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PQTN SOLUTION

Power Quality Testing Network

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Supply Voltage Variations
Sensitive Equipment
System Compatibility

Solving Power Quality Problems in Medical Imaging Systems

Background

A power-line transient disrupts the operation of an infant incubator—the display locks up and the temperature goes out of control, endangering the newborn. During open heart surgery, a voltage fluctuation resets a microprocessor that regulates complex blood-pumping and blood-filtering machinery, corrupting vital data and disrupting the steady flow of life-giving blood to the patient. A voltage sag disrupts an imaging system being used on a patient undergoing heart catheterization—the procedure cannot continue and the catheter cannot be withdrawn until the imaging system is restored.

Although most power quality problems in medical facilities are simply annoying, some, like the examples above, can be life-threatening. Between 1979 and 1993, the U.S. Food and Drug Administration (FDA), Center for Devices and Radiological Health, received reports of more than 100 cases of electromagnetic interference problems with electronic medical devices, some of which were related to power quality. The results of a 1985 survey by the American Association of Medical Systems and Informatics point out poor ac power-line quality as a common cause of problems associated with computerized medical devices. In a 1989 investigation of more than 100 medical facilities throughout the United States, General Electric Medical Systems indicated that many medical systems were intolerant of sags and surges in the typical electrical environment. Moreover, an estimated 80 to 90 percent of electronic medical devices in service in this country do not meet voluntary electromagnetic compatibility standards. Compatibility between electronic medical devices and their intended electrical environments therefore receives a great deal of warranted attention from the healthcare industry, electric utilities, medical equipment manufacturers, and standards organizations, who have increased efforts to catalog cases of incompatibility (see Symptoms, Causes, and Sol-utions table, attached).

Besides crucial, life-sustaining medical devices such as infant incubators, ventilators, and patient monitors, some of the most sensitive devices in a modern medical facility are electronics-based medical imaging equipment, such as ultrasound, magnetic resonance imaging (MRI), and computed tomography (CT) scanners. These microprocessor-controlled imaging devices help healthcare specialists "look" inside the human body and make a diagnosis. In an ever-growing struggle to balance budgets, hospitals depend heavily upon the reliability of these diagnostic machines. Other diagnostic equipment may go unfixed, but the indispensable CT scanner must always be ready for service.

Photo courtesy of Siemens

Figure 1. Computed Tomography Scanner

CT Systems

Computed tomography scanners, such as the one shown in Figure 1, use X-ray tubes similar to standard X-ray systems. However, the CT scanner employs an X-ray tube that rotates around the patient, who must lie very still for up to half an hour, often in uncomfortable positions and frequently after fasting or strenuous exercise. The scanner is controlled by a microcomputer that also records and processes the information from the rotating X-ray tube. It can thus provide high-resolution images unattainable through conventional X-ray imaging. However, its on-board microcomputer and the precision requirements of the entire system make the CT scanner much more susceptible to voltage sags and surges than conventional X-ray machines.

Like that in the conventional X-ray machine, the X-ray tube of a CT scanner switches on and off repeatedly. However, as shown in Figure 2, the rotating X-ray tube in the CT scanner draws current in pulses lasting about two seconds, whereas the current pulses of a conventional X-ray tube last only about four cycles (70 milliseconds). The longer, two-second pulse of the CT scanner's X-ray tube makes its imaging process more vulnerable to power disturbances. For example, a voltage sag occurring during one of these pulses can cause such severe degradation of the X-ray image that it cannot be used for diagnostic purposes, even if the microcomputer processing the image is not interrupted. Or, if the supply voltage sags below the scanner's undervoltage protection limits, the scanner may reset in the middle of a procedure, losing all the images stored in its memory.

