Case #19 - Poor Wiring and Grounding Practices Cause Hospital Computed Tomography (CT) Scanner to Malfunction

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Excessive restart time
Excessive setup
Fac.-gen. pwr disturbances
General hospitals
IEC 601-1-02
IEEE Standard 1100-1992
IEEE Standard 602-1996
in memory
Incorrect diagnostic result
Large stationary equipment
Light emitting diodes (LEDs)
Liquid crystal displays (LCDs)
Loss of data in memory
Lost revenue
Lost time
Med. eq. to bld. eq.
on displays
Process halt
Pwr. up of equip. in diff. State
Radiology
Test disruption
Transient overvoltages
Undervoltage
Utility feed
X-ray

Abstract
This case study describes an equipment-to-equipment incompatibility that occurred in the radiology department of a healthcare facility. Specifically, it discusses poor wiring and grounding practices that led to the malfunction of a computed tomography (CT) scanner. Furthermore, the study demonstrates that if such problems are not controlled, if power-

conditioning equipment is not properly selected, and if sensitive electronic medical equipment is not protected from power-line disturbances and powered by an adequate power source (normal or alternate), medical equipment may be susceptible to malfunction that may render it unavailable, at the very time it is needed. This study includes the description of a power quality analysis conducted in response to this problem and offers recommendations for solutions.

Overview

The following sections present an introduction, description of the problem, and the power quality analysis conducted to eliminate the computer tomography (CT) scanner shutdowns caused by poor wiring and grounding problems.

Introduction

To produce precise reconstructed images of specific areas within the human body, transverse planes of tissue are swept with a pinpoint radiographic beam of energy. Image reconstruction is accomplished by a computerized analysis of the variance in beam absorption. This technology, called computed tomography, has a greater sensitivity in showing the relationship of structures within the body than conventional radiography and is carried out with a computed tomography (CT) scanner. A CT scanner is located in the radiology department of a large hospital. The CT scanner is used to generate real-time digital images that can be used for diagnostic tests of a patient. The anatomical images are digitally enhanced and are stored in computer memory, and may be retrieved at any time for review and consultation. This case study describes an equipment-to-equipment incompatibility involving the operation of a CT scanner.

Description of Problem

End-users of the CT scanner frequently experienced malfunctions of the CT system ranging from computer lockup, to image quality problems, and to problems with retrieving digital images from computer memory. After the CT system was inspected by the imaging equipment manufacturer--who found no apparent problems--the hospital decided to call on the services of the electric company that installed the CT system. They notified this company, and in turn the electric company contacted an independent testing organization and notified them of the problems the hospital was having with the CT system. Both organizations began working towards identifying causes of the problems. Some power-line disturbances were captured by power-line monitoring conducted by an independent testing organization, but no action was taken by the organization or the hospital to solve the problem and the malfunctions continued for as a long as three years. The local utility was called in to investigate the causes of the CT system malfunctions, which significantly decreased once the problems were identified and solved.

Power Quality Analysis and Solutions

The following sections present the analysis performed and recommendations for solutions.

Results of the Power-Line Monitoring Conducted by the Independent Testing Organization

During about a 30-day period, the independent testing organization performed a power quality survey on the CT scanning system. A power-line monitor was connected to the electrical panel providing power to the CT scanner. A three-phase survey was conducted while the neutral-to-ground voltages were also monitored.

The power-line monitor was programmed for the following:

· to capture any steady-state root-mean-squared (RMS) voltage fluctuations between 110 and 125 volts;

· to capture any voltage transients exceeding 50 volts above the maxima of the 60-hertz line voltage; and,

· to capture any neutral-to-ground voltage transients exceeding 5 volts.

During the monitoring period, excursions from the acceptable steady-state voltage range occurred. These events occurred at approximately 8 p.m. on the 17th day of the monitoring period and were voltage sags that occurred on the line input to the CT scanner.

The following data was captured by the power-line monitor during the event:

Time	Phase	Voltage Magnitude	Duration
8 pm	A	108 volts	30 milliseconds
8 pm	B	79 volts	50 milliseconds
8 pm	C	97 volts	70 milliseconds

· The following voltage transients were recorded on the same day.

Time	Phase	Voltage Magnitude	Duration
7 am	A	98 volts	5 microseconds
8:30 pm	B	95 volts	98 microseconds

No voltage transients exceeding the performance ratings as specified by the manufacturer were recorded. No voltage transients on the neutral-to-ground conductors were recorded. No shutdowns or malfunctions occurred during the monitoring period when the events were recorded. Because no CT scanner problems were documented during the power-line monitoring period, no action was recommended by the testing organization other than the possibility of installing an electronic voltage-regulating transformer to mitigate the steady-state fluctuations in the line voltage. The testing organization recommended the use of such a power-conditioning device to mitigate the voltage transients that were recorded. The testing organization further recommended that mitigation may improve if a line filter were installed. Based on these recommendations, the hospital elected to reassess the problem and their options.

