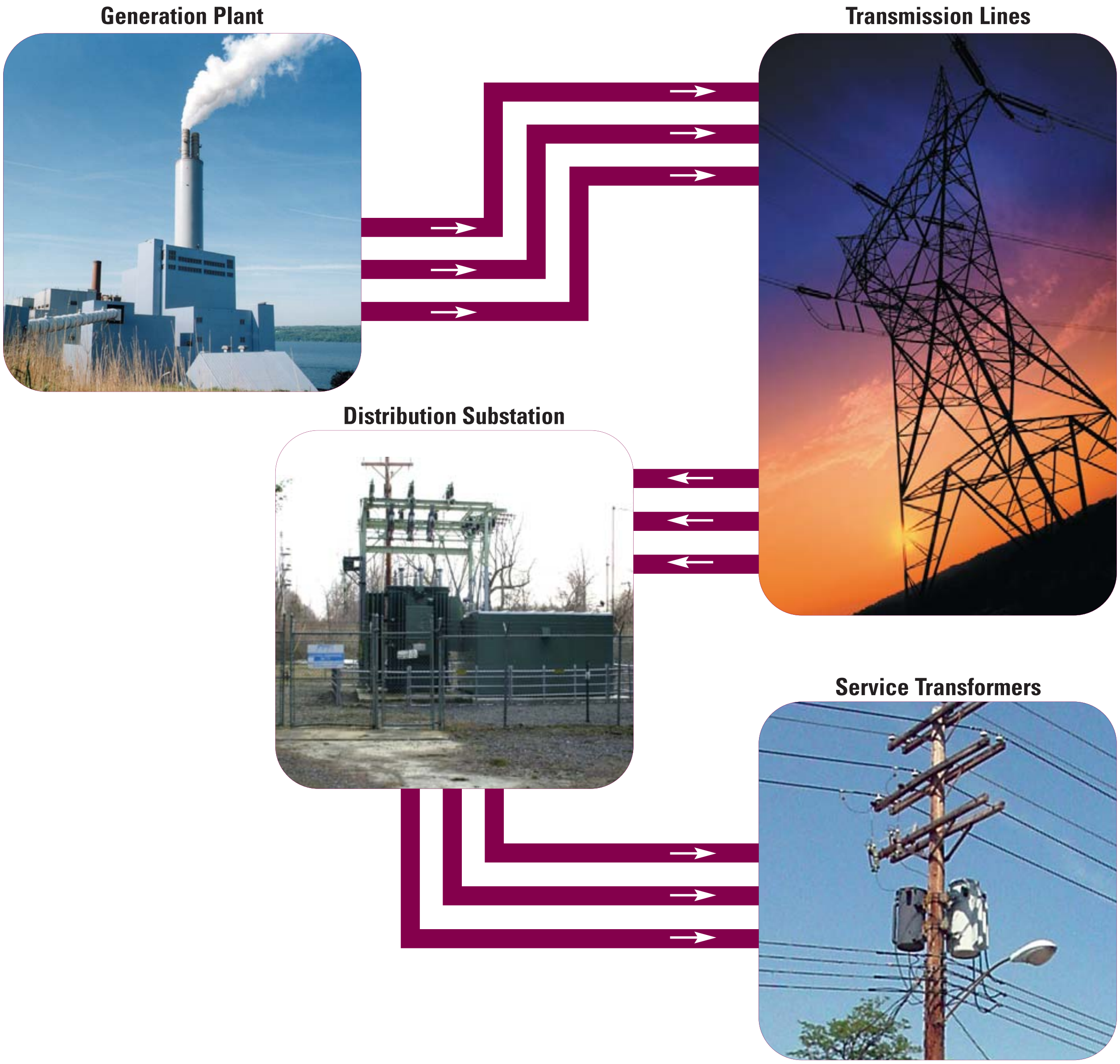
<< Sensitive equipment such as computers, require high quality, disturbance-free power to operate properly.

How Electric Power Is Supplied to You

Electricity is generated at power plants and is transported to you through a complex delivery network. From the generating station, electricity travels along high voltage transmission lines to an electrical substation. At the substation, voltage is “stepped down” to a lower level and sent to distribution substations using subtransmission lines. At the distribution substation, voltage is further reduced and sent to customers through distribution feeders such as the one serving your facility. Electricity can be delivered to large commercial and industrial customers by either subtransmission or distribution lines.

Within your facility, electricity is distributed directly or after another transformation to a lower voltage to various electrical devices. All types of electrical equipment – from large, powerful motors to sensitive, critical computer controllers – are typically connected to the same source of supply within your facility.

Potential disturbances to the quality of the power used within your facility and the causes of these disturbances are discussed in the pages that follow.



Typical Power Quality Problems

Over Voltage/Under Voltage

Occasionally, a utility may supply over or under voltages due to abnormal operating conditions or events. Within your facility, over or under voltage may be caused by improper wiring, such as undersized conductors, or by mis-tapped transformers. Long term over or under voltage may affect sensitive electronic equipment.

Voltage Sags

When an electrical fault occurs either within your facility or on our system, the voltage can drop dramatically. The amount of voltage drop depends largely on the distance between your equipment and the location of the fault. The closer the equipment is to the fault, the greater will be the voltage drop that will be seen at the equipment terminals. The duration of the fault is determined by the speed of the circuit protection device (fuse or circuit breaker) that detects the fault. Starting a large motor or other apparatus can also produce significant voltage drops. If a momentary drop in voltage or a voltage sag is experienced, sensitive electronic equipment may be affected.

Voltage Swell

A voltage swell is a momentary rise in voltage. Swells may be caused by removing a large load from or by adding capacitance to a circuit. Swells may also occur when a fault on one phase results in a temporary voltage rise on the unfaulted phases. Swells may result in voltages that exceed electronic device ratings. Repetitive swells may cause electronic device damage.

Impulses (Spikes)

An impulse is a rapid, steep rise in voltage. Voltage impulses occur on the electrical transmission and distribution system as a result of normal operation of fault clearing devices, capacitor switching, or even normal switching of loads by the utility or its customers. Impulses are also frequently created by the normal operation of customer loads such as silicon controlled rectifier (SCR) loads, adjustable speed drives, photocopiers and abnormal conditions such as faulty wiring.

Since impulses can damage some electronic components, some manufacturers build impulse protection into their products. The protection typically consists of a device that safely diverts the incoming impulse into the grounding system before it enters the equipment.

Momentary Outages

A momentary outage is a complete loss of voltage lasting for less than five minutes. These outages are generally the result of the operation of either utility or customer protective devices such as fuses and breakers. Fuses and breakers are designed to open under abnormal electrical conditions.

Harmonic Distortion

Distortion occurs when the 60-cycle voltage waveform is altered by higher frequencies. The amount of the harmonic distortion is directly related to the harmonic content. The magnitude of the harmonic distortion depends on the amount of computer-based equipment, communications equipment and other electronic equipment in use. A large amount of this equipment in use can generate levels of harmonic distortion that can interfere with the operation of other equipment within a facility.

Electrical Noise

Electrical noise is a high frequency interference that can be induced on electrical system conductors and carried into an electrical system by those conductors. Although generally not destructive, electrical noise can sometimes pass through a computer's power supply transformer as if it were a signal and cause erroneous data output or data loss.

Flicker

A flicker is a variation in input voltage caused by a repetitive series of sags and/or swells sufficient in duration to create a perceivable change in electrical light intensity.

Causes of Power Quality Problems

The quality of the electricity used within your facility may be affected by several conditions, including:

Faults

Faults may severely impair the quality of electricity in the area near the fault. When the fault is cleared, the normal high quality of electricity is usually restored automatically on overhead power lines within four to six electrical alternating current (AC) cycles.

If the fault condition persists, utility protective equipment may automatically cycle the power on and off for several seconds. This may occur two or three times. If a permanent fault occurs on the electrical circuit, all power supply will be interrupted until the cause of the fault is corrected. On underground power lines, there is no automatic reclosing because most faults are permanent.

A variety of conditions can cause faults including:

- ❍ Equipment failure
- ❍ Severe weather like wind, ice, snow and lightning
- ❍ Trees blowing or falling into power lines
- ❍ Vehicles hitting electric utility poles
- ❍ Thrown objects that damage electrical components
- ❍ Animals climbing onto live parts of electrical apparatus

Equipment Interaction

Some equipment can create distortions of the supply voltage and interfere with the operation of other equipment in your facility. These distortions may affect power quality and lead to faulty operation of sensitive equipment. Distortions can take the form of electrical noise, voltage notching or harmonic distortion of the voltage. Electrical noise is a low level AC signal that rides on the AC waveform making the waveform look fuzzy. Voltage notching is a momentary (less than a millisecond) dip in the AC waveform which is usually produced by three-phase rectifiers. The addition of harmonic voltages to the 60-hertz fundamental can produce a noticeable change in the waveform. Possible sources of harmonic interference include adjustable speed drives, electronic ballasts, computer power supplies, power conditioners, and uninterruptible power supplies (UPSs).

Operating Conditions

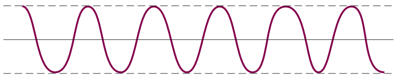
Switching electrical equipment within the plant or on the local electrical distribution system can temporarily impair power quality. Power quality may also be affected when a large piece of equipment such as a motor is switched on or off.

Plant Wiring/Grounding

In many cases, improper wiring and grounding will impair the quality of the power supplied to or distributed within your facility. This problem includes open, loose, or corroded connections; improperly sized conductors; multiple grounding points; and a high resistance ground. Multiple grounding points produce ground-to-neutral loops. Ground-to-neutral loops can be produced by either the use of multiple ground rods (electrodes) at various locations around a facility or by the use of multiple connections between the neutral and ground. Current can flow in these loops and, as a result, can produce a voltage on the neutral. This neutral voltage can then interfere with the operation of a computer that is using the neutral as a zero volt reference source.