Interruption of a CT scan has obvious financial consequences. For instance, the high voltage from inductive discharges during repeated sags can cause the CT scanner's expensive X-ray tube to fail prematurely. A new X-ray tube can cost anywhere from 35 to 60 thousand dollars, depending on its physical size and power rating. And because CT scan procedures are costly, it is not surprising that insurance companies and individual patients refuse to pay for interrupted CT scans that must be repeated. Perhaps the greatest cost of interrupted medical procedures is measured not in dollars but in degrees of the patient's physical and mental discomfort, as well as the patient's safety. A repeated CT scan means another

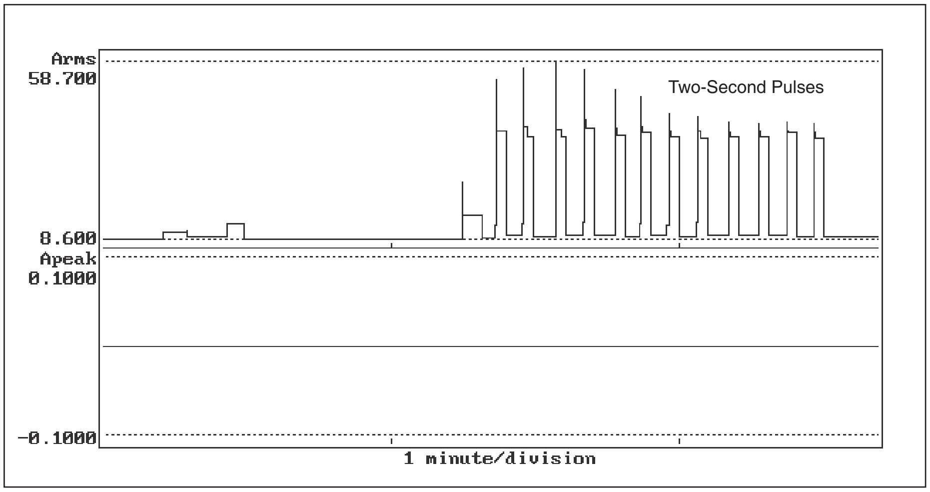
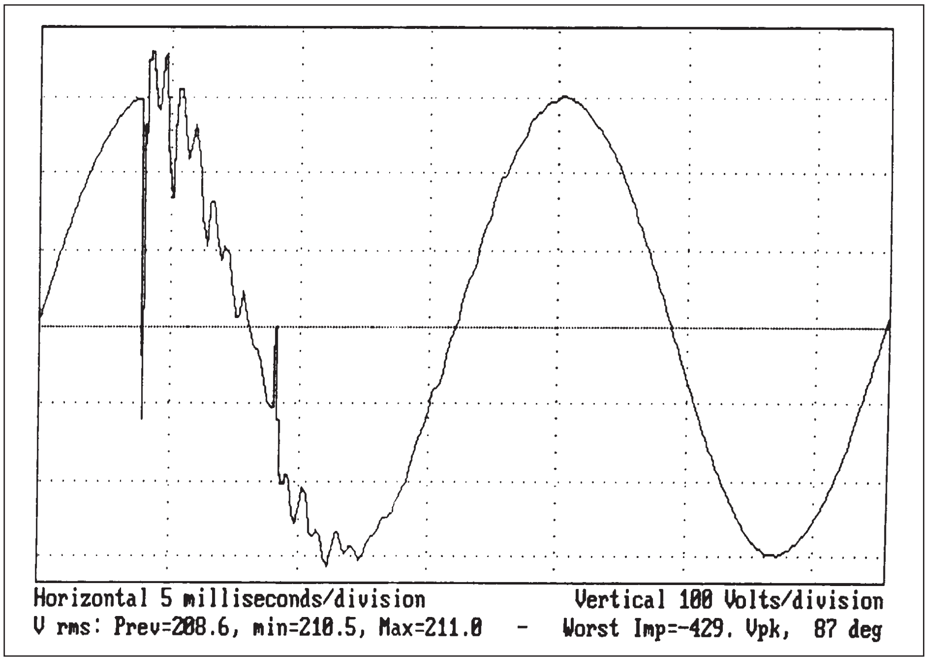


Figure 2. RMS Current of a Typical CT Scanner During a Scan

dose of X-rays for the patient, and, according to the U.S. FDA, this increased radiological exposure to the patient is a potential health concern.

