



Online Continuing Education for Professional Engineers  
Since 2009

# Energy Storage – Flywheel Systems

PDH Credits:

**1 PDH**

Course No.:

**ESF101**

Publication Source:

**US Dept. of Energy**  
(EERE) #DOE/EE-0286

Release Date:

Sept. 2003

**DISCLAIMER:**

All course materials available on this website are not to be construed as a representation or warranty on the part of Online-PDH, or other persons and/or organizations named herein. All course literature is for reference purposes only, and should not be used as a substitute for competent, professional engineering council. Use or application of any information herein, should be done so at the discretion of a licensed professional engineer in that given field of expertise. Any person(s) making use of this information, herein, does so at their own risk and assumes any and all liabilities arising therefrom.



**Leading by example,  
saving energy and  
taxpayers dollars  
in federal facilities**

## Flywheel Energy Storage

*An alternative to batteries for uninterruptible power supply systems*

### Executive Summary

Flywheels have been around for thousands of years. The earliest application is likely the potter's wheel. Perhaps the most common application in more recent times has been in internal combustion engines. A flywheel is a simple form of mechanical (kinetic) energy storage. Energy is stored by causing a disk or rotor to spin on its axis. Stored energy is proportional to the flywheel's mass and the square of its rotational speed.

Advances in power electronics, magnetic bearings, and flywheel materials coupled with innovative integration of components have resulted in direct current (DC) flywheel energy storage systems that can be used as a substitute or supplement to batteries in uninterruptible power supply (UPS) systems. Although generally more expensive than batteries in terms of first cost, the longer life, simpler maintenance, and smaller footprint of the flywheel systems makes them attractive battery alternatives.

### Application Domain

Batteries for UPS application are typically sized for about 15 minutes of full load power. However, the vast majority of power disturbances last for 5 seconds or less. Today, many UPS systems are integrated with fuel-fired generators that can come up to full power within 10 seconds. Thus, the typical DC flywheel system, designed to provide 15 seconds of full load power, could be substituted for batteries in UPS systems with fuel-fired generators. Otherwise, DC flywheel systems could be used in combination with batteries. Frequent discharging and recharging is much more harmful to battery life than flywheel life. Most power disturbances could easily be handled by a DC flywheel system, saving the batteries for longer outages and significantly increasing battery life. A flywheel could also be used alone for applications where longer-term backup capability is not required or economically justified.

### Variations

In general, flywheels can be classified as low speed or high speed. The former operate at revolutions per minute (rpm) measured in thousands, while the latter operate at rpm measured in the tens of thousands. As noted above, doubling the rpm quadruples the stored energy, all else equal, so increasing rpm significantly increases the energy density of a flywheel. Operating at higher rpm necessitates fundamental differences in design approach. While low-speed flywheels are usually made from steel, high-speed flywheels are typically made from carbon or carbon and fiberglass composite materials that will withstand the higher stresses associated with higher rpm. Higher rpm also creates greater concern with friction losses from bearings and air drag. High-speed flywheels universally employ magnetic bearings and vacuum enclosures to reduce or eliminate the two sources of friction. Magnetic bearings allow the flywheel to levitate, essentially eliminating frictional losses associated with conventional bearings. While some low-speed flywheels use only conventional mechanical bearings, most flywheels use a combination of the two bearing types. Vacuums are also employed in some low-speed flywheels.

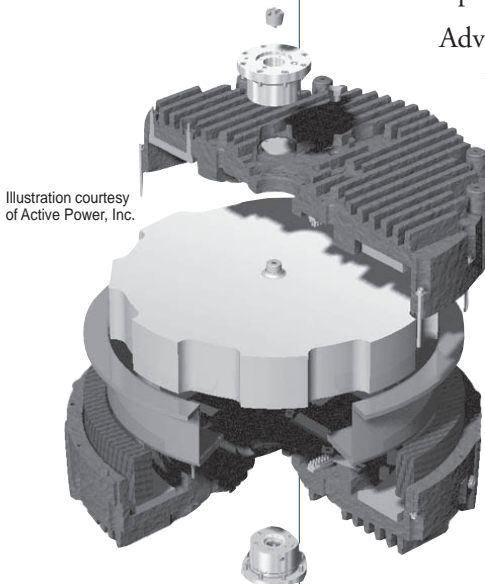


Illustration courtesy  
of Active Power, Inc.

