PQ Connection™

Your Power Quality News Source

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Applying Uninterruptible Power Supplies: System Compatibility Issues

[This is a short excerpt from a more detailed white paper developed by Thomas M. Blooming, P.E. and Daniel H. Eglian of Eaton Corporation's Cutler-Hammer business, and Harold Ketola, P.E. of Sebesta Blomberg. For a copy of the complete UPS Compatibility Issues white paper, or for application questions, contact 1-800-809-2772 (option 1, suboption 2) or e-mail PQHotline@eaton.com].

An uninterruptible power supply (UPS) is applied to provide reliable power to critical loads. Because a UPS has a well-deserved reputation for improving reliability and power quality, it is sometimes taken for granted and not applied with consideration for system compatibility issues that can negatively affect its performance. These include: poor utility voltage regulation, transfer switch operations between out-of-phase sources, and backup generator frequency variations. Some issues, such as harmonics and generator sizing when serving a UPS, are better known. Other issues include poor output voltage waveforms from a UPS, on-line versus standby UPSs, and bypass paths for UPS maintenance.

The following will summarize some of the more important issues and considerations in order to obtain the maximum benefit from the most commonly-used larger industrial and commercial UPS -- the static double conversion, or on-line, UPS.

UPS Basics

There are fundamentally three topologies utilized for static UPSs. These are standby power systems (off-line), line interactive (single conversion), and double conversion (on-line) systems.

UPSs Versus Standby Power Systems

Many of the smaller, lower-end units that are referred to as UPSs are actually standby power systems (SPS). The typical SPS unit will provide backup power but not continuous power; therefore, an interruption will occur. For most computers this brief interruption is not a problem, but some computers and PLCs cannot tolerate it. When using an SPS for a system such as a computer, it is helpful to keep non-critical loads (e.g., an office space heater) from being connected to the critical power circuits.

The output of SPSs and lower-end UPSs is a distorted square wave. Though most equipment will handle this distorted voltage without problems, some won't. Test the system to determine whether your critical loads can tolerate a square wave input, and if it cannot, look for a true on-line UPS with at least a quasi sine wave output to indicate a better quality output voltage waveform (see Figure 1).

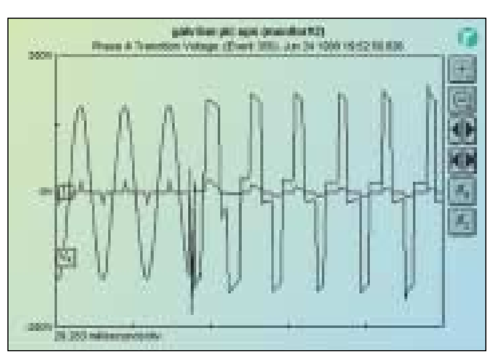

Figure 1 Transition to Square Wave UPS Output

Source Voltage Regulation

When applying a UPS, consider its input voltage. If the input voltage is too low, the UPS will recognize this as an undervoltage and switch to its backup power source, the batteries, to power the load. In a recent case study, a data center had installed computers with built-in SPSs intended to provide backup power. The computer loads tolerated the short outage when switching to backup power and also tolerated the SPS output voltage. But with the SPSs constantly running on battery the batteries were becoming depleted, leaving little backup power available for a true utility outage. Furthermore, when the battery backup did become depleted, the SPS would switch back to utility power. The switching transient during this transition would sometimes cause an overvoltage, which would drop the critical computer load. Suggested solutions included applying a power distribution unit (PDU) with an integral transformer to

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FEATURE

boost the voltage, or choosing a multirange SPS or UPS.

