PQSoft Case Study

General Reference
Wiring and Grounding

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Abstract:

Wiring and grounding problems are responsible for many power quality variations within customer facilities. Some electric utility engineers have estimated that 80% of all the power quality problems reported by customers are found to be due to their own wiring and grounding problems. While end-users may have a different opinion, it is commonplace for many power quality problems to be resolved by simply tightening a loose connection, removing an unnecessary ground connection, bonding ground conductors, or replacing a corroded conductor. Therefore, the first step in any power quality investigation is to evaluate the wiring and grounding practices of the facility.

This case provides general information on proper grounding practices and outlines common problems that are encountered.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

RELATED STANDARDS

IEEE Std. 1100-1999
IEEE Std. 142-1991
National Electric Code (NEC)

GLOSSARY AND ACRONYMS

ADP	Automated Data Processing
CBEMA	Computer and Business Equipment Manufacturers Association
NEC	National Electric Code

INTRODUCTION

This case describes a general review of wiring and grounding with respect to power quality. Wiring and grounding problems are responsible for many power quality variations within customer facilities. Some electric utility engineers have estimated that 80% of all the power quality problems reported by customers are found to be due to their own wiring and grounding problems. While end-users may have a different opinion, it is commonplace for many power quality problems to be resolved by simply tightening a loose connection, removing an unnecessary ground connection, bonding ground conductors, or replacing a corroded conductor. Therefore, the first step in any power quality investigation is to evaluate the wiring and grounding practices of the facility.

IEEE wiring regulations and other important standards provide the minimum standards for wiring and grounding. These work well at 60Hz, or power frequency. However, it is often necessary to go beyond the minimum requirements of safety standards to achieve a system that also minimizes the impact on connected equipment of power quality variations that have higher frequency components.

REASONS FOR GROUNDING

Personnel Safety

Personnel safety is the primary reason that all equipment must have a safety equipment ground. This is designed to prevent the possibility of high touch voltages when there is a fault in a piece of equipment (see Figure 1). The touch voltage is the voltage between any two conducting surfaces that can be simultaneously touched by an individual. The earth may be one of these surfaces.

There should be no "floating" panels or enclosures near electric circuits. In the event of insulation failure or inadvertent application of moisture, any electric charge that appears on a panel, enclosure, or raceway must be drained to "ground" or to an object that is reliably grounded.

