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Power Quality Issues – Standards and Guidelines

– *By* –

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POWER QUALITY ISSUES - STANDARDS AND GUIDELINES

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Abstract-As a result of the wide ranging addition of electronically controlled equipment within the last five to ten years, the lack of industry standards and application criteria in the area of power quality has become very evident. This paper outlines the significant factors associated with power quality by summarizing the key considerations, the relevant standards, the areas where standards are being developed, and useful application guidelines. Power quality is discussed here in terms of three major categories - system disturbances, harmonic distortion, and grounding.

I. INTRODUCTION

The term "Power Quality" has been used to describe the variation of the voltage, current, and frequency on the power system. Historically, most power system equipment has been able to operate successfully with relatively wide variations of these three parameters. However, within the last five to ten years a large amount of equipment has been added to the power system which is not so tolerant of these variations. This has included a large amount of equipment which is controlled by electronics. Some of the control is directly through power conversion electronics, such as ac drives, dc drives, and switch mode power supplies, while some of the electronic equipment is in the peripheral controls, such as computers and programmable logic controllers (PLC's). With the availability of these sophisticated controls, much more precise control of the processes have been developed which make the processes even more susceptible to the affects of power system disturbances. System disturbances, which have been considered to be normal for many years, now may cause disruption to the industrial power system with a resulting loss of production. In addition, new considerations must be taken into account for developing a reliable power system which were not previously considered significant.

It is important to realize that there are other sources of disturbances which are not associated with the incoming power supply. These could include electrostatic discharges, radiated electromagnetic interference, and operator errors. In addition, mechanical and environmental factors can also play a part in system disturbances. These can include excessive temperature, contamination, excessive vibration, and loose connections. Although these can be very important factors, they are not discussed in this paper.

II. SYSTEM DISTURBANCES

System disturbances are generally temporary variations in the system voltage which may cause equipment misoperation or failure. Frequency variation may occasionally be a factor in system disturbances, especially

when a load is being served by an emergency generator or a mismatch of plant load and generation occurs due to the loss of the utility supply. However, when the user's power system is tied to a relatively strong utility source, frequency variation is seldom a significant concern. Voltage variation is generally the major factor and that is the focus of this discussion.

A. Transient Overvoltage Disturbances

Transient overvoltages refer to variations in the voltage waveform which result in overvoltage conditions for a fraction of a cycle of the fundamental frequency. (See Figure 1.) The common sources of these transients are lightning strokes, switching of power system devices, and arcing of loose connections or intermittent faults. The key considerations are summarized as follows:

- 1) For traditional power equipment transient overvoltages have been dealt with by designing equipment to withstand transient overvoltages of magnitudes of several times the normal peak voltage while applying surge arresters and sometimes surge capacitors to assure that the voltages did not exceed the equipment design levels.
- 2) Electronic equipment does not generally have the same withstand capability as that described above for the more traditional power equipment. In fact, the use of surge arresters that limit transients to two to three times the normal peak voltage may not provide adequate protection for this equipment. In that case surge protective devices for electronic equipment may need series reactors, shunt capacitors, and/or electronic devices in addition to non-linear resistive surge arresters to provide adequate protection. When adequate protection is not provided, equipment failure or misoperation may occur.
- 3) The switching of capacitor banks, either in the plant or on the utility system, may cause the misoperation of some equipment. In recent years, it has become a common problem associated with the unexplained tripping of many small ac drives. Many of these drives are designed to trip off line for an overvoltage of only 10% to 20% lasting a fraction of a cycle. Since many utility capacitor banks are switched daily, this problem could occur on a very frequent basis. This undesirable tripping problem can usually be remedied by adding a reactor in series with the sensitive device or modifying its tripping characteristic. Other solutions may include the reduction of the transient at the capacitor bank. Capacitor switching has also occasionally been associated with the misoperation or failure of equipment other than ac drives.

