0104DB0801
10/2008
Palatine, IL USA

Technical White Paper

Important Aspects of a Healthcare Metering System

Electrical Distribution and Metering in a Healthcare Facility
by Jonathan Clough and Jason Rose

Today's typical healthcare facility electrical system is comprised of a complex network of generators, main-tie-main switchgear, automatic transfer switches, automation equipment, building controls, automatic lighting, motor control centers and cable systems. This network serves power to the growing trend of complex systems such as computer servers (now mini-data centers), magnetic resonance imaging (MRI) and computerized tomography (CT)scanners, x-ray, ultrasound equipment, security systems, fire alarm systems and more. This equipment is critical for modern healthcare. Patient digital records are linked with physician offices, nurse stations, patient rooms, labs, x-ray for quicker access to critical data.

Power monitoring systems are now necessary to properly manage the electrical system. This paper will review some of the issues common to healthcare facility electrical systems and the benefits power monitoring can provide.

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SQUARE D

by Schneider Electric

Power quality and the healthcare facility

Healthcare computer workstations

A critical aspect of this trend toward computer controlled systems is the need for power quality. The Computer and Business Equipment Manufacturers Association (CBEMA) recognized this years ago and created the well known CBEMA curve showing the voltage requirements for consistent computer operation (Figure 1).

The purpose of the curve was to show the voltage extents that would impact computer reliability and provide the manufacturers with a voltage range within which their power supplies should operate consistently. The curve shows the percentage of applied voltage on the vertical axis and time on the horizontal axis. The area within the horizontal lines is an acceptable range of voltage over time that the power supplies should be able to sustain proper operation. The area outside of the horizontal lines represents unacceptable ranges for operation.

Healthcare computer controlled systems found throughout the facility will operate reliably when the system voltage stays within the designed parameters. As shown in the curve, these systems will be impacted by voltage sags, swells, transients and outages. It is important for the healthcare engineering team to measure and monitor the electrical power as it distributes through the facility. With this data they can analyze and evaluate the disturbances and determine how the "at risk" equipment is being affected.

Because power quality events can occur over a very brief period, it is important that high sample rate monitoring equipment be used to capture the voltage quality. This equipment will provide data that can be analyzed and compared to the manufacturer's specifications.

The ITI curve (Figure 2) was developed by the Information Technology Industry Council, a working group of CBEMA and with EPRI (Electric Power Research Institute). This curve was developed to show typical performance of computers more accurately. The curve is simply a guide and not a guarantee of performance. Each piece of equipment has its specific design parameters.

EPRI went on to determine that the most common power quality event is the sag event. With high sample rate measurement equipment permanently installed, the facility engineer can document the sag event as it propagates throughout the facility. They can then take appropriate steps to protect the equipment from damage and downtime. The sag event can be plotted against the ITIC curve to determine the magnitude of the event. Mitigation techniques such as an uninterruptible power supply (UPS) can be monitored to confirm equipment protection is adequate.

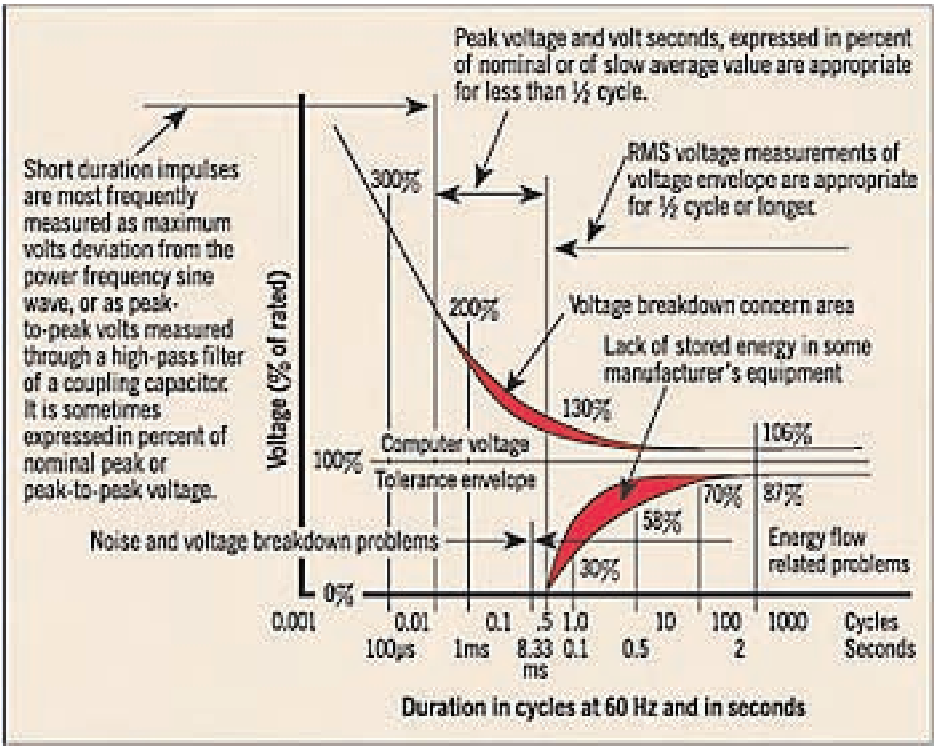
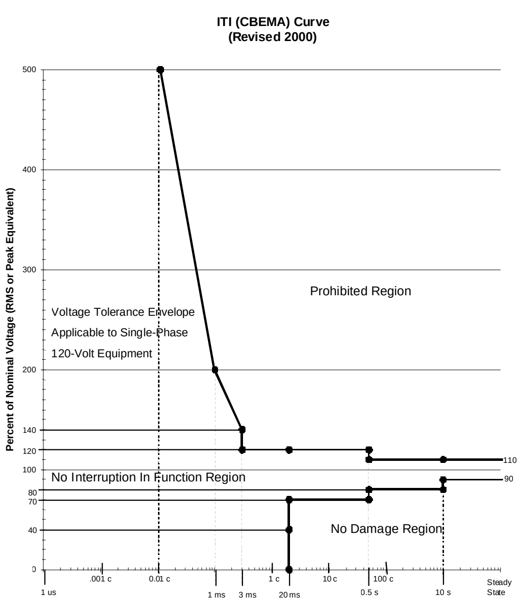


