power on the fly

Storing electric power has always been a problem, even for short-term use. But new flywheel technology is helping overcome some of the challenges faced by energy intensive facilities such as data centres. By **Johnny Gonzales**.

PROTECTING COMPUTING continuity is serious business. According to the META/Gartner Group, a utility outage costs non-data-intensive businesses about half a million dollars per hour. For specialised financial, manufacturing or other critical services, the cost of split-second voltage sag can run to millions. Strategic Research Group determined downtime cost can exceed $6m per minute, virtually all of which is incurred within the first second of their servers going down.

Managing the infrastructure's power management system plays a critical role in the overall reliability of the enterprise. The power management components you select to protect that infrastructure directly translate into uptime reliability: availability that can make or break a business in less than one second.

The typical approach to mitigate power anomalies in enterprises has been to install one or more uninterruptible power supplies (UPSs), banks of lead-acid batteries, power management software, backup generators, automatic transfer switches and other supporting power devices. Based on real-world failures, managers are scrutinising the weakest point in the power certainty scheme: lead-acid batteries. Frequent and costly battery maintenance and replacement, temperature control issues, space constraints, health and safety dangers, fire hazard permitting, toxic and explosive gas emissions, hazardous material handling, disposal concerns, all on top of high failure rates and poor predictability drive facility and IT managers to consider other viable ways to ensure business continuity.

One of the technologies that has caught the eye of many UPS users is flywheel energy storage systems. Commercial flywheel energy storage systems have been around for over a dozen years. This clean energy storage technology is solving sophisticated power problems that challenge corporate IT and freestanding data centres every day. Flywheels used with double-conversion UPS systems provide reliable mission-critical protection against transients, harmonics, voltage sags and spikes, outages and other damaging power disturbances. The latest generation of UPS flywheel systems is delivering better energy, space and cost efficiencies over first-generation flywheel products, as well as environmental benefits and uptime availability advantages over battery-based UPS systems.

A NEW SPIN

Today, there are two types of flywheels for UPS applications. The first to market is a relatively simple design that yields much higher power density (smaller footprint) than VRLA batteries (which are cheaper and more compact than space- and maintenance-demanding wet-cell types).

Using an 800-pound steel 'puck', each of these first-generation systems replace dozens of UPS batteries, eliminating dedicated HVAC needs, hazmat and safety issues, maintenance, frequent replacement and a lot of floor space. The system can deliver 250kW to protected loads for 13 seconds (longer for lower outputs), providing plenty of time to start and switch over to the UPS's backup generator.

A few years ago, a Los Angeles company developed the next-generation flywheel, a system that is lighter, faster, stronger, smaller and much more energy efficient. Using a fast-spinning, light, but stronger-than-steel carbon-fibre-composite cylinder, these new generation flywheel systems are integrated with major UPS brands sold by industry leaders such as Liebert/Emerson Network Power, Toshiba, Socomec and EHWA Technologies. The award-winning models have been on the market for five years, delivering a lighter, compact and near maintenance-free energy storage solution compared with slow, heavy flywheels.

A flywheel system works like a dynamic battery, storing energy kinetically by spinning a mass about an axis. Electrical input to the motor/generator charges this kinetic battery by spinning the flywheel rotor up to speed. A standby charge keeps it spinning 24/7 until called upon to release the stored energy, at which point the motor/generator regenerates that stored energy.

Energy available and its duration is proportional to the mass of the flywheel and the square of its rotational speed. First-generation flywheels rely primarily on mass. Large mass, however, imposes floor loading and mounting issues, and limits maximum safe rotational speed, hampering energy density (the amount of energy stored versus the device's footprint). With flywheels, doubling mass doubles energy capacity, but doubling rotational speed quadruples energy capacity.