Generator Sizing to Serve a UPS

It is common to serve critical loads with a UPS that can supply power to these loads during relatively short power interruptions or short periods when the input power is deemed unacceptable (sags, frequency variations, et cetera). A generator with an automatic transfer switch, which will sense a utility outage, sends a start signal to the generator, and switches from the utility to the generator when its output has reached the proper voltage and frequency, is often used to backup the UPS. The UPS generates harmonics, which affect the generator. And the generator may allow deeper voltage drops and frequency variations when large motors start, which can affect the UPS. So each piece of equipment must be reviewed, to determine the extent of impact upon the other. The double conversion UPS is a source of harmonics, which can cause overheating in rotating machinery (motors and generators). Therefore, it is wise to specify a generator that is de-rated to serve a harmonic-producing load such as a UPS. Although not related to generator sizing, it should be noted that harmonics generated at the UPS output are also a concern. Regardless of the equipment specification, it is a good idea to measure the actual output voltage distortion under normal load conditions.

When a motor starts under generator power it not only drags down the voltage, it also momentarily slows down the generator unless the generator is very conservatively sized. This will cause a variation in frequency. The rate of change of frequency is called the slew rate, measured in Hz/sec. The slew rate of the input power is one of the parameters that UPSs monitor. When the frequency is less stable (greater slew rate) the UPS senses this and believes that there is a problem with the input source power. The UPS will still continue to operate using this source power because part of its normal operation is conditioning the input power. However, if the UPS believes that there is a problem with the input power, it will not switch to static bypass, but, rather, will dump the load. Needless to say, this should be avoided if possible.

Changing the UPS's allowable slew rate setting to accept the greater frequency shifts that had formerly caused it to think there was a problem with the input power can reduce the problem. However, it should also be noted that adjusting the slew rate tolerance might have an adverse impact on the UPS loads. This might not be a problem with most loads but it should be noted. A more expensive solution would be to oversize the generator.

Transition with Residual Voltage

There are also special problems that can arise when a UPS, or other power electronic device, is synchronized to out-of-phase motor residual utility voltages. A DC bus overvoltage may occur and a "frequency error" may be reported. It is not the residual voltage alone that causes the problems, but the presence of the residual voltage when power from another source is reapplied. (see Figure 2)

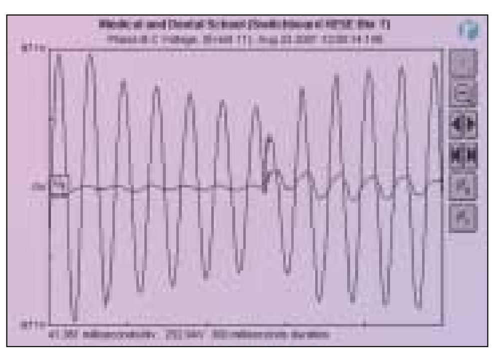

Figure 2 Switch Between Sources (Utility to Generator) with Residual Voltage

Generator Serving a Lightly-Loaded UPS

A generator can find it difficult to properly regulate its output voltage when serving a predominantly UPS-based load if the UPS is lightly loaded and has a very high power factor (unity or possibly slightly leading). This can occur if there is an input filter on the UPS and little other loading on the generator. The generator may oscillate excessively and cause the UPS to cycle on and off because the UPS finds the generator power to be unacceptable (see figure 3). The problem is that the excitation current in a generator is very low during periods of light, capacitive load. This leads to a lower synchronizing torque and allows greater generator variation, possibly leading to oscillation. With additional resistive or inductive load, this problem is less likely to occur.

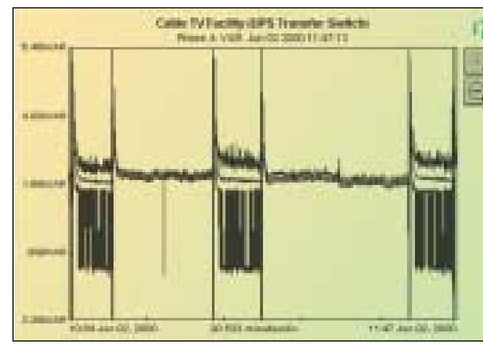

Figure 3 Phase A kVAR, Generator and Utility Power

One solution is power factor adjustment, accomplished by:

- Arranging the automatic transfer schemes to bring the mechanical loads onto E-G power before the UPS is attached. However, some transfer schemes may not accommodate this solution.
- Adding permanent inductive reactance to offset the capacitive load, usually in the form of wound shunt reactors, at the E-Gs or at the generator parallel board. This is easily accomplished and inexpensive, but the reactors draw current at all times and affect load power factor during high load conditions as well as low.
- Adding inductive reactance at each module, sized to balance the capacitance in that module alone, with optional contactor control to engage the reactors during low load conditions only. This solution allows the reactance to be precisely sized, but the number of reactors is larger and the installation and controls are costly.
- Installing contactors ahead of the capacitive elements of the UPS module filters to remove them during low load conditions. The controls may be complex because the timing of the capacitor contactors must be very precise, making this a factory-installed solution only.

Site conditions and equipment specifics will dictate which solution is best.

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UPS Maintenance Bypass

When a UPS is applied it usually does a fine job of providing clean and reliable power to the loads it serves. But at some point it will require maintenance. Maintenance bypasses are necessary to continue to serve the loads without interruption, even though this means that they will be served directly by utility power in a single module system. If a load is important enough to require a UPS, it is also important enough to require a proper maintenance bypass path.

Conclusions

There are several basic types of static uninterruptible power supplies (UPSs) and users should be aware of exactly what they are buying when they buy a "UPS." A standby power supply (SPS) or a line interactive UPS may not suit their needs compared to a double conversion (on-line) UPS, which might be necessary for their critical loads. The lower-end units might allow the critical loads to see very brief outages or supply the loads with very distorted voltages.

It is important that the UPS input voltage be maintained within normal specifications to avoid depleting the battery and not having full backup power available when needed.

Some practical tips:

- The critical load circuits should not serve non-critical loads.
- Critical loads should not be placed on non-critical circuits that may not be designed to accommodate them.
- UPS systems (UPSs and their loads) should be tested periodically. Without testing, users may not know whether their UPS provides fast enough protection and suitable voltage for the critical load.

There are several factors that require a backup generator to be de-rated when serving a UPS. These include harmonics and large motor (or other large load) starting events.

When switching between sources that are out-of-phase with each other, the presence of residual voltage from motor loads can cause problems for UPSs and other static loads.

When a generator is serving a lightly loaded UPS without sufficient additional load, the generator may have a difficult time regulating its output. This will cause the UPS to regard the generator power as bad and switch to its batteries. The UPS will subsequently hunt between generator power and battery power as the generator power smoothes out when the UPS is on battery power.

It is important to have a maintenance bypass path with which to serve critical loads without interruption when the UPS requires maintenance.

FP-5000: Protection, Monitoring and Control in a Single Device

The FP-5000 provides complete protection, metering and control.

The new Cutler-Hammer FP-5000 feeder protection relay from Eaton Corporation is the perfect tool when reliability and uptime are critical. With advanced technology and a rugged design, the FP-5000 provides first rate power distribution protection, comprehensive monitoring and remote or manual control for mains, ties, and feeder circuits of all voltage levels.

The FP-5000 is a major advancement in feeder protection. Capitalizing on microprocessor technology, the FP-5000 continually monitors the circuit voltage and current, protecting against power system faults and equipment failure.

PLC functions for main-tie-main transfer schemes and comprehensive data acquisition are among the FP-5000's key features. Others include trip logs, event logs and waveform capture information for improved fault analysis and system restoration. A data logger provides energy-use profiles for efficient energy use. The FP-5000 meets ANSI, UL, CUL and CSA standards.

Apply the FP-5000 to your most challenging applications and harness the power. Call your local Cuter-Hammer sales person today.

FEATURE

Power Factor Correction And Harmonic Resonance

By Daniel J. Carnovale, P.E.

Introduction

Today, industrial and commercial customers closely scrutinize every charge on their electric utility bill looking to save money. One method of saving money with a quick payback period is to install power factor correction capacitors. Capacitors are being installed on power systems from hospitals to paper mills and the payback period is often as short as 4-6 months.