Figure 1. CBEMA curve showing voltage requirements for consistent computer operation.



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Information Technology Industry Council (ITI)
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Figure 2. ITI Curve (Revised 2000) developed by the Information Technology Industry Council. See Appendix for application note.

Sag, swell, phase loss and system transients

The most frequent power quality event to affect a healthcare facility is the voltage sag. These are typically caused by upstream utility fault events. These events last five to ten cycles in length as the utility relaying and recloser schemes isolate the fault and reroute power back to the customers. The magnitude of the sag usually depends on how close the fault is to the customer site. The duration of the sag is a function of how quickly the fault is cleared from the system by the overcurrent protective device.

Figure 3 is an example of sag data taken with in-place metering on an ultrasound unit at Kadlec Medical Center. The sag magnitude and duration are placed as a data point in the insulated-gate bipolar transistor (IGBT) curve. It shows the magnitude of several events exceeded the manufacturer's voltage regulation requirements. A UPS/generator could solve this problem.

IEEE 1159 categorizes voltage events using the following guideline:

Categories	Typical Duration	Types
1 - Transients	Less than One Cycle	Oscillatory, Impulsive
2 - Short Duration Variations	0.5 Cycles to One Minute	Sags, Swells, Interruptions
3 - Long Duration Variations	Over One Minute	Undervoltages, Overvoltages, Sustained Interruptions
4 - Voltage Imbalance	Steady State	
5 - Waveform Distortion	Steady State	Harmonics, Notching
6 - Voltage Fluctuations	Intermittent	
7 - Frequency Variations	Less than 10s	

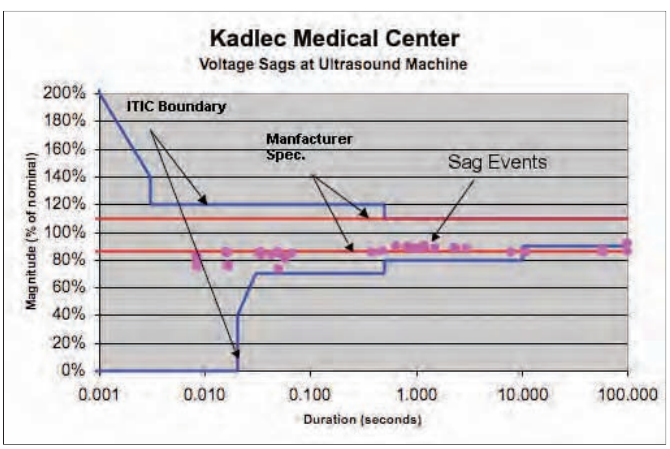

Figure 3. Example of a typical sag waveform.

In Figure 4, the top chart shows the RMS value of each phase over time. The next charts show the actual voltage sine waves during the event. This event was taken at the healthcare service entrance. It shows A phase was severely impacted and that the sag lasted approximately 8 cycles. This would explain why equipment fed from A phase was affected while circuits off of B phase were not. Recent studies on sag events indicate that single phase sags have a more severe impact on variable speed drive insulated-gate bipolar transistor (IGBT) gate firing cards than when all three phases sag simultaneously.