**Flywheel energy storage  
technologies provide reliable  
backup power with many  
attractive features compared  
with conventional battery  
technologies.**

**Bringing you a prosperous  
future where energy  
is clean, abundant, reliable,  
and affordable**



## Where to Apply

DC flywheel energy storage systems are generally more reliable than batteries, so applicability is mostly an issue of cost-effectiveness. Batteries will usually have a lower first cost than flywheels, but suffer from a significantly shorter equipment life and higher annual operation and maintenance expenses. Thus, flywheels will look especially attractive in operating environments that are detrimental to battery life, such as:

- Frequent cycling stemming from main power supply problems.
- High operating temperatures associated with unconditioned space.

Flywheels have a much higher power density<sup>a</sup> than batteries, typically by a factor of 5 to 10. Therefore, the following conditions are also particularly attractive for flywheels.

- Floor space is expensive and has alternative uses.
- Battery floor space must be reclaimed for other purposes to the extent possible.

## What to Avoid

UPS batteries are sized to provide backup power for periods measured in minutes. The period ranges from about 5 minutes up to around 1 hour, but is commonly about 15 minutes. A period of 15 minutes, more or less, is generally presumed adequate to allow an orderly shutdown of equipment. Flywheels, on the other hand, provide

backup power for periods measured in seconds. The backup period for flywheels is commonly about 15 seconds. This is enough time to allow the flywheel to handle the majority of power disruptions that last for 5 seconds or less and still have time to cover slightly longer outages until a backup generator can come up to full power (generally in 10 seconds). However, a flywheel alone will not provide backup power for a period long enough to allow an orderly process shutdown in most cases. Therefore, the following limitations should be considered.

- Flywheels should not be used alone for backup power, without batteries and/or a fuel-fired generator.
- Flywheels should not be used without batteries if a fuel-fired generator cannot reliably come up to full power in 10 seconds or less.

## Conclusion

Flywheels appear poised to replace or supplement batteries as a backup power supply in UPS systems. Six companies currently offer DC flywheel energy storage products. Another half dozen or so are developing products they expect to bring to market within the next few years. Still others offer products where the flywheel is an integral part of the UPS system rather than being a direct substitute for batteries.

The current array of available DC flywheel energy storage products includes low-speed, unenclosed steel rotors with

conventional bearings at one end of the spectrum and high-speed, composite material rotors operating in a vacuum with magnetic bearings at the other end of the spectrum. Intermediate products with elements of these two endpoints also exist. It's not clear yet whether the UPS application will move toward one end of the technology spectrum or the other. Different design approaches may each find their niche within the UPS application market.

Although currently developed DC flywheel energy storage systems offer significant advantages over batteries, the number of companies currently offering products, and an equal or greater number developing products, suggests that further product development and enhancement is likely to occur. Coupled with seemingly ever increasing needs for more reliable, higher quality power, the long-run prospects for flywheel energy storage in UPS applications looks good.

Flywheels will be a strong alternative to batteries in UPS systems with generators that can reliably come on line in 10 seconds or less. Otherwise, flywheels could be used to supplement batteries, thereby significantly extending battery life and increasing UPS system reliability. Although the initial cost of a flywheel is typically greater than batteries it would be replacing or supplementing, its longer life and simpler maintenance will often result in lower life-cycle costs.

<sup>a</sup> Power density is the power output per square foot of building floor space.

## Disclaimer

This report was sponsored by the United States Department of Energy, Office of Federal Energy Management Programs. Neither the United States Government nor any agency or contractor thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency or contractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency or contractor thereof.

# Contents

- Abstract ..... 2
- About the Technology ..... 2
  - Application Domain
  - Energy-Saving Mechanism
  - Other Benefits
  - Variations
  - Installation
- Federal Sector Potential ..... 4
  - Estimated Savings and Market Potential
  - Laboratory Perspective
- Application ..... 5
  - Application Screening
  - Where to Apply
  - What to Avoid
  - Equipment Integration
  - Maintenance Impact
  - Equipment Warranties
  - Costs
  - Utility Incentives and Support
  - Additional Considerations
- Technology Performance ..... 6
  - Peterson Air Force Base
  - Fort Monmouth
  - Dallas VA Medical Center
- Case Study ..... 7
  - Life-Cycle Cost Comparison
  - Battery Costs
  - Flywheel Costs
- The Technology in Perspective ..... 9
  - The Technology’s Development
  - Relation to Other Technologies
  - Technology Outlook
- Manufacturers ..... 9
- Who is Using the Technology ..... 10
- For Further Information ..... 10
- Appendix A Federal Life-Cycle Costing Procedures and the BLCC Software ..... 11
- Appendix B NIST BLCC 5.1-02: Comparative Analysis ..... 12

