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Attn: Mike Davis

Mike,

I am providing comments on powering and grounding of hospital imaging equipment that I think might prove beneficial to you in your upcoming meeting with ***dms Imaging***. I am familiar with ***dms Imaging*** as I have seen their mobile units parked at various hospitals located in smaller towns. In fact, I identified serious power and grounding conditions specific to the ***dms Imaging*** mobile trailer building power supply at one site. Said problems at this location have since been resolved per my design and inspection; refer to the Case Study section at the end of this paper for specific findings and corrective actions.

More often than not, there are multiple conditions contributing to the malfunction or premature failure of sensitive electronics equipment, imaging or otherwise. For example, I was recently called in to troubleshoot a problem with a portable TEE Ultrasound unit used in the heart and lung operating room of a hospital. The Ultrasound image was so cluttered that the equipment was rendered virtually unusable. The multiple causes included the following:

(1) electromagnetic interference generated by three faulty UPS units and distributed through the electrical system to three operating rooms [interestingly enough, the UPS actually supplying power to the TEE Ultrasound was of good quality and in good condition],
(2) electromagnetic interference induced from a heart/lung pump located nearby,
(3) current on grounding conductors generated by two improper neutral-ground bonds,
(4) inadequate transformer grounding to the building grounding electrode system,
(5) undersized grounding feeder conductor for the separately derived electrical system supplying power to three operating rooms,
(6) undersized phase and neutral conductors supplying the heart/lung pump, and
(7) lack of high quality TVSS w/filtering at the branch circuit and distribution panelboards.

Given my experience with troubleshooting commercial, industrial, and hospital facility electrical systems in general, I suspect that <u>few</u> of the small hospitals serviced by mobile imaging systems have adequate power and grounding sources. I would venture to guess that ***dms Imaging*** experiences more frequent problems with their mobile equipment than with their stationary equipment housed within hospitals, although the inside installations are frequently found to be inadequately powered in larger hospitals as well. Some of the more common conditions affecting imaging systems are listed on the following pages.

Undersized Conductors. Conductors supplying hospital imaging equipment are usually undersized [oftentimes substantially] because electricians do not take into consideration adjustments required for load characteristics, number of current carrying conductors in a conduit, ambient temperature, and circuit length. This is particularly true for imaging equipment powered from a 4-wire, 3-phase wye circuit.

Load Characteristics. Hospital imaging equipment loads are nonlinear. Nonlinear loads are a major cause of harmonic currents in modern circuits. Additional conductor heating is just one of the undesirable operational effects often associated with harmonic currents. The FPN following NEC Section 310.10 points out that harmonic current, as well as fundamental current, should be used in determining the heat generated internally in a conductor.

Number of Conductors. On a 4-wire, 3-phase wye circuit where the major portion of the load consists of nonlinear loads, harmonic currents are present in the neutral conductor; the neutral shall therefore be considered a current-carrying conductor. NEC Table 310.15(B)(2)(a) requires an ampacity adjustment to 80% for 4-6 current-carrying conductors in the same conduit.

Ambient Temperature. The definition of the term ampacity states that the maximum current a conductor carries continuously varies with the conditions of use as well as with the temperature rating of the conductor insulation. For example, ambient temperature is a condition of use. A conductor with insulation rated at 60°C, installed near a furnace where the ambient temperature is continuously maintained at 60°C, has no current-carrying capacity. Any current flowing through the conductor will raise its temperature above the 60°C insulation rating. Therefore, the ampacity of this conductor, regardless of its size, is zero.

The ampacity correction factors for temperature at the bottom of NEC Table 310.16 through Table 310.20, are almost never taken into consideration when sizing conductors. Conductors installed in locations with a temperature exceeding 30°C (86°F) must be derated. For example, 90°C conductors installed in a location with an ambient temperature of 46-50°C (114-122°F) requires an ampacity adjustment to 82%. The temperature in this example may appear excessive at first glance; however, consider the routing of the conductors from their origin to their destination. What is the temperature at the ceiling in the boiler room, the roof, the exterior of the southwest facing wall, or other locations that the conductors traverse?

Circuit Length. The resistance or impedance of conductors may cause a substantial difference between voltage at service equipment and voltage at the point-of-utilization equipment. Excessive voltage drop impairs the starting and the operation of electrical equipment. To compensate for voltage drop in a long circuit, larger conductors with a higher ampacity are required. There is no NEC requirement to consider voltage drop; however, it is prudent engineering practice to do so.

Improper Transformer Application. General-purpose transformers continue to be the choice of electrical contractors due to cheapest initial cost and ignorance. These transformers are extremely inefficient, typically undersized, and frequently misapplied.

