Integrated Flywheel UPS for Industrial Applications

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Objective

This white paper will review the significant growth in industrial applications that have become mission critical as a result of highly digitized processes. In an attempt to drive efficiencies, many of these manufacturing processes have turned digital and as a result are controlled by highly sophisticated computer equipment. This paper will discuss how an integrated flywheel uninterruptible power supply (UPS) can effectively and predictably protect the mission critical computer loads that directly drive manufacturing output.

Industrial Processes Turning Mission Critical

Global competition is driving industrial users to reevaluate every aspect of factory efficiency. Ever-increasing levels of automation are being employed, especially in the areas of process and machine control, communications and computerized optimization of material flow. In essence, electronics have invaded the manufacturing floor in much the same way desktop computers proliferated in offices 10 to 20 years ago. The average factory worker, like his or her office counterpart, is now armed with state-of-the-art computer technology in the never-ending quest for higher productivity, better quality and lower overhead costs. An array of automated equipment is now commonplace on the factory floor (see Figure 1).

Figure 1. Bottles of beer proceed down an automated bottling plant

Both low horsepower motor controllers and high-power adjustable-speed drives are being deployed to lower electrical energy bills and provide better control over processes. Programmable controllers have become commonplace due to their significant value in improving product quality through enhanced control, data collection and communications. Real-time production statistics are being used by an ever-widening audience to affect decisions from the machine operator to the CEO.

These tools for enhancing competitiveness are vulnerable to the same power quality issues that threaten more traditional IT applications. Power outages and voltage transients or sags can temporarily disrupt operations or cause significant equipment damage or inventory loss. For example, certain diffusion steps in the semiconductor industry are critical, and an incorrect temperature or loss of a timer can render an entire production lot into very expensive scrap. Failures in certain serially integrated extrusion processes result in a lost batch of finished product and cause serious machine damage. Machines can become choked with raw material if a heating function fails or if a motor controller trips off-line.

In addition, an industrial or factory environment presents significantly more hazards to electronics than an air conditioned data center, with wide temperature extremes and high airborne particulate densities. Factories and plants may also be located in remote locations or be served by an older and less robust portion of the electrical grid. An Electric Power Research Institute (EPRI) study on recurring U.S. power problems revealed that greater than 90 percent of manufacturing facilities will experience sags of utility voltage greater than 20 percent from nominal each year.[1] The study also states there will be in excess of 30 dips over 10 percent from nominal annually. Complete outages, which vary in frequency throughout the world, are also a potential issue.

Power Protection Solutions

There have been historical attempts at solving electrical problems with distributed or localized solutions, such as placing small UPS systems on the controls portion of machines or by placing energy storage devices on the DC bus of the motor controllers. Diesel generators are also employed, but typically they are used only after the plant has experienced an unexpected shutdown and are not well coordinated with the total power needs.

More recently, the industrial market has turned to centralized UPS systems providing power quality and ride-through energy storage to keep industrial and manufacturing facilities running smoothly.

UPS Designs

There are two main types of UPS systems sold to industrial and manufacturing facilities. They vary both in the power quality topology and in the energy storage method used.

Double-conversion
Double-conversion UPS systems completely isolate IT loads from unconditioned utility power. As the name indicates, they convert unconditioned utility power two times under normal operating conditions – first from AC to DC electricity and then back again from DC electricity into a conditioned AC signal. Double-conversion UPS systems always provide the load with a conditioned AC signal even during normal operation when utility power is available and no disturbances are present. Most double conversion systems use chemical batteries – known as valve-regulated lead acid batteries, or VRLAs – to provide the energy storage used to bridge to emergency power.

Parallel online
Parallel online UPS systems place the inverter and charger circuitry or transformers in parallel with the AC utility signal. In this design, the quality of the output waveform is determined by the internal inverter, not the input waveform. If output waveform deviates from a pure sine wave, the UPS changes the inverter firing to boost the voltage back to the nominal waveform if it is low, or pull it down if it is high. This is very similar to the techniques that a double conversion UPS uses to maintain a good quality waveform on the output. The difference is that, except during discharge, the inverter doesn't have to supply the portion of the output current that is needed for bulk power. When utility power is unavailable or reaches unacceptable limits, a parallel online UPS enters stored energy mode. The UPS disconnects the load from utility power and reroutes this load with a static switch to backup power.

