POWER QUALITY SOLUTIONS
FOR THE
COMMERCIAL MARKET

The Caterpillar UPS

Competitiveness in the commercial sector is rapidly becoming acute. The classical retail operation is under severe pressure from the Internet based companies, and the Internet companies are in vigorous competition with each other. Business hours have escalated from the days of "blue laws" and family Sundays to 24 hour operation, 7 days a week. Wal-Mart led the way and now many other chains have followed suit. Some commodities can no longer sustain the overhead of actual "stores" and shopping is done in "virtual stores", over the Internet or via mail order. Most software, for example, is now sold in this manner. In general, it is becoming harder and harder to browse through actual racks of product, but easier and easier to browse and buy over the network. Both sides of this retail struggle realize that the customer is going to buy from that company that has the product, has it at a competitive price, can get it into the customers hands quickly and will provide excellent support. Today the customer is going to buy when the mood or need is present. Waiting is no longer an option - or a necessity. If supplier one doesn't have the product, is not open for business, or cannot complete the sales transaction, the customer will immediately go to supplier two. Revenue is lost, customers are lost and continuing service income will be lost.

Availability (the opportunity to make the sale) has become the recognizable mantra for all retailers. The same is true for the service sector. Whether it is hotel rooms, rental cars, or airline reservations, the business owner must complete the sale when the customer "calls" or the customer will go somewhere else. And during the actual sale event, every effort must be made by the seller to provide the buyer a good experience, so there will be return business. For example, electronic hotel room doors must open even when there is no utility power, elevators must work and phone systems must be able to down-load internet based information, on demand, for the time-constrained executive.

As the world moves inexorably toward 7x24 availability, call centers continue to grow in importance. The catalog retailer is an obvious example: customers expect to be able to 'shop' at 3:00 AM, and be served immediately by an agent who relies on a panoply of computerized systems that must be up and operational—even at 3:00 AM. Computerized call distribution systems queue up calls to the preferred agents, computer telephony integration (CTI) software calls up customer records associated with the calling number, and orders are processed on computer-based ordering systems, all day, every day. An outage of any of the components is critical to an operation that measures agent call handling in fractional minutes.

Call centers do more than handle catalog orders—there is a $15 B call center market in the US, comprising about 1.8M agent positions. Selling is actually a small part of what they do. Customer service desk, internal help desks, and the like make up the bulk of the activity, and they rely on the same types of networked systems as the retails operations do. The newest dimension in call centers is the web contact center, with variations ranging from a call button on the web site to a fully integrated web/voice call.

In order to achieve this extended opportunity to sell and service, all business support systems must have very high availability. The telephone companies, for example, led the way with a long history of phone reliability. No one doubts that the phone is going to work – no matter what happens. The phone company measures availability with five nines (A = 0.99999). This means that out of 520,200 minutes in a year, the phone (on average) will only be non-functional for 5. They would love to add another nine to this excellent record and are working toward that goal. That would take give them less than 1 minute of non-availability per year. Now other businesses, especially the Internet based companies, are measuring and working to improve their own availability. Telephone service and counting "nines" has become the model. Downtime costs money and customers. How many times have you heard "sorry, I can't help you because the computer is off-line"? This is quickly becoming an excuse of the past. Continuous uptime as measured by availability is being employed either in part or for the entire commercial enterprise.

Broadcasting is another commercial application in which availability is becoming more critical in the competitive world. There are over 1600 high power UHF TV transmitters in the United States. These employ high-voltage power supplies that drive from one to four, 100 kw transmitting tubes, with the average station using two and a half tubes, or about 250 kw of power. Most transmitters are redundant although there is usually a detectable outage as the spare transmitter takes over for a failure. In general, following a power outage, it will take at least three minutes to bring a transmitter back on line. Engine-generators are routinely used with the transmitters but to date are being used to bring back a station after a total outage – not to prevent an off-the-air event. UPS have not been routinely used for a number of reasons, however this is changing in the competitive word of broadcasting. The transmitter characteristics are quite harsh for an UPS, since the tube has an intrinsic susceptibility to arcing. In an attempt to successfully recover the tube, an automatic shutdown "crowbar" shorting of the DC voltage is employed. Between the tube arcing and the crowbar function, it is quite common to experience 12 to 20 times rated current during the arcing event. This transient over-current has been a problem for many static UPS, even on bypass. Either the semiconductors or the contactors used in the bypass tend to fail because of the high arcing event currents.

