Effects on the electrical equipment from the quality of the power

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Abstract - In order to improve the quality of the power, the electrical engineer must understand the types of disturbances as well as their cause and effect. She or he must also know something about the susceptibility of the equipment being protected. In the computer and power conditioning industries, opinions very widely as to the types of disturbances, which are most likely to cause power quality, related electrical equipment failures, and the best technology for eliminating them.

For this reason, the engineer must work closely with the user and equipment manufacturer in order to determine the need for a power conditioner and the proper conditioner if needed to improve the power quality.

Introduction

No single power conditioner on the market will eliminate all possible disturbances, which effect the power quality. So, the electrical engineer must try to find the right power conditioner that is compatible with the power system and the equipment s/he is trying to protect.

This paper attempts to provide a common sense method for selecting the proper protection for a given piece of utilization equipment connected to a given power system. Also this paper attempts to deal with the power conditioning issue in terms that can be understood and applied by the plant or consulting electrical engineer.

Two approaches can be taken in selecting power conditioning equipment. The *first* approach would be to select a power conditioner based on the requirements of the equipment to be protected and the power systems problems that can be expected. For example, a particular type of voltage regulator might be selected where equipment cannot tolerate swings in voltage and the utility has a history of changing voltage. The *second* approach would be the "if it ain't broke, don't fix it". From a first-cost standpoint, this approach is unbeatable. If the quality of power at the equipment site is unknown, and the sensitive equipment to be protected has ill defined power requirements. It does not make much sense to specify or purchase an expensive conditioner if one does not know the constraints of voltage, frequency, and waveshape required for the equipment. If things do not go as expected, the power system can be retrofitted with a power conditioner, after establishing and documenting the history of power system disturbances. The cost of the unprotected equipment, the likelihood of catastrophic loss might be evaluated and carefully before trying this approach. Before going further with the selection process, it is important to look at equipment tolerances, the nature of effects on the power quality, and available power conditioning equipment.

What the quality of the power means?

Electric power quality means different things to different people. To most electric power engineers, the term refers to a certain sufficiently high grade of electric service, but beyond that generality, there is no universal agreement [1].

In some sense, all of power engineering is devoted to power quality, but the term has come to mean a more restricted area of interest which generally relates to the faithfulness of the load bus voltage to maintain a sinusoidal waveform at rated voltage and frequency.

Perfect power quality will have a perfectly sinusoidal voltage, constant amplitude and frequency. Voltage amplitude will be adequate for the application, the voltage source will have no impedance, and the frequency will be 60 Hz or 50 Hz depend on the country. The waveshape will be perfectly free of harmonics, noise, and transients. Of course, such a perfect source of power does not exist, even in a laboratory. According to the ANSI[12], reasonably good quality of power is considered when its steady-state voltage falls between + 6 and - 13 percent of nominal. The ANSI standard says utilities must hold voltage between +15 and -20 percent.

What may cause problems in the quality of the power?

If we are going to do anything about the problems on the power quality, it is also important to know something about their sources and effects they have on hardware. A voltage variation refers to any change or swing in steady state voltage above or below the prescribed input range for a given piece of equipment. Voltage variations result in improper function of logic and memory circuits and overheating in the case of voltage increases. *Voltage variations* are caused by unregulated utility feeders,

which experience changes in load over a period of time. Sometimes they may occur when utilities switch their systems to change the way that particular customer is served. Voltage variations may also occur within a building or plant due to load changes occurring within the premises, even when utility voltage is constant. Another effect on the power quality and a very common one is the *power-fail*. The power-fail is defined as the total removal of the input voltage for at least 5 ms. Power-fails can cause the floating heads of disk drives to "crash down" on the disk causing memory loss, unscheduled shutdown, or equipment damage. Some disk drives have heads, which automatically retract upon loss of power, but the designer cannot assume that this is the case. Power-fails also cause improper operation of logic and memory circuits of the computer. The length of power-fail a particular computer can tolerate will depend on the ride through provided by the LC filtering circuit of the possibly and the load on the power supply at the time of the power-fail. Often, ac motors connected to the power system will act as generators for a few cycles to provide additional ride through. Power-fails result from utility switching operations and equipment failures.
Lightning arrestors cause short (one cycle or less) power-fails. The most common power-fail is that caused by utility reclosing circuit breakers acting to clear a lightning - induced flashover or a fault caused by a power line coming in contact with a tree branch or other grounded object.