**Abstract**

DC system flywheel energy storage technology can be used as a substitute for batteries to provide backup power to an uninterruptible power supply (UPS) system. Although the initial cost will usually be higher, flywheels offer a much longer life, reduced maintenance, a smaller footprint, and better reliability compared to a battery. The combination of these characteristics will generally result in a lower life-cycle cost for a flywheel compared to batteries.

Flywheels intended for UPS application (see Figure 1) are typically designed to provide power at their maximum rate for a period of about 15 seconds. In contrast, most batteries for UPS applications are designed to provide their maximum-rated power for about 15 minutes. Therefore, using a flywheel instead of batteries will generally require a generator that can come up to full power within about 10 seconds, which is well within the capabilities of standby generators.

With or without a standby generator, flywheels could be used to significantly extend battery life and reliability. The vast majority of power quality events last 5 seconds or less. A flywheel could be added to an existing battery-backed UPS system and controlled so that the flywheel provides backup power for short-duration events while the battery is saved for longer outages. Such an approach plays to the inherent strengths of each technology, that is, flywheels are highly tolerant to frequent cycling (while batteries are not) and batteries can provide power for a longer period.

The first section of this report describes the technology, its variations, and installation requirements. The next three sections describe the market for the technology, application advice, and descriptions of the experiences of several federal users. One federal application is highlighted as a “case study,” followed by an illustrative life-cycle cost comparison of batteries and flywheels. Latter sections list manufacturers, selected federal users, and reference

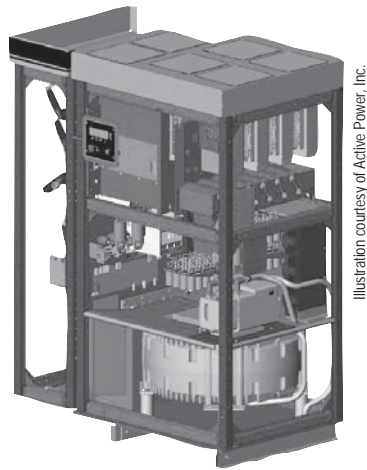


Illustration courtesy of Active Power, Inc.

**Figure 1.** A flywheel (lower right), integrated with UPS system.

materials. Life-cycle costing procedures and results are presented in appendixes.

**About the Technology**

Flywheels have been around for thousands of years. The earliest application is likely the potter’s wheel. Perhaps the most common application in more recent times has been in internal combustion engines. A flywheel is a simple form of mechanical (kinetic) energy storage. Energy is stored by causing a disk or rotor to spin on its axis. Stored energy is proportional to the flywheel’s mass (more accurately, its mass moment of inertia) and the square of its rotational speed.

Flywheels are not new to the power quality market either. Motor-generator

pairs have been used for years as a means to isolate electric loads from electricity supply disturbances. Flywheels have been incorporated into these devices, as shown in Figure 2, to increase rotary inertia, hence the tolerable disturbance period. The usefulness of flywheels directly connected in this manner is limited because the frequency of the electricity generated drops in proportion to flywheel rpm as energy is extracted from the flywheel. Intolerance to significant frequency variation will typically limit such devices to less than 1 second of backup power and only use a few percent of the flywheel’s stored energy.

More effective use of flywheel technology in power quality applications requires some means of disconnecting the kinetic energy stored in its rotating mass from the electric energy demands of the load being served. The addition of rectifier and inverter components to the above system, as shown in Figure 3, allows voltage and frequency control while using up to 75% of the energy stored in the flywheel. Adding variable speed drive increases system efficiency and allows the use of a smaller motor. However, the multi-component system shown in Figure 3 had historically been too cumbersome and/or too expensive.