Two Problems

At times, as often as twice a day, a CT scanner in a Kansas hospital would shut down before a series of scans could be completed. The recorded X-ray images of the patient's body, accumulated by the microcomputer up to the point of shutdown, would be lost, along with the time of the medical technician, hours of X-ray tube life, and the good will of the patient, destined by mischance to repeat the procedure. Initially, the hospital contacted the CT scanner manufacturer for help. The manu-facturer's field engineer performed an exhaustive inspection of the device, but found nothing wrong. Suspecting the quality of the power feeding the scanner, the engineer recommended that the hospital install a 75-kVA uninterruptible power supply (UPS) at the input of the scanner. The UPS would provide continuous power to the scanner during any significant voltage sag or brief power interruption. However, a 75-kVA UPS would be a significant expense to the hospital, nearly $40,000.



Courtesy of Dranetz Technologies, Inc.

Figure 3. Ringing Transient Recorded at the Nevada CT Scanner

In another medical clinic in Nevada, a CT scanner was experiencing repeated computer lockups and component failures. The power was brought to the CT scanner by a 480-volt service feeding a 480-to-208-volt isolation transformer. Using a power monitor, the medical equipment service company identified the cause of the failures: a voltage transient, shown in Figure 3, produced by the local utility switching on a power-factor-correction capacitor bank, located only a block away. The hospital's isolation transformer had little effect upon the ringing transient.

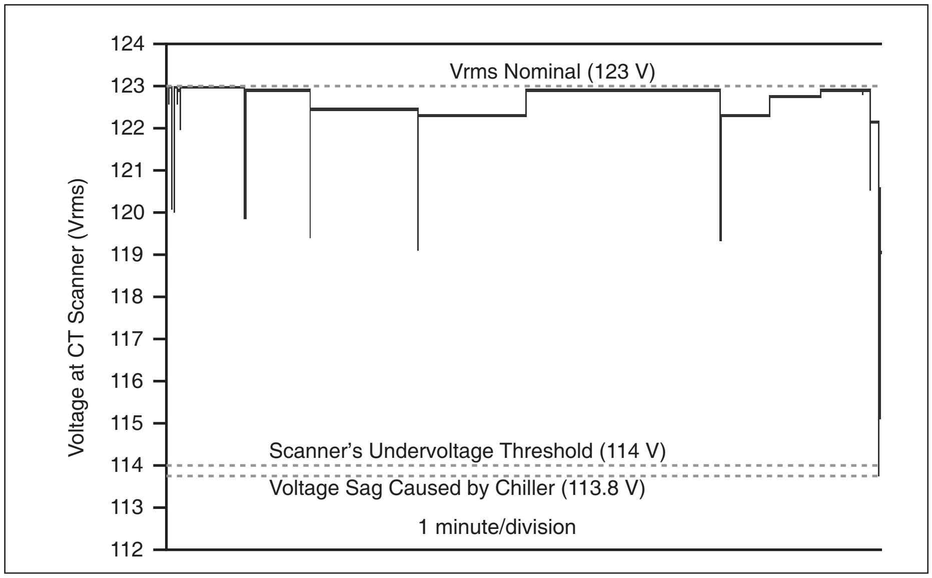


Figure 4. RMS Voltage Recorded at the Kansas CT Scanner

Two Solutions

In the Kansas case, the hospital asked Western Resources, the local electric utility, to help determine if utility-supplied power was at fault. William Winnerling, the utility's field engineer, monitored the voltage at the hospital service entrance. Although the utility-supplied voltage was consistently within specified tolerances, voltage sags were occurring more often than Winnerling had expected. Such sags, lasting less than a second, are often the results of clearing short circuits on distribution lines.

A visual inspection of the power lines serving the hospital revealed tree branches brushing against the lines during windy weather. These overhanging tree branches were causing temporary short circuits to ground, which in turn were causing momentary power interruptions that were believed to shut down the CT scanner. The utility trim-med the trees around the power lines serving the hospital, which greatly re-duced the number of voltage sags. However, reducing the sags only slightly reduced the frequency of CT scanner shutdowns.