Active Power's CleanSource UPS® and CleanSource HD UPS systems are examples of the parallel online technology. They are driven by motion: at the core of each UPS is an integrated flywheel machine that stores kinetic energy – energy produced by motion – by constantly spinning a compact rotor in a low-friction environment (see Figure 2). When short-term backup power is required because utility power fluctuates or is lost, the inertia of the flywheel allows the rotor to continue spinning and the resulting kinetic energy is converted to electricity. The flywheel takes the place of battery-based energy storage, providing a smaller, more reliable, and more economical solution well-suited to the needs of industrial facilities.

300 Series Flywheel

4.4” high; 25.5” in diameter; 600 lbs rotating mass

Stores 4.3 MJ of stored energy (240 kW for 15 seconds)

HD Series Flywheel

12.5” high; 25.5” in diameter; 1700 lbs rotating mass

Stores 12.65 MJ of stored (675 kW for 15 seconds)

Figure 2. CleanSource Flywheels

UPS Selection Considerations

Selecting a UPS requires comparing several factors to identify the right fit for the particular facility. Among these considerations are:

- Energy storage method
- Power protection
- Reliability
- Footprint
- Total cost of ownership

Energy Storage

Conventional UPS systems use VRLA batteries to store energy for a number of minutes in order to provide time for emergency power to come online. While batteries are a common technology able to store large amounts of power economically, they have limitations in an industrial installation.

First, batteries wear out with frequent use, and must be replaced every 4-6 years in normal use in order to retain their energy storage capability. In an industrial plant where the UPS is called upon frequently, they may need to be replaced more often.

Second, batteries must be installed and maintained in a climate controlled environment at precisely 25 degrees Celsius. Variations above or below that temperature may significantly degrade the battery’s useful life. This generally requires the addition of cooling systems for the room where the batteries are located, and increases electricity costs to operate that cooling system.

Third, special care must be taken to install and maintain batteries safely. They require

ventilation, fire safety, monitoring, and personnel safety systems specific to their operation, and may require extra permits or approvals from regulatory and permitting agencies due to these concerns.

Compared to batteries, the CleanSource flywheel offers significant advantages. The CleanSource flywheel suffers no degradation of runtime when discharged. The flywheel can be called upon to protect the load frequently and deeply for its 20-year life and still provide the same amount of stored energy as on day one. This provides significant convenience and cost savings. In the case of an industrial application with frequent sags and flywheel discharges, this makes for a more reliable and more economical solution than a typical battery-based UPS.

The CleanSource flywheel supports a wide ambient temperature operating range from 0 to 40 degrees Celsius without any performance impact. This allows the UPS to be placed in locations where cooling is expensive or not available, such as directly on the factory floor. CleanSource UPS can also operate at higher ambient temperatures with less heat rejection, measurably improving cooling loading and costs.

Finally, the battery-free design reduces installation and operating costs, such as ventilation and fire safety, compared to conventional UPS solutions. This simplifies and improves the flexibility of the UPS and may ease concerns of regulatory and permitting agencies.

Power Protection

Both double conversion and parallel online UPS systems are appropriate ways of managing power quality disturbances. As shown in Figure 3 below, CleanSource UPS features a true parallel online topology enabled by the flywheel, addressing all types of power quality issues. The output of the CleanSource UPS is directly connected to a high speed IGBT (insulated-gate bipolar transistor) inverter that is producing voltage for the load. Since the inverter is switching at a rate that is over 100 times faster than 60 Hz, it can make corrections to the output voltage sine wave on a sub-cycle basis. This means that when any of the nine IEEE-defined power disturbances are detected by the CleanSource UPS input, they are actively corrected by use of transient voltage surge suppressor (TVSS), line inductance, active filtering, power converters, and load-tolerant flywheel energy storage.