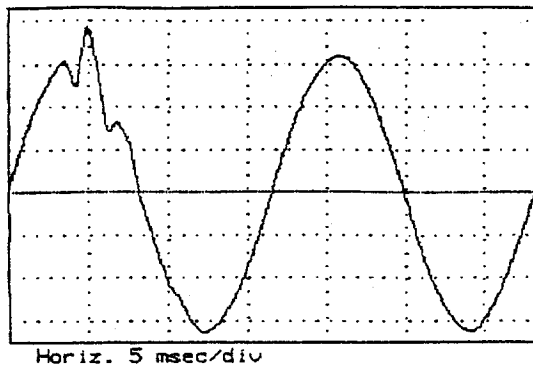


Figure 1
Example of Transient Overvoltage

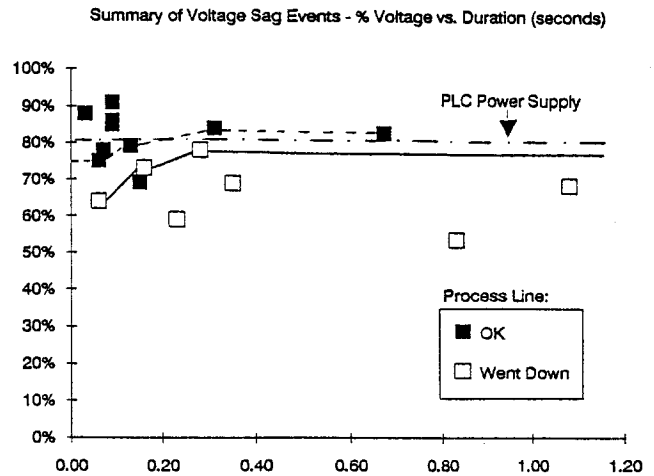


Figure 2
Example of Momentary Undervoltages

B. Momentary Undervoltage Disturbances

Sags or momentary voltage dips in the 60 Hz voltage have become a common problem in recent years from blinking digital clocks in homes to disrupted industrial processes. This is a condition which typically occurs when a fault is initiated on the power system and lasts until the fault is cleared by an overcurrent device. The fault may occur in the plant or on the utility system. This type of condition may also occur during the starting of large motors. Many electrical products are not made to ride through these temporary low voltage conditions. The temporary undervoltage condition tends to occur on the order of ten times more often than a complete loss of power. The major factors in dealing with momentary undervoltages are summarized as follows:

- 1) In an industrial plant high intensity discharge (HID) lighting is often the most sensitive equipment to low voltages. It will typically extinguish for voltages in the range of 85% to 90% of nominal for periods of time as short as 1 cycle and will take several minutes to restart. A way to minimize this effect is to use HID lighting that has instant restrike capability or use quartz bulbs with HID lights. The quartz bulb would come on immediately and go off approximately 10 minutes later. Either method could be used in approximately 10% of the HID light locations in a facility to provide temporary lighting until all the lights come back on. It is also possible to obtain regulator ballasts that can ride through voltage sags as low as 50%.
- 2) PLC's that are used to control devices such as dc and ac drives may shut down the devices for voltages on the order of 80% to 85% of nominal. This can be improved for momentary low voltage conditions by providing instantaneous voltage regulation for the PLC through a voltage regulator or an uninterruptible power supply (UPS). In Figure 2, an example of voltage dip measurements at an industrial facility is given, which indicates the events that caused the process line to go down. The PLC power supply was the key component in the ride through capability of the process line as it would trip out for a voltage dip to 81% of nominal. It actually had better ride through for short duration events.

- 3) Ac and dc drives are typically designed for continuous operation with voltage variations of +10% to -5% to -15%. Outside of this range the drive may not be able to maintain speed or other parameters that are critical to the process and may proceed to shut down. The duration and magnitude of the voltage dip that may cause that to happen varies from device to device. In addition, even if the drive were designed to ride through this condition, the product, which is being made in the process, may be damaged or suffer in quality such that it is not acceptable for use. However, motor inertia will help in successfully riding through those types of events. If the process is unaffected by this transient condition, then consideration may be given to equipping the drive with automatic restart. (Safety and equipment damage are factors in determining if automatic restart is appropriate.)
- 4) Motor contactor coils will generally drop out for voltages in the range of 50% to 75% for durations of 1 to 5 cycles. If necessary, this can be improved for momentary low voltage conditions by providing instantaneous voltage regulation for the coil.
- 5) If 100% of the voltage sags include voltages of 90% or less, system studies [1] have typically shown that approximately
 - a) 30% of the sags include voltages of 80% or less,
 - b) 15% of the sags include voltages of 70% or less,
 - c) 5% of the sags include voltages of 60% or less.
 These values illustrate how relatively minor improvements in ride through capability can significantly reduce the number of undervoltage disturbances. For example, improving a particular device's ride through capability from 80% to 70% would typically cut the number of disturbing events by 50%. Going from 80% to 60% could reduce the number by over 80%.