Types of Disturbances and Protection Equipment Effectiveness

>> Normal Power



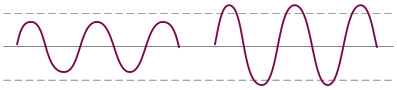
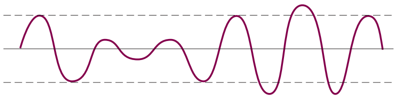
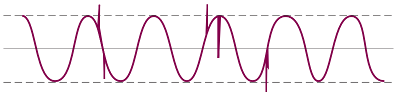
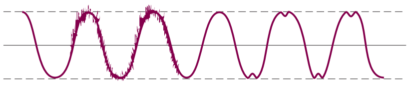
Type of Disturbance	Type of Equipment Affected	Effective Protection Equipment
Undervoltage or overvoltage are conditions of abnormally high or low voltage lasting for more than a few seconds. They are caused by circuit overloads, poor voltage regulation, and intentional reductions by the utility (brown out).  **Undervoltage** **Overvoltage**	Undervoltage and overvoltage affect all equipment, although most equipment is designed to tolerate 120 V ± 10%.	Voltage regulator, ferroresonant transformer, line conditioner or uninterruptible power supply (UPS).
Voltage sag is a momentary (less than a few seconds) decrease in the voltage outside the normal tolerance. (Swells are corresponding voltage increases.) Voltage sags are often caused when heavy loads are started, by lightning and by power system faults. **Voltage swells** are often caused by sudden load decreases or turn-off of heavy equipment. A series of sags or swells that results in a perceivable change in light intensity is called Flicker.  **Sag** **Swell**	Sags affect power-down sensing circuitry on computer and large controllers and can cause equipment to shutdown. “Swells” can damage equipment (including spike suppressors) that have insufficient tolerance.	Voltage regulator, ferroresonant transformer, line conditioner, or uninterruptible power supply (UPS).
Spikes (impulses, switching or transient lightning) are very short in duration (microsecond to millisecond) voltage increases. Spikes can range in amplitude up to thousands of volts and are caused by lightning, switching of heavy loads and short circuits or power system faults. **Spikes, Impulses, Surges** 	Spikes can destroy electronic loads and breakdown transformer or motor insulation.	Spike suppressors (also called surge suppressor) or some line conditioners.
An **outage** is a complete loss of power that may last from several milliseconds to several hours and may be caused by power system faults, accidents involving power lines, transformer failures and generator failures. Some sensitive equipment may be disrupted by outages as short as 15 milliseconds. **Outage** 	Outages affect all equipment.	Uninterruptible power supply or standby power supply.
Electrical noise is a distortion of the normal sinewave power and can be caused by radar and radio transmitters, fluorescent lights, power electronics control circuits, arcing utility and industrial equipment, loads with solid-state rectifiers and switching power supplies typically used in computer systems. **Electrical Noise, Harmonic Distortion** 	Electrical noise disturbs microprocessor-based equipment, such as microcomputers and programmable controllers. Harmonic distortion causes motor loads, such as compressors, pumps and disk drives, to overheat.	Filter, isolation transformer, uninterruptible power supply (UPS) or some line conditioners.

Chart courtesy of the U.S. Department of Commerce, National Institute of Standards and Technology (NIST SP768A)

Power Quality Required by Sensitive Loads

Steady State Voltage

The voltage that sensitive electronic equipment requires for reliable operation falls within rather narrow limits in comparison to the voltage requirements of other equipment. The ITIC (Information Technology Industry Council) curve (Figure A) was created by computer manufacturers to serve as a voluntary guideline within which most computers are designed to operate. This curve depicts the limits and duration of changes in the steady state voltage which computers can tolerate.

Steady state voltage is the value after all transients have decayed to a negligible value. The ITIC curve shows steady state as the value the voltage settles out to two minutes after a transient has occurred. On the right side of the ITIC curve, the typical tolerance for 120-volt sensitive electronic equipment is 104 to 127 volts (-13/+6%). NYSEG and RG&E's goal is to provide steady state voltage levels at the meter according to ANSI C84.1 (service voltage range A).

Voltage Sag Ride-Through

Sensitive electronic equipment should have a built-in tolerance to voltage sags. The amount of ride-through capability varies by manufacturer. For example, as depicted on the ITIC curve, a sag to 100 volts (83% of 120 volts) for .1 second falls within the tolerance envelope and should not disturb sensitive electronic equipment. Ride-through capability is an important equipment characteristic for the reliable operation of sensitive electronic equipment.

Impulse Tolerance

Typical sensitive electronic equipment can tolerate voltage impulses of up to 1,000 to 1,500 volts because of built-in surge protection. Much lower level voltage impulses, depending on their duration, can affect equipment operation. For example, as depicted on the ITIC curve, an impulse of one millisecond duration and 260 volts exceeds the tolerance envelope and may impact sensitive equipment. Therefore, impulse protection is another important feature for the reliable operation of this equipment.

Outage Ride-Through

Sensitive electronic equipment has limited outage ride-through capability, typically up to 20 milliseconds. Some equipment has longer ride-through capability. Other equipment has the ability to provide an orderly shutdown of its system when outages occur. Still other equipment is programmed to begin normal operation when power is restored or when the equipment is manually reset. In order to obtain longer outage ride-through capability, an uninterruptible power supply may be used.

Harmonic Distortion

Sensitive electronic equipment operates best when the total voltage harmonic distortion (THD) factor is less than 5% of the fundamental voltage and any single harmonic does not exceed 3% of the peak of the fundamental voltage level. Harmonic distortion is generally caused by other electronic equipment served from the same electric system.

Electrical Noise

Typically the noise magnitudes superimposed on the 60-hertz voltage waveform are less than 1% of voltage magnitude. Filters, isolation transformers or line conditioners may be needed if the electrical noise level exceeds this amount.

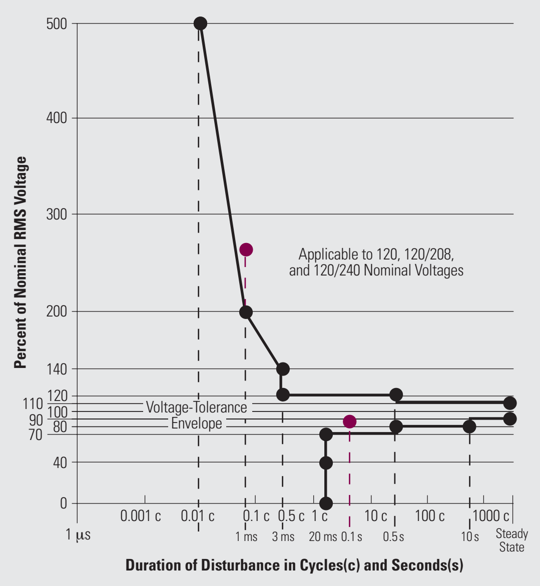


Fig. A - ITIC Curve

Steps You Can Take

If you suspect that you have a power quality problem, the following three-step procedure is recommended to identify the source and to eliminate or minimize the problem:

1. Perform initial system checks
2. Monitor the power supply
3. Implement mitigation measures

STEP 1 – Performing Initial System Checks

The following is a list of steps that you can take to resolve or mitigate a power quality problem. Some of these steps will require the use of electrical measuring instruments.

Remember that any electrical work completed should meet the requirements of the National Electrical Code (NEC) and be performed only by qualified personnel.

1. Keep records noting which equipment is affected including the times and dates that the problem occurred. Also make a note of other equipment that was operating when the problem occurred (Appendix H-Power Disturbance Log, page 26).
2. Where practicable, sensitive equipment should be installed on dedicated circuits. A dedicated circuit should have its own circuit breaker, a properly sized neutral wire and not have other equipment connected to it such as motors and heating, ventilating and air conditioning equipment.
3. Using a true root mean square AC voltmeter, check the voltage being supplied to the equipment. If the voltage supplied is outside recommended limits, consider changing taps on the transformers supplying the sensitive electronic equipment. Make sure that the circuit wire size meets NEC requirements.
4. Using an AC voltmeter and AC ammeter, determine if the voltage and current on each phase of a three-phase supply current are balanced. Voltage imbalance should not exceed 3% or the maximum limit specified by the equipment manufacturer. Keeping the current balance will minimize the neutral current.
5. With the aid of a harmonic analyzer, ensure that the voltage waveform is free of distortion. Acceptable harmonic levels are 5% for total harmonic voltage distortion and 3% for any single harmonic voltage. If these harmonic limitations cannot be met, consider installing filters or traps on the power lines feeding the equipment producing the harmonics. Facilities that use power factor correction capacitors may require the addition of reactors to detune the system. An alternative is to install new capacitor banks with filtering that will detune the system and trap undesirable harmonics. A consultant is recommended.
6. Check the condition of the supply circuit wiring. Faulty wiring can result in intermittent circuit discontinuity or faults which can affect sensitive equipment.
7. Using a ground resistance measuring instrument, determine if an adequate ground exists. Each ground should have a resistance of 25 ohms or less (per NEC section 250.56). Inadequate grounding is a major cause of sensitive equipment malfunction due to neutral-to-ground noise. Have your electrician verify that all grounding meets the requirements of the NEC.
8. Measure the effect of switching large blocks of load within the facility with a voltage monitoring instrument. If the effect is detrimental, reduce the size of the load blocks switched. Switching too much load at one time can result in terminal voltages that are outside of equipment tolerances.
9. With the aid of a voltage monitoring instrument, determine if motor starting could be the source of poor power quality. If the starting of motors is depressing the voltage to the point of affecting your sensitive equipment, install motor starters or adjustable speed drives to provide “soft start” for your largest motors. This should reduce the voltage sags.
10. Check the susceptibility of the sensitive electronic equipment to electric and/or magnetic fields. Some sensitive equipment can be affected by these fields. For example, a computer screen operating in a strong magnetic field will exhibit image wavering. Because magnetic and electric fields vary significantly with distance, one solution is simply to move the affected equipment or the field source to a different location.