The term "*transient*" generally refers to an increase in voltage of less than one half-cycle. More specifically, a transient is a high-amplitude short-duration disturbance of from less than 1 µs to several milliseconds superimposed on the normal voltage wave. The term transient is often used loosely to describe any disturbance that is transitory, such as common mode noise, surges, sags, and other phenomena, but for the purpose of this paper, a transient must be less than half a cycle and must have a significant overvoltage content. Lightning, capacitor switching, fault switching arcing grounds cause transients, brush type motors (i.e. drills and office machines), and switching inductive load such as motors, transformers, lighting ballast, X-ray equipment or solenoids. Damping causes these oscillating overvoltages to decay rapidly, so we are primarily concerned with the leading edge or the first two or three half-cycles of these oscillatory transients as "spikes" or "notches", depending on whether they are additive or subtractive to the 60 Hz sine wave. The most common transient caused by inductive switching is the simple recovery transient, which occurs as a result of a circuit breaker or switch interrupting an inductive load at current zero.

Voltage spikes are traveling waves on electrical circuits and follow all of the laws of transmission line theory. For this reason, it is extremely difficult to predict accurately their rise time, amplitude, or frequency of occurrence. Spikes are naturally attenuated as they travel along electrical circuit and the rise time of the leading edge increases. The greater the series inductance and the greater the parallel capacitance, the more attenuation and the greater increase in rise time will occur. The effect of transients on the some of the electrical equipments and computers, can be errors due to the dv/dt coupling through the stray and interwinding capacitances of the power supply. Damage to the equipment can result if very high voltage is present.

Sag is a sudden reduction in voltage greater than a half-cycle in duration. According to one source, the duration is from one-half to two cycles. However, some use the term to describe reductions in voltage in greater than two cycles. Probably the best way to differentiate between sags and negative voltage variations is the cause. Utility faults and motor starting most frequently cause sags, while negative voltage variations are caused by increases in steady state load on unregulated circuits.

Dip is a sag which lasts less than half a cycle. Dips are caused by improper grounding, electric drills, and brush type motors.

Sags and dips may or may not be troublesome to the some of the electrical equipments and the computers. For the computers, depending on their regulating ability, power supply and its ride-through ability may or may not be troublesome. If the power supply output voltage is effected appreciably error can result.

Again, sags rarely damage equipment, but performance can be compromised. Only very severe transient overvoltages are expected to disturb most computers [6].

When talking about quality of the power, also it is important to consider waveshape and frequency. Frequency variations are very rare on today's utility systems, which are connected to or networked with neighboring utilities. Even if a utility should stand alone, its generator will be large compared to the greatest anticipated load fluctuation. On the other hand, standby power system commonly used in industry, health-care facilities, large office buildings, and computer centers often experience variations in frequency, because engine governors take time to sense speed variations and change fuel output. Some electrical equipment, and some of the mainframe computers, is sensitive to frequency variations, and some are not. Disk and tape drives and the other pieces of equipment are always sensitive to frequency change because they utilize ac motors. Computers that use ferroresonant regulators are generally very sensitive to frequency changes. Although Table I lists 0.5-1.0 percent for acceptable frequency variation, some Central Processing Units (CPU) manufacturer permit frequencies of 47 - 63 Hz and sell the same units for use on 50- and 60-Hz systems.

Typical ranges of input power quality and load parameters of major computer manufactories are presented in Table I[5], below.