Advances in electronic power conversion and control technology, coupled with innovative integration of the components depicted in Figure 3, have resulted in DC flywheel energy storage systems

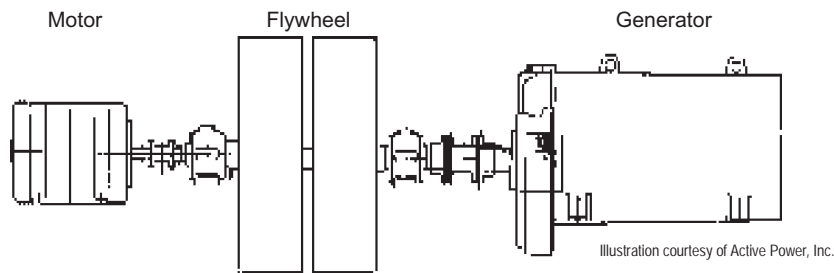


Illustration courtesy of Active Power, Inc.

**Figure 2.** Motor-generator with flywheel.

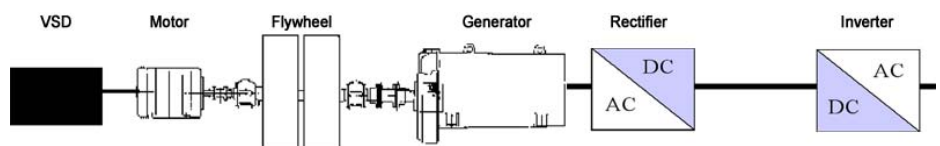


Illustration courtesy of Active Power, Inc.

**Figure 3.** Motor-generator with flywheel and power electronics.

that can be used as a substitute or supplement to batteries in UPS systems. Although generally more expensive than batteries in terms of first cost, the longer life, simpler maintenance, and smaller footprint of the flywheel systems makes them attractive battery alternatives. The substitution or augmentation of batteries within a UPS system is illustrated in Figure 4.

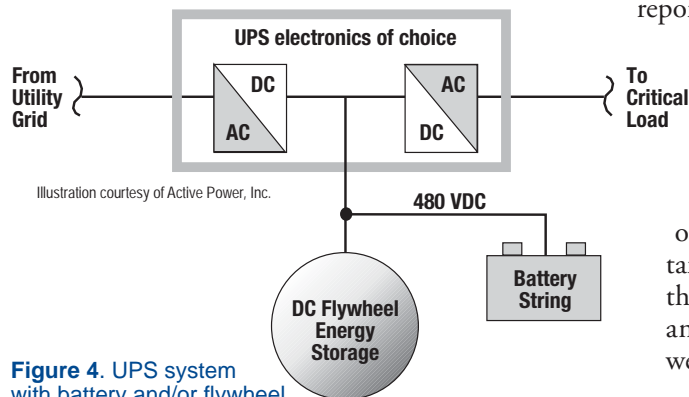


Figure 4. UPS system with battery and/or flywheel.

### Application Domain

DC flywheel energy storage systems could potentially be used anywhere batteries are currently used in UPS systems. Batteries for UPS application are typically sized for about 15 minutes of full load power. Historically, this period was determined by the time required for the systems being protected to come to an orderly shutdown, should power be lost for an extended period of time. Today, many UPS systems are integrated with fuel-fired generators that can come up to full power within 10 seconds. Thus, the typical DC flywheel system, designed to provide 15 seconds of full load power, could be substituted for batteries in UPS systems with fuel-fired generators. Otherwise, DC flywheel systems could be used in combination with batteries. Frequent discharging and recharging is much more harmful to battery life than flywheel life. However, the vast majority of power disturbances last for 5 seconds or less. These disturbances could easily be handled by a DC flywheel system, saving the batteries for

longer outages and significantly increasing battery life. A flywheel could also be used alone for applications where longer-term backup capability is not required or economically justified.

At least six companies currently offer DC flywheel energy storage systems, with another seven companies developing the technology.<sup>1</sup> Collectively, several hundred units were reported by manufacturers to have been installed as of fall 2002. Of these, approximately a dozen were at federal facilities. Most of these were at military installations, but the State Department and Veterans Affairs were also customers.