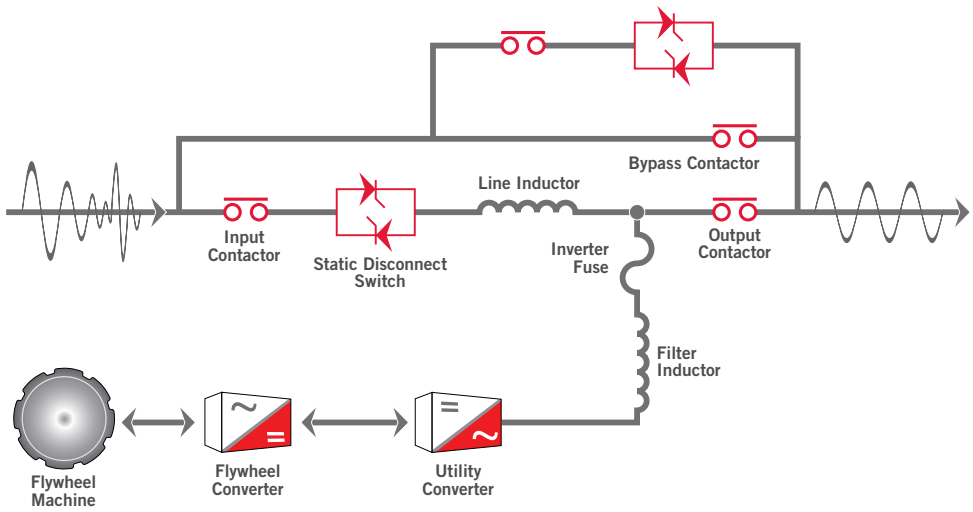

Figure 3. CleanSource Parallel Online Architecture

The EPRI report on power disturbances points out a majority of power system problems are voltage sags of 10 to 30 percent below nominal and they extend from three to 30 cycles in duration. These are the kind of disturbances that cause adjustable speed drive controlled processes to be momentarily interrupted or permanently tripped off-line.

The CleanSource UPS is continuously operating to ensure output voltage is within 1 percent of nominal. The integrated flywheel UPS system will correct surges or sags up to 10 percent above and 15 percent below nominal for any duration without use of the flywheel energy storage. For deviations outside that range, the UPS will disconnect from the source and immediately begin to supply the load with flywheel energy with no change to output voltage, and re-connect to the source when voltage returns to nominal.

Reliability

Given the economic stakes riding on the availability of a UPS in an industrial facility, the reliability of the system is critical to evaluating its use.

In most conventional UPS systems, batteries are the most prone to failure of any component or subsystem. Battery failures are the leading cause of UPS load loss and system downtime, causing more than one-third of all outages.[2] Batteries fail unpredictably due to aging, state-of-charge, charge and discharge events, and rest periods, resulting in diminished reliability.

The integrated flywheel energy storage at the core of CleanSource UPS makes it inherently reliable, delivering predictable, consistent backup power. The normal state of CleanSource UPS is with the flywheel spinning constantly, storing kinetic energy. When called upon during a utility outage or other power quality event, the flywheel is ready to assume the load. A study by risk assessment firm MTechnology, Inc. shows that the Active Power CleanSource 750HD can reduce the risk of electrical system failure by 80 percent compared to conventional UPS with batteries in a short utility outage lasting less than 10 seconds.[3]

Footprint

The physical space that a UPS requires is also a key consideration. The footprint required for a UPS and other backup power systems may, in many cases, be better used by equipment more central to the mission of the facility or may cause the facility to incur extra costs to accommodate the UPS.

CleanSource UPS and CleanSource HD UPS are significantly more power dense than conventional UPS technologies with batteries. As illustrated in Figure 4 below, CleanSource HD takes up about half the floor space of leading conventional UPS. The benefits of power density for industrial facilities are significant. Operators can reduce the amount of space required for electrical infrastructure, freeing up room for additional equipment or employee space. If identified early in the project, a smaller UPS may result in a smaller land purchase or building construction, resulting in tremendous savings. A smaller footprint also makes it easier to add a UPS to an existing facility that is looking to upgrade its power protection.