Voltage Sag and Interruption

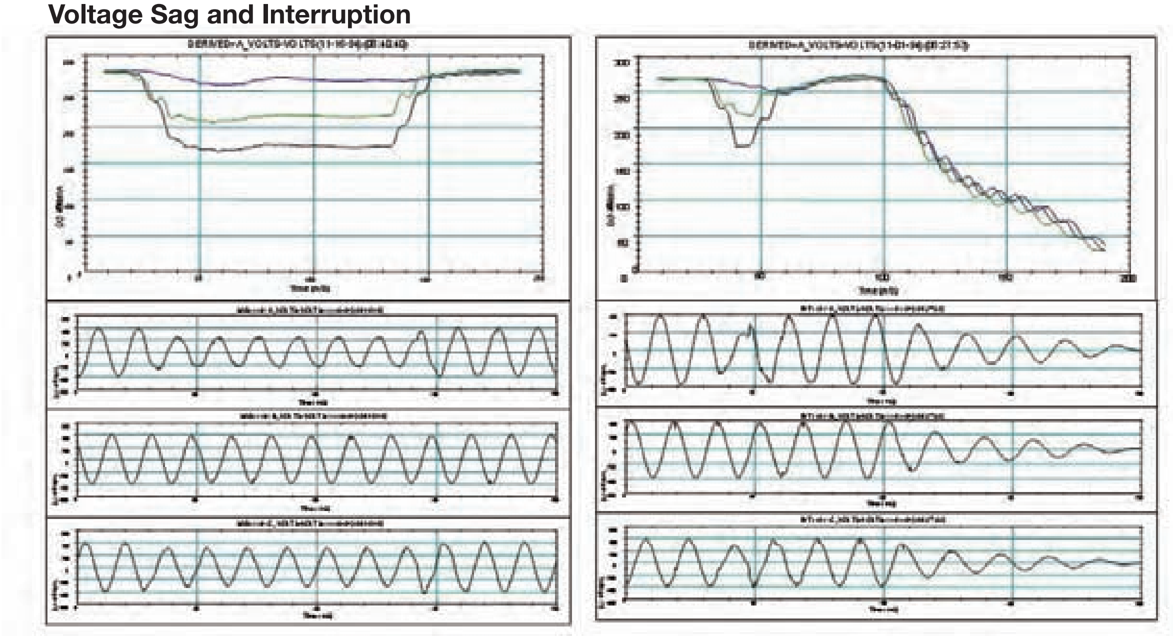

Figure 4. Discussions with the utility service provider are possible with this type of data since it documents the event. It is important to note that high speed sample rates are very important to capture sub-cycle events such as lightning or transients.

Power quality demands of MRI and other equipment

Magnetic resonance imaging (MRI) technology is an important tool as it is a non-invasive method of procedure that can show two dimensional views of organs and tissues, especially spinal cord and brain. These expensive computer based systems have specific power quality limits to ensure reliable operation.

Recently installed MRI

A new MRI (top left) was recently installed at Kadlec Medical Center. Evaluating the quality of power supplied was important for determining if the new system would operate properly. Power monitoring equipment was installed on the proposed circuit and data taken for one month. Voltage minimum and maximum levels were evaluated and checked against manufacturer's recommendations. In this case, the manufacturer recommended:

1. Voltage range +/- 10% at 480V through out operation
2. Voltage balance -2% maximum difference between phases
3. Maximum allowable voltage drop at maximum power 4%

Permanently installed monitoring and protection system

MRI power demands were:

1. Highest Average Power – 37 KW
2. Maximum Power – 85KVA (less than 5 minutes)
3. Momentary Power – 100KVA (less than 5 seconds)

With the use of portable metering, the system parameters were evaluated to the manufacturer's specification. The system has a permanently installed power meter (bottom left) in place to continuously evaluate power quality to verify it remains within the manufacturer's recommended parameters. The meter will also shunt trip the breaker supplying power to the MRI unit should there be an excursion outside the prescribed parameters. The meter is connected to the hopsital's Ethernet network so data will be captured, logged and analyzed.

This is an excellent example of how modern power system metering can non-invasive hospital equipment. Similar approaches can be used for computed tomography (CT) scanners and other hospital equipment.

Power quality demands of healthcare data center

With the advances of the computer in all aspects of the business, healthcare facilities now have the requirements of today's data center. Good power quality is critical to the health and uptime of the data center. Power quality is a broad topic but can be simply defined as power that can damage or disrupt sensitive electronic devices such as sags, surges and harmonics.

Data center

Healthcare relies heavily on data centers (left) for patient record storage and management software to increase operation efficiency and provide accurate patient care. In healthcare data centers unplanned disruptions are undesirable and can result in equipment failure and costly down time which can impact patient care. Most established healthcare data centers may have been or are currently victims of poor power quality issues.

Power quality issues in a data center can be complicated and difficult to resolve. Early identification, intervention or prevention of poor power quality is critical to avoiding equipment damage and or loss of data. Power monitoring systems with alarming can quickly indicate there is a problem and the facility maintenance team can take quick action. This minimizes data loss and the cost of equipment repair.

Prolonged exposure to poor power quality can also shorten estimated equipment life resulting in premature expense for replacement or repair. Why is this important? The early detection and intervention of poor power quality can help ensure equipment up-time and preserve a healthcare facility's critical database.

"An electrical utility research group estimates that mission –critical losses attributed to power outages are close to $13.5 billion, with a full 50 percent of that are attributed to power quality issues," according to article "Avoiding Power Quality Headaches in Data Centers" by K.L. Godrich published in November 2004 issue of Building Operating Management. Although this statement does not accurately reflect healthcare systems, you can see the magnitude of the financial burdens that can be attributed to power quality.

System protection

An important aspect of a reliable electrical healthcare power system is overcurrent protective device selective coordination. Overcurrent coordination is the application of current actuated devices in the power system that responds to a fault or overload and removes only the minimum amount of equipment from service. The objective of overcurrent coordination is not only to minimize the equipment damage and costs associated with power loss but also to protect personnel from the effects of these failures. Metering can be installed in such a manner to capture current flow through out the healthcare system. The current flow data can be analyzed to compare it to device trip values and check for proper operation.

The following graph of a utility service shows the inrush current that occurred when a large transformer was energized. (Figure 5). This type of data can be very helpful in determining proper relay settings for service entrance equipment.