Table I

	Parameters	Range or Maximum
1	Voltage regulation, steady state	+5, -10 to + 10 percent (ANSI C84.1.1970is + 6, - 13 percent)
2	Voltage disturbances	
	Momentary undervoltage	-25 to -30 percent for less 0,5 with -100 percent acceptable for 4-20ms
	Transient overvoltage	+150-200 percent for less than 0,2 ms
3	Voltage harmonic distortion	3-5 percent (with linear load)
4	Noise	No standard
5	Frequency variation	60 Hz ± 55 Hz to ± 1 Hz
6	Frequency rate of change	1 Hz/s (slew rate)
7	3Φ. Phase voltage unbalance2	5-5 percent
8	3Φ Load unbalance	5-20 percent max for any one phase
9	Power factor	0.8-0.9
10	Load demand	0.75-0.85 (of connected load)

Probably the greatest cause of harmonic distortion in today's power systems is SCR switching. Often, the computer power supply is the worst offender. In general low-frequency harmonics (i.e. square wave) can affect gating or turn-on of switching power supplies. High-frequency harmonics (i.e. noise) can cause computer error.

Computer power supplies

Most of the transients that affect computers do not pass through the power supply at. The transients get into computer logic and memory circuits by other means (i.e. poor grounding or EMI).

The most popular computer power supply is the preregulated linear power supply, which uses a switching and filtering circuit to produce a preregulated dc supply. This dc supply is then regulated again to "fine tune" it for the computer. The LC filtering circuits in the power supply store enough energy to provide from 15 to 35 ms of ride through (typically 20-25 ms). Some power supplies have been known to provide as little as 8 ms and as much as 50 ms. In the case of voltage sags, the regulator - whether switching or ferroresonant-may be fast enough to bring voltage back to nominal before the ride through period is over. This, of course, depends on the ride through time available. Efforts have been made by computer manufacturers to reduce the effect switching power supplies have on the line by placing a filter at the ac input. Some manufacturers have gone to nonswitching schemes to prevent line problems.

Published data notwithstanding, regulating computer power supplies have wide input voltage windows. Older power supplies have 108-125V. Newer power supplies have 90-250 V. It is important to get this information from the manufacturer. He has it, because someone had to design his power supply to these specifications. So, insist on power supply data.

Isolation transformers

Grounding the secondary of the delta-wye isolation transformer provides the computer with a clean noise-free ground. Most power conditioner manufacturers agree this is among the most important factors in providing a trouble – free computer environment. The shielded isolation transformer also provides excellent common mode noise rejection because of the low capacitance between the primary and secondary windings. Capacitive or electrostatic coupling is the only way common mode noise can be transmitted from primary to secondary. There is no magnetic coupling, because common mode voltages do not impress any line-to-line or line-to-neutral voltages across the primary windings.

Isolation transformer shields are generally ineffective in rejecting transverse (normal) mode transients, although there is some attenuation. Transverse mode transients or noise (unlike common mode) do impress a voltage across the primary windings. However, the transformer steel is unable to respond to frequencies over about 4000Hz. Thus magnetic coupling is strictly air core coupling with the flux scattered instead of following the path of the steel. For this reason, coupling is poor and there is some attenuation. As transverse mode transients travel along the electrical circuits, they often become common mode because of mutual coupling between their conductors and ground. This is particularly true where the transient must travel long distances. Two other factors bear upon the transverse mode transient problem. First, the greater the line capacitance, the more transverse mode spikes will be attenuated. Second, loading has a great deal to do with transverse mode transient suppression. Loaded circuits (and power supplies) provide more attenuation than unloaded circuits. Although other factors (such as mutual coupling and attenuation) tend to help, it is not reasonable to expect good transverse mode noise rejection even from the best ultraisolation transformer. The isolation transformer is also useless in protecting against surges, sags, dips, and variations in steady-state voltage.

Some manufacturer markets a conditioners that uses an isolation transformer together with a filter circuit that provides common and transverse mode transient attenuation along with very low output and transfer impedances. That manufacturer believes low impedance is the most important factor in power conditioning.