### Energy-Saving Mechanism

Flywheels, like batteries, are energy storage devices. Neither is designed to reduce energy consumption; instead, both are designed to provide backup power when the normal supply is lost. Both types of storage devices experience standby losses associated with maintaining the storage unit in a fully charged condition. Losses also occur as energy is charged and discharged, but this loss mechanism is relatively unimportant in a UPS application, where the storage devices are not frequently charging and discharging. Standby losses for flywheels range from about 0.1 to 1.0 % of rated power. This includes recharging power to overcome frictional losses plus auxiliary equipment. Battery standby losses, also known as float power, also vary, but are roughly one-tenth of that for flywheels.

### Other Benefits

While batteries can supply backup power for a significantly longer period than a flywheel and consumes less standby power, most other characteristics favor a flywheel.

- The design life for a flywheel is typically about 20 years, while most batteries in UPS applications will only last 3 to 5 years.
- Batteries must be kept within a narrow operating temperature range typical of space-conditioning requirements for people, while flywheels are tolerant of normal outdoor ambient temperature conditions.
- Frequent cycling has little impact on flywheel life. In contrast, frequent cycling significantly reduces battery life.
- Flywheel reliability is 5 to 10 times greater than a single battery string or about equal to two battery strings operating in parallel.
- Flywheels are more compact, using only about 10 to 20% of the space required to provide the same power output from batteries.
- Flywheels avoid battery safety issues associated with chemical release.
- Flywheel maintenance is generally less frequent and less complicated than for batteries.

### Variations

Many design variations exist in the flywheels currently available and those being developed for UPS application. In general, flywheels can be classified as low speed or high speed. The former operate at revolutions per minute (rpm) measured in thousands, while the latter operate at rpm measured in the tens of thousands. As noted above, doubling the rpm quadruples the stored energy, all else equal, so increasing rpm significantly increases the energy density of a flywheel. Operating at higher rpm necessitates fundamental differences in design approach. While low-speed flywheels are usually made from steel, high-speed flywheels are typically made from carbon or carbon and fiberglass composite materials that will withstand the higher stresses associated with higher rpm. Higher rpm also creates greater concern with friction losses from bearings

<sup>1</sup> Contact information for companies currently offering or developing DC flywheel energy storage systems, and companies with other UPS products incorporating flywheels are listed later in this report.

and air drag. High-speed flywheels universally employ magnetic bearings and vacuum enclosures to reduce or eliminate the two sources of friction. Magnetic bearings allow the flywheel to levitate, essentially eliminating frictional losses associated with conventional bearings. While some low-speed flywheels use only conventional mechanical bearings, most flywheels use a combination of the two bearing types. Vacuums are also employed in some low-speed flywheels. Currently available DC flywheel energy storage systems are shown in Figures 5 through 8.

**Installation**

Flywheel installation is relatively simple. Most require hardware to attach the flywheel to a concrete slab. All require

cabling to connect to the DC bus of the UPS system and a DC disconnect switch to allow servicing. 120 V AC service is required for most flywheel systems to operate auxiliary equipment such as vacuum pumps. Some require a higher voltage AC service for recharging the flywheel. Care must be taken to select a DC flywheel system with an output voltage that matches the UPS system DC bus voltage. The UPS manufacturer should be consulted to ensure electrical compatibility.

**Federal Sector Potential**

The UPS system market grew at double-digit rates during most of the 1990s, before slowing in the more recent years in response to the general economic slowdown. Increasing demands for more reliable and/or higher quality power are likely to maintain strong growth in this market, especially as the economy recovers. The federal government, responsible for a broad spectrum of critical services, represents about 5% of the total UPS market in the United States.

**Estimated Savings and Market Potential<sup>4</sup>**

The primary attractions of flywheels in UPS applications are not energy savings. Instead, flywheels offer the possibility of improved UPS system reliability and reduced life-cycle costs.

The UPS market in the United States is worth about \$2 billion per year. Of this, about 20% is spent on systems 50 kVA and larger, where flywheels are potentially applicable. As noted above, the federal government represents about 5% of the U.S. market. Therefore, the federal market for larger UPS systems is about \$20 million. This is roughly equivalent to 40 MVA of new or replacement systems each year. The current installed stock is estimated to be about 10 times this or 400 MVA.

As discussed further below, flywheels are usually envisioned as an alternative to batteries in a UPS system with a reliable generator, but could also be used as a supplement to batteries to increase system reliability and significantly extend battery life. Therefore, flywheels are generally applicable to all of the markets identified above for UPS systems 50 kVA and above.