With physics on its side, Pentadyne Power Corporation broke the mould earlier this decade when it commercialised a high-speed, carbon-fibre-composite flywheel system. Instead of mass as the primary source of storage, it takes advantage of rotational speed. The higher the speed, the less the mass needed for any given energy output. The lightweight rotating group makes possible complete, frictionless magnetic levitation of the spinning mass. This assures silent, energy-efficient, vibration-free operation and eliminates the need for power-robbing bearings that require annual services as well as replacement every few years.

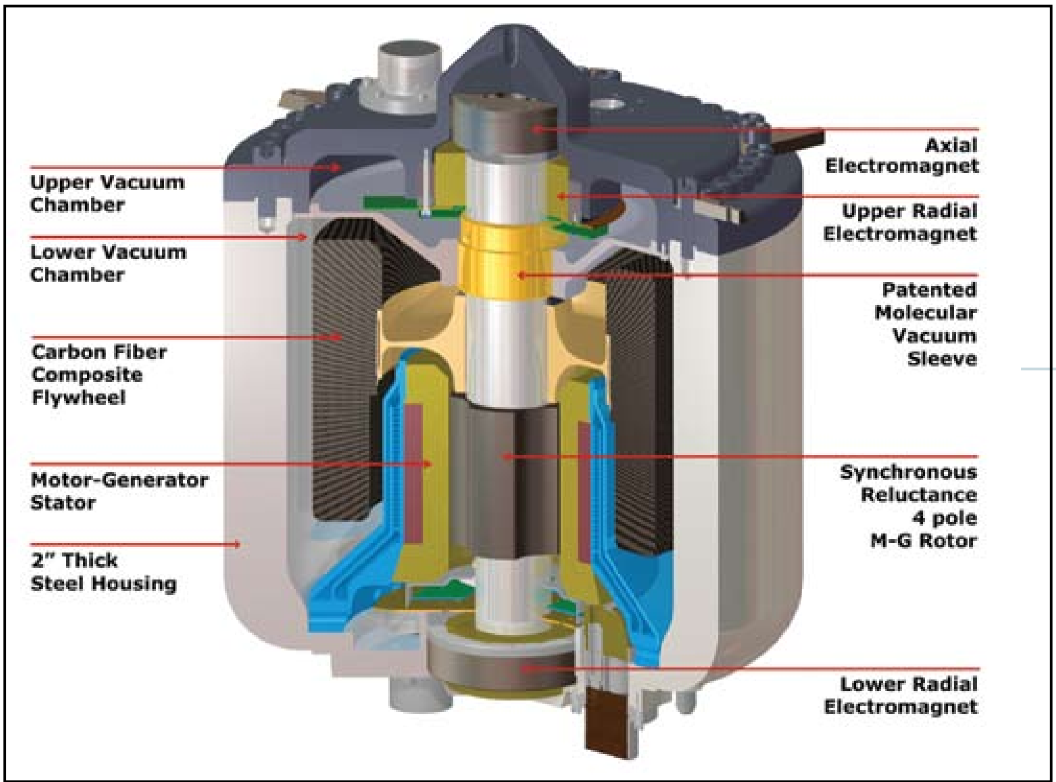
Heavy and light flywheels both spin in a vacuum chamber to reduce aerodynamic drag. Most use a continually running mechanical pump to maintain that vacuum, but the lightweight carbon-fibre offering has a factory-sealed vacuum and employs a patented molecular vacuum sleeve integrated into its central shaft. The fast rotation of the shaft allows helical grooves in the maintenance-free sleeve to maintain high vacuum. It also eliminates oil changes and semi-annual replacements of this costly mechanical point of failure.

POWER QUALITY

Battery-based UPS systems provide high-quality, seamless ride-through power to protected loads in the event of poor utility feed power quality or a power failure. Double-conversion UPS systems eliminate all AC abnormalities by converting AC input into DC, then back again into clean AC fed to the protected loads.