- 6) 80% of sag events have durations of less than .2 to .5 seconds. Transmission systems tend to have faster clearing times than distribution systems, but it is a function of utility relaying practices.

To design the proper ride-through capability into electrical equipment, it is important to know the magnitude, duration, and frequency of occurrence that is expected for the momentary undervoltage conditions. Facilities which are fed from utility distribution systems are likely to see longer duration events as well as a greater frequency of events compared to those facilities fed from utility transmission systems. The local utility would be able to provide more detailed information for a particular service point. Depending upon the circumstances, the utility may be able to reduce the number of events by improved tree trimming, addition of animal guards, improved grounding, addition of surge arresters, and revised overcurrent coordination methods. The duration of the events may also be able to be reduced by revised overcurrent coordination methods.

C. Outages

The complete loss of power to a facility is generally an order of magnitude less frequent than a momentary undervoltage disturbance. However, if the frequency is significant enough, then steps must be taken to have an alternate source available on a timely basis.

D. Industry Standards

System disturbances were a factor in designing reliable computer power systems as far back as the late 60's and 70's. It is only in the last five to ten years that computer controls have become common in all parts of the power system. Consequently, very few standards deal with defining acceptable short time voltage variations, but work is being done to develop standards in this area. The significant standards with regard to voltage variation are summarized as follows:

- 1) Steady state voltage variations are defined by ANSI Std. C84.1 [2]. Normal service voltage is expected to be within +/-5% of nominal for service voltages up to 600 volts with variations of as much as +5.8% to -8.3% for short periods of time. Acceptable variations for other system voltages are given in ANSI Std. C84.1-1989. (See Figure 3.)
- 2) NEMA Standards Publication No. MG-1-1987, Motors and Generators (Section 1-12.45) [3] states that "ac polyphase motors shall operate successfully under running conditions at rated load when the voltage unbalance at the motor terminals does not exceed 1%". Section 1-14.35 of the same standard gives a reduced loading curve for greater voltage unbalances: 90% at 3% unbalance and 75% at 5% unbalance. (See Figure 4.) Motor operation for voltage unbalances above 5% is not recommended. ANSI Std. C84.1-1989 recommends that "electric supply systems should be designed and operated to limit the maximum voltage unbalance to 3% when measured at the electric-utility revenue meter under no-load conditions".