The Caterpillar UPS is the UPS of choice in this application. It is integral with a CAT engine-generator and will successfully power the transmitter through all power quality anomalies from short transients to complete long term outages of power. The designers also recognized the severe over-current characteristics of tube-arching and have provided components that can withstand the inrush current from these events.

In general, the Caterpillar UPS system with its continuous power monitoring capability is perfect for the broad arena of commercial applications. Whether it is a network server, client PC, point-of-sale terminal, satellite communications system, phone system or just lighting backup, the power solution can be one tightly integrated, easily installed UPS system.

Commercial Power Quality And Reliability Issues:

An Electric Power Research Institute (EPRI) study on recurring U.S. power problems revealed that greater than 90% of manufacturing facilities will experience sags of utility voltage greater than 20% from nominal. The study also states there will be in excess of 30 dips over 10% per year. These disturbances are at the electrical input to the building and are a function of both natural events as well as random occurrences caused elsewhere in the power grid. Also to be considered are complete outages, which vary in frequency though out the world.
Even in the United States, with relatively stable power production, there is a significant variation in the number of total outages by region:

- Areas with high Kuronic rates (lightning strikes) will experience more naturally caused power losses than areas with lower incidences of thunderstorms.
- Industries that are at the end of long feeder routes are at higher risk for outages than facilities that are closely coupled to electrical sub-stations.
- Buildings in older parts of a city or suburb may experience higher failure rates due to equipment aging or poor maintenance.

In general, it is clear that the electrical power infrastructure needed to support an operation that has requirements for "multiple nine's" of electric reliability, is not generally available from the public utility today -- and will certainly degrade in the future as factors such as deregulation take effect.

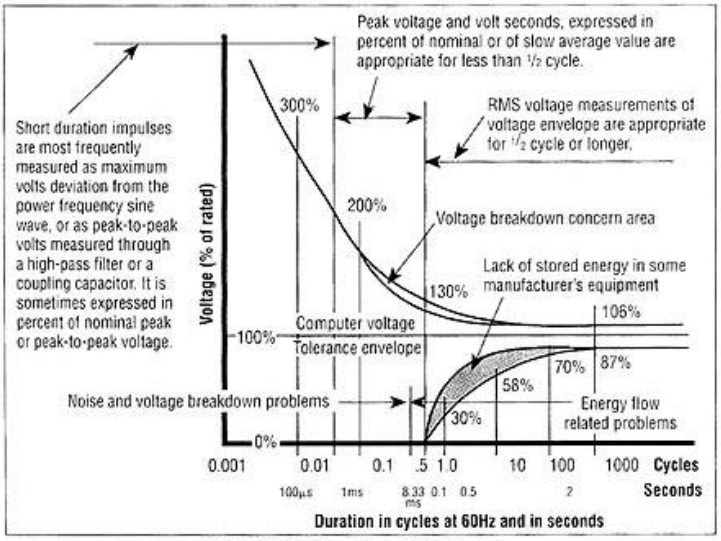
This power delivery reliability problem is universally recognized and is outlined in EPRI's "Roadmap Initiative". As part of the Power Delivery Infrastructure Challenge, EPRI states that … " The existing radial, electromechanically controlled grid needs to be transformed into an electronically controlled, smart electricity network in order to handle the escalating demands of competitive markets in terms of scale, transactional complexity, and power quality… These reliability and power quality limitations already cost the U.S. economy more than $30 billion each year. The upgraded system is not a luxury, nor even an option for the future. Rather it is an imperative to build productivity and ensure global competitiveness in the $8+ trillion U.S. economy." The bad news is that this program has been established as a 50-year endeavor, which leaves American businesses with profound limitations due to the lack of power reliability.