By this time, the director of maintenance for the Kansas hospital had pinpointed another possible cause for the scanner failures: The scanner shutdowns most often occurred when the chiller in the hospital's air conditioning system started. The maintenance director solved the problem by manually starting the chiller only when the CT scanner was not in use. However, this solution was less than ideal—manually starting the chiller overrode the hospital's energy-management system, significantly increasing the facility's energy costs.

Again, the hospital contacted Western Resources, who called in Ward Jewell, electrical engineer and Associate Professor at Wichita State University. Jewell monitored the voltage at the CT scanner to confirm that the voltage sags corresponded to the starting of the chiller. Figure 4 shows the RMS voltage at the CT scanner. Most of the voltage sags were caused by the normal operation of the CT scanner. These sags dipped to no less than 119 volts. However, the sag caused by the chiller-starting dipped to 113.8 volts. Jewell determined that the scanner's undervoltage trip threshold was set too high (at 114 volts) by the installer, who misunderstood the manufacturer's instructions. After the manufacturer's field technician reset the threshold to 108 volts, the scanner was able to oper-

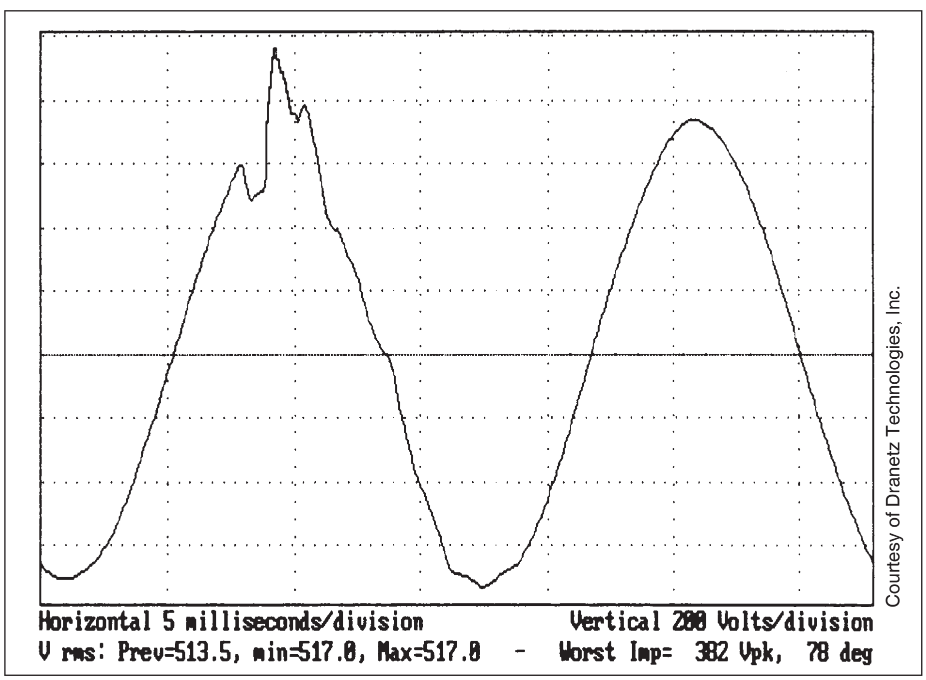


Figure 5. Attenuated Transient Recorded at the Nevada CT Scanner

ate while the hospital chiller started.

In the Nevada case, where capacitor switching caused a CT scanner to lock up, the medical equipment company recommended the use of an "active-tracking filter" (a low-pass filter with surge suppressors), which was specifically designed to attenuate the ringing transient of about 1 kHz caused by energizing the capacitor bank. The filter, installed on the 480-volt line to protect all downstream equipment, significantly attenuated the transient and eliminated the scanner lock-ups and component failures. Figure 5, on page 3, shows the attenuated transient at the CT scanner.