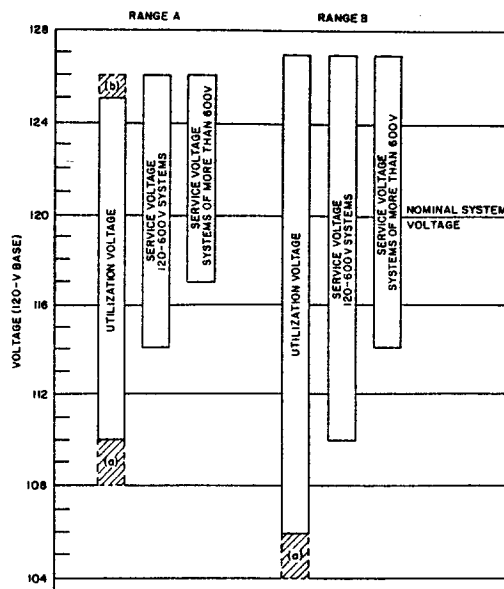


Figure 3
Voltage Limits In C84.1-1989

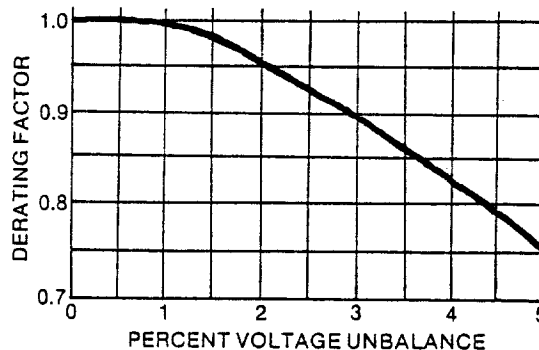


Figure 4
Motor Derating Due to Unbalance Voltage

- 3) Flicker curves have been developed over the years to provide guidance on limits for voltage variations for fast changing loads as they affect other equipment on the system. One of the major loads of concern has been arc furnaces, as well as many other types of loads that vary frequently. These voltage variations are generally in the range of .5% to 6% that may vary in frequency from 10/second to 1/hour. This information is summarized in Section 10.5 of IEEE Std. 519-1992 [4].
- 4) IEEE Draft Std. 1250 [5] provides a good discussion of momentary disturbances and some guidance for the mitigation of these problems. This document does not recommend limits.

- 5) Temporary fundamental frequency under-voltages at the equipment which go below the 88.3% level specified by ANSI Std C84.1 may result in the disruption of the operation of some equipment. There are no standards related to these types of disturbances; but, there is a curve included in ANSI/IEEE Std. 446-1987, The Orange Book [6], which is a good point of reference. This curve was subsequently developed into the CBEMA curve by the Computer Business Equipment Manufacturers Association as a guideline in designing computer power supplies. In Figure 5 the ride-through capability suggested in the CBEMA curve is illustrated with the example given in Figure 2. Work is currently underway to consider short-time voltage disturbance requirements to ANSI C84.1. (They were dropped from the document in 1982.) IEEE Std 493-1990, The Gold Book [7], is currently being revised to include a chapter on methods to predict the number and magnitude of voltage sags expected at any point of interest on the electrical system. Also, IEEE Working Group P1346 is working to develop a broad consensus regarding compatibility issues [8].
- 6) Transient overvoltage protection of low voltage equipment is addressed in the ANSI/IEEE C62 Standards [9]. Existing standards include: ANSI/IEEE C62.41-1991, Recommended Practice on Surge Voltages in Low-Voltage AC Power Systems, and ANSI/IEEE C62.45-1987, Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits. Work is currently underway to provide guidance on the surge protective devices which will be included in documents C62.42, C62.43, and C62.64. There are, however, no standards on surge withstand levels for much of the low voltage equipment.

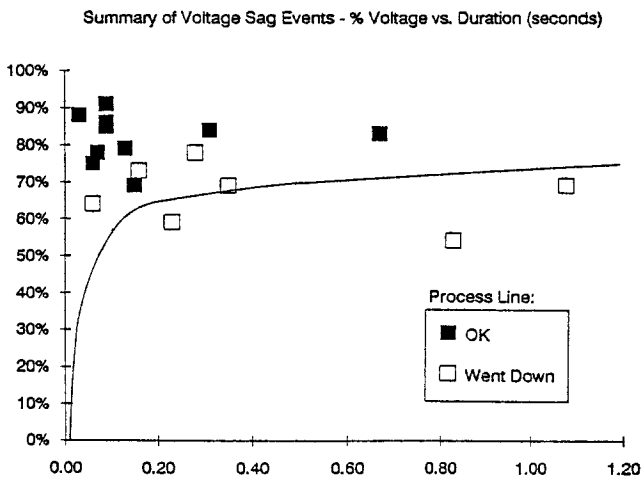


Figure 5
Example of Momentary Undervoltages
With CBEMA Curve

III. HARMONIC DISTORTION

Harmonic distortion describes the continuous or steady state variation in the fundamental frequency waveform. For this steady state condition the frequencies are integer multiples of the fundamental frequency. Typical symptoms of harmonic problems include spurious fuse blowings, unexplained breaker trips, overheating of transformers and motors, misoperation of drives, relays, computers, etc. The following outline gives a brief summary of the trends and guidelines with regard to harmonic considerations.