11. Be sure that any power conditioning equipment being applied is compatible (voltage range, frequency, power rating, etc.) with the equipment it supplies. If the power conditioning equipment is not compatible, its application may actually worsen a power quality problem.
12. If power factor correction capacitors are being used within your facility, ensure that they have not formed a resonant circuit at one of the 60-hertz harmonic frequencies. Harmonic resonance conditions can produce excessive harmonic currents and/or harmonic voltages. These can be eliminated by detuning the circuit from the harmonic frequency involved. An electrical consultant may be useful in making this determination.
13. Protect sensitive electronic equipment from spikes or transients by installing three stages of surge protection. Have a qualified electrician install surge suppressors at the main distribution panel, at sub-panels and at the outlets where the sensitive electronic equipment is connected.
14. Obtain an uninterruptible power supply to protect sensitive equipment against momentary losses of power.

STEP 2 – Monitoring the Power Supply

If the power quality problem still exists after going through the checklist, then monitoring the electric supply may be needed.

A convenient tool to monitor the electric supply is a power line disturbance analyzer. These devices monitor voltage and/or current continuously and store the data. Some analyzers provide a printed record while others require the data to be downloaded to a personal computer. The data will show the date and time that the voltage and/or current were monitored. There are several instruments and manufacturers available. Monitoring instruments can usually be rented or purchased.

STEP 3 – Selecting Mitigation Measures

The following are various measures for mitigating power quality problems. The cost of these measures can vary widely.

Purchase More Tolerant Sensitive Electronic Equipment > Sensitive electronic equipment tolerance envelopes vary by manufacturer. If monitoring indicates that your equipment is overly sensitive to power disturbances, equipment can be acquired that has a greater tolerance for power fluctuations.

Some adjustable speed drive manufacturers now include line reactors as part of the drive. Computer manufacturers are increasing the ride-through capability in their products to minimize malfunctions due to voltage sags and momentary outages.

When purchasing sensitive electronic equipment, you may be able to specify equipment capabilities such as sag ride-through time and harmonic distortion limits. It may also be possible to obtain performance guarantees, given the power quality environment in which the equipment must operate.

Discuss the results of your power quality monitoring with your equipment suppliers. Future problems might be mitigated by specifying equipment designed to resist the effects of power disturbances.

Wiring and Grounding Solutions > As mentioned earlier, proper wiring techniques may solve a power quality problem, particularly neutral to ground noise problems. Grounding that meets the current National Electrical Code and the use of dedicated circuits can solve many problems. You may want to consult with the IEEE Green Book on grounding (Appendix G, page 25).

Surge Suppressors > Some manufacturers of sensitive electronic equipment build protection into their products to prevent damage caused by voltage impulses. Your equipment vendor should be able to provide information about your equipment's protection.

If your sensitive electronic equipment is not protected, NYSEG and RG&E recommend installing surge suppressors. Surges may enter your facility through power lines, data lines, telephone lines and cable TV lines which should all be protected. Power lines can be protected by installing surge suppressors at the main service disconnect, the main distribution panel, sub-panels and at outlets to which the sensitive electronic equipment is connected. Contact your telephone company and/or cable TV supplier for their recommendations.

Harmonic Filters > Harmonic filters composed of passive electronic components can be used to reduce the harmonic waveform distortion. The harmonic content of the current distortion and the power factor must be determined to permit proper design of the filter. Electronic equipment such as computers and electronic lighting ballasts with single-phase rectifiers and switch mode power supplies are a major source of the third harmonic. Third harmonic currents can be reduced with filters installed either at the outlets where this equipment is connected or at the circuit panel.

Adjustable speed motor drives with three-phase rectifiers are a major source of higher order harmonics. Drives with six-pulse rectifiers generate high amounts of the fifth and seventh harmonics while drives with 12-pulse rectifiers generate high amounts of the 11th and 13th harmonics.

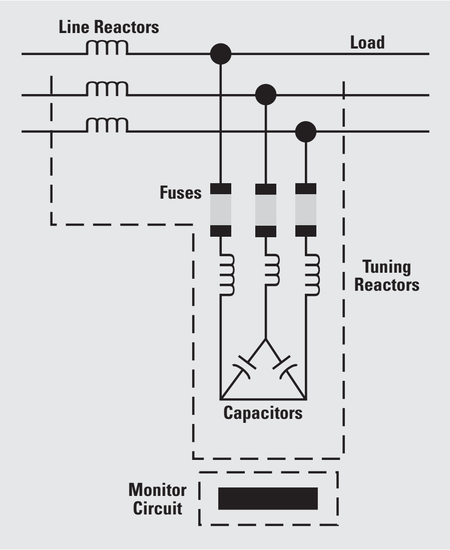


Fig. B - The typical composition of a harmonic filter consists of inductors and capacitors used to reduce harmonic distortion.

Courtesy of TransCoil, Inc., Milwaukee, Wis.

These harmonics are filtered with traps consisting of line reactors, tuning reactors and capacitors as shown in Figure B. They are typically installed on the power lines at the equipment producing the harmonics. In addition, the capacitive element of the filter can provide power factor correction. More information on harmonics is provided in Appendix A on page 12.

Line Reactors > In cases of nuisance tripping of adjustable speed drives, line reactors are often the recommended solution. A line reactor is a conductive coil that impedes voltage and current impulses which can cause nuisance tripping of adjustable speed drives. This problem is discussed further in Appendix B on page 14.

Isolation Transformers > Any transformer that does not share conductors between secondary and primary windings (including a neutral) can be considered an isolation transformer (Figure C). Some isolation transformers have special shielding to reduce noise. Isolation transformers are considered a “separately derived source” by the National Electrical Code and as such can provide an ideal dedicated source for sensitive electronic equipment.

A separately derived source can eliminate neutral-to-ground voltage if that source is properly grounded. It can also dampen the interference that other loads have on sensitive electronic equipment. Some manufacturers of sensitive electronic equipment now recommend providing power to their equipment through isolation transformers.

Check with your electrician to ensure that the manufacturer’s recommendation meets with National Electrical Code rules for applying separately derived sources.

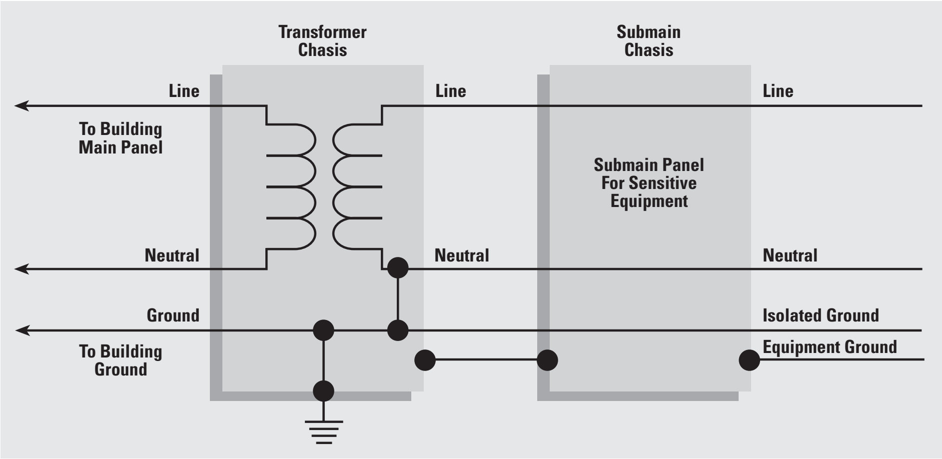


Fig. C - An isolation transformer is a good method for eliminating annoying and sometimes damaging neutral-to-ground noise.

Voltage Regulators > The purpose of a voltage regulator is to maintain constant output voltage to the load in the face of variations in the input line voltage. There are seven basic techniques to regulate voltage.

The *motor actuated voltage regulator* is generally inexpensive, can handle heavy loads, but is slow to respond to change and can only correct for gradual load changes. The *saturable reactor regulator* controls output voltage by varying the impedance of the saturable reactor winding in series with a step-up autotransformer. These regulators are relatively inexpensive, have a fairly wide load range, but have a sluggish response (5 to 10 cycles) high output impedance and are sensitive to a lagging load power factor.

Ferroresonant or constant voltage transformers operate in a saturated mode. By operating in saturation, these devices provide regulation and transient protection. They rely on a resonance between the winding inductance and a capacitance to operate in the saturated region. The basic ferroresonant transformer puts out a square wave which has high harmonic content. Most of the harmonic components, however, can be cancelled out with a specially designed neutralizing winding. They have a 1.5 cycle response time and regulating range from +17% to -35%.

The *electronic tap switching transformer* uses triacs or silicon-controlled rectifiers to change taps quickly on an autotransformer. They respond in 0.5 cycle and are insensitive to load power factor and unbalances. The *automatic voltage regulator* functions as an uninterruptible power supply with no energy storage. It has fast response (1 to 2 milliseconds) but the need for a fully rated, 60-hertz transformer can make the cost unacceptably high.

A *hybrid electronic voltage regulator* uses a series transformer and a power converter to accomplish the voltage regulation function. A *soft switching automatic voltage regulator* combines the performance of high performance active line filters with the lower cost of the more conventional solutions. The electromagnetic interference generated by these units is low in spite of the high frequency switching employed.

Power Conditioners > A power conditioner generally combines one of the voltage regulation techniques described above with a noise rejection system or filter for protection against common mode noise and the enhancement of voltage stabilization. The most accurate and sophisticated type of line conditioner uses a complex linear amplifier in a feedback arrangement to cancel out the effects of voltage variations and normal mode noise.