Voltage regulators

Voltage regulator is any device that attempts to regulate, control or hold output voltages constant as impute voltages vary. Depending on response time, voltage regulators may or may not be of value in correcting dips, sags, or surges. When selecting a voltage regulator several things need to be considered. Regulation of the output voltage has to be seven percent to virtually zero. If the regulator provide electrical isolation from primary to secondary, regulator can be used to obtain a clean ground without adding an isolation transformer to the system. Also is the regulator compatible with the microprocessor or computer being protected? Does the computer have a regulated power supply that will interact poorly with the external voltage regulator? What is the output waveform like? What is the energy efficiency of the regulator? Has the manufacturer or vendor explained the technology behind his voltage regulator? Since we are purchasing technology, we need to know what this technology is.

Perhaps the two most commonly used voltage regulators for use with computers are the electronic tap switching regulator and a constant voltage transformer which uses ferroresonant technology to provide voltage immunity as opposed to the pure regulation provided by tap switching regulators.

The electronic tap switching regulator monitors output voltage and changes transformer taps by means of solid-state switching. Each tap change takes ½ cycle (8.3 ms) or less. Sometimes more than one switching operation is required to achieve the desired regulation of output voltage, but the entire sequence generally takes less than five or six cycles. Most regulators of this type provide electrical isolation, but some utilize autotransformers. Electronic tap changing regulators are available in sizes up to 500 kVA. Output waveshape is good, so tap changing regulators will work with switching power supplies. On the other hand, nothing is done to improve waveshape, but this is usually of little concern.

The regulated computer power supply has a negative resistance effect, since an increase in voltage causes a decrease in current. When the external voltage regulator causes the voltage at the output of the external voltage regulator to go up, this triggers an attempt y the computer voltage regulator to reduce voltage. As computer current decreases, the external voltage regulator acts to reduce voltage when the response time of the two voltage regulators are the same, this "hunting" goes on indefinitely.

Constant voltage transformers using forroresonant technology and is a popular as electronic tap switching regulators. They utilize a ferroresonant circuit consistingof a capacitor in series with a transformer coil. The saturated core provides immunity to input voltage variations. Because of that, secondary voltage remains constant in spite of changes in ptimary voltage.

Where a high degree of voltage regulation and total isolation from surges, sags, dips, and transients is required, motor generator (MG) sets and uninterruptible power supplies (UPS) are used.

The ability of MG set is to tolerate the frequency changes and to have normal operations when input voltage is reapplied.

UPS are devices, which are used to supply electrical loads from the commercial power mains during normal operation, and, as a backup, from a standby source during standby operation. The standby mode is also called the "emergency" or "backup" mode. Another words, UPS provide standby capacity for powerfails and short outages and provide constant frequency.

Most computer room operators prefer simply to shut down their systems when a storm is approaching. This, of course, is not an option for some applications, especial computer-controlled industrial processes and other real-time applications. Perhaps the biggest disadvantage of using UPS and MG sets is their high impedance and the high-voltage drops associated with impedance. For example, MG sets usually have impedance six or seven times that of comparably rated transformer. This is of particular importance with switching power supplies, which are noise generators, especially when voltage source impedance is high. Sometimes it is necessary to size these systems for one or more multiples of normal operating current in order to compensate for voltage drop. Since MG sets and UPS actually reconstruct the voltage source by converting the ac input voltage another form of energy and then regenerate an ac voltage, these units are not pure power conditioners.

Since UPS and MG sets are considerably more expensive than pure power conditioners, especially when they are required to be oversized, the user should be sure they are really needed before making an investment. The only way for the electrical engineer to make this determination is to consult with the computer manufacturer and the user.

Grounding

Grounding must serve many purposes, not all, which are simultaneously compatible. The problems arise when many system references must be connected together. In a typical computer or instrument location there will be a utility distribution ground, possibly including a substation ground, a building lightning protection ground, a building power ground for the low-voltage circuit(s), and a local reference for each instrument or computer/peripheral device.