Many of the same power quality issues in the commercial sector are similar to the industrial sector, but several differences should be noted. Commercial business sites tend to be more widely distributed than heavier 'industrial park" companies. This distributed profile means the electric power feeders are smaller and longer, which adds up to higher source impedance. The increased distance from a main sub-station increases the opportunity for failure at a local level. Whereas the EPRI report forecasted a nation-wide average number of voltage dips per year, this sector will be on the higher end of the distribution. Therefore, the number of times that the commercial site will need to use stored energy to ride-through the disturbance will also increase.

Because the commercial site is usually a farther distance from the main sub-station, outages tend to run longer. Small feeder breakers and switches tend to be older and slower. Repair dispatching also tends to take longer; therefore there will be significantly more small problems that turn into larger problems. The power protection UPS must account for this.

COMMERCIAL EQUIPMENT LIMITATIONS:

For the most part, commercial applications employ computer, office and point-of-use equipment which was designed and built in more recent years. These types of equipment typically use power supplies that are based on switching techniques rather than the older linear models. This allows a lower cost and higher contribution to the overall competitive product pricing necessary in this market. Unlike the industrial market where there is a significant mixture of load types, the commercial market is more homogenous in the load characteristics presented by the power supplies and for their ability in dealing with power disturbances. Many of the switching power supplies used will conform to the CBEMA power capability recommendation as shown in Figure 1 and are designed to be universal with respect to world frequencies of 50 and 60 Hz. Typically these power supplies will handle any frequency from 45 to 65 Hz (50/60 +/- 10%). Many will even work over a greater range of frequency since there are no internal low frequency transformers employed. This broad power frequency range is why smaller engine-generators have been so successful as providing back-up power in this market place. Therefore as we examine the requirements of power protection in the commercial venue, references to the CBEMA curve and the EPRI power quality studies will be made.



The CBEMA Curve from FIPS No. 94.

Figure 1: CBEMA Curve

THE CATERPILLAR UPS SYSTEM (A TOTAL SOLUTION)

The robust Caterpillar UPS system has been designed to fit the commercial application where floor space is at a premium and where supplemental air conditioning is difficult to employ. It will provide a single solution for all of the power quality issues experienced in today's business locations – worldwide. The Caterpillar UPS incorporates total protection from transient over-voltages, dips and sags to total power outages -- with no time constraints. In order to understand the operational performance of the UPS system, we will use the CBEMA curve and EPRI data as references to power disturbances and then discuss the actions and performance of the new system in mitigating these power quality problems. Comparisons to the well known battery-based, double-conversion UPS will also be made.

Voltage Transients:
A true line-interactive inverter was chosen for this UPS product because it represents the best solution when the entire protection package is considered. In this system, the inverter is continuously operational and is constantly monitoring the quality of input power. Any transient over-voltage that occurs will be attenuated by two actions. First, there are high-energy transient-voltage surge suppressors (TVSS) and large line-isolating inductors on the input. There are redundant surge suppressors on the output of the inverter terminals. Both of these assemblies have been designed to meet the ANSI C-62.41 - 1991 standards for high-energy (6kv @ 3ka), high exposure transients. In addition to these fast acting passive energy absorbers, some energy will also be harmlessly transferred to the DC capacitors through the inverter Through the use of these transient reduction techniques, a stiff six thousand-volt peak on the input will be reduced to a harmless voltage deviation on the output. This level of transient protection is consistent with the typical double-conversion UPS.

Voltage Sags:
The EPRI report on power disturbances points out that a majority of power system problems are voltage sags of 10% to 30 % below nominal, and they extend from 3 to 30 cycles in duration. These are the kind of disturbances that cause motor controlled processes, such as elevators, to be momentarily interrupted or permanently tripped off line. The Caterpillar UPS system will sense the beginning of a voltage-sag and immediately begin to take energy from the integrated flywheel to compensate. If we examine the worst case of a 30 cycle, 30% dip, followed by a controlled walk-in back to normal operation, this will represent an energy draw of less than 10% of the total stored. Recovery of the energy used, following the 30% dip, is very rapid, bringing the flywheel back to its full outage capability within 20 seconds. Unlike a lead-acid battery energy-storage system used in a conventional double-conversion UPS, the flywheel has no restrictions on the number of energy discharge cycles and has no significant wear-out mechanism based on the number of discharges. The flywheel also has a much broader operating temperature range than does the lead-acid battery. Installations in offices, hotels and at unattended sites can be completed without the mandatory air-conditioning required to achieve the life and performance of batteries.