Efficiency. Even high quality general purpose transformers are highly inefficient. Be aware that the published efficiencies for these transformers is based on testing with purely linear loads. It is easy to justify replacing existing general purpose transformers with energy-efficient, harmonics canceling transformers on the basis of energy cost savings alone. The decision to select the newer technology transformers in lieu of general purpose transformers for new construction is a no-brainer.

Capacity. General-purpose transformers supplying non-linear loads require derating to a range of 50-70% to compensate for harmonic currents produced by the nonlinear loads of today. The most common effect for failing to derate general-purpose transformers is the burning-open of the neutral path, with the result that the line-neutral connected loads are left connected to a floating neutral. This condition easily results in current unbalance conditions with the result that the victim loads are forced to carry excess line current. They also experience excessive voltage being applied to their input power terminals. Therefore, damage to the involved loads is almost certain and can be extremely costly.

Improper Application. Another common form of transformer misapplication is the installation of step-down transformers to step-up voltage. There is a frequent requirement to power a 480V imaging system at a hospital having a 208Y/120V electrical distribution system. It is common practice, due to ready availability, to install a delta-wye transformer manufactured with a 480V primary and 208Y/120V secondary. The transformer is wired in reverse. This practice will work ONLY when there is no requirement for a neutral to be supplied to the load. However, it is a common occurrence to find that the neutral is being used and the imaging equipment is experiencing short MTBF. It is therefore prudent practice to ALWAYS install a transformer that is manufactured with the primary matching the electrical distribution system and the secondary matching the load power requirement.

Grounding. Improper and inadequate grounding of imaging equipment is commonplace. This is particularly true for units housed in mobile trailers, which will be the focus for this section of this paper.

Grounding Electrode. The provider of this mobile imaging equipment typically has a specific power and grounding requirement; however, the grounding electrode requirement is usually limited to the installation of a single ground rod. There is frequently no description of the ground rod, grounding conductor, or maximum grounding resistance.

NEC 250.54 Supplementary Grounding Electrodes. Supplementary grounding electrodes shall be permitted to be connected to the equipment grounding conductors specified in 250.118 and shall not be required to comply with the electrode bonding requirements of 250.50 or 250.53(C) or the resistance requirements of 250.56.

Manufacturers' Requirements. Even if there were an NEC requirement that the supplementary ground rod meet the resistance requirements of 250.26, it would not be sufficient to comply with electronics and/or imaging equipment manufacturers requirements, which typically fall in the 2-5 ohms range. The requirement to install a single 8-foot ground rod is woefully inadequate because it will typically yield a ground resistance of between 40 and 200 ohms in this region, depending on soil resistivity.

Transient-Voltage Surge Suppression. Transient-voltage surge suppression equipment has long been a primary component in overall power quality solutions. It continues to amaze me when I find facilities housing expensive, mission critical systems void of TVSS protection.

Multiple-Level Protection. Prudent transient-voltage surge suppression application involves installation of TVSS equipment at three exposure levels of the electrical distribution system. These exposure levels as defined by IEEE are relative to external catastrophic surges/transients (i.e., lightning, storms, utility faults, etc.) and are referred to as:

> Category A, for low exposure areas such as branch circuit panelboards and specialty equipment located at the load-end of the electrical distribution system.
> Category B, for medium exposure areas such as distribution panelboards, elevators, uninterruptible power systems, motor control centers, and electronic controls.
> Category C, for high exposure areas such as main service equipment, roof-top air conditioning units, mobile electronics systems,

Manufacturers and Technology. There must be a hundred or more manufacturers of surge protection devices or transient-voltage surge suppressors. There are several technologies and components used in the manufacture of these devices. As with any product, the customer/client is advised to stick with an established manufacturer and a trusted supplier with experience in the field. The best TVSS product is only as good as its application and installation. And, the best applications engineer cannot provide a workable solution using low-end products. Try to avoid being "penny-wise and pound foolish" and consider return-on-investment over the entire life-cycle of the transient-voltage surge suppression equipment when evaluating solutions for protecting buildings and equipment.

Case Study. Hospital Supplied Power for Mobile Imaging Equipment. The power and mobile grounding requirements referred to herein are taken from a Calumet Coach Company document, Revision 02, dated June 2000 and provided to a client by ***dms Imaging*** in June, 2002. The findings listed below are limited to identified deficiencies or items in non-compliance with the Calumet requirements.

I have detailed data for frequency, voltage, surges, current, harmonics, etc., for this circuit that was recorded with a fully-configured Reliable Power Meter, model 1650, during a complete usage cycle of several hours, after corrective actions were taken. However, I have chosen not to include said data because I have not had the opportunity to request approval from my client.