In years past, individual capacitors were applied and switched with a motor to compensate for that motor's low power factor. Today, with the increased use of variable frequency drives (VFD's) and other loads that create harmonics (also known as non-linear loads), power factor correction capacitors cannot be indiscriminately added to a power system. Considerations must be made for the existence of harmonic sources and the inductive reactance of the existing system – otherwise, parallel resonance can occur.

Unfortunately, parallel resonance is said to be a "self correcting" problem – most times capacitor fuses will open, capacitor cans will fail or the source transformer could fail – any of which removes one of the components that causes the parallel resonant condition.

Failed Power Factor Correction Capacitor

Parallel resonance explained

Harmonic resonance can occur if both of the following are true:

1. Harmonic loads are operating on the power system:
   - AC / DC Drive Systems
   - Induction Heaters
   - Arcing Devices
   - Switch Mode Power Supplies
   - Rectifiers
   - Other

2. A capacitor (or a group of capacitors) and the source impedance have the same reactance (impedance) at a frequency equal to one of the "characteristic" frequencies created by the loads.

It is extremely unlikely that resonance occurs where these two impedances are exactly identical but near resonance can be very damaging.

What is an Obvious Sign of Resonance?

The operation of non-linear loads in a power distribution system creates harmonic currents that flow throughout the power system. Generally, harmonic resonance is a steady state phenomena set off by an event where the harmonic source changes or where the source impedance or capacitor size changes (i.e. if capacitors are switched on or off in steps, for example).

When installing power factor correction capacitors, the resulting parallel resonant frequency (harmonic order) can be estimated using the following equation:

$$f_R = \sqrt{\frac{MVA_{SC}}{MVAR_{CAP}}}$$

where,

f_R is the parallel resonant frequency harmonic order (i.e. 5th, 7th, etc.)

MVA_{SC} is the source impedance at the bus of interest, in MVA

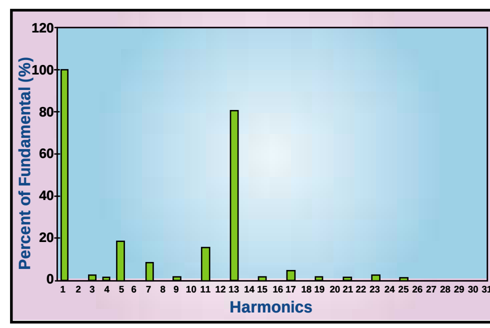
$MVAR_{CAP}$ is the three-phase rating of the capacitor bank in MVA

For example,
If the source impedance at a bus is 500MVA, a capacitor bank of 10 MVA will be parallel resonant with that source impedance at the 7th harmonic. Therefore, if any magnitude of 7th harmonic current is flowing on the power system (at that bus), the effect could be catastrophic.

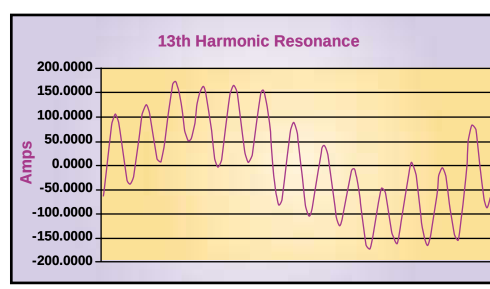
$$f_R = \sqrt{\frac{500}{10}} = 7.07$$

If the non-linear loads generate harmonic current at the resonance frequency, large harmonic voltages will be developed at the capacitor and transformer bus, and serious equipment damage can occur.

If taking measurements, one (or more) of the harmonics will be uncharacteristically high. Normally, the "characteristic" harmonics decrease as frequency increases (i.e. the 5th should be higher than the 7th and the 7th should be higher than the 11th, etc.).



Frequency Spectrum for Harmonic Resonance Near 13th Harmonic



Waveform for Harmonic Resonance Near 13th Harmonic

Did you know you can take a "harmonic snapshot" with your Cutler-Hammer IQ Analyzer? A snapshot will help you check various load conditions or capacitor switching conditions. Press the HARM button on the IQ Analyzer, then press NEW for a new snapshot. View the harmonic current and voltage data that you've just taken by reviewing the graphical or text data for the most recent event number.