Less common are the line-interactive UPS systems that use filtration and active correction to try to mitigate AC line issues. While they can be three or four points more efficient than double-conversion UPSs, few data centre operators are willing to trim a few dollars off their monthly power bills by taking the risk of correction rather than elimination. What's more, the higher efficiency claims of line-interactive systems only hold true when utility line input is perfect. Problem is, utility input is very often not perfect, and all that extra correction eliminates efficiency gains.

A typical double-conversion UPS uses a string of batteries



Cutaway illustration of Pentadyne flywheel

connected to the DC bus between the rectifier and the inverter. In most cases, less than ten seconds are needed to bridge the gap between sag or collapse of AC input and a gradual load handoff to the backup genset.

Predictability of battery performance, however, is a big issue. Batteries are wired in series and their expected MTBF is little more than 2,000 hours – truly the weakest link of any UPS system.

The only way to know battery state of charge and what will happen when load is suddenly applied is little more than finger crossing. Power management systems provide a guess, but knowing whether batteries will save the day is only after the fact. Like a string of Christmas lights, one battery cell suddenly going bad in a string of VRLA batteries renders the entire string inoperable, resulting in a load crash.

Battery manufacturers state UPS battery life can be maintained as advertised if, and only if, these heat-generating batteries are temperature controlled to a constant 75°F and experience “no excessive cycling”, i.e., they’re not used.

Battery manufacturers say that the major reasons batteries fail are attributable to heat, cold, poor maintenance, corrosion, loose connectors and ripple current. However, the primary source of battery failure is quite simply their usage. Every time the battery is used in a short discharge activity, it experiences a chemical ‘coup de fouet’ or ‘whiplash’ effect, rendering it significantly less capable of operating properly next time.

On the upside, flywheel energy storage systems operating in parallel with battery strings can eliminate the coup de fouet and, when properly specified, all battery usage. The flywheel’s discharge voltage level is set higher than that of the associated battery bank. If the UPS’s DC bus voltage is nominally 540V, and the batteries will discharge at 480V, the flywheel is programmed to support the DC bus if it dips below 520V. Since the flywheel alone will maintain the DC bus through all split-second anomalies, or ride the protected load all the way through to a smooth handoff to the generator, the batteries are isolated and completely redundant.

For data centres – whether freestanding or corporate IT facilities – continuous power is mandatory and such a flywheel-plus-redundant-battery-banks scheme is commonplace.

A flywheel operating in parallel with batteries ‘hardens’ them, increasing longevity and reliability since the flywheel will absorb all short-term anomalies and disturbances, leaving the batteries untouched. In this configuration, the batteries would only be called upon in the event of a genset failing to start. Unfortunately, the few minutes of battery time would be of little help in such a scenario: not enough time to fix the genset and not enough time to ride through a longer outage that would cause uncooled servers to overheat and shut themselves down within two or three minutes of HVAC loss.

Although there is often undue concern about genset starts, the IEEE Gold Book (appendix L, table XII) acknowledges that this is exceptionally uncommon. Compiling six separate studies encompassing a total of 25,000 gensets – both critical (such as hospital generators tested every month) and non-critical (rarely, if ever, tested) – IEEE reports that 99.5 per cent start on the first attempt.

Since genset starting can be made highly reliable, and batteries cannot, many facilities – particularly industrial applications where temperature control is problematic, and at hospitals and other facilities where floor-space is at a premium – flywheel bridging to the genset is an ideal solution to entirely eliminate troublesome batteries. Over the course of its 20-year design life between major service intervals (an onsite replacement of the flywheel module), Pentadyne says that each flywheel cabinet used instead of UPS batteries will eliminate hundreds of gallons of sulphuric acid and more than 15,000lbs of lead.

National and local utility studies confirm electric grid reliability is in decline and that common power disturbances will become more so.

On the other side of the coin, increased use of microprocessors in a large variety of power, control, processes and manufacturing equipment boosts sensitivity to common electric grid power fluctuations.