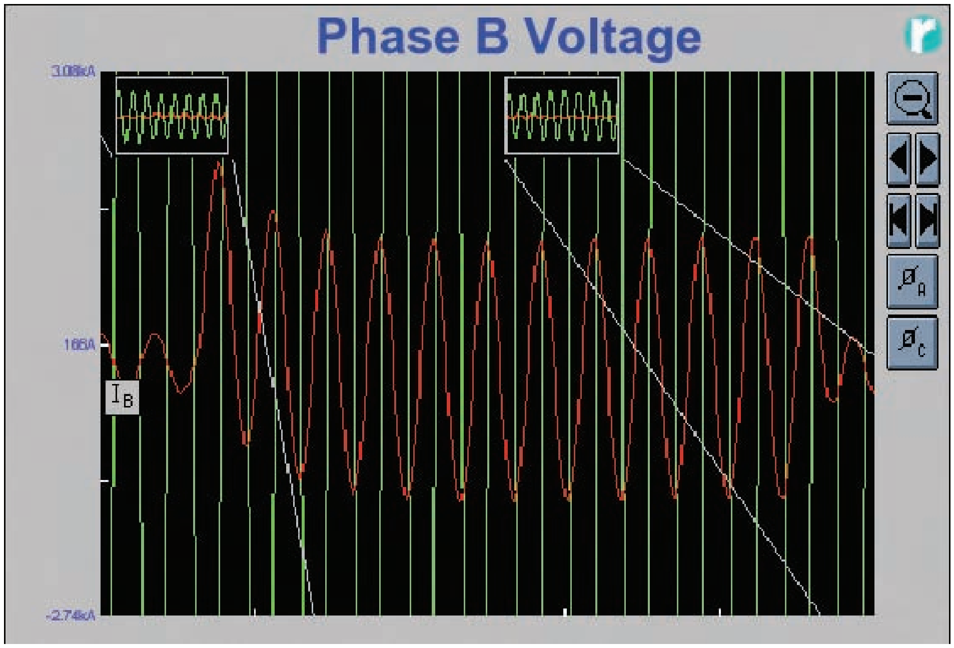

Figure 5. This approach to verifying system protection proper operation can be applied to both low voltage circuit breakers and medium voltage relays.

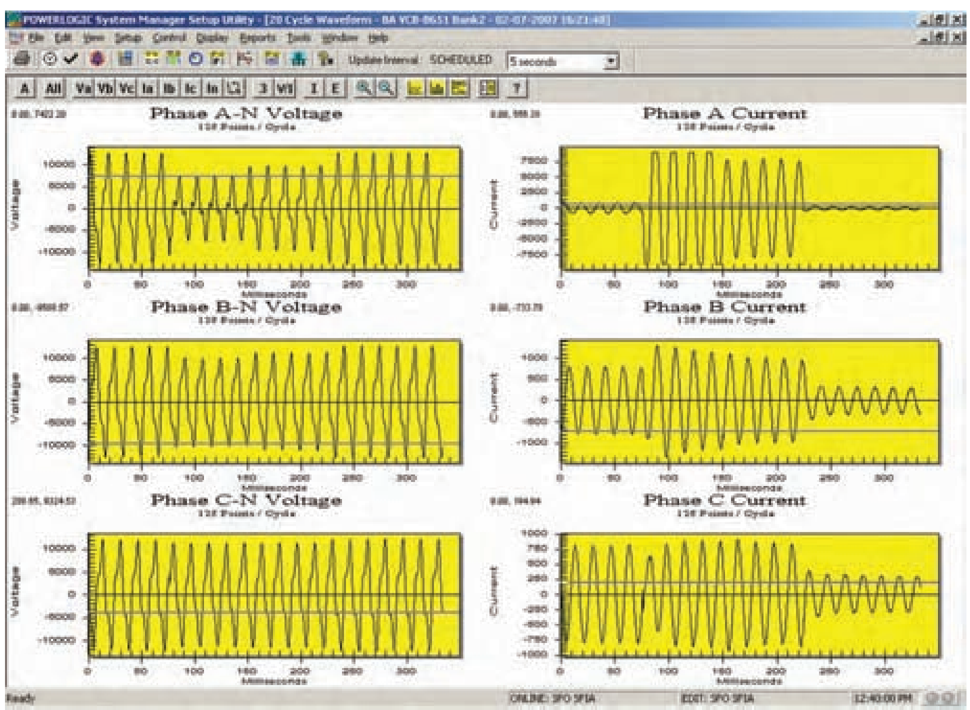

Figure 6. Data was taken at a large facility. The current and voltage waveforms were automatically captured during a severe medium voltage fault on the underground cable system. The fault data shows that A phase and B phase were involved and that the fault was cleared in 8.5 cycles. This immediately informed the maintenance staff of the cables that were involved and provided the engineering staff with critical information for relay settings. Metering current transformer saturation is evident in A phase.

Monitoring systems data and their uses

Historical data is a very powerful benefit from a metering system. A typical system can be set up to capture data on a programmed interval such as 15 minutes. Electrical values such as voltage, current, kilovolt-amps (kVA), kilowatts (kW), Total Harmonic Distortionc (THD) can be tracked and trended over time. This can provide critical data such as maximum values, average values, and day versus night time loads to name a few. This data can be used to make decisions such as future load growth, maintenance, equipment performance and equipment loading.

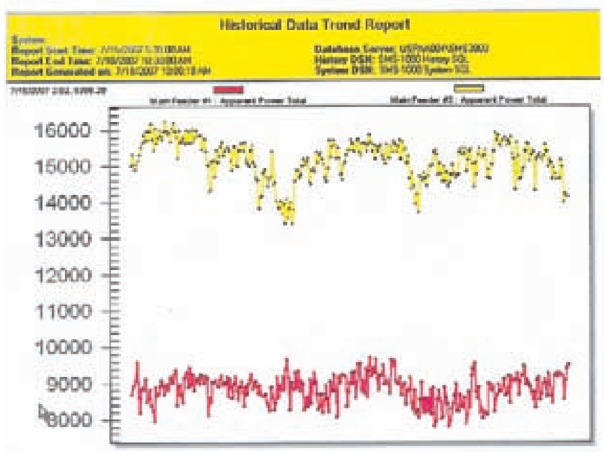

Figure 7. This graph shows transformer T1 and T2 kVA over a three day period. These values are taken from hourly samples of two different large transformers. One of the transformers required tap servicing. The customer was interested moving the T1 transformer load to transformer T2 and performing maintenance while maintaining full operation. The main concern was transformer and feeder overload during maintenance. This data provided the necessary information to make an informed decision.