Significance

The case of the Kansas CT scanner illustrates the potential complexity of hospital power quality problems. Although the final solution was simple, arriving at the solution was a complex procedure. It involved diagnosing and solving a number of concurrent power quality problems, the causes of which originated both outside and inside the medical facility. In the end, the simple remedy—adjusting the undervoltage threshold of the CT scanner—illustrates the importance of installing sophisticated medical devices according to manufacturer specifications. Although the problem with the Nevada CT scanner began outside the facility, troubleshooting soon led investigators inside to discover a promoting factor—an ineffective isolation transformer. In both of the cases reported in this PQTN Solution, the problem was identified and solved with a team effort—a utility, its healthcare customer, and the manufacturer of the medical equipment. In the absence of universal standards for medical equipment performance, cooperation is the key to solving power quality problems in medical facilities. However, preventing such problems will require an even greater union of efforts, including participation with standards organizations, power quality researchers, medical equipment designers, and manufacturers of power-conditioning equipment.

ACKNOWLEDGMENTS

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NOTES

Symptoms Causes & Solutions

A hospital in Arizona was spending up to $80,000 annually on each piece of X-ray equipment for maintenance and parts.	The energy used by the X-ray tubes was dissipating through the electronic components of the imaging devices, causing premature tube failure and component damage. A local power quality firm installed filters and tuned them to damp the harmful energy.
In Idaho, an MRI system in a van outside the hospital was experiencing image quality problems, software lockups, and component failures.	A silicon-controlled rectifier device in the hospital was causing electrical disturbances in the power line connected to the van, which disrupted the MRI system. Equipping the van with a low-pass filter protected the mobile equipment against the disturbances.
A hospital MRI system experienced software lockups in its controller and poor image quality.	Monitoring the 480-V line-to-line feeder to the MRI system revealed intermittent pairs of impulses. The cause of these impulses was traced to contact bounce from the contactor in the humidifier of the building air-handling system. A UPS was installed to isolate the MRI system.
An MRI system in Virginia was experiencing intermittent software and component failures.	Voltage sags and interruptions during thunderstorms and capacitor-switching transients were causing the failures in the MRI system. Installing a UPS protected the equipment against both.
An MRI system in New Mexico suffered from software lockups and image quality problems.	Impulses from infrared heaters in the building HVAC system and periodic power outages were causing the lockups and poor images. A UPS now protects the MRI system against both.
A CT scanner and digital fluoroscopy system in the vascular room of an Arkansas hospital were experiencing intermittent software lockups.	Transients created by a large industrial utility customer were being propagated through the power system to the Arkansas hospital. Installing a low-pass filter eliminated the transients.
A California vendor refused to repair a hospital's X-ray machine under warranty because of power problems the vendor blamed on hospital power.	Power monitors connected by the vendor at the X-ray machine showed that the power quality problems were originating inside the hospital. The hospital's clinical engineer used the same type of power monitor connected on the line side to show that the X-ray machine was actually causing the power quality problems. The vendor repaired the X-ray machine.
In Georgia, an MRI system was experiencing software and hardware failures.	Capacitor-switching transients damped by a ferro-resonant transformer on the input of the MRI system were causing voltage sags at the transformer secondary. Removing the transformer solved the initial problems, but intermittent lockups then began to occur from transients on the power line. Connecting the MRI system to a UPS protected it from the transients and the voltage sags.

Symptoms Causes & Solutions

An MRI machine was having intermittent errors. EMF levels of 4–6 milligauss every 36 seconds were recorded in the area of the machine.	The EMF could have been originating from a number of sources: cycling loads, such as a motors starting, poor building wiring coupling current into the building steel, and subway trains and trash trucks causing fluctuations in the dc magnetic field of the MRI machine. A solution is to move the machine.
The computer controlling a medical clinic's CT scanner periodically locked up.	Excess harmonic current was distorting the voltage to the CT scanner. Adding a harmonic filter to the CT equipment stopped the lockups.
A hospital facility in Kentucky experienced repeated errors in the control section of a CT scanner several months after its installation. The errors increased throughout the summer months.	Variable-speed drives for the hospital HVAC system were creating impulsive transients on the line powering the CT scanner. An inadequate earth ground was promoting the transients. The problem became worse in summer because the soil around the facility grounding system had dried. New ground rods and improved bonding of the grounding system eliminated the transients.

Note: The items in this table are typical responses of end users to symptoms of system incompatibility. The solutions in these cases were not verified to be either the most economical or the most effective of all potential solutions.

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