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Flywheel UPS Systems

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The management of data centers and the protection of their systems is at the mercy of power reliability. Data centers require uninterrupted power of the highest quality. Power fluctuations, harmonic distortion, frequency variations, and voltage reductions, much less the full loss of power, can be disastrous with serious cost and reputational implications.

Years ago, a data center could undergo an orderly shutdown if there was a disrupting power event. No longer. An orderly shutdown leads to a major outage, because it may take hours to bring servers, storage devices, and the network back online.

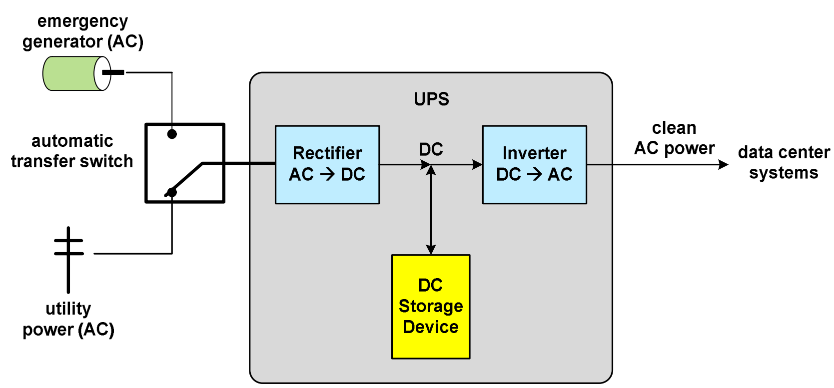
A recent Ponemon Institute survey[1] of almost 600 data centers found that 85% had experienced at least one power failure in the last 24 months. Ninety-one percent of these said that they had experienced unplanned outages as a result of a power failure. Clearly, the reliability of primary utility power is a consideration that must be dealt with.

The need for UPS systems

What Is a UPS System

Power reliability is solved in modern-day data centers with backup generators. However, it takes several seconds for a generator to start up and come online. During this time, a power loss occurs unless there is another source of power that can instantly come online for a time long enough for the generators to begin supplying power.

This other source of power is an Uninterruptible Power Supply (UPS) system. As shown in Figure 1, a UPS contains a rechargeable energy source that is thrown into service when the primary utility power is lost. It provides power to the data center until the backup generators come into service. Should there be a generator failure, the UPS system provides power for a long enough period of time to support an orderly shutdown of



A UPS System
Figure 1

[1] Study of Data Center Outages, *Ponemon Institute;* Sept. 10, 2013

the systems in the data center.

A typical UPS system is shown in Figure 1. Its first job is to clean utility power to the standards required by the data center. To do this, the potentially dirty utility power is fed to a rectifier in the UPS system. The rectifier converts the AC (alternating current) utility power to DC (direct current). This relatively clean power is then converted back to AC by an inverter in the UPS system to provide clean power to the data center.

In the event of a utility power failure, an automatic transfer switch detects the power loss and rapidly connects the UPS rectifier to the emergency generator system. The UPS generates the controls to start the generator and power is restored to the data center.

One problem with this approach is that there will be a several second outage to the data center, which is likely to be disastrous. This is where the 'uninterruptible' in "UPS" comes in. Connected to the DC bus from the rectifier to the inverter in the UPS is a device that stores energy in DC form. When the output of the rectifier fails, the energy from the DC storage device feeds the inverter and keeps power flowing to the data center until the emergency generators can come online. This is typically a time measured in seconds.

In addition to this delay, the automatic transfer switch is often designed to not switch to the backup generator for a few seconds so that brief utility power outages do not deplete the DC energy stored in the DC storage device. Eighty percent of power outages last less than two seconds, and 98% last less than ten seconds.

There are two types of DC storage devices in common use in UPS systems today – batteries and flywheels. Though batteries are the predominant form of DC storage device in use, they have several disadvantages that are overcome by flywheel storage devices.

Disadvantages of Battery Systems

Battery storage systems have not proven to be reliable. The Ponemon study referenced above found that 55% of respondents blamed battery failure as the root cause of an outage due to a primary power failure. Human error came in second.

A typical data center operating on one megawatt of power will have about five strings of 40 batteries each. This is a total of 200 batteries. The failure of any one battery will take its string out of service. With one string out, there may not be enough backup energy to provide data center power for the time it takes to get the generators online. This will cause a data center outage. Statistics show that 70% of UPS service calls are the result of bad batteries. 40% of cases where power was lost to a critical load were the result of battery failures.