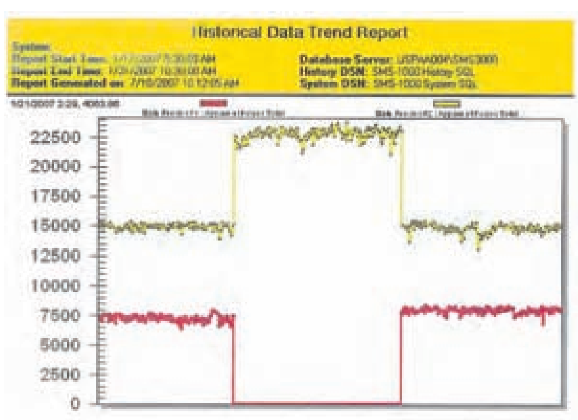

Figure 8. This graph shows the load shift to transformer T2. The transformer could be analyzed for hot spot temperature rise and feeders checked for overload using this data.

Using load data for expansion and energy savings opportunities

Today's healthcare facility is constantly challenged with the expanding needs of the business. Equipment must be added to meet this demand. A huge benefit of the monitoring system is the ability to determine the existing capacity of the electrical system by 24 hour per day continuous monitoring. With this information, the design engineer can determine whether or not the electrical infrastructure can handle the expansion loads. Designs that maximize the dollars spent on infrastructure can be generated. Load flow studies can be performed with real site data such a kW, kVA, voltage and current. Load flow models can have a high degree of accuracy showing not only existing loads but also the expected new loads. These models can show benefits of power factor correction, transformer output voltages, voltage drops, and system losses. Power monitoring results in increased reliability, reduced operating costs and optimized design solutions.

Typical load flow models that do not have real time power measurement are based on demand factors. Demand factors are best guesses as to what the "typical" load would be. The risk of healthcare downtime drives these demand factors to be very conservative and create inaccuracy in the model. This leads to oversized systems and higher installation costs.

Monitoring real time load information

Load planning vs. actual loads

With the rapid expansion of the healthcare environment several factors have to be evaluated when planning for hospital loads. Calculated equipment loads, generator capacity, and, importantly, actual loads all need careful consideration. Design of an electrical system for healthcare becomes increasingly difficult with the development of new medical equipment that has special electrical requirements as mentioned earlier in the section on power quality demands of MRI and other equipment.

Upon initial design of a healthcare facility all loads are calculated in accordance with applicable governing bodies. Designing excess load capacity for future expansion is inherently dollar driven. Depending on the project size, the calculated expansion is usually limited to five years of growth, if any at all.

However, once a healthcare facility is operational new medical technology will cause the review of initial designs to incorporate new technology within existing electrical systems. This is where documentation of actual loads become a vital part of planning.

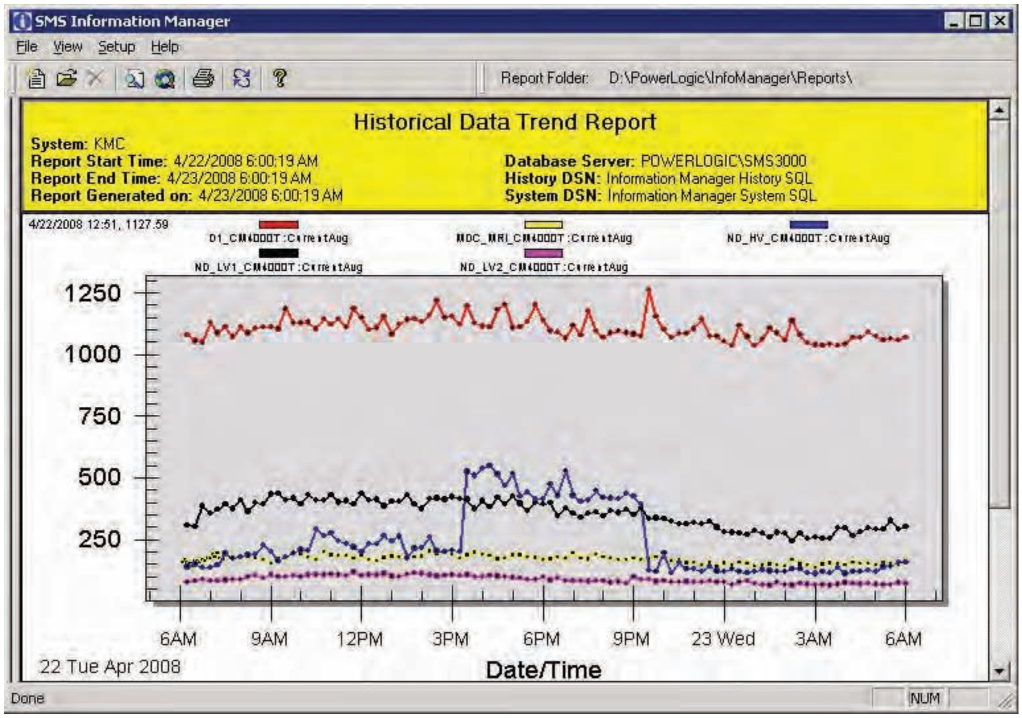

Figure 9. In healthcare facilities emergency powered systems play an essential role in maintaining the facility's operation. As experienced during Hurricane Katrina, the understanding of load shedding and generator capacity is critical information to have prior to a catastrophe. With strategically placed metering that monitors electrical systems, a facility can accurately develop a load shedding plan or accurately determine if load shedding will even be required. Additionally, properly placed metering will allow the user to predict when load shedding would be required allowing time for proper planning and notification. Loads in summer months will differ from winter months, and a one time load capture is not sufficient data to determine the capacity of a system.