The utility grounds must handle lightning and ground fault currents, while maintaining a voltage reference for insulation coordination. The building lightning protection system ground must handle lightning currents. The building power supply ground maintains an upper limit on phase-to-ground voltages while providing an adequate return path for ground fault currents and surge suppressor currents. All of these grounds are connected together through made grounds or by direct connection or both.

There are two approaches to limiting ground potential differences. The simplest is one-point grounding for an instrument group or small computer installation. By connecting computer component references together at a single point, stray currents in the ground system are prevented from producing potential differences between components. Also, leads must be dressed (placed close together and close to ground conductors) to eliminate large open loops since open loops convert stray magnetic fields into noise voltages. In larger systems, a ground mat may be used. In ground mats, a low-impedance plane replaces the single point. Ground leads must also be insulated to prevent incidental contact with other grounded objects. All metal contact must be positively connected to prevent small arcs and resultant noise.

Conclusion

Selection of power conditioning equipment is a job for an electrical engineer that understands power system disturbances and understands the available technologies for eliminating them. However, even the most knowledgeable consultant cannot make an informed choice without understanding the needs of the user and the power requirements of the equipment. It is also important to understand the consequences and the cost of downtime, unscheduled outages, and equipment damage. In addition to understanding the problem and consulting with the user and the manufacturer, a few key things should be understood.

i. Know and understand the technology behind the power conditioner before applying it, because the power conditioning can be full of suprises.
ii. Modem computer power supplies usually provide all the voltage regulation that is needed, so voltage regulation is not generally required when selecting a power conditioner for a computer. It is also important to know how effective the power supply will be as a filter for power-line transients.
iii. Since most power-line transients do not get to the computer memory circuits through the power supply, proper grounding is extremely important.
iv. Common mode noise must be attenuated, because the computer power supply does a poor job of filtering them.
v. Do not misapply high impedance or load-sensitive conditioners or conditioners that will introduce noise into the protected equipment. Of course, this can be avoided by consulting with the computer manufacturer.
vi. Be sure all components of an interconnected data processing system are connected to the same conditioner and the same ground system.
vii. Continue to improve electrical equipment and computer power supplies, grounding, and shielding.

Reference:

[1] G. T. Heydt, *Electric Power Quality*, Stars in a Circle Publications, West LaFayette, Indiana, Second printing1994.

[2] A. Greenwood, *Electric Transients in Power Systems*, New York: Wiley-Interscience, 1971

[3] IEEE 519 (1992). *Recommended practices and requirements for harmonic control in electrical Power Systems.*

[4] G. W. Allen and D. Segall, "Monitoring of computer installations for power line disturbances," IEEE PES Winter Meeting, Conferences Paper, Jan. 1974.

[5] IEEE *Recommended Practice for Emergency and standby Power systems for Industrial and Commercial Applications*, ANSI Standard 446, 1980.

[6] T. S. Key, "Diagnosing power quality-related computer problems, *IEEE Trans. Ind Appl.*,July/Aug. 1979.

[7] E. F. Fuchs, D. J. Roesler, and K. P. Kovacs, " Sensitivity of electrical appliances to harmonics and fractional harmonics of the power system's voltage," *IEEE Transactions on Power delivery*, Vol. PWRD-2, April 1987.

[8] *IEEE Guide for Surge Voltages in Low-Voltage AC Power Circuits*, ANSI/IEEE C62.41, 1980.

[9] A. W. Duell, and W. V. Roland, "Power line disturbances and their effect on computer design and performance," *Hewlett-Packard J.*, Aug. 1981.

[10] *Surge Protection HandBook*, Key Tek Instrument Corp. 1987.

[11] H. O. Nash, and F. M. Wells, "Power systems Disturbances and Considerations for Power Conditions," *IEEE Transactions on Industry Applications*, Nov./Dec. 1985.

[12] *Electrical Power Systems and Equipment, 60 Hz*, ANSI 1977.