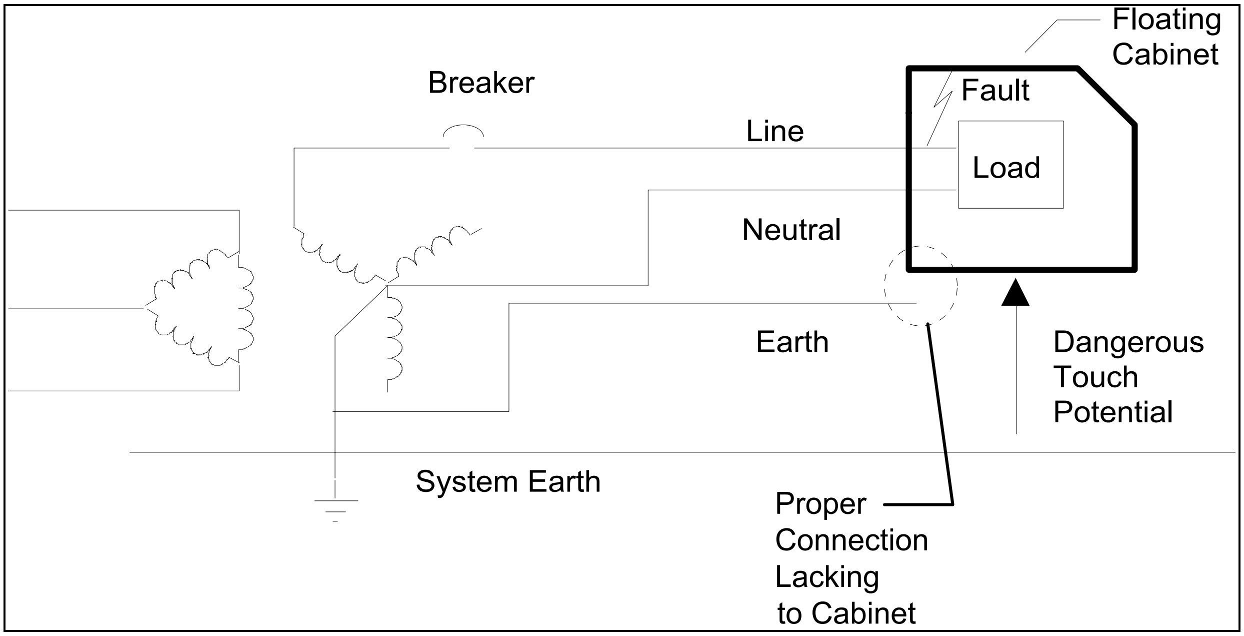

Figure 1 – High Touch Voltage due to Improper Grounding

Grounding to Assure Protective Device Operation

A ground fault return path to the point where the power source neutral conductor is grounded is an essential safety feature. The NEC and some local wiring codes permit electrically continuous conduit and wiring device enclosures to serve as this ground return path. Some codes require the conduit to be supplemented with a bare or insulated conductor included with the other power conductors.
An insulation failure or other fault that allows a phase wire to make contact with an enclosure will find a low impedance path back to the power source neutral. The resulting overcurrent will cause the circuit breaker or fuse to disconnect the faulted circuit promptly. NEC, Article 250-51 states that an Effective Grounding Path (the path to ground 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.

Noise Control

This is where grounding relates to power quality. The safety reasons for grounding described above are not related to power quality concerns. However, they define the minimum requirements for a grounding system. Anything that is done to the grounding system to improve the noise performance must be done in addition to the minimum requirements defined in the National Electric Code and local codes.

The primary objective of grounding for noise control is to create an equipotential ground system. Potential differences between different ground locations can create circulating ground currents and interference with sensitive equipment that may be grounded in multiple locations. Steady state circulating currents and associated potential differences will be at 60 Hz or at harmonic frequencies and are caused by potential differences at the main ground locations of the two facilities. Transient potential differences will be caused by switching events or lightning surges that cause ground currents or protective device operation from line-to-ground.

Ground Voltage Equalization of voltage differences between parts of an Automated Data Processing (ADP) grounding system is accomplished in part when the equipment grounding conductors are connected to the grounding point of a single power source. However, if the equipment grounding conductors are long, and if the ground currents are significant, the impedance of grounding conductors may be too high to achieve a constant potential throughout the grounding system. Supplementary conductors that may be needed for improving power quality must be in addition to the equipment ground conductors that are required for safety and not a replacement for them.

Often, selection of proper size grounding conductors and assuring good ground connections is sufficient to achieve an equipotential ground system. However, with higher speed communication and processing, the high frequency characteristics of the ground system can also be important. A Signal Reference Grid (see Figure 2), or Zero Reference Grid as used in IEEE Std. 1100, can provide an equipotential reference over a wide frequency range for computers and data processing equipment. This type of configuration is most common in mainframe computer installations.

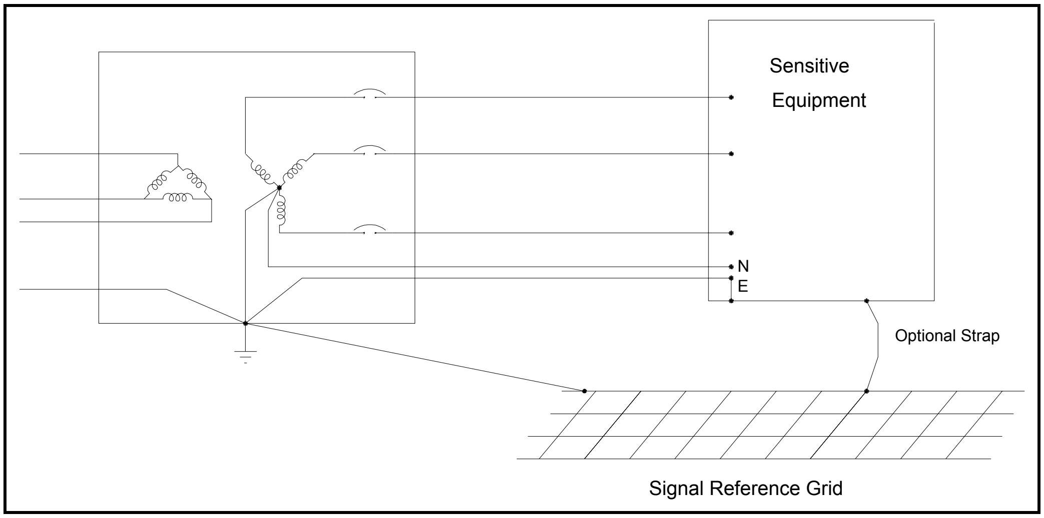

Figure 2 – Use of a Signal Reference Grid

PROPER GROUNDING PRACTICES

Figure 3 illustrates the basic elements of a properly grounded electrical system. The important elements of the electrical system grounding are described below.