Voltage Surges:
The inverter has output voltage sense ranges; which can be easily tailored for the customer through software. The range of acceptable voltage on the output of the UPS (chosen by the customer) will determine when the system takes energy from the flywheel or when it starts the engine-generator. There is a fast response range to take action for dips and there is a slower response range that can take alternate actions for sags and surges. For electrical power that temporarily exceeds these programmable ranges of acceptability, energy will either be seamlessly taken from the flywheel, on a temporary basis, or from the engine-generator for longer periods. The load voltage will always remain within the selected voltage range for any disturbance time from sub-cycle to continuous.

Power Loss:
The flywheel will be used to supply short duration energy needs from single cycle to 12.5 seconds (as standard) or longer. For all outages that are in excess of the flywheel storage time, the diesel-generator will be used as the preferred source. In order to achieve high reliability with the engine-generator, a special redundant start function was added to the Caterpillar UPS system that uses energy from the flywheel for starting. Since the flywheel process is constantly monitored and controlled, the end-user has instantaneous knowledge of the availability of the flywheel for starting purposes – there can be no surprises at the absolute worst time. Mil Handbook 217 reliability studies of this novel new integrated start function reveal a Caterpillar UPS system that has very similar MTBFs as a classical lead-acid battery-based static double-conversion UPS – but without the maintenance, wear-out and failure problems of batteries. It also has the novel characteristic that the protection time is not limited to 15 minutes, as is the typical battery-based double-conversion UPS, but is only limited by the diesel fuel supply. It could therefore extend protection for natural disasters -- which seem to occur on a regular basis.

The novelty of using the engine-generator for protection times that have been typically in the realm of the battery (5 – 15 minutes) is an excellent fit for a diesel. All engine manufacturers recommend running their engines for at least 30 minutes under load; as a minimum, once every two weeks. This is done to maximize the life of the engine. The Caterpillar UPS application will generally cycle the engine enough times that a

separate maintenance-only program will not have to be planned and executed. By examining the EPRI regional outage data, complete power failures occur, on the average, less than one per month. However, allowing additional engine starts during the month, as part of the normal system operation, we have integrated our diesel run maintenance into actual protection events.

Static UPS – Generator Interface:
Since there is an increasing trend to install engine-generators to ensure continuous power availability, then the Caterpillar UPS system will allow a more cost-effective solution than by installing a classical, battery-based, double-conversion UPS, and a separate engine-generator. Because this is a CAT product, all of the generator – UPS interface problems have been eliminated, with the generator sized appropriately for the application. The end-user totally avoids the finger-pointing problems that are rife in typical UPS engine-generator integration.

Frequency Limitations and Efficiency:
Line-interactive UPS technology was also chosen for this new product in order to provide the customer with operating efficiencies (typically 98 %) that were significantly higher than a double-conversion UPS (92 – 94 %), therefore lowering life-cycle costs significantly. However, a characteristic of the line-interactive technology is that there is no frequency isolation from input to output. This is not an issue while operating from the utility since the utility has to be extremely frequency stable in order to maintain a connected grid. Minor frequency deviations (> 0.1%) can cause the entire grid to begin to collapse if not addressed by the utility infrastructure. Larger frequency deviations typically come from free-running engine-generators or small co-generation plants. Although their base frequency stability is quite good (acceptable with all known industrial, commercial and IT loads), large cycling loads can cause frequency swings, especially on improperly sized generators. CAT addressed this in two ways. First, the static inverter of the Caterpillar UPS and the generator were sized to be totally compatible. Second, the UPS will sense any transient or inrush-current load change and with the use of flywheel energy, prevent the transient from impacting the frequency presented to the load. In effect, the UPS and flywheel act as a large filter between the engine and the load. When a load transient occurs which would result in a line frequency disturbance, the UPS will detect and intervene, providing a stable operating frequency to the load at a maximum tolerance of ± 1.0 Hz. This is the same tolerance that a double-conversion UPS is typically set for in order to track an engine-generator. Double-conversion UPSs advertise a very stable run frequency (typically ± 0.1 Hz). However they also track the frequency of a connected generator to ± 1.0 Hz. This is done in order to keep in synchronization with the source, so that in case of UPS failure the load can be switched to the generator via the bypass and still be in phase with the generator. Therefore the Caterpillar UPS system operates with the same frequency limits that a double-conversion UPS does and like the double-conversion, can be software configured for tighter requirements – if an actual need is determined. However, keep in mind that most loads will have frequency tolerances that are quite wide as previously discussed. In these instances the frequency window may be opened to ± 5 Hz before flywheel energy is called for.