FLYWHEEL VS. BATTERY

Weaning oneself away from the love-hate relationship with batteries is no easy task. Batteries are a cheap and known commodity, and experienced users are fully aware of their significant shortcomings. Some users even refuse to monitor or test their battery strings, since doing so negatively impacts performance and may hasten a cell failure that will make the entire string useless when called upon to do real-world duty.

Yet the gamble is taken and batteries continue to be installed, along with requirements that include: frequent and costly maintenance; excessive HVAC needs, which introduce further expense and failure issues; expensive monitoring; large footprint; massive weight, limiting siting flexibility; slow recharge; frequent individual cell replacement; second string redundancy to halve failure odds; fire hazard permits, employee safety and OSHA requirements for toxic chemicals and explosive gases; environmental and disposal issues; and an overarching ‘cross-your-fingers’ approach to power reliability

Employing a flywheel instead of UPS batteries reverses the negative impact of each of the above, resulting in: infrequent, low-cost maintenance (near none with carbon fibre flywheels); no temperature control or ventilation requirements; built-in precise monitoring and diagnostics; minimal footprint/high power density; lower weight (much lower with newer flywheels) enabling siting virtually anywhere; rapid recharge functionality; flywheel module not replaced for at least 20 years; redundancy due to poor reliability no longer required; no hazardous materials or dangerous emissions; no disposal issues; a reliable strategy for power reliability

LIFE CYCLE COSTS

While a flywheel system costs about one-and-a-half to two times as much as a similarly sized monitored five-minute VRLA battery bank (the cheapest available), it recovers its cost rapidly, usually in two to three years. Thereafter, the flywheel solution becomes an ongoing source of both power security and cost-containment.

'Based on real-world failures, managers are scrutinising the weakest point in the power certainty scheme: lead-acid batteries'

Over a 20-year design lifespan, the cost savings are in the range of $100,000 per unit deployed – enough to repay the cost of the flywheel several times over.

The cost savings are vastly lower due to the greatly reduced maintenance and replacement needs. For the lowest-maintenance flywheel model on the market, recommended hardware service is just a quick, low-cost capacitor replacement once every six years (52,000 hours), similar to that required by UPS manufacturers.

For the same period, battery strings would need to be replaced five times based upon an optimistic life expectancy of four years. In addition to entire string replacements, there would be a very high number of individual cell replacements (which degrades the entire string), monitoring system costs, temperature control and ventilation expenses, and costs related to battery disposal, space utilisation, fire-hazard permitting, hazardous-materials handling, stored replacement cells, acid spill containment, inspections, OSHA compliance, and – the most costly of all – lack of reliability and resulting downtime.

Energy efficiency is increasingly important and that was one area where most flywheels fall short.

Standby electric usage by the most popular steel flywheel is about 3,500 watts. With the generational leap made by maglev carbon fibre technology, energy efficient high-speed models use less than one-tenth that amount – a mere 300 watts – which is comparable or less than the float charge of a similar sized battery bank. With the elimination of the temperature control and ventilation needs of batteries, energy efficiency of flywheel energy storage is vastly better than that of batteries.

Throughout the US, and around the world, data centres (IDCs and corporate IT), broadcasters, hospitals, laboratories, airports, manufacturers, military facilities and other sites are hardening their battery strings, or eliminating them altogether, by applying flywheel energy storage to their UPS systems.

Data centre design expert Robert McFarlane of leading technology systems specifier Shen, Milsom & Wilke has said: "I'm starting to consider recommending a combination of UPS and flywheels."

Giving up old habits, especially bad ones, does take a little intestinal fortitude. However, those who have taken the plunge are glad they did. John Smith of the NetAlliant data centre in Chattanooga, Tennessee, says: "We take power protection seriously, I hate batteries, they're nothing but trouble." His flywheel system has endured the vagrancies of more than 100 power disturbances a year, all without missing a beat.

Smith – and hundreds of others – are sold on the reliability and performance of their battery-free UPS system and have no plans to look back. ■

■ **Johnny Gonzales is vice president of sales & service for Pentadyne Power Corporation**