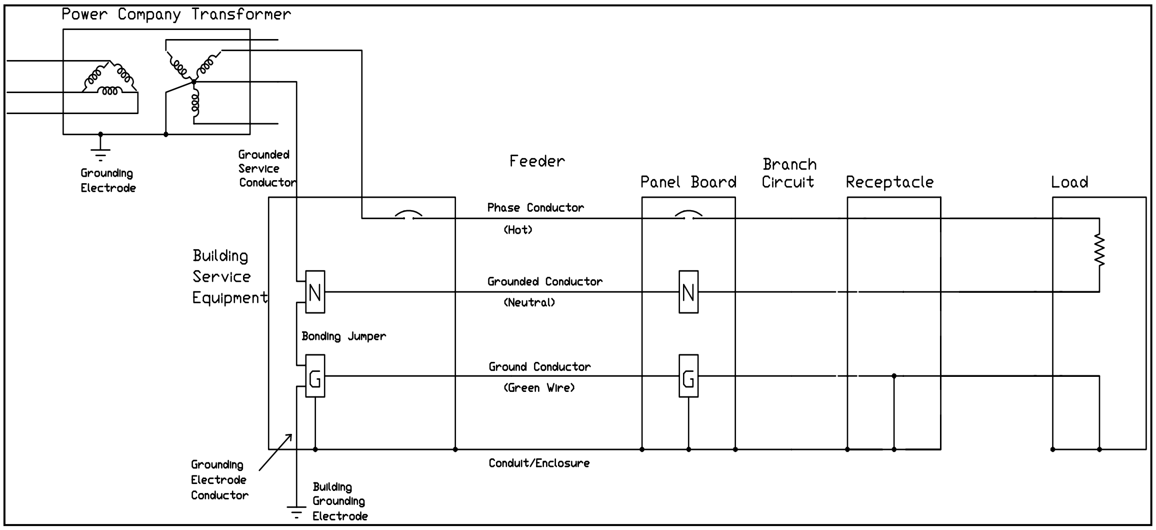

Figure 3 – Basic Elements of Proper Grounding of an Electrical System

Ground Rod

The grounding rod is the basic component of most grounding schemes to provide the electrical connection from the power system ground to earth. The item of primary interest in evaluating the adequacy of the ground rod is the resistance of this connection. There are three basic components of resistance in a grounding rod:

- **Electrode Resistance.** Resistance due to the physical connection of the grounding wire to the grounding rod.

- **Rod-Earth Contact Resistance.** Resistance due to the interface between the soil and the rod. This resistance is inversely proportional to the surface area of the grounding rod (i.e. more area of contact means lower resistance).
- **Ground Resistance.** Due to the resistivity of the soil near the grounding rod, the soil resistivity varies over a wide range, depending on the soil type and moisture content.

The resistance of the ground rod connection is important because it influences transient voltage levels during switching events and lightning transients. High magnitude currents during lightning strokes result in a voltage across the resistance, raising the ground reference for the entire facility. The difference in voltage between the ground reference and true earth ground will appear at grounded equipment within the facility and this can result in dangerous touch potentials.

Service Entrance Connections

The service entrance is where the primary components of a properly grounded system are found. The neutral point of the supply power system is connected to the grounded conductor (neutral wire) at this point. This is also the one location in the system (except in the case of a separately derived system) where the grounded conductor is connected to the ground conductor (green wire) via the bonding jumper. The ground conductor is also connected to the building grounding electrode via the grounding electrode conductor at the service entrance. For most effective grounding, the grounding electrode conductor should be exothermically welded at both ends.

The grounding electrode conductor is sized based on guidelines in the National Electric Code (Section 250-94). Table 250-94 from the Code provides the basic guidelines.
There are a number of options for the building grounding electrode. It is important that all of the different grounding electrodes used in a building are connected together at the service entrance. The following are permissible for grounding electrodes:

- Underground Water Pipe (see Table 250-94 for grounding electrode conductor requirements for connection to the neutral bus)
- Building Steel (see Table 250-94 for grounding electrode conductor requirements for connection to the neutral bus or the underground water pipe)
- Ground Ring. A ground ring can be used in addition to building steel to provide a better equipotential ground for the grounding electrode. It is connected to the main grounding electrode with a conductor that is not larger than the ground ring conductor.
- Concrete Encased Electrode. This can serve a similar purpose to a ground ring and is connected to the main grounding electrode with a conductor that has a minimum size #4 AWG.
- Ground Rod. The ground rod is connected to the main building grounding electrode with a conductor that has a minimum size #6 AWG.