Motor Generator Sets > Motor generator sets are an older form of voltage waveform regeneration. The incoming or source voltage is used to drive a motor that is connected by a shaft to a generator. The generator produces a voltage waveform independent of the incoming supply. The mechanical shaft acts as a buffer between incoming voltage and the voltage that is supplied to the computer.

The ability to ride through voltage sag conditions depends on the load on the motor generator set and the amount of inertia in the rotating parts that provide energy during transient low voltage conditions. The voltage setting on the contactor for the motor can be another limiting factor. If the voltage sags enough to open the contact, the motor generator set will be disconnected from its supply line. When considering a motor generator set, loading and sag conditions should be evaluated.

Uninterruptible Power Supply (UPS) > None of the devices described thus far will allow continuous operation of your sensitive electronic equipment. In the event of a voltage outage lasting beyond the ride-through capability of the equipment, a UPS will typically provide 15 minutes or more of continued operation of the equipment depending on the battery size.

Fifteen minutes is usually a sufficient time to perform an orderly shut down of critical equipment and processes. There are many possible UPS configurations. Some produce harmonic distortion which might contribute to your power quality problem. A further discussion of UPSs can be found in Appendix C on page 15.

What We're Doing

In response to the growing use of sensitive electronic equipment by our customers, we have initiated a Power Quality Program. Through this program, NYSEG and RG&E offer a variety of service to our customers.

Initial Power Quality Audit > NYSEG's or RG&E's power quality investigator will ask you questions like those listed in Appendix D. Your answers to these questions will assist in determining the cause of the problem. If necessary, we will visit your facility to evaluate the voltage at your meter and to inspect the NYSEG or RG&E connections to your facility to ensure the integrity of your electricity service.

Diagnostic Services > Following the evaluation of the electricity service, we can assist your personnel by conducting a walk-through inspection to determine the possible sources of problems. This inspection may include examination of your wiring where it is accessible. If available, a power line disturbance analyzer could be installed to monitor power conditions at the service entrance. The results of such monitoring might be needed to provide insight as to the cause of the problem.

Recommendations > If a site visit and walk-through inspection are conducted, we will discuss solution alternatives with you. For difficult problems requiring a more detailed study of your facility, a power quality consultant might be needed. We can provide a list of consultants that might be available to you, if needed. Consultants can also design power quality mitigation measures.

Follow-up > We will remain in contact with you from the investigation stage through the resolution of the problem.

Education > Our desire is to share our experience and knowledge of power quality issues with you and all of our customers.

>> A power quality disturbance analyzer is used to investigate an electrical abnormality on a plastic molding injection machine.

Photo setting courtesy of Empire Precision, Inc. of Rochester

Appendix A – Harmonics

What are Harmonics?

Harmonics are voltages and/or currents present on an electrical system at some multiple of the fundamental frequency (generally 60-hertz). Typical harmonics of the 60-hertz fundamental include the third (180-hertz), fifth (300-hertz), seventh (420-hertz), 11th (660-hertz) and 13th (780-hertz). The harmonic voltages or currents present combine with the fundamental voltage or current to change or distort the fundamental waveform.

Figure 1 below illustrates an undistorted, 60-hertz, sinusoidal voltage waveform representing the presence of the first or fundamental frequency only. The waveform in Figure 2 illustrates a distorted waveform produced by combining of the fundamental voltage with the third and fifth harmonics waveforms.

Sources of Harmonics

Harmonics are generated by nonlinear loads. A nonlinear load is a circuit element where the voltage drop across it is not proportional to the current flowing through it. Until recently, most industrial loads were primarily linear with the current waveform closely matching the sinusoidal voltage waveform and changing in proportion to the load. Industrial loads today, however, have many nonlinear components.

There are three major classes of harmonic producing devices:

1. Ferromagnetic – such as transformers and motors operating close to and beyond their rated voltage.
2. Arcing – such as arc furnaces, welding equipment and lighting ballasts.
3. Electronic rectifiers – such as diodes and thyristors.

The magnetizing current in the core of transformers and motor laminations is rich in the third and fifth harmonics. Arcing devices, single-phase rectifiers and unbalanced three-phase currents produce primarily the third harmonic. Three phase, six-pulse rectifiers generate primarily the fifth and seventh harmonics, 12-pulse rectifiers generate primarily the 11th and 13th harmonics.

While transformers are numerous, they generally do not produce enough waveform distortion to cause any problems. Arcing devices and electronic rectifiers, however, produce much higher levels of distortions (typically 20% to 30% of their ratings). The increasing use of the latter two types may result in more power related problems due to harmonics.

Problems Caused by Harmonics

AC electrical systems with excessive levels of harmonics may produce any or all of the following: temperature rise of motors and transformers; motor noise and vibration; nuisance tripping of circuit breakers; overloaded neutral conductors; blown fuses; failed capacitors; telephone interference; and disruptions in the operation of electronic equipment.

Motors and transformers, for example, will run at a higher temperature in the presence of harmonics. The higher frequencies of the harmonics result in larger losses in the windings which produce more heat. The additional heat can result in a breakdown of the insulating material and a reduction in the life of the equipment.

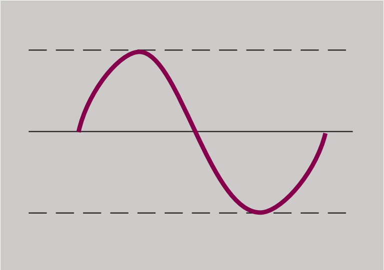


Fig. 1 - Voltage waveform with no distortion

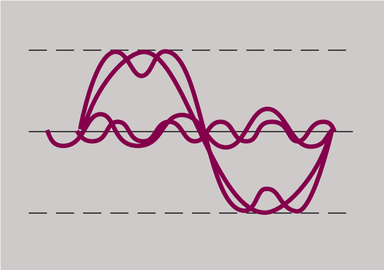


Fig. 2 - Distorted voltage wave and associated harmonics

Triplen Harmonics

Harmonics that appear in multiples of three of the 60-hertz fundamental are called triplen harmonics. They are produced by single-phase rectifiers found in computers, office machines and hospital equipment. Triplen harmonic currents resulting from single-phase loads on each phase of a three-phase service do not cancel in the neutral conductor as the currents at the fundamental frequency do. Rather, they add to the normal neutral current and can result in an overloaded neutral conductor. The Institute of Electrical and Electronic Engineers (IEEE) Standard 1100 (Emerald Book) recommends using neutral conductors that are double the size of the phase conductors in three phase, four wire circuits that supply nonlinear loads.

Resonance

The introduction of capacitors into an electrical system that contains harmonic generating equipment can create the potential for a harmonic resonance condition. Every inductive-capacitive (LC) circuit has a resonant frequency where the inductive reactance equals the capacitive reactance. If this resonant frequency equals, or approximately equals, one of the frequencies generated by a harmonic current and/or voltage, overvoltages and overcurrents can occur. This problem can be avoided by using harmonic filters which combine the benefits of power factor correction capacitors with the removal of undesired harmonics.

How Much is Too Much?

Total harmonic distortion (THD) is the ratio between the total root mean square (RMS) value of the harmonics present and the RMS value of the fundamental frequency. THD is defined as:

$$\text{THD} = \sqrt{\frac{\Sigma Vn^2 (n \neq 1)}{V_1^2}} \times 100\%$$

Where:
V_1 = RMS value of the fundamental voltage
Vn = RMS value of the nth harmonic voltage

As an example, consider the distorted waveform in Figure 2 on page 12. If the measured values of the individual harmonic voltages are:
V_1 = 105 volts
V_3 = 21 volts
V_5 = 9 volts

Then the corresponding THD value is calculated to be:

$$\text{THD} = \sqrt{\frac{21^2 + 9^2}{105^2}} \times 100\% = 21.8\%$$

The IEEE has recommended guidelines for acceptable limits of harmonic content. For systems below 69-kilovolts, maximum voltage THD is 5%, with no individual harmonic component exceeding 3%. A complete table can be found in IEEE Standard 519.

Solutions to Harmonic Problems

Solving a problem caused by harmonics begins by determining the harmonic and the equipment causing the problem. This is done with the aid of a harmonic analyzer. Harmonic problems are mitigated with filters. Different filters are employed depending on the harmonic causing the problem. Third harmonic problems may be caused by electronic lighting ballasts, welding equipment, unbalanced three-phase service or electronic equipment like computers. The third harmonic may be reduced using filters installed at the outlet where the equipment is connected or at the circuit panel.

Traps are used to filter higher order harmonics (5th, 7th, 11th, 13th, etc.) that are often produced by three-phase rectifiers found in adjustable speed motor drives. Traps are generally installed on the power lines at the equipment producing the harmonics.

An alternative for facilities that have developed harmonic problems and use power factor correction capacitors consists of detuning the system. This is done by adding inductors in series with the capacitor bank.

An electrical consultant may be helpful in determining the appropriate solution for a facility.

Appendix B – Motors and Adjustable Speed Drives

For improved energy efficiency and expanded flexibility, companies are increasingly applying adjustable speed drive (ASD) technology for control of motor speed. Despite the many advantages provided by ASDs, there are potential inherent power quality concerns.