A. Small Commercial and Office Building Systems

Small commercial and office building power systems are largely composed of single phase loads which are often fed from a 4-wire, wye-grounded source. With the advent of the personal computer and the switch mode power supply in the early 1980's, a larger and larger percentage of these types of loads are nonlinear in nature, i.e. they produce harmonics. Single phase devices generally exhibit the following harmonics of the fundamental in the current waveform: 3, 5, 7, 9, 11, 13, etc. (This includes all of the odd harmonics.) In these types of applications the following items should be noted:

- 1) Even with balanced load conditions, harmonics which are multiples of three will add in the neutral conductor. The third harmonic is generally much higher than the rest and is usually the most significant. An example of phase and neutral currents with a high content of single phase harmonic producing loads is given in Figure 6.

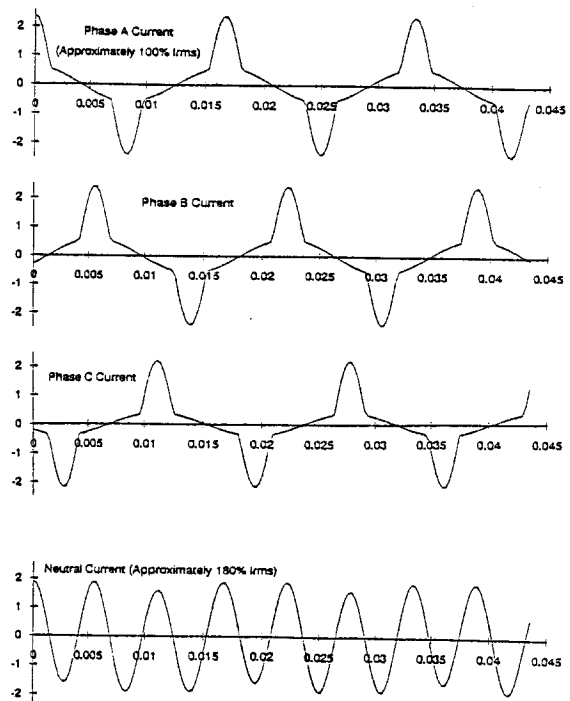


Figure 6
Example of Office Building
Phase and Neutral Currents

- 2) Supply transformers which are connected delta/wye-grounded will block most of the third harmonic current and its multiples from flowing into the higher voltage system. Consequently, this transformer connection is preferred in this application.
- 3) Due to the potentially high neutral currents in this application, a common neutral conductor may be rated as much as double the phase conductors or separate neutrals may be run on each phase.
- 4) Transformers need to be rated or derated to handle the high harmonic currents. This is the major application of K-factor rated transformers.
- 5) True RMS operating circuit breakers are recommended.
- 6) Filters can be applied at the loads to reduce harmonics throughout the system. This may reduce the K-factor rating of the transformer needed as well as the neutral current requirement.
- 7) Zig-Zag or wye-delta transformers may be used to trap zero-sequence harmonics such as $h = 3, 6, 9, \text{etc.}$ This will reduce the duty on upstream equipment.

B. Large Commercial and Industrial Systems

Large commercial and industrial power systems are largely composed of three phase loads. These are predominantly composed of ac motor drives, dc motor drives, other rectifier devices, and power controlled heating circuits. The current harmonics which are characteristic of most continuous three phase loads are the odd harmonics except for multiples of three (5, 7, 11, 13, etc.). In these types of applications the following items should be noted:

- 1) The third harmonic neutral current problem is generally not a consideration in these applications.
- 2) Occasionally small 3-pulse devices will be used. They also have even harmonics as part of their characteristics (e.g. 2, 4, 5, 7, 8, 10, 11, 13, etc.). These types of devices have seldom been used in recent years due to their dc component which can cause significant transformer heating.
- 3) If the kVA of harmonic producing load is less than 30% of the transformer kVA rating, the voltage distortion will typically be less than 5% at the secondary of the transformer when there are no shunt capacitors on the system.
- 4) Harmonic distortion can generally be reduced by following these guidelines:
 - a) Do not use 3-pulse devices or power controllers that use combined SCR and diode configurations due to the even harmonics which they produce.
 - b) Use dc reactors, ac reactors, or transformers with PWM drives to reduce lower order harmonics (i.e., the 5th and 7th harmonics). When buying new 6-pulse equipment, specify $I_{THD} < 40\%$. An

example of the current distortion with and without the input reactor is illustrated in Table 1.