Throughout the system, a safety ground must be maintained to ensure that all exposed conductors that may be touched are kept at an equal potential. This safety ground also provides a ground fault return path to the point where the power source neutral conductor is grounded. The safety ground can consist of the conduit itself or the conduit and a separate conductor (ground conductor or green wire) in the conduit. This safety ground originates at the service entrance and is carried throughout the building.

Panel Board

The panel board is the point in the system where the various branch circuits are supplied by a feeder from the service entrance. The panel board provides breakers in series with the phase conductors, connects the grounded conductor (neutral) of the branch circuit to that of the feeder circuit, and connects the ground conductor (green wire) to the feeder ground conductor, conduit, and enclosure. It is important to note that there should not be a neutral to ground connection at the panel board. This neutral-to-ground connection is prohibited in the National Electric Code, as it would result in load return currents flowing in the ground path between the panel board and the service entrance. In order to maintain an equipotential grounding system, the ground path should not contain any load return current. In addition, fault currents would split between the neutral conductor and the ground return path. Protection is based on the fault current flowing in the ground path.

Isolated Ground

The noise performance of the supply to sensitive loads can sometimes be improved by providing an isolated ground to the load. This is done using isolated ground receptacles, which are orange in color. If an isolated ground receptacle is being used downline from the panel board, the isolated ground conductor is not connected to the conduit or enclosure in the panel board, but only to the ground conductor of the supply feeder (see Figure 4). The conduit is the safety ground in this case and is connected to the enclosure. A separate conductor can also be used for the safety ground in addition to the conduit. This technique is described in the NEC, Article 274, Exception 4 on receptacles. It is not described as a grounding technique.

The isolated ground receptacle is orange in color for identification purposes. This receptacle does not have the ground conductor connected to the receptacle enclosure or conduit. The isolated ground conductor may pass back through several panel boards without being connected to local ground until grounded at the service entrance or other separately derived ground. The use of isolated ground receptacles requires careful wiring practices to avoid unintentional connections between the isolated ground and the safety ground. In general, dedicated branch circuits accomplish the same objective as isolated ground receptacles without the concern for complicated wiring.