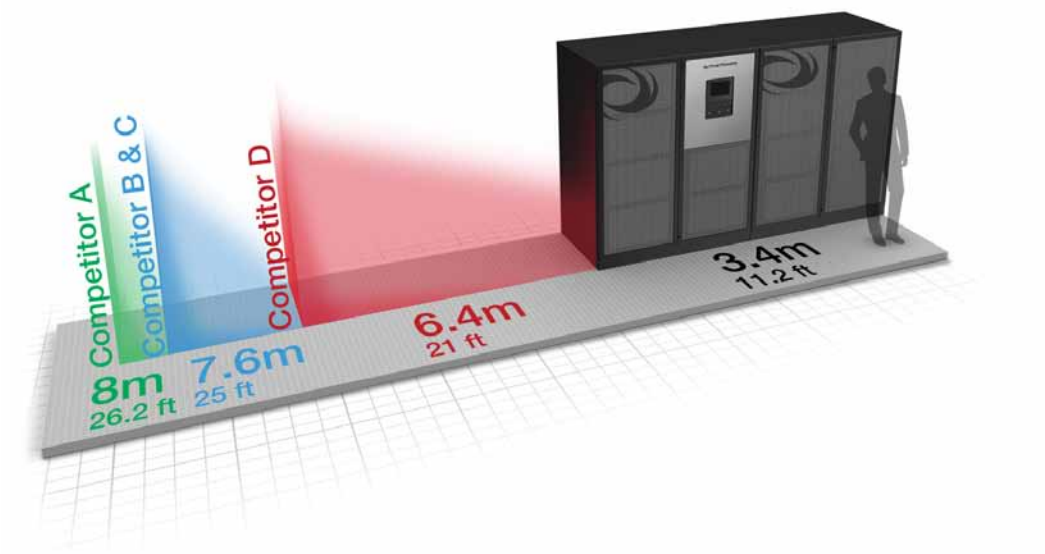

Figure 4. 750 kVA UPS Footprint Comparison. Comparison based on published specifications of 750 kVA (480V) and 625 kVA (400V) units with 4 standard battery cabinets vs. CleanSource 750HD

Total Cost of Ownership

The most thorough measure of the economic value of a UPS system is the total cost of ownership (TCO), assessing the purchase price, installation costs, and long run operating costs over the appropriate time period for the facility. TCO is commonly evaluated over 5 or 10 years so that the full economic impact over the life of the system can be estimated.

There are a number of factors that drive the TCO of a UPS :

Primary Tco Factors	Secondary Factors
System cost Installation costs UPS energy efficiency Energy cost Cost of replaceable items Maintenance requirements	Footprint / cost of floor space Cooling requirements / cost of cooling Battery monitoring

A major benefit of the integrated flywheel UPS system is its operating efficiency. Whereas most double-conversion UPS have efficiencies in the range of 92-94 percent, CleanSource UPS operates at 98 percent efficiency at full load. This difference in efficiency can quickly add up to significant cost savings. As an example, for a UPS system protecting a one megawatt load at $0.10 per kilowatt hour, a four percentage point difference in efficiency will result in an annual savings of more than $40,000. Further energy savings are achieved through the elimination of cooling required to maintain a fixed temperature for the battery and to eliminate the waste heat from the UPS inefficiency, adding another $12,000 in savings per year.

The flywheel energy storage itself is a second major source of lifecycle savings. A lead-acid

battery system used with a conventional UPS will typically need to be replaced twice over a 10 year period. On a 675 kW system, each replacement would typically exceed $75,000. By contrast, the flywheel in the CleanSource UPS has a 20-year life, resulting in savings of more than $150,000 in a 10-year period.

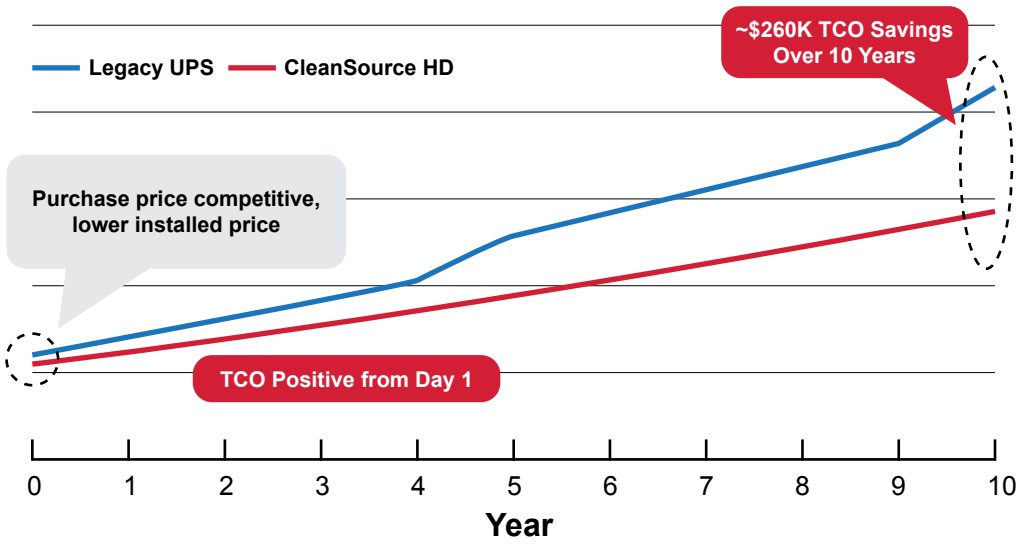

Figure 5. TCO comparison between CleanSource HD UPS and a legacy UPS. Assumptions: 1 MW load with 2N design; CleanSource 750HD: 96% efficient; legacy UPS: 94% efficient, 6 minute VRLA batteries w/ 5 year replacement cycle; $0.10/kWh energy cost

As shown in Figure 5, CleanSource HD delivers more than 50 percent annual operating expenses savings versus an equivalent conventional UPS system, and more than $260,000 in total savings over 10 years. Combined with a competitive first cost, the total lifecycle cost savings of CleanSource UPS and CleanSource HD UPS easily make them the ideal choice for the industrial market.