The basic components of a three-phase, 60-hertz ASD are illustrated in Figure 3. The rectifier converts the 60-hertz AC input to a DC signal. Depending on the type of system, an inductor, a capacitor or a combination of both filters are installed to mitigate the 60-hertz ripple voltage on the DC signal in the DC link. The inverter converts the DC signal into a variable frequency AC voltage. This voltage is used to control the speed of the induction motor. Depending on whether the signal is derived from AC voltage or DC current, certain power quality conditions may affect the performance of ASDs or other loads in your facility. These conditions include harmonic distortion, impulses, voltage sags, and notching. Some of the effects of these conditions are as follows:

Harmonic Distortion

In converting AC power to DC power, a rectifier breaks or chops the AC current waveform, allowing current to flow during only a portion of the cycle. The resulting distorted AC current waveform is rich in harmonics. Because they include rectifiers, ASDs can be considered "harmonic generators" and can distort the voltage supplied to other equipment in your facility. Possible consequences include faulty operation of relays or controls, induced communications interference, blown fuses or excessive power losses and heating in motors, capacitors and transformers.

Care should also be taken on the load side of an ASD, i.e. controlling the motor. Excessive motor heating resulting from power losses through the windings can cause damage to the winding insulation. In general, the largest harmonic components in loads such as ASDs with six-pulse converters are the fifth and seventh harmonics. Motors that are to be used with ASDs should be inverter duty ready.

Impulses

Nuisance tripping of ASDs is a common concern. For certain types of ASDs, the DC link includes a DC capacitor to smooth voltage ripple. Voltage tolerance thresholds for these drives are generally very narrow. The switching of capacitors can lead to nuisance tripping. Impulses caused by the switching event can lead to a current surge into the DC link capacitor, charging of the capacitor and causing an overvoltage to occur. This overvoltage, if outside the threshold levels of the ASD, will cause the ASD to trip out of service. Nuisance tripping caused by impulses can be mitigated by installing reactors or chokes in the power lines at the ASD.

Voltage Sags

Ideally, ASD controls should be designed to withstand voltage sag conditions without tripping, regardless of the source of the voltage sag. Ride-through capability can be included in ASD specifications.

Notching

Voltage notching is a problem caused by three-phase ASDs. The rectifier component of an ASD is composed of one or more diodes on each of the three phases through which current is commutated (switched) from one phase to another. During commutation, there is a period of time during which diodes of two different phases are both closed, effectively creating a fault. This results in a voltage notch on the input waveform. The most severe problem resulting from voltage notching is interference with the controls of other ASDs and other loads.

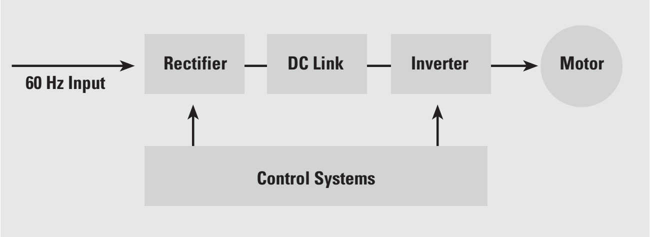


Fig. 3 - ASD components

Appendix C – Uninterruptible Power Supplies

If the operation of computers or other electrical loads must continue under power supply outage conditions, an uninterruptible power supply (UPS) might be required. Key components of a UPS are an AC to DC rectifier, a storage battery system and a DC to AC inverter. There are three types of UPSs: standby, on-line and line interactive. Both the standby and on-line are referred to as double conversion units because they both have a rectifier and an inverter. The line interactive type is referred to as a single conversion unit because it has only one circuit which functions as both the rectifier and inverter. With each type, incoming utility AC is changed to DC. The DC is then supplied to a battery charger and battery, and then on to an inverter that converts DC back to AC for use by the computer's power supply.

With a UPS, loss of voltage on the AC lines does not cause an interruption of the voltage supplied to the computer. The battery is usually selected to provide about 15 minutes of continued operation to the computer after a complete power interruption. This is typically sufficient time to download data from memory to disks and to complete an orderly shutdown of the computer.

Standby (Off-Line) and On-Line UPSs

A standby UPS (where load is normally supplied by the utility), as shown in Figure 4 with an automatic transfer switch in the utility position, is programmed to select either the normal utility power supply or the battery/inverter supply should the normal power supply be unavailable.

With standby UPSs, the computer may be subject to misoperation or damage due to transients or other power quality conditions on the unconditioned power supply. To avoid this, surge suppression in the form of metal oxide varistors (MOVs) and filtering is often installed. Most of today's standby UPSs will switch to the inverter within the outage tolerance envelope for most computers and permit continuous operation.

Also, some sensitive electronic equipment may be affected by the electrical noise generated by some standby UPSs when switching between battery and utility power.

An on-line UPS (where load is normally supplied by the inverter), as shown in Figure 5 on page 16, converts the incoming AC power to DC by means of a rectifier/charger. The resultant DC charges the batteries and supplies the inverter during normal operation. Upon loss of the normal power supply or during a voltage sag, power is pulled from the batteries to maintain the DC bus voltage. This DC voltage is converted by the inverter to computer grade AC power and then passed on to the load. All on-line UPSs offer line-to-neutral impulse protection. On-line UPSs may require increased maintenance and will use more energy than standby UPSs.

In order to assure continued operation of the computer, should failure occur in an on-line UPS at the rectifier, battery charger, battery, or inverter, a bypass circuit is provided as shown in Figure 5 on page 16. A manual transfer switch can be closed to connect the utility supply to the computer via the bypass circuit. Note though that in the bypass mode, your computer is being operated with unconditioned power. The bypass switch must operate in a shorter period of time than the ride-through capability of your equipment.

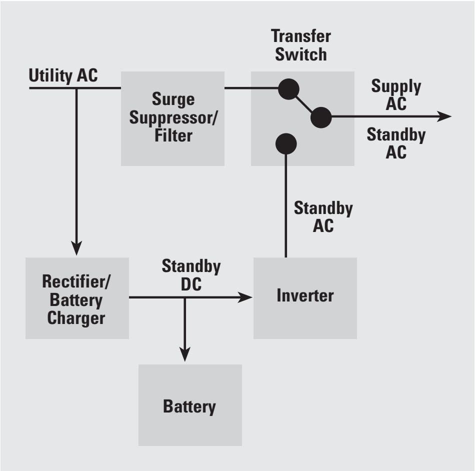


Fig. 4 - Standby (Off-Line) UPS Showing All The UPS Components (Line Preferred System)

Line Interactive UPSs

Line interactive technology (Figure 6) is a hybrid approach from both on-line and standby technologies. Under normal operation, the filter maintains the required energy for the load during short disturbances. The rectifier inverter charges the battery during normal operation and when the power is interrupted, it reverses operation and converts DC power from the batteries to AC power for the load. Since the inverter is constantly on, the changeover to battery operation requires minimal time and is highly reliable.

Conditioning

Because standby UPSs might not contain line-to-neutral impulse protection, supplemental surge protection and other power conditioning may be required. Some manufacturers use isolation or ferroresonant transformers to achieve this protection, and to eliminate neutral to ground noise.

Summary

Because of the wide variety of UPS technologies and options, we advise that you seek the advice of a UPS supplier before you select a UPS. We are available to provide assistance where we can.

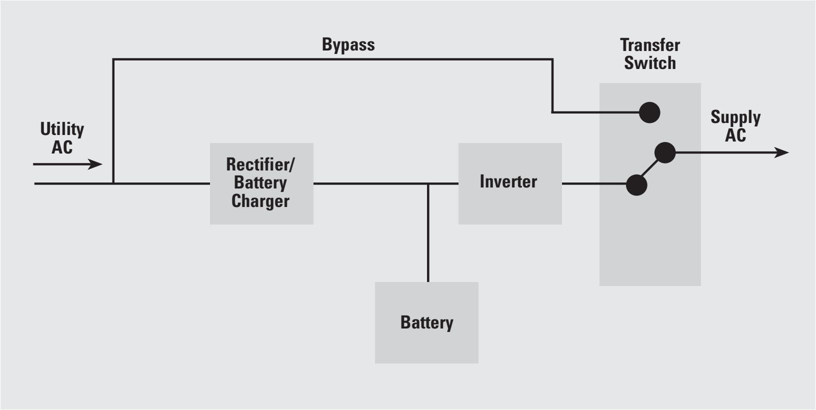


Fig. 5 - On-Line UPS with a Bypass Circuit (Inverter Preferred System)

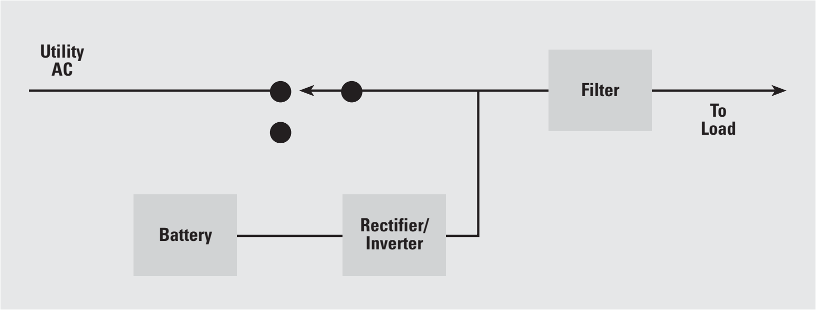


Fig. 6 - Line Interactive UPS

Appendix D –
Questions for Initial Power Quality Audit

Below are some examples of the types of questions that might be asked by our investigator during an initial contact concerning your power quality problem.

Past History

- ❍ What equipment is affected?
- ❍ What happens to the equipment (failure mode)?
- ❍ Has this problem ever occurred in the past? If so, what was the cause and how was it solved?
- ❍ How long ago was the problem first noticed? How often does it occur?
- ❍ What actions have been taken to date to investigate or resolve the problem?
- ❍ What actions are needed to recover from this problem when it does occur? For example, does equipment need to be re-started? Are repairs needed?
- ❍ What were the weather conditions when the equipment misoperated?
- ❍ What is the date and time when the problem occurred?
- ❍ When was the equipment obtained?

Type of Problem

- ❍ Does equipment operate incorrectly (loss of instructions, resets, etc.)?
- ❍ Have repairs been made to the equipment? If so, what was done and when.
- ❍ When the problem occurs, does anything else happen at the same time? Does a particular load get switched on or off when the problem is noticed?