Requirement	Finding	Comment
Configuration, pg.6: Three phase wye connection, with neutral and ground.	Conductors: Three phase, no neutral, one ground.	The supply transformer neutral was grounded, thereby introducing current on the ground. Worse yet, the delta-wye supply transformer had a 480V primary and 208Y/120V secondary and was reverse wired to produce 480V from a 208V source. A new 480Y/277V service has been installed at this hospital to power all imaging equipment, thereby eliminating the need for replacement of the misapplied step-down transformer with a step-up transformer.
Voltage Surges, pg.6: Transient voltage variations caused by external loads must not exceed +5%, exceed 5 cycles duration, occur more than 10/hour.	No transient-voltage surge suppressors were installed at any location.	The hospital will soon install Total Power Solutions by Joslyn TVSS units at various locations, including a SurgeTrack 300kA TVSS with component level fusing that allows for direct bus connection at the 480Y/277V main distribution panelboard supplying the imaging equipment.
Ground Conductor, pg.7: The customer shall provide an additional grounding rod at the trailer pad.	No grounding rod was provided at the trailer pad.	The standard ground rod, when installed will be either 5/8 or 3/4 in. x 8 feet. We initially installed a 3/4 in. x 30 ft. Copper Clad steel rod that measured in excess of 100 ohms for ground resistance.
Grounding, pg.8: The connection at the power source shall be at the grounding point of the "N-G" if a "WYE" transformer is being use.	A WYE transformer was being used; however, it was being used with primary & secondary reversed. The transformer neutral was grounded; however, no neutral conductor was run.	Not only was the wrong transformer being used, the entire facility did not have the neutral grounded at the main service entrance. This has since been corrected by installation of an extensive building grounding electrode system and properly grounding electrical distribution system equipment to it.
Ground Wire, pg.8: The ground wire impedance, including ground rod, shall not have an impedance greater than 2 ohms to earth.	No grounding rod was provided at the trailer pad.	The standard ground rod will be only 8 ft. long. We initially installed a 3/4 in. x 30 ft. Copper Clad steel ground rod that measured >100 ohms. We then constructed a counterpoise system that incorporated the trailer pad ground rod, and tied it to the extensive building grounding electrode system, to meet this requirement.
Figure 3, pg.13	100A safety-switch installed, which appears to meet the requirement of this drawing.	100A safety-switch cabinet is not large enough to house the required conductor sizes; therefore, a 200A fusible-safety switch was installed with LPS-RK110SP fuses. These fuses are class RK1 and are rated at 50% more kAIC than the RK5 fuses shown on the drawing.

Requirement	Finding	Comment
Wiring Chart & Diagram, pg.14: 3-phase, wye connection, 100A. Total: 3 phase, neutral, & ground	No neutral conductor installed. Neutral-ground bonding at supply transformer X_0 caused neutral current to flow on the grounding conductor.	Neutral current flowing on the grounding conductor was fed back into the entire building electrical distribution system. Existing conductors were replaced with 3-3/0 PH, 1-2/0 N, & 1-1/0 G, type THWN-2, in the existing 2-inch conduit. Increase in conductor sizes required for load characteristics, ambient temperature, and circuit length.
Wiring Diagram, pg.14: 3-phase, wye connection, 100A. Total: 3 phase, neutral, & ground	Not Applicable	Receptacle diagram has 480V colors swapped between Phases "A" and "C". The Calumet drawing should be revised to annotate Phase "A" as BROWN (480V) and Phase "C" as YELLOW (480V) to match standard wiring practice.

Conclusion. Hospital imaging equipment has very specific power and grounding requirements that are not being provided in many cases. My experience leads me to believe that this is true at most locations. It doesn't matter how detailed the requirements are, they are no good without compliance. I find Code violations on every project that I survey.

It is extremely rare to find an electrician who has ever seen the more stringent IEEE standards like 1100-1999, Powering and Grounding Electronic Equipment. What good does it do to specify that "the ground wire impedance from our system disconnect, including the ground rod, shall not have an impedance greater than 2 ohms to earth as measured by one of the applicable techniques described in Section 4 of ANSI IEEE Standard 142-1982" unless someone with the necessary equipment and knowledge actually measures it?

Given the substantial investment that ***dms Imaging*** has in these mobile imaging equipment trailers, I would recommend that they not only install high quality Powersmiths transformers and Total Protection Solutions TVSS units in them, but that they give due consideration to implementing a QA/QC program to insure that the power and grounding sources for their equipment is the best that it can be at each and every site. I would expect the payback timeframe for the cost of inspecting and correcting power and grounding problems at each location to be awfully short for this high-dollar equipment, especially if ***dms Imaging*** has some type of contractual performance agreement with the respective hospitals.

I wish you great success in your upcoming meeting. Don't hesitate to contact me if I can be of further assistance.

Glen Coffman