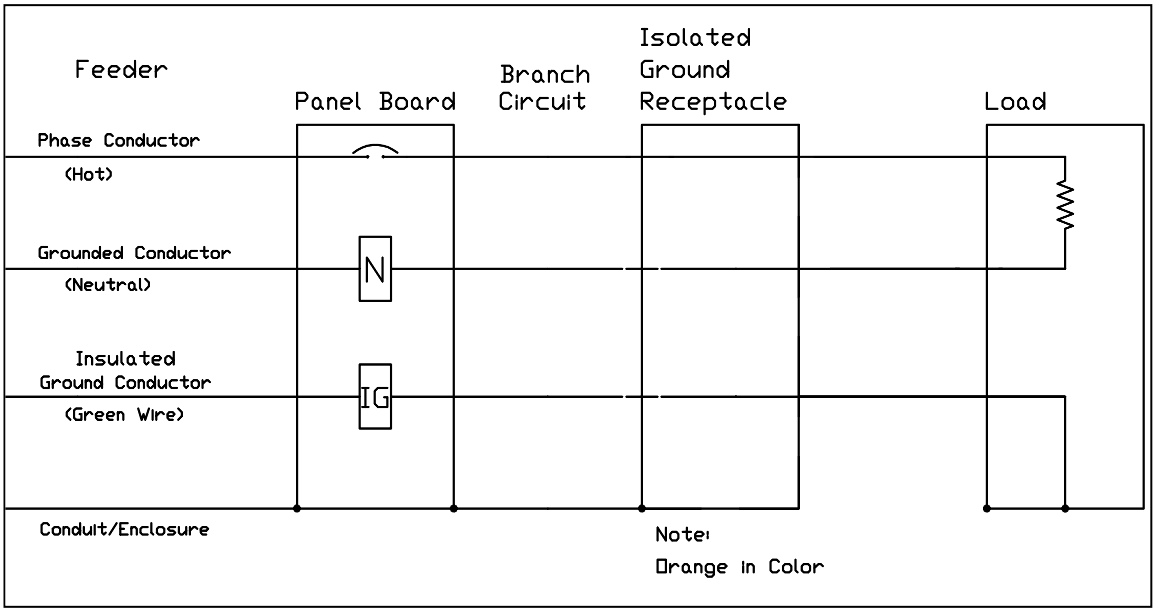

Figure 4 – Grounding Configuration for an Isolated Ground

Separately Derived Systems

A separately derived system has a ground reference that is independent from other systems. A common example of this is a delta-wye grounded transformer (see Figure 5). The wye connected secondary neutral is connected to local building ground (not a separate ground rod) to provide a new ground reference independent from the rest of the system. The point in the system where this new ground reference is defined is like a service entrance in that the system neutral is connected to the grounded conductor (neutral wire) that is connected to the ground conductor with a bonding jumper.

Separately derived systems are used to provide a local ground reference for sensitive loads. The local ground reference can have significantly reduced noise levels as compared to the system ground if an isolation transformer is used to supply the separately derived system. An additional benefit is that neutral currents are localized to the load side of the separately derived system. This can help reduce neutral current magnitudes in the overall system when there are large numbers of single-phase nonlinear loads.

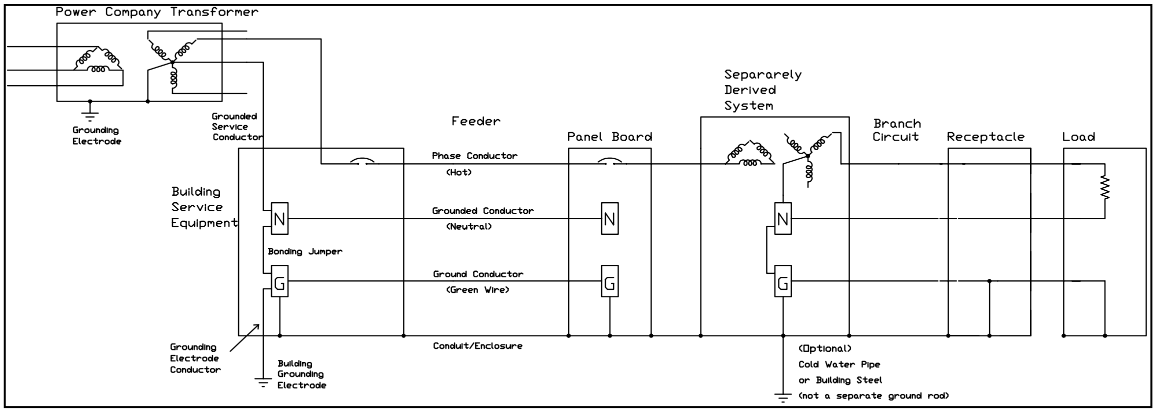

Figure 5 – Configuration for a Separately Derived System

Grounding Techniques for Signal Reference

Most of the grounding requirements previously described deal with the concerns for safety and proper operation of protective devices. Grounding is also used to provide a signal reference point for equipment exchanging signals over communication or control circuits within a facility. The requirements for a signal reference ground are often significantly different from the requirements for a safety ground. However, the safety ground requirements must always be considered first whenever designing a grounding scheme.

The most important characteristic of a signal reference ground is that it must have low impedance. One way to accomplish this (at least for low frequencies) is to use an adequately sized ground conductor. Conduit is particularly bad for a signal reference ground because it relies on continuity of connections and the impedance is high relative to the phase and neutral conductors. Undersized ground conductors have the same problem of high impedance.

For reducing power quality problems, the ground conductor should be at least the same size as the phase conductors and the neutral conductor (the neutral conductor may need to be larger than the phase conductors in some special cases involving nonlinear single phase loads).

The signal reference ground must look like a ground over a wide range of frequencies. The safety ground requirements are based only on 60 Hz. As frequency increases, the wavelength becomes short enough to cause resonances for relatively short lengths of wire. A good rule of thumb is that when the length of the ground conductor is greater than 1/20th of the signal wavelength, the ground conductor is no longer effective at that frequency. Since the grounding system is more complicated than a simple conductor, there is actually a complicated impedance vs. frequency characteristic involved.

One way to provide a signal reference ground to sensitive equipment that is effective over a wide range of frequencies (0-30 MHz) is to use a signal reference grid or zero reference grid. This technique uses a rectangular mesh of copper wire with about two-foot spacing. Even if a portion of the conductor system is in resonance at a particular frequency, there will always be other paths of the grid that are not in resonance due to the multiple paths available for current to flow. When using a signal reference grid, the enclosure of each piece of equipment must still be connected to a single common ground via the ground conductor (NEC requirement). The enclosures may also be connected to the closest interconnection of the grid to provide a high frequency, low impedance signal reference.