Power Supply Requirements of the Affected Equipment

- ❍ What is the ride-through capability of the affected equipment?
- ❍ What are the voltage tolerance requirements of the affected equipment?
- ❍ Does the equipment have internal protection against power quality problems? If so, has it been checked to ensure that the protection is operating correctly?
- ❍ What are the nameplate ratings of the affected equipment?

Contributing Factors

- ❍ Have you added new equipment? Might new equipment have been added in a neighboring facility?
- ❍ Has work recently been done on your electrical system?
- ❍ Have there been storms or high winds in your area?
- ❍ Have NYSEG or RG&E personnel been working in your area?
- ❍ Has anyone been digging in the area?
- ❍ Has any general maintenance been performed on or within your facility?

Appendix E – Transients

Transients or impulses are high voltage, high current, fast bursts of energy riding on the 60-hertz sine wave. A transient is a nonrepetitive electrical event. They could be the result of utility or customer switching, power outages or starting and stopping large motors. Lightning also can induce transients on power, data, cable TV and telephone lines.

Transients are classified into two categories: “impulses” and “oscillations.” These terms describe the wave shape of the current or voltage transient.

A transient impulse is considered a voltage or current wave of single polarity. Magnitude and direction characterize the transient impulse. Rate of rise, or how quickly the transient builds up to a peak value is another important variable which influences the effect on sensitive electronic equipment.

Lightning causes most transient impulses. Electrostatic discharge (ESD) is a special type of transient impulse. ESD refers to the abrupt release of charge that has accumulated on a person or object. This charge can result in voltages above 15,000 volts. A direct ESD spark can cause component failures or malfunction.

An oscillatory transient consists of a voltage or current whose instantaneous value rapidly changes polarity. These are categorized according to their frequency, which can range from less than 500-hertz to more than 100-kilohertz. Higher frequency transients dampen quickly and are most prevalent when close to the source which generates them. The energy content of an oscillatory transient is related to its frequency content and duration.

Guidelines for Surge Suppression

It is important to protect your sensitive electronic equipment from the harmful effects of transients. Transient surges can cause destruction or disruption, as evidenced by hard failures and upsets. A hard failure is sudden, permanent damage requiring repair or replacement of electronic components. An upset is a temporary computer malfunction without hardware failure.

A **surge protection device** (SPD) can be a good investment to guard against costly electronic equipment repair or replacement expenses. The term is a common generic one used to define arresters, transient voltage surge suppressors (TVSS) and protectors. Arresters and TVSS devices are applied to the AC power circuit while protectors are applied to communication circuits.

Diverters are the most common type of suppressors. They have properties that allow transients to find a path to ground, and are connected in parallel from line to ground. There are two basic kinds of diverting devices: **clamps** and **crowbars**.

Clamps are voltage clamping devices that simply limit the surge. These devices change impedance depending on the current flowing through them or the voltage across them. Examples include metal oxide varistors (MOVs) and avalanche diodes.

A **crowbar** is a device which reacts to overvoltage by abruptly changing from a high impedance to a low impedance device. This low impedance state then offers a path to ground, shunting unwanted surges away from sensitive circuits.

Gas discharge tubes are one type of crowbar device. They offer a low resistance path for large currents to shunt high current transients to ground. The major advantage of a crowbar device is its ability to handle large surge currents without breaking down or overheating. Unlike avalanche diodes, gas discharge tubes do not respond quickly to a surge. Therefore, the transient may occur faster than this device can respond.

Most surge suppressors combine these technologies into one product – a process called multistaging, These circuits, made up of different kinds of protectors, each separated by suitable impedance, are referred to as **hybrids**. A typical hybrid combines MOVs for first stage protection with a gas discharge tube which operates only when a surge exceeds the MOV maximum current rating.

Sine wave tracking technologies track the AC power sine wave, enabling instant response to minor spikes and transients that may pass through conventional protection. These devices cost significantly more than conventional suppression technology.

TVSS devices can be designed to protect against transients in four electrical modes including common mode (line-to-ground, neutral-to-ground) or normal mode (line-to-neutral, line-to-line) disturbances.

TVSS devices should be listed for compliance with Underwriters Laboratories Standard #1449 Second Edition. The testing mark on the product verifies compliance and includes the product's identity (Transient Voltage Surge Suppressor) along with the U.L. symbol and the word "listed" all in close proximity. Various protection levels are covered under U.L. 1449 listing, including suppressed voltage ratings of 330, 400, 500, 600, 800 and six other levels up to 6,000 volts. Also review IEEE, ANSI C62 Publication "Surge Protection" before writing any specifications for the purchase of a TVSS.

Equipment specifications should include a statement about the **maximum continuous operating voltage** (MCOV). This is the maximum designated root mean square value of 60-hertz voltage that may be applied between the terminals of the arrester. Choose an MCOV rating capable of sustaining 115% of the nominal rms voltage without degradation.

With TVSS devices, important application considerations include the location of the TVSS device, energy rating or surge current-handling capability, clamping or protection voltage levels, modes of protection, the MCOV and the coordination with other SPD devices located elsewhere in the power system. The location of the TVSS influences the expected surge activity that the TVSS may experience. This expectation should be used to determine the required energy rating or surge current handling capability. Surge suppression at the service entrance protects the facility from high energy lightning surges and switching transients originating from the utility system. Surge suppressors installed near the service entrance should be extremely rugged.

Mounting location is another important consideration. For example, a huge potential exists for complete panel failure if a TVSS device mounted inside a panel should fail. Manufacturers therefore recommend installing TVSSs, designed for switching panels, outside the panel. They have found that mounting outside the panel also provides the shortest possible lead length.

Additional suppression may be required throughout the facility and near any sensitive piece of electronic equipment. These suppressors further attenuate surges generated externally to the facility as well as those generated internally.

It is important to design and install multi-stage protection with proper coordination between the devices. Good coordination is achieved when the SPD closest to the source of the impinging surge, typically at the service entrance, diverts the majority of the energy from an impinging surge. A downstream SPD at the end use equipment, diverts the remaining or residual surge energy.

Major variables affecting successful SPD coordination are as follows:

- Waveshape and duration of the impinging surge.
- **Distances between the SPDs and the power distribution system.**
- Distance between the origin of a surge and the sensitive end use equipment requiring protection.
- **Voltage clamping levels (suppressed voltage ratings) and response times of the components within the SPD.**
- Surge capacity current of the SPD.
- Age of the SPD.
- Connections to and integrity of the grounding system of the power distribution system.
- Modes of protection selected for each SPD in the power distribution system.
- Configuration of the power distribution system.
- SPDs integrally connected within end use equipment.

Two very significant variables are shown in bold print above. As an example, successful coordination might be obtained by using an SPD at the service entrance with high surge current capability and clamping voltage that is lower than that of the downstream SPD. Such a device might have a 40mm diameter MOV with 25 kiloamps (kA) to 40 kA surge current rating and a suppressed voltage rating of 330 volts. The downstream device might consist of a 20mm diameter MOV with a 6 kA to 9 kA surge current rating and a suppressed voltage rating of 400 volts. This combination will result in the SPD at the service entrance conducting first resulting in most of the surge energy flowing into it.

The selected level of clamping surge protection is a technical and economic decision involving the level of protection required for the protected equipment versus TVSS product life and reliability. Proper design will prevent excessive clamping activity while providing adequate protection. It is important to understand the particular electrical environment and application of a TVSS before properly selecting a clamping level.

The surge suppressor should be fused or have a melting link to safely isolate the device should the surge protective device fail. There are two protective device failure mode designs for surge suppressors. One option is to interrupt power to the load being served by the SPD while another method is to isolate the SPD without power interruption to the load being served.

Choose a TVSS with an indicator light on the surge suppressor which shows that the protective components are functioning. Some suppressors have both visual and audible alarms or provide auxiliary contacts for supervisory control.

Another consideration is the proper surge protection for telephone or data entry and exit ports which may be a path for destructive energy during lightning. **Protectors** are available to safeguard your sensitive equipment from this occurrence. For equipment with power and data ports, such as FAX machines, answering machines or cable TVs, use a protective device which combines both ports.

Balance the cost of the surge suppressor with the importance and cost of the equipment to be protected. Different surge suppression units offer varying levels of protection, but all have the same basic job to prevent damaging voltage spikes from reaching the device they were intended to protect. Finally, in order for any SPD device to perform properly, it is imperative to follow proper installation and grounding practices. **The leads connecting the SPD to the power system conductors must be kept as short as possible.** The inductive voltage drop in the SPD leads caused by an impulse with a rate of rise of 1 kA/µsec. will be approximately 1 kV/m of lead length. This voltage drop is dependent on the rise time of the impulse and may reduce the voltage of the impulse to a level below the clamping voltage of the SPD rendering it inoperative.

Product warranty is another area of comparison. Products that carry a warranty on both the product and labor say something about the confidence the supplier has in his product.

Enclosure type also needs to be considered. A TVSS for an indoor application should have a NEMA (National Electrical Manufacturer's Association) 12 enclosure. Outdoor applications should have a NEMA 4X enclosure.