The Electrical Performance Characteristics of the CT Scanner
The manufacturer of the CT scanner provided the testing organization with the following electrical requirements for the CT scanning system:

· In steady-state operation, the system requires a 208-volt, three-phase service whose voltage shall be within the limits of +10% (228.8) to -5% (197.6).
· For voltage transient limits, the following limits are required:
- 2 x peak line-to-line voltage (i.e., 508 volts*) for up to 0.5 microseconds,
- 1 x peak line-to-line voltage (i.e., 294 volts*) for 0.5 to 400 microseconds, and
- 0.5 x peak line-to-line voltage (i.e., 147 volts*) for 400 to 800 microseconds.
*These voltage transients are referenced to the maximum of the 60-hertz line voltage.

No specifications for voltage sags (ride-through performance), voltage swells, outages, or voltage distortion were given.

The CT manufacturer said the CT scanner should operate satisfactorily with up to six voltage transients (no magnitudes or durations specified) per hour, but that any number of severe voltage transients over a long period of time would degrade the insulation of the electronic components within the CT system.

A Power Quality Site Survey Performed by the Local Utility
After the independent testing organization conducted their investigation, the hospital contacted their local utility power-quality-engineering group to identify the cause of the power-line disturbances that were recorded. At this time, the malfunctions had been occurring for three years, ever since the CT scanning equipment had been installed. The CT scanning equipment manufacturer maintained that the equipment malfunctions were due to low voltage conditions caused by the utility.

The local utility conducted a power quality site survey of the wiring and grounding at the main switchboard that provided power to a local distribution panel which in turn provided power to the CT scanner system. The local distribution panel, the CT scanner, its peripherals, and the hospital's emergency generator were also inspected for wiring and grounding problems. Two-power line monitors were installed to monitor and record the voltage at the main switchboard for a 22-day period and at the CT scanner's equipment terminals for a 15-day period.

Results of the Utility Power Quality Site Survey and Monitoring
The results of the utility-supported power quality site survey and power-line monitoring period are summarized below:

· The wiring and grounding survey revealed a variety of improper, incomplete, and poorly made connections at the local distribution panel in the CT scanning area and at the hospital's emergency generator. These inadequacies were verified and documented by a local inspection agency in a letter to the hospital's director of engineering.

· The power-line monitor at the local distribution panel in the CT scanning area was connected to measure three phase-to-ground voltages. However the ground connection to the CT scanner was found to be disconnected, rendering all of the power-line data meaningless.

· The power-line monitor at the main switchboard revealed that the voltage at this location was extremely stable and within tolerances throughout the monitoring period. There were no outages, momentary interruptions, over- or undervoltage conditions or voltage transient activities at any time during the monitoring period at this location.

· It was determined that the CT scanner was disconnected from its power source by hospital personnel when the CT scanning system was not in use.

It was recommended that an electrician from an electric company not involved with the installation of the CT scanner correct the wiring and grounding problems.

Conclusions

The incomplete and improper wiring and grounding practices employed in the electrical installation of the CT scanner and its power supply proved to be the source of the malfunctions over the three-year period. The number and frequency of malfunctions decreased significantly once the wiring and grounding errors were corrected.

Applicable Codes, Recommended Practices, References and Standards

The following references apply to applying proper wiring and grounding within healthcare facilities:

· IEEE Recommended Practice on Surge Voltages in Low Voltage AC Power Circuits, IEEE Standard C62.41-1991.

· International Electrotechnical Commission. Medical electrical equipment, International Standard IEC 601-2-31, Second Edition. Geneva, Switzerland: International Electrotechnical Commission, 1996. See Section 36.202.3: Electrical Fast Transients and Bursts and Section 36.202.4: Surges. This draft standard includes references to the other IEC 1000-x-x standards as applicable. This overall standard is presently being reviewed by medical equipment manufacturers in the United States for adoption by ANSI and AAMI (Association for the Advancement of Medical Instrumentation).

· IEEE Recommended Practice for Electric Systems in Health Care Facilities, ANSI/IEEE Std 602-1996. See Chapter 3, Electrical Power Distribution Systems, Section 3.4.3: Voltage Variation and Disturbances; Section 3.4.4: Voltage Problem Diagnosis; Section 3.4.5: High Transient Loads; Section 3.6: Grounding. Chapter 9, Medical Equipment and Instrumentation, Section 9.2.1: Pre-purchase Evaluation Form; Section 9.3.1.10: AC Power and Grounding; Section 9.3.5: Radiology Equipment; Chapter 10, Health Care Renovations, and Section 10.4: Updating Power Distribution Systems.

· IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment, ANSI/IEEE Std 1100-1992. See Chapter 4, Fundamentals, Section 4.5: Voltage Surges; Section 4.7: Shielding Concepts; Chapter 5, Instrumentation, Section 5.2: Wiring and Grounding Measurement Instruments; Chapter 8, Specification and Selection of Equipment and Materials, Section 8.2.4: Surge Suppressors; Section 8.2.9: Uninterruptible Power Supplies; Chapter 9, Recommended Design/Installation Practices, Section 9.3.1: Typical Forms of Unwanted Interaction on Shared Circuits; Section 9.3.2: Dedicated Load Circuits; Section 9.10: General Grounding; Section 9.11.2: Premise Electrical System Lightning/Surge Protection.