Additional Practices for Sensitive Equipment

The following practices are appropriate for any installation with equipment that may be sensitive to noise or disturbances introduced due to coupling in the ground system:

- Whenever possible, use individual branch circuits to power sensitive equipment. Individual branch circuits provide good isolation for high frequency transients and noise.
- Conduit should never be the sole source of grounding for sensitive equipment (even though it may be legal). Currents flowing on the conduit can cause interference with communications and electronics.
- Green wire grounds should be the same size as the current carrying conductors and the individual circuit conduit should be bonded at both ends.
- Use building steel as a ground reference, whenever available. The building steel usually provides an excellent, low impedance ground reference for a building. Additional ground electrodes (water pipes, etc.) can be used as supplemental to the building steel.
- These practices are often applied in computer rooms, where the frequency response of the grounding system is even more important due to communication requirements between different parts of a computer system.
- Either install a signal reference grid under a raised floor or use the raised floor as a signal reference grid. This is not a replacement for the safety ground, but augments the safety ground for noise reduction.
- Addition of a transient suppression plate at or near the power entry point (with the power cabling laid on top of it) to provide a controlled capacitive and magnetic coupling noise bypass between building reinforced steel and the electrical ground conductors.

TYPICAL WIRING AND GROUNDING PROBLEMS

The previous sections described proper procedures for grounding of electrical systems. The following sections outline some typical problems that can be experienced with the wiring and grounding of electrical systems. It is useful to be aware of these typical problems when performing site surveys. Many of the problems can be detected through simple observations. Other problems require measurements of voltages, currents, or impedances in the circuits.

Problems with Conductors and Connectors

The first things to look for when inspecting the service entrance, panel boards, and equipment wiring during a site survey are problems with conductors or connections. A bad connection (faulty, loose, or resistive connection) will result in heating, possible arcing, and burning of insulation. Table 1 summarizes some of the wiring problems that can be uncovered during a site survey.

Table 1 – Problems with Conductors and Connectors

Noted Problem	**Possible Cause**
Burnt smell at the panel, junction box, or load equipment	Faulted conductor, bad connection, arcing, or overloaded wiring
Panel or junction box is warm to the touch	Faulty circuit breaker or bad connection
Buzzing (corona effect)	Arcing
Scorched insulation	Overloaded wiring, faulted conductor, or bad connection
No voltage at load equipment	Tripped breaker, bad connection, or faulted conductor
Intermittent voltage at the load equipment	Bad connection or arcing
Scorched panel or junction box	Bad connection, faulted conductor

Missing Safety Ground

If the safety ground is missing, a fault in the equipment from the phase conductor to the enclosure results in line potential on the exposed surfaces of the equipment. No breakers will trip and a hazardous situation results.

Multiple Neutral to Ground Connections

Unless there is a separately derived system, the only neutral to ground bond should be at the service entrance. The neutral and ground should be kept separate at all panel boards and junction boxes. Down neutral-to-ground bonds result in parallel paths for the load return current where one of the paths becomes the ground circuit. This can cause misoperation of protective devices. In addition, during a fault condition, the fault current will split between the ground and the neutral that could prevent proper operation of protective devices (a serious safety concern). This is a direct violation of the NEC.

Ungrounded Equipment

Isolated grounds are sometimes used due to the perceived notion of obtaining a "clean" ground. Procedures which involve an illegal insulating bushing in the power source conduit and replacing the prescribed equipment grounding conductor with one to an "Isolated Dedicated Computer Ground" are dangerous, violate code, and are unlikely to solve noise problems.

Additional Ground Rods

Ground rods for a facility should be part of a grounding system, connected where all the building grounding electrodes (building steel, metal water pipe, etc.) are bonded together. Multiple ground rods can be bused together at the service entrance to reduce the overall ground resistance. Isolated grounds can be used for sensitive equipment, as described previously. However, these should not include isolated ground rods to establish a new ground reference for the equipment. The most important problem with additional ground rods is that they create additional paths for lightning stroke currents to flow. With the ground rod at the service entrance, any lightning stroke current reaching the facility goes to ground at the service entrance and the ground potential of the whole facility rises together. With additional ground rods, a portion of the lightning stroke current will flow on the building wiring (green ground conductor and/or conduit) to reach the additional ground rods. This creates a possible transient voltage problem for equipment and a possible overload problem for the conductors.