Guidelines for Selecting a Surge Suppressor

Select a Surge Suppressor With The Following >

- ❍ Indicator lights to indicate the unit is still working, protection is ok.
- ❍ UL 1449 Revision 2 listing.
- ❍ All mode protection – Line to neutral and/or line to line, line to ground, and neutral to ground.
- ❍ Warranty – on both the product and replacement labor.
- ❍ Let-Through Voltage – typically lower is better for single device installations with 330 volt being the lowest but for applications with cascaded surge suppressors, best coordination is achieved with the upstream device (closest to the incoming power lines) having a lower let-through voltage than the downstream device (closest to the load).
- ❍ High peak surge current – 45 kA or more is good for a surge suppressor applied at an outlet, 80 kA or more is good for a panel mounted surge suppressor.
- ❍ Electromagnetic and radio frequency (EMI/RFI) interference filtering – helps to strip noise signal off the power going into a radio or TV, improves performance – 35 decibel attenuation at 100 kilohertz and above is good.
- ❍ Sine wave tracking – a surge suppressor with this feature will clamp (limit) the incoming voltage to a specified level no matter where the impulse occurs on the waveform

Appendix F –
Wiring and Grounding Information

(Courtesy of EPRI Solutions, Inc. and NEC 250)

Wiring and grounding issues are one of the issues associated with power quality problems. It is essential to ground your sensitive electronic equipment properly in order for the correct operation of the equipment. The following are the reasons to ground your sensitive equipment properly:

1. Safety

Electrical shocks can be prevented by using proper grounding techniques (see Figure 7A and B on page 22). Grounding is essential in order to avoid sensitive electrical equipment damage.

2. Performance

Proper grounding will control stray currents from causing a difference in potential between grounds. Equal-potential planes result from good grounding techniques. Communication noise will be reduced by utilizing proper grounding.

3. Lightning and Surge Mitigation

Transients can be controlled with grounding. Grounding will remove the static charge. Bond the grounds between all ingresses to a building, i.e. cable, telephone and electric. Grounding will equalize a surge reference point.

Power and Grounding Recommended Practices in IEEE

The following references from IEEE can be used for grounding issues:

❍ IEEE 141 – Industrial Power Distribution (Red Book)
❍ IEEE 142 – Grounding (Green Book)
❍ IEEE 446 – Emergency and Standby Power (Orange Book)
❍ IEEE 1100 – Powering and Grounding Electronics (Emerald)
❍ IEEE 1159 – Monitoring Power Quality
❍ IEEE 1250 – Service to Critical Loads
❍ IEEE P1346 – System Compatibility in Industrial Environment

Grounding Related Definitions from the National Electric Code (Courtesy NFPA 70)

Ground: A conducting connection – intentional or accidental – between an electrical circuit or equipment and the earth, or some conducting body that serves in place of earth.

Grounded Conductor: A system or circuit (current carrying) conductor that is intentionally grounded. This is the neutral wire or White Wire.

Grounding Conductor: A conductor used to connect equipment or the grounded circuit of a wiring system to grounding electrode(s). It is not intended to conduct current and is called the Green Wire.

Premises Wiring: Interior and exterior wiring, including power, lighting, ...from service point of the utility or a separately derived power source.

Basic Equipment Grounding (Courtesy NEC -250)

Effective Grounding Path

❍ Create a permanent, low impedance ground path.
❍ Conduits enclosing electrical conductors or equipment shall be connected to earth.
❍ Capable of safely carrying the maximum ground fault current. (NOTE: The earth shall not be considered as an effective ground path.)
❍ Limit the voltage to ground caused by lightning, surges and unintentional contact with higher voltage lines.

OR

The path from circuits, equipment and conductor enclosures shall:

❍ Be permanent and continuous.
❍ Have capacity to conduct safely any fault current likely to be imposed on it.
❍ Have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit.
❍ The earth shall not be used as the sole equipment ground conductor.

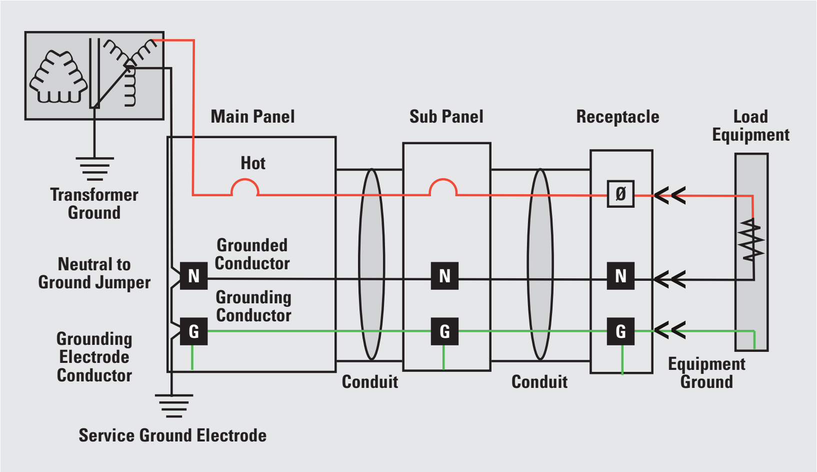


Fig. 7A - Proper Neutral-to-Ground Bond Without a Separately Derived Power Source > A neutral-to-ground bond is permitted at the main service panel only. Neutral-to-ground bonds shall not be made at any grounded circuit conductor (neutral) on the load side of the service disconnect..

Courtesy of EPRI Solutions, Inc.

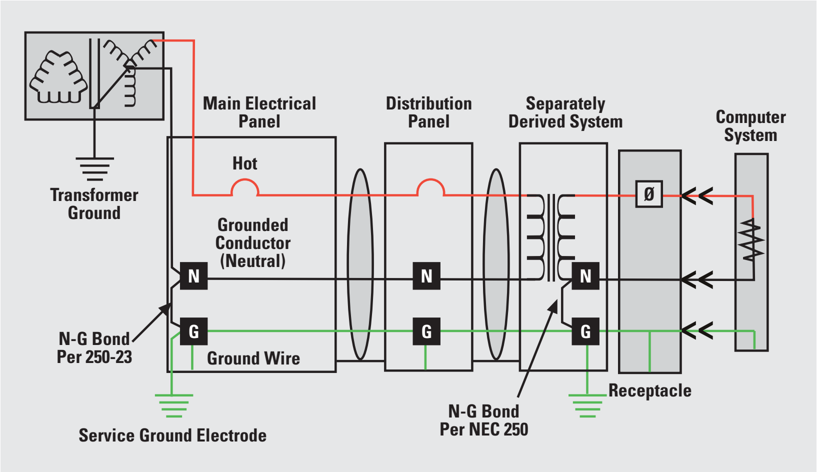


Fig. 7B - Proper Neutral-to-Ground Bond With a Separately Derived Power Source > Neutral-to-ground bonds are required at main service (NEC 250) and at any separately derived power sources.

Courtesy of EPRI Solutions, Inc.

Power Quality Grounding Guidelines

- ❍ Make sure all ground connections are mechanically tight.
- ❍ If possible, ground sensitive electronic equipment to the service entrance ground.
- ❍ Contact the sensitive electronic equipment manufacturer for their recommendation on grounding.
- ❍ If possible, use individual branch circuits for each piece of sensitive electronic equipment.
- ❍ Connect the neutral to the ground at the service entrance.
- ❍ If possible, use the same size ground (Green) wire as the neutral.
- ❍ A single point ground as illustrated in Figure 8, is preferable to multiple grounds due to noise considerations.

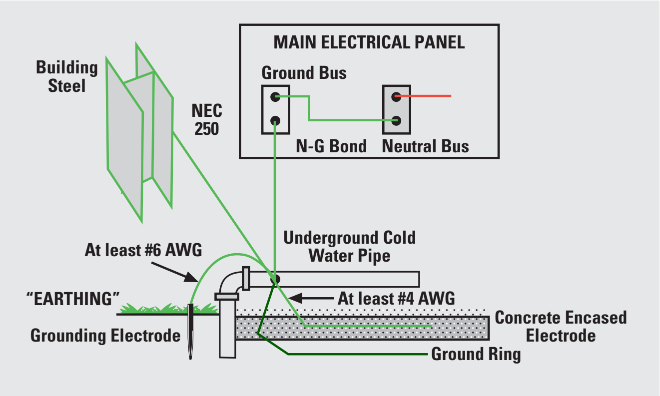


Fig. 8 - Premises Grounding Technique - Single Point Ground

Courtesy of EPRI Solutions, Inc.

Wiring Guidelines

In order for your sensitive electronic equipment to operate properly, here is some power quality wiring guidelines:

- Make sure all wiring connections are tight.
- Make sure the wires are of the proper size to limit the voltage drop to your equipment.
- Ensure the equipment will operate properly at the minimum utilization voltage that can be supplied by the utility as specified in the ANSI C84.1.
- For proper operation of single phase non-linear loads on a three phase circuit, use a separate neutral conductor for each phase.
- If third harmonic currents are an issue at the load, use a third harmonic filter at the load instead of costly wiring changes.
- Make sure existing or new transformers and motors can allow for the extra heating of harmonic currents caused by electronic devices such as adjustable speed drives (ASDs). There are K-rated transformers available that can successfully manage harmonic currents from non-linear loads.
- Electrically separate the sensitive electronic loads (CNC machines, variable speed drives, computers, etc.) from the perturbing motor loads in order to prevent large voltage drops from affecting the sensitive electronic loads. See Figure 9 below.