**Laboratory Perspective**

Flywheels appear poised to replace or supplement batteries as a backup power supply in UPS systems. Commercial

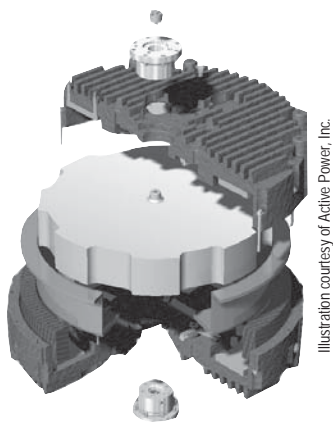


Illustration courtesy of Active Power, Inc.

**Figure 5. Active Power flywheel.<sup>2</sup>**

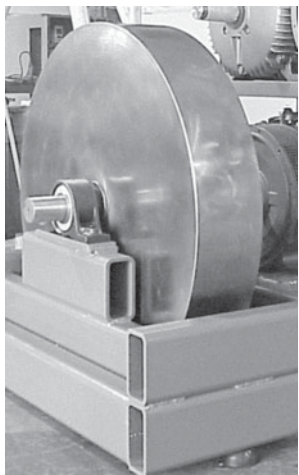


Photo courtesy of Design Power Solutions, Inc.

**Figure 6. Designed Power Solutions flywheel.**

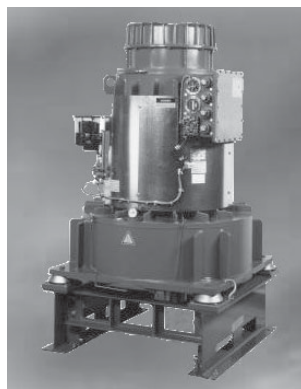


Photo courtesy of Piller, Inc.

**Figure 7. Piller flywheel.**

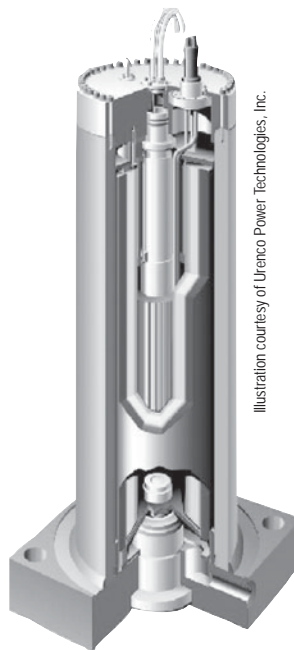


Illustration courtesy of Urenco Power Technologies, Inc.

**Figure 8. Urenco Power Technologies flywheel.<sup>3</sup>**

<sup>2</sup> The Active Power flywheel is also used in products sold by Caterpillar and Powerware, so separate illustrations are not provided for these companies.

<sup>3</sup> The Urenco Power flywheel is also marketed by Beacon Power, so a separate illustration is not provided for the latter company.

<sup>4</sup> Based on data provided by Active Power, Inc.

products are currently offered by several vendors, and several additional vendors are planning to enter the market in the near future. Such competition should facilitate further technology improvements and/or cost reductions over time. Flywheels will be a strong alternative to batteries in UPS systems with generators that can reliably come on line in 10 seconds or less. Otherwise, flywheels could be used to supplement batteries, thereby significantly extending battery life and increasing UPS system reliability. Although the initial cost of a flywheel is typically greater than the batteries it would be replacing or supplementing, its longer life and simpler maintenance will often result in lower life-cycle costs.

## Application

This section addresses the technical aspects of applying DC flywheel energy storage. The conditions in which the technology can be best applied are addressed. The advantages, limitations, benefits, and concerns with applying DC flywheel energy storage are described. Design and integration considerations for the technology are discussed, including equipment and installation costs, installation requirements, and maintenance impacts.

### Application Screening

DC flywheel energy storage could be applied anywhere batteries are currently used to provide backup power for a UPS system. The flywheel could be used as either a substitute or supplement for batteries. Like batteries, DC flywheel energy storage is designed to connect to the DC bus of a UPS system. The technology is not applicable to power management technologies lacking a DC bus, such as a simple motor-generator device.