As a battery ages, its internal resistance goes up. This prevents the battery from delivering its rated power. In many cases, the pending failure of a battery cannot be detected until the battery is called upon to deliver power.

Some other disadvantages of batteries include:

- Environmental hazards (lead-acid batteries contain led plates and sulfuric acid and must be disposed of properly).
- The continuing replacement cost of batteries.
- Large space demands.
- Fire hazard and explosion (the Planet experienced a battery-room explosion that took its data center down for four days[2]).

[2] The Planet Blows Up, *Availability Digest*; September 2008. http://www.availabilitydigest.com/public_articles/0309/planet_explosion.pdf

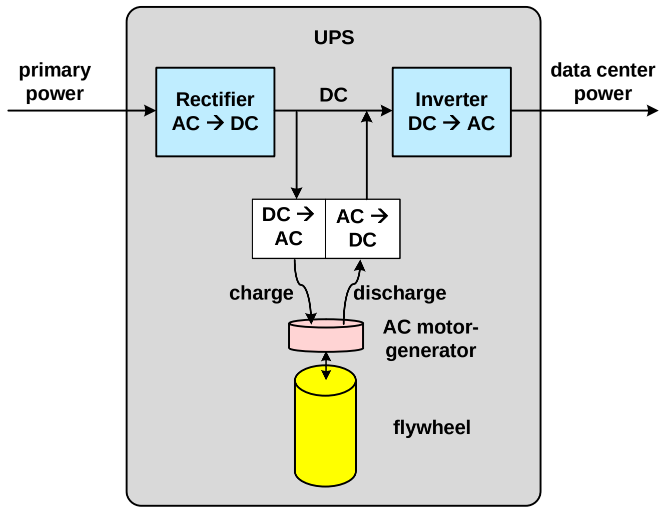
- Cooling requirements (batteries degrade if not cooled properly).
- The requirement for excessive amounts of testing, monitoring, and maintenance.

How a Flywheel UPS Works

A flywheel solves many of the problems associated with batteries. A flywheel can store energy just like a battery. The primary difference is that a flywheel stores kinetic energy whereas a battery stores electrical energy.

A flywheel is a disk that is spun up to a very high speed, typically in a vacuum to reduce drag. Once it reaches its operating speed, it takes very little additional energy to maintain the speed. Current flywheel technology results in flywheel UPSs that are up to 98% efficient. That is, it takes only about 2% of the delivered power of the UPS to maintain the speed of a flywheel (in battery terminology, to keep it fully charged).

The flywheel is connected to the DC bus via a generator. Should the main power fail, the generator driven by the flywheel continues to deliver DC energy to the inverter and maintain the data center power until the backup generators can come online. In battery terminology, this is the discharge of energy from the flywheel.



A Flywheel UPS
Figure 2

In principle, a DC motor-generator is used. However, DC motor-generators require brushes and commutators that are subject to wear and require maintenance. To solve this challenge, an AC motor-generator, which does not have these problems, is often used as shown in Figure 2,. To interface the AC motor-generator to the DC bus of the UPS, an inverter is used to convert the UPS DC bus voltage to AC, which is then used to drive the AC motor-generator working as a motor to charge the flywheel. If the primary power fails, the energy in the flywheel is used to drive the AC motor-generator as a generator. Its AC output is converted to DC via a rectifier and is used to power the data center until the generators can be brought online.

The amount of energy stored in a flywheel is proportional to the mass of the flywheel and to the square of its speed. Therefore, it makes engineering sense to trade mass for speed. Early flywheel UPSs used steel disks and rotated at speeds in the order of 7,000 rpm. Newer flywheels use relatively light-weight carbon filaments that have a great deal more tensile strength than steel. These flywheels are spun at tens of thousands of rpms (a flywheel system from Vycon Energy spins at 37,000 rpm).

Equally important, the light mass of fiber filament flywheels means that they can be suspended by magnetic bearings, as opposed to the mechanical bearings of older flywheels. The older mechanical bearings required periodic maintenance and replacement. Magnetic bearings are maintenance-free.

Most flywheel systems come with a remote monitoring capability. As opposed to batteries, it is easy to measure the charge stored in a flywheel system. It is basically just the speed of rotation.