Without an electrical monitoring system it becomes very difficult to know your actual electrical loads or if critical loads are operating within the initial design parameters. Essentially you are blind to what is happening with your electrical system and are not in a position to properly plan for future expansion. Documenting actual loads can allow governing bodies to approve operation of equipment under metered loading instead of initial design calculations (contact applicable authorities to determine what requirements need to be met for metering loads). Figure 9 is a diagram that shows the current of multiple services that feed a healthcare facility in one operational day.

Load data for adjusting supply voltage and system adjustment

Who is watching the supply voltage to your facility? In most cases it is not your local utility provider. When your facility was brought online, transformers were tapped in accordance with the designed loads then often times forgotten thereafter. Loads in most healthcare facilities are constantly changing, additions have become common place and the tolerance in which a healthcare facility must operate has become even more critical. Monitoring the supply voltage becomes a critical factor for the health of an existing electrical system. Required adjustments are readily identified with a strategically installed metering system. At the distribution level, the constant monitoring of voltages will allow you to determine when your system is operating at peak capacity and show the effects this may have on supply voltages. Metering will allow you to determine if adjustments are required.

In addition, a metering system can give you a graphical representation of real time values and set up alarming to send out urgent messages when your services are operating out side of the desired tolerances. Not only does this monitoring feature alert you of potential problems but also it provides you with documentation to present to your local utility for changes in tap setting on transformers. Figure 10 is a graphical representation of five services being monitored in a healthcare facility.

Figure 10. Graphical representation of five services being monitored at Kadlec Medical Center.

Load data for monitoring of energy savings opportunities

Many companies advertise energy saving products claiming to save large amounts of money. After you have invested time and money to install the equipment, how much did you actually save? Was that huge energy savings for a lighting upgrade or the installation of high efficiency motors worth the investment? You can look at the monthly power bill to get a general idea of savings. But was that savings a result of a lower temperature day where environmental control equipment was not being utilized?

Without a base line of current power usage, the task of calculating true energy savings proves to be a challenge. The accuracy of those calculations will only be determined after you have installed the energy saving device, and in some cases, after investing large amounts of money. With properly placed metering you can monitor power effects from energy saving upgrades in small sample areas within a healthcare facility and use that data to determine if you are actually saving what was advertised. Not only does this data allow you to make informed decisions on larger scale projects but it also empowers energy managers to prevent costly mistakes.

Load monitoring can also complement heating, ventilation and air conditioning (HVAC) building automation by providing data that can be used to see if temperature set point changes to environmental controls provide desired energy savings within the facility. If you are not able to monitor your facilities loads, you are really guessing whether you are saving dollars. Figure 11 shows a 24 hour trend of a chiller set point change and the dramatic effect that improper temperature set points can have on power savings.

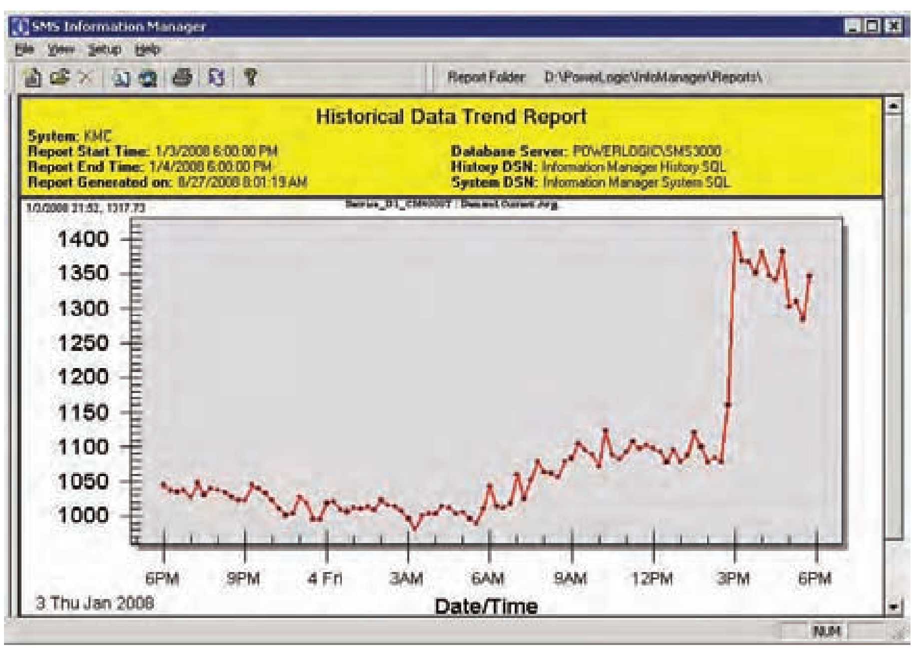

Figure 11. Trend of a chiller set point change and the dramatic effect that improper temperature set points can have on power savings.