- c) When multiple transformers are used to feed many drives in a plant, consider using delta-delta and delta-wye transformer connections. This will reduce the 5th, 7th, 17th, 19th, etc., harmonics.
 - d) Use 12-pulse or higher for large drives or rectifiers.
- 5) In low voltage installations where capacitors are applied for power factor correction, the following guidelines typically apply:
 - a) If the kVA of harmonic producing load is less than 10% of the transformer kVA rating, capacitors can be applied without concern for excessive distortion.
 - b) If the kVA of harmonic producing load is less than 30% of the transformer kVA rating and the capacitor kvar rating is less than 20% of the transformer kVA rating, capacitors can be applied without concern for excessive distortion.
 - c) If the kVA of harmonic producing load exceeds 30% of the transformer kVA rating, capacitors should be applied as filters.
 - 6) In medium and low voltage systems where harmonic distortion is excessive, filter capacitor banks can be applied to reduce the harmonic distortion. Typical filter configurations for these applications include:
 - 5th harmonic filter
 - 5th/7th harmonic filter
 - 5th/7th/11th harmonic filter
 - 5th/7th/11th high pass harmonic filter
 The 5th harmonic filter is by far the most common. Where lower order harmonics exist, filters tuned near the 3rd and 4th harmonics may be used. The other more complex and more expensive filter arrangements are used only when the distortion levels dictate it. At times filters tuned to other frequencies may be needed. When determining the optimum filter requirements, power factor needs should also be considered in the evaluation.

Table 1
Example PWM Drive Harmonic Current Spectrums

Harmonic	High Distortion (No Reactors)	Reduced Distortion (With Reactors)
1	100.0%	100.0%
3	5.2%	1.9%
5	71.9%	25.0%
7	43.1%	11.0%
11	9.3%	7.5%
13	5.7%	5.0%
17	6.5%	4.4%
19	2.0%	3.2%
23	3.2%	2.6%
25	1.8%	2.0%
THD	85.2%	29.6%

C. Utility Systems

The sources of harmonic distortion predominantly come from the loads used by the customers of the utility. The following general comments are noted:

- 1) Harmonic distortion levels are generally higher on the customer's power system than on the utility system. Consequently, most harmonic related problems occur on the customer's system.
- 2) Where no single large customer or harmonic producing load is fed from the distribution system, it is generally advantageous to distribute small capacitor banks on the distribution feeders rather than place a large bank at only one location. Distributed capacitor banks have the effect of causing several resonance points but of relatively low magnitudes compared to one large one with a single large capacitor bank.
- 3) It is possible for harmonics produced by one customer to cause problems for another utility customer fed from the same distribution system. This type of problem often involves resonances with capacitor banks. It is usually best solved by taking action at the source of the harmonics or by addressing the capacitors that may be causing resonance.
- 4) Telephone interference is another problem which occasionally occurs on utility distribution systems. This tends to occur when relatively large harmonic producing loads are fed from a utility distribution system (12 kV to 35 kV) and telephone lines share the same right-of-way with the power lines. Again, this is usually best solved by taking action at the source of the harmonics; although it is sometimes solved by moving or removing capacitors on the utility distribution system. It is a function of coupling between the electric utility and telephone lines; but, most times, there is little that can be done about the physical arrangement of the conductors. However, this high frequency content often identifies open shields on the telephone circuits. Once the shield connections are fixed, the noise is usually greatly reduced.