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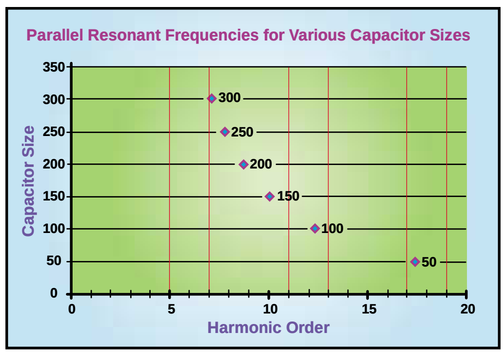
How Much Can My Capacitor Take?

IEEE Standard 18 titled "IEEE Standard for Shunt Power Capacitors" states that power capacitors must withstand a maximum continuous RMS overvoltage of 110% and an overcurrent of 180% based on the nameplate rating. This overvoltage and overcurrent includes both the fundamental frequency and harmonic contributions. Also, the VA rating of the capacitor cannot exceed 135%. Typically, engineers will recommend protecting a capacitor at 135% of its full load current although it may be protected at a higher percentage of its full load current so that the overcurrent protection doesn't operate during capacitor energization. Harmonic filter banks have inductors that limit the capacitor energization currents, but fusing above 135% may still be desired to take into account the additional harmonic current seen by the filter.

How Can I Avoid Harmonic Resonance?

Cutler-Hammer power systems specialists generally recommend applying "tuned" or "de-tuned" harmonic filters or applying a capacitor that is sized appropriately to avoid resonance. Careful consideration can help to avoid resonance so you can reap the ($$$) benefits of applying capacitive compensation.

Special considerations are also very important for switched power factor correction banks. Every step (capacitor size) must be evaluated to determine possible resonant conditions. The graph below shows a 6-step capacitor bank versus harmonic



6-Step Capacitor Bank Showing Resonant Frequencies vs. Capacitor Step

resonant order. This graph highlights (red lines) the orders to avoid (5th, 7th, 11th, etc.).

Also keep in mind:

- Always consider harmonic resonance even if you are applying a "small" capacitor on a "large" system.
- Don't convert 480V capacitors to 480V filters – continuous overvoltage may damage the capacitors.
- Make sure you account for actual kVAR when applying higher (voltage) rated capacitors on a lower (voltage) rated system (i.e. applying 600V capacitors on a 480V system yields 64% of rated kVAR).

Eaton's Cutler-Hammer business now offers low voltage and medium voltage capacitors and harmonic filters! If you think you have a harmonic resonance problem or you'd like to find out more information about harmonics, capacitors, and power factor correction, please contact the PQ Hotline at (800) 809-2772, Option 1, Suboption 2.

PowerWatch Voltage Recorder: the Ultimate Power Quality Tool

Surges, sags, spikes, frequency variations and outages can cause electronic devices to lock-up or fail, causing expensive downtime. Pinpointing the cause can be frustrating and time consuming. The Cutler-Hammer PowerWatch by Eaton Corporation determines the when, why and how of voltage disturbance events, providing you with the needed information to accurately address them. Simply setup your predetermined threshold values or use the industry standard default values and plug it in.

Features:

- Optical alarm indicating events occurred
- Safe, stand alone operation
- No wires, alligator clips or other exposed wiring
- 4000 event memory
- Graphical, statistical and event viewing software
- Hot-Neutral; Neutral-Ground monitoring
- User-settable thresholds
- No wiring, cable
- Safe operation
- Optically isolated interface cable
- Data accessible by modem

ASK THE EXPERT

Questions and Answers

Q: Our church has a relatively old power system where the main incoming service is a couple hundred feet from the distribution panel that feeds the sound system. The sound system often exhibits interference, which appears to be related to the electrical power system. Will an isolation transformer work in this application? If so, what type?