Load data for downtime planning and temporary power

For our purposes, downtime refers to a planned electrical shutdown for maintenance or repair. If you have a large electrical system planning downtime can be quite a juggling act. In a healthcare electrical system, poor maintenance planning can put patients and staff in danger and force inopportune shutdowns that result in an undesired effect. Determining the time of day that the least amount of load is used can often translate into a reduction of staff usage and the lowest impact to the facility. Feeders can be monitored for energy usage and verified that systems are not in service prior to de-energization.

Plant loads can be monitored to determine what the temporary generator demand will be during a downtime event. Rental generators can be properly sized with confidence minimizing rental costs. Fuel demand can also be determined. Analyzing load data leads to better downtime results and utilization of temporary power.

Catastrophic event planning

Emergency power supply system (EPSS).

If you operate in a healthcare facility for any length of time, you will be subject to unplanned power outages. Your ability to react properly will make the difference in the successful operations of your facility. The Joint Commission® requires all healthcare facilities to react to Sentinel Event Alert, Issue 37, which includes a gap analysis of healthcare electrical systems and action plans to ensure hospital operations in the event of a power outage. Planning for the worst or predicting the worst is not a small task, and without a detailed understanding of your existing electrical system, planning for emergency scenarios can often times be just a guess. Unfortunately for many healthcare facilities during Hurricane Katrina, the lack of catastrophic planning proved fatal and, in some instances, permanently closed healthcare facilities.

Understanding your healthcare electrical system can save you valuable time in the event of a crisis. Here is a general example of catastrophic planning which could apply to multiple events.

Extreme cold weather just wiped out your local utility provider. Can you answer the following questions off the top of your head?

- How long can your generators run given your current fuel capacity?
- What are the current generator loads and how does that impact your fuel supply?
- What at the current loads on life safety, critical power and equipment buses?

- What nonessential loads can be shed so that generator power can be better utilized?
- What is the bare minimum generator capacity needed to run the facility in the event of low fuel supply?
- When can I shut down and service one generator and still run the facility?
- If the utility can only provide a portion of my usual demand what would I do?

These are some of the questions that a facility electrical manager needs to be able to answer during a catastrophic event. A power monitoring system provides the real time data necessary to answer these questions.

Power systems troubleshooting

Power monitoring and protection devices.

In the previous sections, power system problems such as sags, swells and transients were discussed. When using a power monitoring system (left) to capture power quality data and to and determine if a problem is steady state or intermittent, important conclusions can be drawn if the user can see the magnitude and duration of the power system event. Intermittent problems are difficult to evaluate as some time may pass between implementation of a possible solution and determination of success of the repair. The power monitoring system can be the “watch dog” of the system.

Multi-variable problem solving is a challenging troubleshooting exercise. Because a power monitoring system can capture many values with extremely accurate time and date stamping at multiple locations, a power system engineer can assess the relationships of problems as they propagate through a power system.

Another valuable feature that can be incorporated into state of the art power monitoring systems is sequence of events recording. This troubleshooting tool provides a time sequenced listing of the events. The engineer can see the order of events such as a current spike followed by a series of breaker trips all with sub-second time and date stamps. This tool provides a chronological event list essential for analyzing a complex event.

Power monitoring systems can be an indispensable asset for operating a reliable electrical system in a healthcare facility. Technological advances and the addition of complex equipment and systems require comprehensive power management techniques. Protecting sensitive medical equipment, ensuring patient and staff safety, planning for expansion and maintenance, understanding energy savings and preparing for catastrophic events can all be simplified using data from a monitoring system.

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ITI Curve (Revised 2000) developed by the Information Technology Industry Council.

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Appendix: ITI (CBEMA) Curve Application Note

The ITI (CBEMA) Curve, included within this Application Note, is published by Technical Committee 3 (TC3) of the Information Technology Industry Council (ITI, formerly known as the Computer & Business Equipment Manufacturers Association). It is available at http://.www.itic.org/technical/iticurv.pdf.

1) SCOPE
The ITI (CBEMA) Curve and this Application Note describe an AC input voltage envelope which typically can be tolerated (no interruption in function) by most Information Technology Equipment (ITE). The Curve and this Application Note comprise a single document and are not to be considered separately from each other. They are not intended to serve as a design specification for products or AC distribution systems. The Curve and this Application Note describe both steady-state and transitory conditions.

2) APPLICABILITY
The Curve and this Application Note are applicable to 120V nominal voltages obtained from 120V, 208Y/120V, and 120/240V 60Hz systems. Other nominal voltages and frequencies are not specifically considered and it is the responsibility of the user to determine the applicability of these documents for such conditions.

3) DISCUSSION
This section provides a brief description of the individual conditions which are considered in the Curve. For all conditions, the term “nominal voltage” implies an ideal condition of 120V RMS, 60Hz.

Seven types of events are described in this composite envelope. Each event is briefly described in the following sections, with two similar line voltage sags being described under a single heading. Two regions outside the envelope are also noted. All conditions are assumed to be mutually exclusive at any point in time, and with the exception of steady-state tolerances, are assumed to commence from the nominal voltage. The timing between transients is assumed to be such that the ITE returns to equilibrium (electrical, mechanical, and thermal) prior to commencement of the next transient.

3.1) Steady-State Tolerances
The steady-state range describes an RMS voltage which is either very slowly varying or is constant. The subject range is +/- 10% from the nominal voltage. Any voltages in this range may be present for an indefinite period, and are a function of normal loadings and losses in the distribution system.