D. Industry Standards

Historically, harmonics did not start to become a significant factor in the design of power systems until the 1960's. The invention of the SCR in 1957 started a gradual move towards the use of power electronics to supply significant amounts of power. This has continued to increase to the present day, and it is expected to continue to increase in future decades. Consequently, industry standards did not start to reflect the consideration of harmonics until the last 10 to 20 years. The significant standards with regard to harmonic considerations are summarized as follows:

- 1) IEEE Std. 519 was first issued in 1981. It gave the first guidelines for system harmonic limitations. Below 69 kV it was recommended in this document that the voltage distortion be kept to less than 5%. Lower

voltage distortion levels were recommended at higher system operating voltages.

- 2) IEEE 519 was revised in 1992.[4] The 5% voltage limitation remains while there is a limitation on current distortion at the point where the utility and customer tie together. This limit on current distortion is in the range of 2.5% to 20% depending upon the size of the customer and the system voltage. This document also gives guidance on notch depth and areas associated with electronic switching devices, as well as telephone interference considerations.
- 3) ANSI/IEEE Std. 18 [10] gives limitations for shunt capacitor banks that allow for significant harmonic distortion. These limits are:
 - 110% of rated rms voltage
 - 120% of rated peak voltage
 - 180% of rated rms current
 - 135% of rated kvar
- 4) ANSI/IEEE Std. C57.12.00 [11] and C57.12.01 [12] gives the limitation for current distortion in transformers at 5% at full load. This value can easily be exceeded when the harmonic producing load on a transformer exceeds 10% to 20% of its kVA rating.
- 5) ANSI/IEEE Std. C57.110 [13] gives a recommended practice for establishing transformer capability when the current distortion exceeds 5%.
- 6) In 1992 Underwriters Laboratories (UL) revised UL 1561 [14] and UL 1562 [15] to address the harmonic capability of transformers covered by these documents. The changes are based on the so-called "K-factor" rating method, which is derived from ANSI/IEEE Std. C57.110, and which defines a transformer rating system when the current distortion exceeds 5%. This has resulted in many manufacturers offering K-factor rated transformers.
- 7) In Table 310, Note 10(c) of the 1993 National Electrical Code [16], it is noted that "on a 4-wire, 3-phase wye circuit where the major portion of the load consists of nonlinear loads such as electric-discharge lighting, electronic computer/data processing, or similar equipment, there are harmonic currents present in the neutral conductor, and the neutral shall be considered to be a current-carrying conductor".
- 8) A 1992 draft revision of ANSI C82.1, "Specification for High Frequency Fluorescent Lamp Ballasts" [17], recommends a maximum I_{THD} of 32%. As a result of the concern in this area, many recently designed electronic ballasts have $I_{THD} < 15\%$. This is one of the few equipment standards which addresses harmonic current limitations.

More details are available in each of these documents and they should be available for reference by those who are doing significant work in the area of harmonics.

IV. GROUNDING

Improper grounding can cause what might be a marginal problem to be a significant problem. Grounding problems generally occur on 120 volt systems. They may occasionally occur at the 480 volt level, but rarely at medium voltage (>1000 volts). Grounding is done for the following major reasons: (1) protect personnel, (2) reduce damage due to lightning, (3) isolate a faulty feeder, and (4) provide a signal reference. Many of the problems occur when grounding errors are made and when trying to implement the objective of providing a signal reference with the same techniques that are used for personnel and lightning protection. Some of the significant considerations with regard to grounding are summarized as follows:

- 1) Solid state chips usually operate at voltages in the range of 5 to 12 volts. Extraneous signals in this voltage range or higher may cause them to misoperate or fail.
- 2) The neutral conductor must be connected to ground in only one location, at the main panel or transformer secondary. Although the National Electrical Code (ANSI/NFPA 70-1993) [16] requires this connection, missing or improper neutral-to-ground connections are a common problem. When the neutral is connected to ground at multiple locations, interference can occur with sensitive electronic devices due to the normal operation of other equipment on the power system. (See Figure 7.)
- 3) Power conductors and control conductors should not be run physically in parallel, especially not in the same conduit.
- 4) Sensitive loads and disturbance generating loads should not share neutral and ground conductors. Separate green wires should be run.
- 5) It is best to use the green wire for ground return. A conduit should not be relied upon for ground return.
- 6) When detailed grounding considerations are needed beyond those described above for sensitive electronic devices, a good reference is IEEE Std 1100-1992, The Emerald Book [18].