A single flywheel system can deliver several hundred kilowatts of power. In fact, some existing commercial systems provide over a megawatt of power. Think about it – 200 batteries can be replaced with one flywheel system!

This power can be delivered for times ranging from seconds to minutes depending upon how much power must be delivered by the flywheel compared to its capacity. Figure 3 shows a typical range of power usage versus UPS time for a series of products from Vycon Energy.

VDC-XE

UPS Output Power Rating (kVA)

Number of Flywheels	40	60	80	100	120	160	225	300	400	600	750	1100
1	105	71	53	42	34	24	13	7				
2			102	82	68	51	36	26	16	7		
3						77	55	41	30	16	10	
4	Run time in seconds							54	41	25	18	8
5									51	34	25	13
6										41	32	19

Vycon Energy

Flywheel Discharge Time versus Power Output
Figure 3

For maximum availability, flywheel systems can be installed in *n+m* configurations, where *n* is the number of flywheels needed to obtain the desired power, and *m* is the number of spares. All flywheels feed the data center with power. If one flywheel fails, there are enough other flywheels to maintain power. These configurations also allow a flywheel to be taken offline for its occasional maintenance (in most cases, only once every several years).

Advantages of a Flywheel UPS

Flywheel UPSs have several advantages over battery UPSs:

- Instead of dozens of 100-pound containers of lead plates suspended in sulfuric acid, flywheel UPSs contain no noxious materials that must be disposed of properly.
- Flywheels charge (come up to speed) much faster than batteries. Typical charge time for a flywheel is a few minutes. Batteries can take hours to charge. Consequently, flywheels are more adept at handling sequential power outages, a frequent occurrence.
- Flywheel UPSs do not need a special battery room to vent explosive battery fumes.
- Flywheel UPSs have a smaller footprint than battery UPSs. Some manufacturers claim a savings in floor space of 75%.
- Flywheel UPSs require significantly less maintenance than battery UPSs. There is no need to periodically replace batteries.
- The typical life for a flywheel UPS is twenty years. (Caterpillar claims a 65-year MTBF for its CAT UPS systems when delivering full power.)
- It is easy to measure the charge stored in a flywheel by simply measuring its rotation speed. It is difficult to measure the charge stored in a battery system.

- Flywheel energy efficiency is generally greater than battery efficiency (though both are in the 90% range).

- Flywheels can operate over a much wider temperature range than batteries and therefore need less cooling.

Where to Get One

There are many vendors of flywheel UPSs. The following list is only a smattering of flywheel UPS vendors:

Vycon Energy http://vyconenergy.com/
Caterpillar CAT http://www.cat.com/en_US/power-systems/electric-power-generation/ups-flywheel.html
Active/Power http://www.activepower.com/upssystems
POWER*THRU* http://www.power-thru.com
Hitec http://www.hitec-ups.com/
Eaton http://powerquality.eaton.com/products-services/accessories/Flywheel.asp
Beacon Power http://beaconpower.com/

Summary

An uninterruptible power supply is a requirement for modern-day data centers to ensure that the data center systems continue to operate during a primary power failure until the backup generators can be brought online. The classic UPS uses lead-acid batteries to provide several seconds of power to the data center while the backup generators are brought into service.

However, battery-based UPS systems face several challenges. They use lead-acid batteries that are not environmentally friendly. They are not as reliable as one would like – 55% of respondents to a survey indicated that battery failure was the root cause of most of their data center outages due to the loss of primary power. They are expensive to maintain and generally require a specially-constructed battery room. They are difficult to monitor and to detect bad batteries that should be replaced.

The newer flywheel-based UPS systems solve these challenges. They are virtually maintenance-free with MTBFs measured in years. Monitoring of flywheel health is simple as only the speed of rotation need by measured. There are many vendors of flywheel UPSs capable of delivering over a megawatt of power per UPS. Flywheels may well be the future of UPS systems.

Acknowledgements

Information for this article was taken from the following sources:

Maintaining the Long Term Reliability of Critical Power Systems, *Schneider Electric White Paper*; December 2010.
Battery Failure, Human Error Still Cause Most Data Center Outages, *Government Technology*; September 17, 2013.
Greening the Data Center: Flywheels and True IT Efficiency, *Data Center Journal*; October 12, 2013.
Next-Generation Data Center, *Network Computing*; October 21, 2013.
Flywheels, *Wikipedia*.
Various vendor websites.