CleanSource UPS In Action

Pemex Refinación

Pemex Refinación is a subsidiary of Pemex, Mexico's national oil company. Pemex is the world's second largest non-publicly listed company in terms of total market value and the largest oil-producing entity outside of the Middle East. The organization operates re-pumping stations that pump crude oil, gasoline, and diesel to and from various cities across Mexico.

The motors and turbines at Pemex Refinación re-pumping stations contain sensitive controls making quality power critical for efficient operations. With many of the stations in remote areas and located at the end of utility lines, incoming power is poor and unreliable. The re-pumping stations also operate in series and are interdependent of each other – if one pump is down, the others cease pumping as well – magnifying the importance of keeping each station up and running.

Pemex Refinación has deployed more than 20 megawatts of Active Power CleanSource UPS systems across 22 stations in Mexico, effectively protecting the stations' motor loads from power interruptions. The parallel online architecture of CleanSource UPS enables these systems to effectively manage in-rush currents typical of inductive loads. In addition, the battery-free UPS' ability to operate in industrial environments, smaller footprint, and overall lower maintenance costs make it a better solution for Pemex's needs. The rugged and inherently reliable design of CleanSource UPS made it an ideal solution to support these mission critical re-pumping stations, ensuring oil and gas continues to flow and prevents potential revenue loss and equipment damage.

"The lack of consistent and reliable power to support our operations was an ever present management headache before we installed CleanSource UPS. Since installation, we are very pleased with the improvement in our day-to-day operations."

– Mauro Caceres, General Superintendent, Operations

Heineken

Founded in 1864, Heineken International is the third largest brewer in the world and owns more than 190 breweries in more than 70 countries. Heineken brews and sells more than 170 international premium, regional, local, and specialty beers.

One of Heineken's production facilities is located in Saint Denis, Réunion, a French island off the east coast of Africa. Commercial utility power is unreliable causing micro-outages and other electrical disturbances that at times impact production causing downtime and economic loss. Every second of downtime cost the brewer approximately $2 in operating loss, or over $170,000 per day. Heineken required a rugged critical backup power solution insensitive to ambient temperature changes that could be deployed right on the production floor.

Heineken chose to deploy an Active Power CleanSource 750 kVA UPS to protect its sensitive operations from inconsistent utility power. The system was deployed on the facility's production floor without the need for cooling equipment because of its rugged, electromechanical design. A legacy battery UPS would have required additional design and build cost to house batteries in conditioned space which was not an option for the brewer. The solution provides 25 seconds of backup power, enough time for a soft shutdown of the bottling line.

Since installation, CleanSource UPS has experienced hundreds of discharges with no interruption to the customer's production lines. The brewer has since installed CleanSource UPS systems at five more production sites, including Congo and Haiti.

Conclusion

Computerization of the industrial market is changing the philosophy of manufacturing from batch processing to mission critical. Even a small power glitch can have significant implications on the output of a given industrial plant, whether that is a paper mill or water bottling company.

The integrated flywheel UPS system provides significant benefits for these applications. It effectively controls the major causes of downtime such as transients and voltage sags and surges, and protects against complete outages. Further, it is well suited for harsh environments like those of industrial plants. The fact the system can be placed virtually anywhere and in close proximity of the equipment it is protecting is very appealing. Since there are no chemical batteries, strict temperature control is no longer needed. At 98 percent efficiency, there are significant efficiency benefits to be gained, resulting in a lower total cost of ownership than competitive technologies. Finally, the flywheel UPS has been proven to provide significant reliability benefits over battery-based systems, reducing risk of system failure by 80 percent.

The integration of flywheel energy storage into UPS systems industrial and manufacturing facilities addresses the central concerns of these industries. Active Power's CleanSource UPS systems have proven unequivocally to be safer, more reliable, and less costly to own and operate than comparable legacy, battery based UPS systems.

References

[1] EPRI, "An Assessment of Distribution System Power Quality," TR 106249-V2, May 1996.

[2] P. Jones, Avoiding Battery Failure and Outages, DatacenterDynamics, http://www.datacenterdynamics.com/critical-environment/avoiding-battery-failure-and-outages/85881.fullarticle, Apr. 14, 2014.

[3] Active Power White Paper 115, Mitigating Risk of UPS System Failure, http://www.activepower.com/white-paper-115/, Aug. 2014.