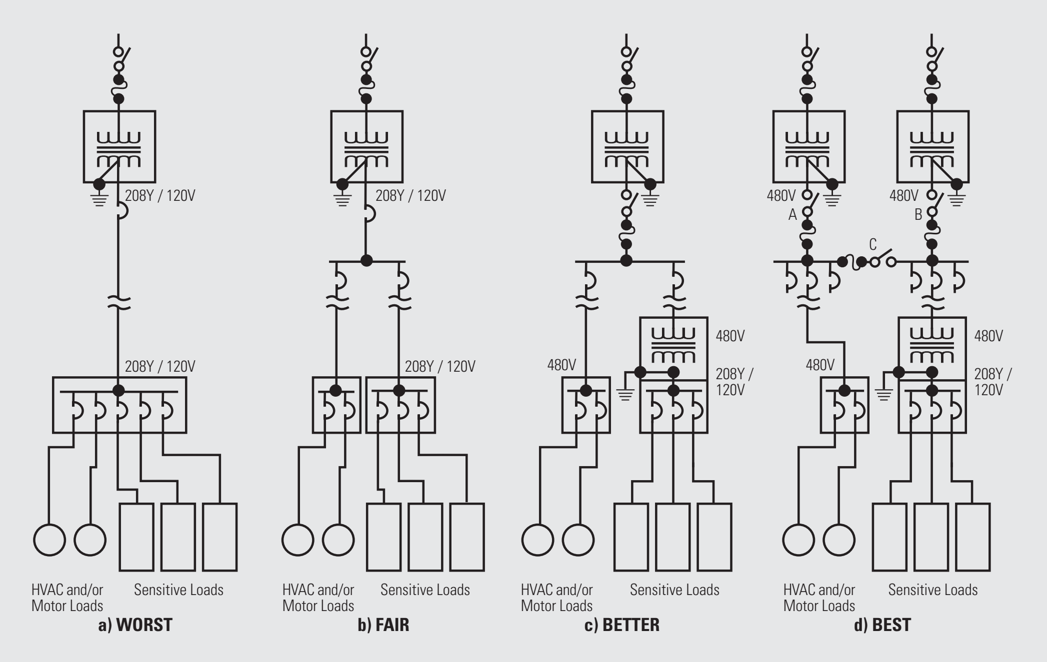


Fig. 9 - Isolating Sensitive Loads > Common vs. separate feeders: Arrangements "c" and "d" enable the power source ground to be close to the sensitive loads. Arrangement "d" greatly reduces common voltage drop by using separate transformers while switch #C is open. If either transformer #A or #B or their power source fails, each is large enough to carry all important loads when switch #C is closed and #A or #B open.

Courtesy of FIPS PUB 94 U.S. Department of Commerce/National Bureau of Standards

Grounding Considerations for Computer Numeric Controlled (CNC) Machines

CNC machines are sensitive to grounding issues. In order to validate the machine manufacturer's warranty, make sure you ground the CNC machine as the CNC machine manufacturer states.

However, the best approach to grounding for a three-phase four-wire system, if there are no recommendations from the CNC machine manufacturer, is to ground the CNC at a single point. "Single point grounding" means that there is only one ground to the CNC machine which is at the utility service entrance. Thus, no ground loops for multiple grounds would exist which could cause erroneous operations of the CNC machine and create a voltage on the machine as a safety issue. See Figure 10 below for single point grounding for a three-phase four-wire system.

If your electrical service is a three-phase three-wire system, it is difficult to find a ground fault. A ground fault on a three-phase three-wire will not create any ground fault current until the second ground fault occurs. Some businesses like this approach since they can continue to operate and find the first ground fault before the second ground fault occurs. However, it is difficult to find the first ground fault because no circuit breakers or fuses will blow because there is no fault current. Single point grounding for a three-phase three-wire circuit is depicted in Figure 11 below.

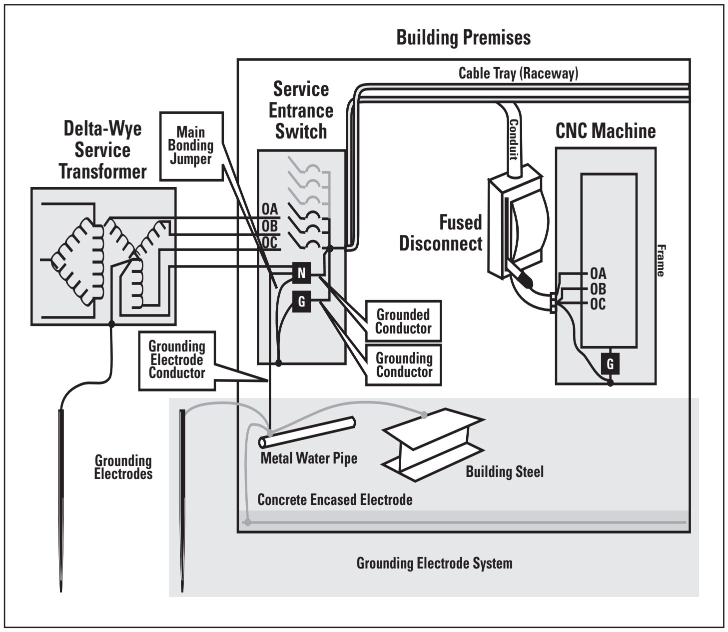


Fig. 10 - Typical building service and grounding system for a three-phase, four-wire circuit.

Courtesy of EPRI Solutions, Inc.

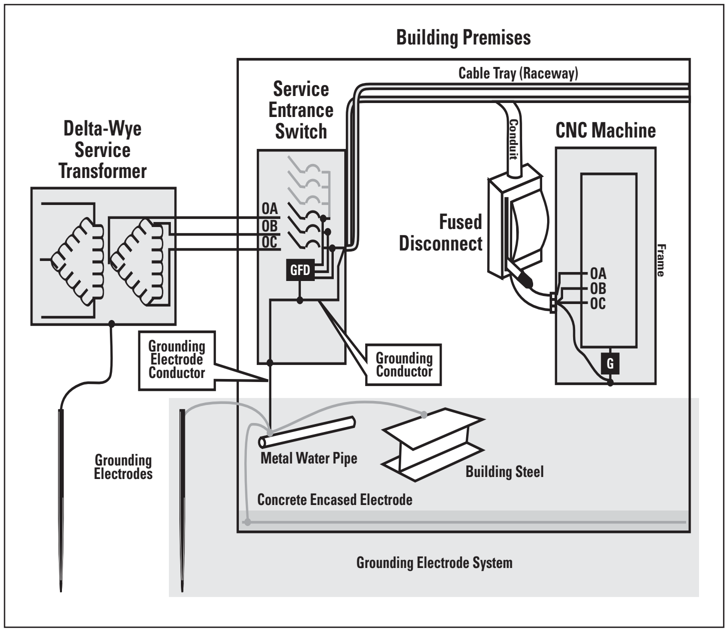


Fig. 11 - Typical building service and grounding system for a three-phase, three-wire circuit.

Courtesy of EPRI Solutions, Inc.

Appendix G – Reference Material

ANSI C84.1
American National Standard for Electrical Power Systems and Equipment – Voltage Ratings (60Hertz) American National Standards Institute, New York, NY

Dranetz Field Handbook of Power Quality Analysis
Dranetz Technologies, Inc. Edison, NJ

Dranetz-BMI Handbook of Power Signatures
Dranetz-BMI Technologies, Inc. Edison, NJ

FIPS PUB 94
Federal Information Processing Standards Publication Guidelines on Electrical Power for ADP Installations, U.S. Department of Commerce/National Bureau of Standards. FIPS PUB 94 describes methods for solving the typical power quality problems related to large-to-medium scale computer (automated data processing) systems.

The information on computer power requirements and on grounding for both safety and computer performances applies to most sensitive electronic equipment.

IEEE/ANSI C62 Surge Protection

IEEE "Brown Book"
IEEE Recommended Practice for Electric Power Industrial and Commercial Power System Analysis (ANSI/IEEE STD 399), The Institute of Electrical & Electronic Engineers, New York, NY

IEEE "Emerald Book"
IEEE Recommended Practice of Powering and Grounding Sensitive Electronic Equipment (IEEE Std 1100), The Institute of Electrical & Electronic Engineers, New York, NY

IEEE "Gold Book"
Design of Reliable Industrial and Commercial Power Systems (ANSI/IEEE STD 493), The Institute of Electrical & Electronic Engineers, New York, NY

IEEE "Gray Book"
IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (ANSI/IEEE STD 241), The Institute of Electrical & Electronic Engineers, New York, NY

IEEE " Green Book"
IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (ANSI/IEEE TSD 142), The Institute of Electrical and Electronic Engineers, New York, NY

IEEE "Orange Book"
IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (ANSI/IEEE STD 446), The Institute of Electrical and Electronic Engineers, New York, NY

IEEE "Red Book"
IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (ANSI/IEEE STD 141), The Institute of Electrical & Electronic Engineers, New York, NY

IEEE "White Book"
IEEE Recommended Practice for Electric Power Systems in Health Care Facilities (ANSI/IEEE STD 602), The Institute of Electrical & Electronic Engineers, New York, NY

IEEE 1453
IEEE Recommended Practices for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems, The Institute of Electrical and Electronic Engineers, New York, NY

IEEE 519
IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, The Institute of Electrical and Electronic Engineers, New York, NY

IEEE 519 explains how harmonics are generated, the effects of harmonics solutions to harmonic problems, measurement techniques, and recommended limits on harmonic generation for individual consumers, individual loads and utilities.

N.E.C. Handbook
The National Electrical Code (National Fire Protection Associated), Quincy, MA. This handbook explains grounding, separately derived sources, and installing and isolated ground. All special grounding practices, even those recommended by the equipment manufacturer, must follow the National Electrical Code.

UL 1449 Standard for Safety for Transient Voltage Surge Suppressors Edition 2

National Electrical Safety Code
American National Standards Institute C2) Institute of Electrical and Electronic Engineers. This code is referenced in the National Electrical Code. This standard covers basic provisions for safeguarding of persons from hazards arising from the installation, operation or maintenance of 1) conductors and equipment in electric supply stations and 2) overhead and underground electric supply and communication lines.

Appendix H – Power Disturbance Log

	DATE	TIME	WEATHER CONDITIONS	EQUIPMENT AFFECTED
Example:	5/21/07	1:30 p.m.	Clear and dry	Feed mill variable speed drive tripped off-line

Appendix H –
Power Disturbance Log

DATE	TIME	WEATHER CONDITIONS	EQUIPMENT AFFECTED

Printed on recycled paper
1/08 07-0347 CP-299