A: Yes, an isolation transformer will often solve electrical noise problems like this by establishing a new ground reference (creating what is often called a separately derived system). This type of arrangement is often used in data centers where a Power Distribution Unit (PDU) is placed close to the load it is serving to limit the electrical "noise" that may be conducted from elsewhere in the power system. A "shielded" isolation transformer is your best choice. Install the shielded isolation transformer and ground the secondary (neutral and shield) locally with building steel or if none exists, ground the neutral and shield with the ground coming from the main source. In either case, always carry the ground wire from the original source to the transformer primary (and metal enclosure) for a safety ground.

Editor's note: The customer installed a Cutler-Hammer S29N11E10N shielded isolation transformer, grounded it, and the problem went away.

Q: Can I convert a 480V capacitor bank to a harmonic filter simply by adding a line reactor to it?

A: You should replace the capacitor with a higher voltage (rated) capacitor. In a filter arrangement, the reactor has a voltage drop whereas the capacitor has a voltage rise. The voltage difference from terminal to terminal (or line-to-line) remains 480 so the capacitor "sees" greater than 480V. The capacitor standards limit the rms over-voltage to 110% of nominal rating (in this case, 480V). Along with this voltage rise and "normal" voltage fluctuations on the utility power grid, 480V capacitors applied as part of a 480V harmonic filter would be at risk of damage. Generally, 525, 550 or 600V capacitors ought to be used for most filter applications to account for the voltage rise across the capacitor. If you simply convert your capacitor to a filter, it may fail.

Q: My customer has a 500 kVA 4160/480V delta/delta transformer supplying a 300 kVA delta/wye-grounded 480/120-208 V transformer. The two transformers are $1^{1}/_{4}$ miles apart. The 300 kVA transformer has failed twice. What could be wrong?

A: The fact that the 480V section of the power system is ungrounded (delta connected) is probably allowing significant overvoltage problems on the 300 kVA transformer primary windings. The distributed capacitance of $1^{1}/_{4}$ miles of line is significant and under very light loading conditions, the voltage at the 300 kVA transformer end could be high. In addition, transients on the power system may significantly stress the insulation at the 300 kVA transformer as the primary winding is a reflection point for high frequencies. We suggest the following: as a first step, monitoring (and trend) the line-to-line and line-to-ground voltage at the 480V input to the 300 kVA transformer. Ground the 4160/480V transformer either by replacing the existing transformer with a delta/wye-grounded transformer or, at a minimum, install a high resistance grounding system to limit arcing ground fault effects. Consider installing surge protection on the 480V side of the 480/120-208V transformer. Other underlying problems may exist but these suggestions should get you started.

Q: I had a ground fault on my 480V system last week and two feeder breakers tripped. The ground fault was on one of the feeders but why would the other breaker trip? Note that my 480V system is ungrounded.

A: If you have an ungrounded 480V system, the first ground fault will not cause a trip because the flow current will typically be less than 5 amps. The distributed system capacitance will restrict the current to this low value. However, when a second ground fault occurs on the power system, and if the ground fault is on a different phase than the first ground fault, significant fault current will flow (1000's of amps) resulting in a phase-to-phase fault and tripping of both protective devices. Therefore, it's likely that you had two ground faults on two different phases on two different feeders. Consider using high resistance grounding with ground fault detection. High resistance grounding also has some significant benefits over "ungrounded" systems while maintaining the service continuity that you demand from your ungrounded system.

We encourage you to submit your questions and/or case studies. If your submission is published, you will receive a Home Surge Protection Package.

E-mail: pqconnection@eaton.com

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Retrofitting generators with peaking switches is a cost-saving investment

By David Loucks, P.E., Manager, Systems Integration, Distributed Generation System

Standby generator sets are an expensive, if necessary, investment in facilities that require backup power when utility power is not available. However, if they are only used in emergency situations, their return on investment is not maximized. For those applications where a standby generator is already required and installed, retrofitting a relatively low-cost peaking switch permits using the standby generator as a source power even when utility power is present.