Ground Loops

Ground loops are one of the most important grounding problems in many commercial and industrial environments that include data processing and communication equipment. If two devices are grounded via different paths and a communication cable between the devices provides another ground connection between them, a ground loop results. Slightly different potentials in the two power system grounds can cause circulating currents in this ground loop. Because the communication signal levels can be quite low (e.g., five volts), very low magnitudes of circulating current can cause serious noise problems. The best solution to this problem is to use optical couplers in the communication lines, thereby eliminating the ground loop.

Insufficient Neutral Conductor

An example current waveform for a switched-mode power supply was provided in the harmonics section. This type of load, as well as fluorescent lighting with electronic ballasts is becoming increasingly prevalent in commercial environments. The high harmonic contents present in these load currents can have a very important impact on the required neutral conductor rating for the supply circuits.

The most important harmonic component in these load currents is the third. Third harmonic currents in a balanced system appear in the zero sequence circuit. This means that third harmonic currents from three single phase loads will add in the neutral, rather than cancel as is the case for the 60 Hz current. For the current waveform shown in Figure 6, this means that the neutral current could be as high as 240% (80% third harmonic current on each phase) of the fundamental frequency phase current magnitude. In typical commercial buildings with a diversity of switch mode power supply loads, the neutral current is typically in the range 140%-170% of the fundamental frequency phase current magnitude. CBEMA has recognized this concern and has prepared a brief to alert the industry to problems caused by harmonics from computer power supplies.

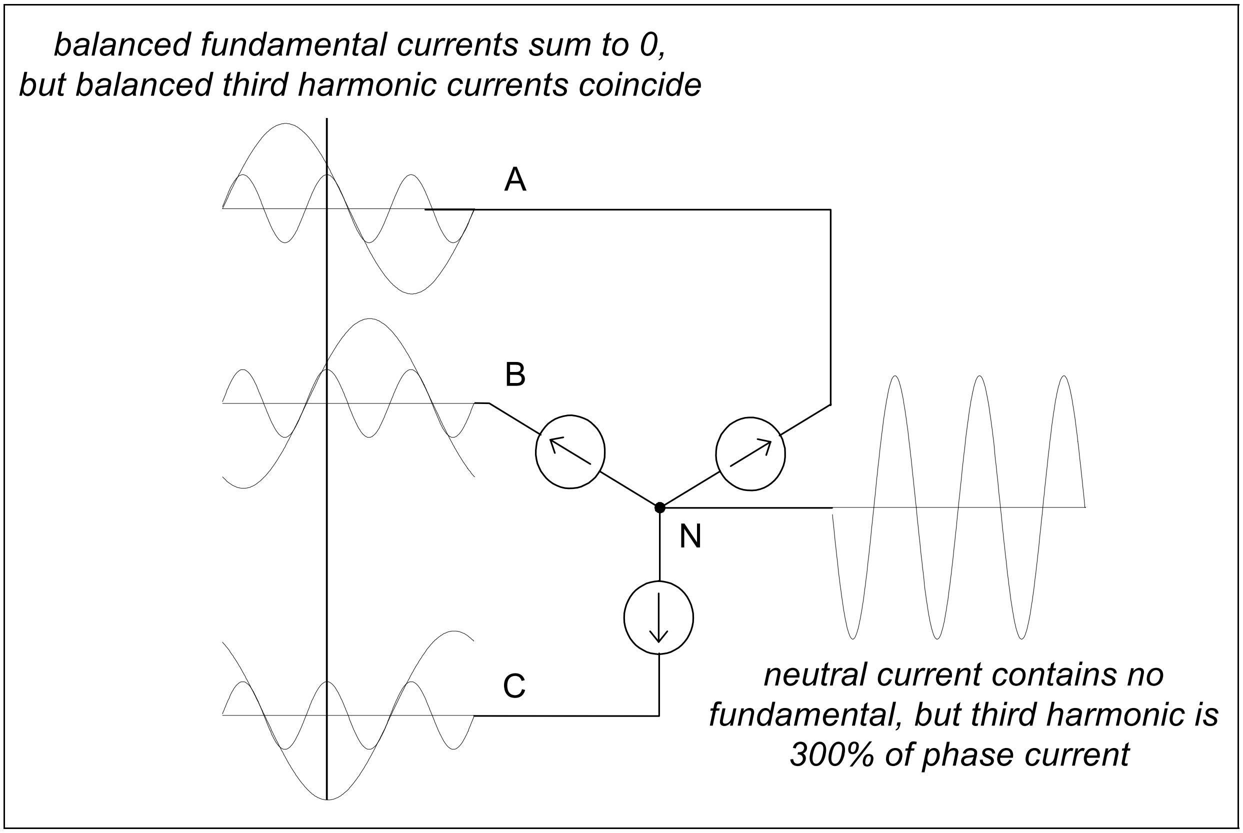

Figure 6 – High Neutral Current from Single-Phase Nonlinear Loads

The possible solutions to neutral conductor overloading include the following:

- Run a separate neutral conductor for each phase in a three-phase circuit that serves single-phase nonlinear loads.
- When a shared neutral must be used in a three-phase circuit with single-phase nonlinear loads, the neutral conductor capacity should be approximately double the phase conductor capacity.
- Delta-wye transformers designed for nonlinear loads can be used to limit the penetration of high neutral currents. These transformers should be placed as close as possible to the nonlinear loads (e.g., in the computer room). The neutral conductors on the secondary of each separately derived system must be rated based on the expected neutral current magnitudes.
- Filters to control the third harmonic current that can be placed at the individual loads are becoming available. These will be an alternative in existing installations where changing the wiring may be an expensive proposition.

SOLUTIONS TO WIRING AND GROUNDING PROBLEMS

The grounding system should be designed to accomplish these minimum objectives:

- There should never be load currents flowing in the grounding system under normal operating conditions. There is likely to be low currents in the grounding system due to the connection of protective devices and other connections between line and ground (in fact, if the ground current is actually zero, there is probably an open ground connection). However, these currents should be much smaller than the load currents.
- There should be, as near as possible, an equipotential reference for all devices and locations in the system.
- To avoid excessive touch potential safety risks, all equipment and enclosures should be connected to the equipotential grounding system.

The most important implications resulting from these objectives are:

- There can only be one neutral-to-ground bond for any subsystem. A separately derived system may be created with a transformer, allowing establishment of a new neutral-to-ground bond.
- There must be sufficient interconnections in the equipotential plane to achieve low impedance over a wide frequency range.
- All equipment and enclosures should be grounded.

Finally, consideration should be given to how various loads are grouped in the distribution panel as shown in Figure 7. Electronic tills, computers, lab equipment, and other loads should be powered from a dedicated circuit with separate conductors.

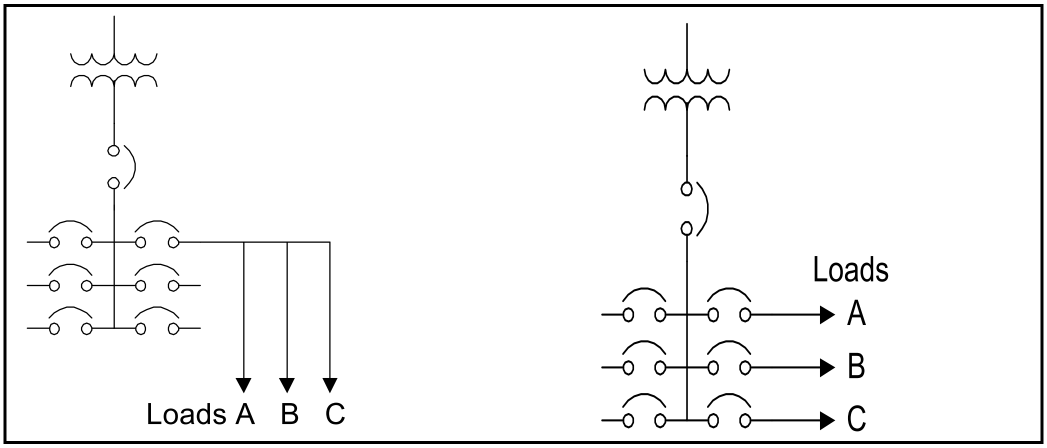

Figure 7 – Samples of a Load Grouping

SUMMARY

Wiring and grounding problems are responsible for many power quality variations within customer facilities. Some electric utility engineers have estimated that 80% of all the power quality problems reported by customers are found to be due to their own wiring and grounding problems. While end-users may have a different opinion, it is commonplace for many power quality problems to be resolved by simply tightening a loose connection, removing an unnecessary ground connection, bonding ground conductors, or replacing a corroded conductor. Therefore, the first step in any power quality investigation is to evaluate the wiring and grounding practices of the facility.

This case provided general information on proper grounding practices and outlines common problems that are encountered.

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