Fault Clearing Capability:
To maximize availability of the entire enterprise, the UPS system must be able to provide circuit breaker or fuse fault-clearing energy without degrading the output power to the point where other critical loads are compromised. The Caterpillar UPS has a more reliable chance of successfully clearing a branch breaker than does a double-conversion UPS. The double-conversion system will typically sense a fault-based overload and immediately transfer to bypass to provide the maximum amount of fault-clearing current. The Caterpillar UPS system is already connected to the utility and does not need to switch the load through a static switch. Therefore the probability of failure of the static switch must be considered in the evaluation of the double-conversion UPS fault-clearing action.

Output Voltage Total Harmonic Distortion (THD):
Under normal operation, the UPS output voltage distortion will be a reflection of the source voltage. Since commercial applications tend to employ newer equipment, the typical load current of the switching power supplies tend to be power-factor corrected. However, allowing a mixture of older highly non-linear loads with the newer linear input supplies, a total load power factor of 0.9 is quite typical. Under worst case continuous conditions, the mixture of linear appearing loads and the non-linear loads from uncorrected low power-factor supplies will typically cause a voltage distortion of 2 to 5 percent. The isolating inductors of

the line-interactive UPS will add a small amount to this level of distortion but it should remain below 7%, for most applications.

Input Current Distortion (THD):
Most double-conversion UPSs use a six-pulse rectifier on the input. This controlled rectifier has a characteristic input current distortion of 28 – 30 % regardless of the non-linearity of the load. Even in the presence of a unity power factor load (all real power), the UPS will continue to pull 28 – 30 % non-linear current. Because of this distortion, the manufacturers of the double-conversion solution offer passive input filters that will reduce this distortion down to 10 %. Unfortunately these filters can cause system problems especially when the UPS is lightly loaded. They can circulate large reactive currents to an engine-generator, especially if there is any question of instability between the UPS and the generator controls. They can also cause a "fast response" generator output voltage to go very high if the UPS load appears as a capacitive impedance. The capacitors in the filter can also cause certain types of motors to "self-excite" and continue to run even after utility power has been lost – causing an out of control situation and safety risk.

The line-interactive inverter of the Caterpillar UPS system works differently than the controlled rectifier and normally will pass the load current distortion through to the source. However, since the industry trend is rapidly moving toward power-factor-corrected loads, the typical distortion that the Caterpillar UPS system will place back on the utility will typically be less than the standard double-conversion UPS.

Life-Cycle Costs:
A major benefit of the Caterpillar UPS system is its operating efficiency. Whereas most double-conversion UPSs have efficiencies in the range of 92 – 94%, this system operates at 98%, which includes the necessary power to keep the flywheel rotating at its fully charged point. A simple examination of the operating costs will reveal that at $ 0.07 per kw hr., a three percentage point difference in efficiency will result in a savings of $46,000 over a ten year period. These savings could easily pay for a new network. If we add to this value the replacement cost of a typical lead-acid battery as used with conventional UPS, they would have worn out from one to two times over the same ten-year period, the total savings could be many times the value indicated. Therefore the total life-cycle cost savings easily make the Caterpillar UPS System an excellent choice for the commercial application.

Energy Discharge Cycles:
Most double-conversion UPSs use the failure-prone lead-acid battery as the source of stored energy. Therefore, in the commercial application, where there is a tendency for more frequent dips, sags and outages, the UPS will call for a higher rate of battery discharges. Whereas batteries have a complete discharge cycle limit of 300 times and then they will need to be replaced, the flywheel does not have that limitation and will easily achieve 100,000 discharge cycles and more without degradation in performance.