"Peaking switches are the perfect solution for making efficient use of the customer's generator," noted Dave Loucks, Manager of Systems Integration. "With a peaking switch, the generator provides increased capacity and is a cost-effective alternative to using utility power during peak periods." During times of great need, the value of the power produced by that standby generator can be one or two orders of magnitude above its cost of operation, resulting in exceptionally short payback times and high returns on investment. "The customer wins both ways," Loucks emphasized. "They get more use out of a capital investment while eliminating or reducing the need to purchase power at peak rates."

> For those installations where a standby generator is already required and installed, installing a relatively low-cost peaking switch allows the standby generator to become an alternate peak shaving power source. The savings can result in exceptionally short payback times and high returns on your generation system investment.

Is a peaking switch retrofit right for you?

The following is an easy test to determine whether a retrofitted peaking switch is appropriate for your facility. Simply choose a factor, from 0 to 2, that best corresponds to your energy needs/usage, and add it to the empty box in the third column. Then, total the score from the third column ...and give your Cutler-Hammer representative a call!

	Possible Choices	Your Choice	Explanation
1. **Cost of energy ($/kWh)**	2: more than $0.12 / kWh 1: $0.07 to $0.12 / kWh 0: less than $0.07 / kWh		Higher cost of energy makes peak shaving more attractive by making the locally generated power more competitive.
2. **Demand charge ($/kW)**	2: more than $15 / kW 1: $11 to $15 / kW 0: under $11		Higher demand charges make peak shaving more attractive.
3. **Duration of peak demand "ratchet" time**	2: longer than 6 months 1: 2 to 6 months 0: 1 month		The longer the new peak demand persist on the energy bill, the better the application.
4. **Average hours per week where new peak would be set**	2: less than 4 hours/week 1: 4 to 8 hours/week 0: more than 8 hours/week		Environmental rules limit the number of hours a standby diesel generator can be operated. The project is more attractive if the engine is run for fewer hours per year.
5. **Size of generator**	2: less than 25% of total load 1: 25 to 50% of total load 0: more than 50% of total load		More relaxed generator intertie requirements reduce complexity, thereby reducing project cost. Lower-cost projects improve ROI.
6. **Type of engine**	2: natural gas/propane 1: dual fuel 0: diesel/fuel oil		Natural gas / propane powered engines are more expensive, but produce less noxious exhaust. This simplifies the permitting requirements.
7. **Existing engine-gen and transfer switch already installed?**	2: yes 0: no		Justifying a peaking retrofit is simpler when the engine generator is already installed.
	Total		

Score	
10 or more	Excellent application for peaking switch retrofit (under 1 year payback likely).
8-9	Good application for peaking switch retrofit (under 2 year payback likely).
7 or less	Longer payback, but may be a viable option if other issues are important. Contact the Cutler-Hammer business for details.

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Cutler-Hammer peaking switches provide an economical retrofit solution

The Cutler-Hammer peaking switch is a retrofit solution to an existing transfer switch that converts an engine generator into a full-time parallel system for industrial and commercial customers. The customer can purchase a peaking system and have it installed with their existing generator and transfer switch for a fraction of the cost of replacing the existing transfer switch with a "paralleling-capable" transfer switch. In some markets, the local utility has actively promoted the peaking switch retrofit to their customer base.

Cutler-Hammer low voltage peaking switches are available from 400-4000 amps, which service a range of 140 kW to more than two megawatts. They come in 208, 480 and 600 volt sizes. "We also have the capability of supplying a larger or smaller product," said Loucks. "A communication network can also be added so that the peaking switch can be remotely started and stopped within your desired settings."

"A retrofitted peaking switch system can pay for itself in a couple of months," Loucks noted. "In fact, using peaking switches to take advantage of peak shaving opportunities can save substantial energy dollars month to month. This can dramatically increase the overall generator system's return on investment, and improve bottom line operating costs."

For more information on peaking switches, contact Dave Loucks (DaveGLoucks@eaton.com).

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Future Issues

We will continue to include "Ask the Expert" in upcoming issues and we encourage you to submit power quality questions or comments. Please fax your questions to (403) 717-0579 or e-mail pqconnection@eaton.com, attention "Questions for the Power Quality Expert".

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