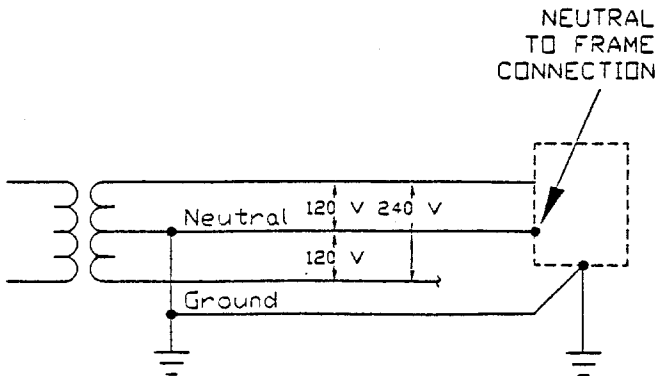


Figure 7

Example of Excessive Neutral-to-Ground Connections

V. CONCLUSIONS

Although there are many variations on the types of power quality problems that can occur, the most significant power quality issues are summarized as follows.

1. The biggest power quality issue for industrial facilities is momentary undervoltage disturbances. When a significant event occurs, it disrupts the process which results in production down time and lost revenue. There are two major steps to take in addressing this issue:
 - a) Improve the ride-through capability of the sensitive electrical equipment. Never let the process controls be the most sensitive component. For the major process equipment, such as a large drive or drives, the cost of ride-through capability may not be able to be justified on the drive itself, but, may be justified for its controls. There are no standards in this area. It is important to work with the equipment manufacturers to achieve the desired results.
 - b) Work with your utility to reduce the number and the duration of the events, if that is possible. Most of the initiating events are temporary faults on the utility system. Sometimes action can be taken by the utility to improve this situation.Standards are needed in the area of momentary undervoltage disturbances.
2. The major harmonic issues can be divided into two categories:
 - a) In commercial and office building applications, the harmonic producing loads are generally single phase which typically results in high current distortion and a significant third harmonic component. The major issues generally include the high neutral conductor current and transformer overheating. Both issues are generally resolved by rating the equipment properly for the application.
 - b) In industrial applications, the harmonic producing loads are generally three phase. When problems occur, they generally focus on resonance conditions with power factor correction capacitors. These problems are generally resolved by applying the capacitor banks as filter banks.

3. In terms of number of problems, wiring and grounding errors far exceed any other power quality consideration. These problems tend to be most common at 120 volts. Safety has always been an issue with regard to grounding, but in recent years signal reference has become a major issue while still maintaining safe grounding practices. One of the most significant grounding concerns is that the neutral conductor must be connected to ground in one and only one location.

It is important to remember that power quality problems are ultimately economics problems which require a systems approach to solve.

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VII. BIOGRAPHY

W. Edward Reid is Director, Analytical Studies with Qual-Tech Engineers, Inc. of Pittsburgh, PA. He has over 20 years of experience in electrical power system analysis. This has included system design, insulation coordination, harmonics, transients, load flow, short circuit, overcurrent coordination, and specialty field measurements. His experience has contained a special emphasis on problem solving including shunt and series capacitor applications, filter design from low voltage industrial to HVDC applications, equipment insulation failures, switchgear transient recovery voltage considerations, power quality and power outage problems, and equipment application considerations. He has taught seminars and undergraduate classes on several of these topics related to electrical power system applications. He has had extensive experience in series and shunt capacitor applications and is the Chairman of the IEEE Capacitor Subcommittee. He also is or has been a member of the IEEE Power Engineering Society, T&D Committee, IEEE Pulp and Paper Committee, Working Group on Transient Recovery Voltages, Harmonics Working Group, Transformer Task Force on External Clearance Requirements, Insulation Coordination Subcommittee, and Standards Coordinating Committee 22 on Power Quality. He has coauthored over 10 technical papers.