3.2) Line Voltage Swell
This region describes a voltage swell having an RMS amplitude of up to 120% of the RMS nominal voltage, with a duration of up to 0.5

seconds. This transient may occur when large loads are removed from the system or when voltage is supplied from sources other than the electric utility.

3.3) Low-Frequency Decaying Ringwave
This region describes a decaying ringwave transient which typically results from the connection of power•factor-correction capacitors to an AC distribution system. The frequency of this transient may range from 200Hz to 5KHz, depending upon the resonant frequency of the AC distribution system. The magnitude of the transient is expressed as a percentage of the peak 60Hz nominal voltage (not the RMS value). The transient is assumed to be completely decayed by the end of the half-cycle in which it occurs. The transient is assumed to occur near the peak of the nominal voltage waveform. The amplitude of the transient varies from 140% for 200Hz ringwaves to 200% for 5KHz ringwaves, with a linear increase in amplitude with increasing frequency. Refer to Figure 1 for an example of a typical waveform.

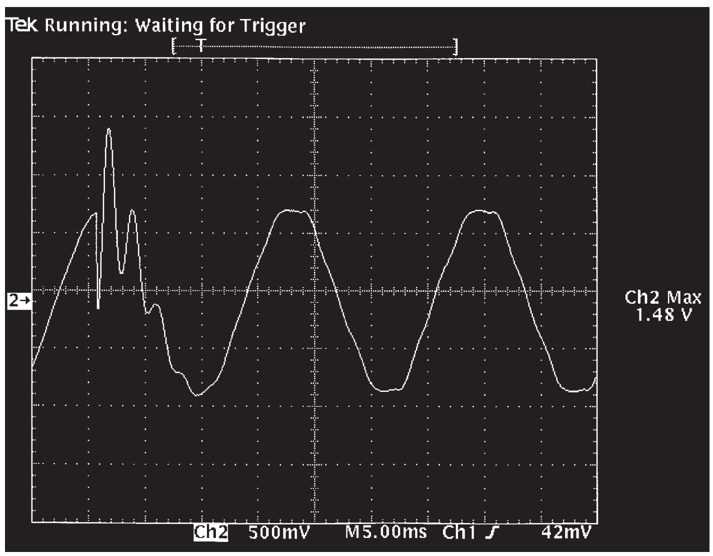


Figure 1. Typical Low Frequency Decaying Ringwave

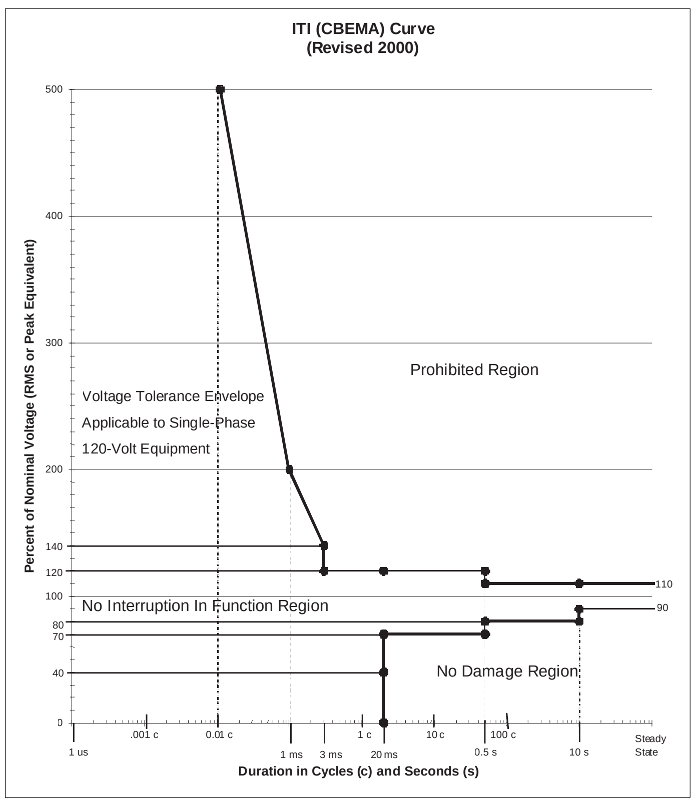
3.4) High-Frequency Impulse and Ringwave
This region describes the transients which typically occur as a result of lightning strikes. Wave shapes applicable to this transient and general test conditions are described in ANSI/IEEE C62.41-1991. This region of the curve deals with both amplitude and duration (energy), rather than RMS amplitude. The intent is to provide an 80 Joule minimum transient immunity.

3.5) Voltage Sags
Two different RMS voltage sags are described. Generally, these transients result from application of heavy loads, as well as fault conditions, at various points in the AC distribution system. Sags to 80% of nominal (maximum deviation of 20%) are assumed to have a typical duration of up to 10 seconds, and sags to 70% of nominal (maximum deviation of 30%) are assumed to have a duration of up to 0.5 seconds.

3.6) Dropout
A voltage dropout includes both severe RMS voltage sags and complete interruptions of the applied voltage, followed by immediate re-application of the nominal voltage. The interruption may last up to 20 milliseconds. This transient typically results from the occurrence and subsequent clearing of faults in the AC distribution system.

3.7) No Damage Region
Events in this region include sags and dropouts which are more severe than those specified in the preceding paragraphs, and continuously applied voltages which are less than the lower limit of the steady-state tolerance range. The normal functional state of the ITE is not typically expected during these conditions, but no damage to the ITE should result.

3.8) Prohibited Region
This region includes any surge or swell which exceeds the upper limit of the envelope. If ITE is subjected to such conditions, damage to the ITE may result.



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