### Where to Apply

DC flywheel energy storage systems are generally more reliable than batteries, so applicability is mostly an issue of

cost-effectiveness. Batteries will usually have a lower first cost than flywheels, but suffer from a significantly shorter equipment life and higher annual operation and maintenance expenses. Thus, flywheels will look especially attractive in operating environments that are detrimental to battery life, such as:

- Frequent cycling stemming from main power supply problems.
- High operating temperatures associated with unconditioned space.

Flywheels have a much higher power density than batteries, typically by a factor of 5 to 10. Therefore, the following conditions are also particularly attractive for flywheels.

- Floor space is expensive and has alternative uses.
- Battery floor space must be reclaimed for other purposes to the extent possible.

### What to Avoid

UPS batteries are sized to provide backup power for periods measured in minutes. The period ranges from about 5 minutes up to around 1 hour, but is commonly about 15 minutes. A period of 15 minutes, more or less, is generally presumed adequate to allow an orderly shutdown of equipment. Flywheels, on the other hand, provide backup power for periods measured in seconds. The backup period for flywheels is commonly about 15 seconds. This is enough time to allow the flywheel to handle the majority of power disruptions that last for 5 seconds or less and still have time to cover slightly longer outages until a backup generator can come up to full power (generally in 10 seconds). However, a flywheel alone will not provide backup power for a period long enough to allow an orderly process shutdown in most cases. Therefore, the following limitations should be considered:

- Flywheels should not be used alone for backup power, without batteries and/or a fuel-fired generator.

- Flywheels should not be used without batteries if a fuel-fired generator cannot reliably come up to full power in 10 seconds or less.

### Equipment Integration

Where a reliable fuel-fired backup generator exists, DC flywheel energy storage can be directly substituted for batteries at the DC bus of the UPS system. As previously described, installation is relatively simple, consisting mostly of physical attachment to the floor, connection via cabling to the DC bus, and provision of AC service for auxiliary loads (e.g., vacuum pump) and (for some models) recharging power. Care must be taken to match the voltage range of the DC bus with that for the flywheel. A mismatch would require selection of a different model or a custom-built model. Careful consideration should also be given to the backup power period required. This period will vary depending on the specific characteristics of the existing generator and UPS system. Both UPS and generator manufacturers should be consulted to ensure electrical compatibility.

### Maintenance Impact

DC flywheel energy storage maintenance requirements vary depending on the specific flywheel design features, but are generally less frequent and less expensive than for batteries. Although modern valve regulated lead acid (VRLA) batteries do not require monitoring and maintenance of electrolyte fluid levels, manufacturers generally recommend quarterly inspections to check the tightness of connections, remove corrosion, measure voltages, and check for cracks and swells in the battery cases. Periodic replacement of individual batteries will likely be required, while replacement of the entire battery system can be expected about every 4 years<sup>5</sup>. Common routine maintenance items for flywheels are changing cabinet air filters and checking

<sup>5</sup> Battery life varies greatly depending on the duty cycle and operating temperature experienced. Powerware reports an average of 3.7 years for battery storage systems it provides as part of UPS systems.



vacuum pump oil level every few months. The vacuum pump oil should be changed once a year. Magnetic bearings require no maintenance, while replacement of mechanical bearings is expected every 3 to 10 years, depending on the flywheel design. The vacuum pump will also likely need replacing every 5 to 10 years. Otherwise, most flywheels have a design life of about 20 years, but will probably last longer with regular maintenance.

### Equipment Warranties

A 1-year warranty covering parts and labor is most common, but two flywheel manufacturers provide 2-year and 5-year warranties as part of their standard package. Extended warranties are generally available for a premium charge above the standard purchase price.

### Costs

Flywheel purchase costs will vary from \$100/kW to \$300/kW. The lower end of the range represents larger and/or lower rpm models, while smaller and/or higher rpm models will have higher per kW costs. Installation is relatively simple and inexpensive, typically running about \$20/kW to \$40/kW, including an allowance for electrical connections. Operating and maintenance costs will generally be modest, but vary significantly depending on the type of flywheel and maintenance approach. Routine maintenance (see description above) is minimal and simple, and could be handled by existing maintenance staff for a few \$/kW/year. Service contracts are offered by some vendors for about \$5/kW/year, which may be more expensive than using internal staff, but may also include 24/7 response and extended warranties. Bearing replacement for lower rpm flywheels with mechanical bearings will cost from \$5/kW to \$15/kW, depending on flywheel design. Replacing the vacuum pump, where required, will likely cost about \$5/kW. The expected replacement periods for bearings and vacuum pumps were noted above. Standby power consumption will run about \$5/kW/year for lower rpm flywheels

using mechanical bearings or combinations of mechanical and magnetic bearings, but generally about 1/10th of this for higher rpm flywheels using only magnetic bearings.

VRLA battery purchase costs, measured in \$/kWm (dollars per kilowatt-minute), decrease with increasing minutes at the same kW rating, but increase for the same battery discharged at higher kW. The combined effect is that \$/kWm is roughly constant for the same number of minutes at different kW. Purchase costs are roughly \$17/kWm for 5 minutes of backup power, dropping to about \$13/kWm, \$10/kWm, and \$8/kWm for 10, 20, and 30 minutes of backup power, respectively. Battery cabinet costs are included in these estimates. VRLA battery installation, like flywheels, is also relatively simple and should be in the same cost range per kW. Routine maintenance requirements for batteries are more time-consuming than for flywheels; hence, maintenance costs can be expected to be higher. Contracted maintenance costs are largely driven by the number of battery cabinets or strings required to serve a particular combination of power and minute ratings. As might be expected, service costs per cabinet decline where there are more cabinets at a single site. Similar to purchase costs, maintenance costs measured in \$/kWm/year are roughly constant for the same number of minutes at different kW. Annual battery maintenance costs are roughly \$3.50/kWm for 5 minutes of backup power, dropping to about \$2.25/kWm, \$1.50/kWm, and \$1.25/kWm for 10, 20, and 30 minutes of backup power, respectively. Standby power consumption, or float loss, is negligible for batteries compared to flywheels, but the differences in footprint and floor-space requirements should be considered. Flywheel footprint, including an allowance for service space, ranges from 0.04 ft<sup>2</sup>/kW to 0.12 ft<sup>2</sup>/kW depending on the size and type; 0.08 ft<sup>2</sup>/kW is typical. Battery footprint per kW varies significantly depending on the rated backup time. For 5 minutes of backup power, VRLA battery footprint, again

including an allowance for service space, will be about 0.15 ft<sup>2</sup>/kW. This rises to approximately 0.22 ft<sup>2</sup>/kW, 0.30 ft<sup>2</sup>/kW, and 0.36 ft<sup>2</sup>/kW for 10, 20, and 30 minutes of backup power, respectively. The value of the floor-space differential will vary, of course, depending on site-specific conditions.

### Utility Incentives and Support

Neither batteries nor flywheels reduce energy consumption or peak power demand from a utility in a UPS application. Therefore, it is not surprising that no utility incentives or support exist for this application of these technologies.

### Additional Considerations

In general, the use of electromechanical flywheels instead of electrochemical batteries will avoid the environmental and safety issues associated with the latter. This includes battery requirements for material safety data sheets, eye wash stations, spill containment, hydrogen detection, and relatively high room ventilation rates. Batteries must also be kept at normal indoor air temperatures or suffer from significant degradation in expected life. This adds to cooling system operating cost in existing buildings and cooling system size and initial cost in new buildings or when cooling systems are being replaced.

### Technology Performance

Several hundred flywheels are currently being used as backup power sources for UPS. Of these, about a dozen are installed at federal facilities. Although flywheels have been used for many years as part of motor-generator devices, flywheels designed as a substitute or supplement to batteries in UPS systems have been available since 1998. The experiences of a few federal users are documented below.

#### Peterson Air Force Base

Peterson Air Force Base (AFB) installed three flywheels in 1998 in response to looming Year 2000 (Y2K) concerns at the time. The flywheels were installed as a supplement to batteries to shield

the batteries from relatively frequent, but short-term power glitches. Master Sergeant Brian Bills described the flywheels as being easy to integrate. The control system is set up to draw power from the flywheels first, then the batteries, and then backup generators for longer outages. The Air Force requirements for this computer system's support application included full backup generators, 15 minutes of battery power, flywheels to extend the life expectancy of the batteries, and a battery monitoring system. The overall system reliability requirement is "5 nines" (99.999% reliable).

Of 47 power outages experienced through 2002, load was placed on the batteries only twice; the load was met entirely by the flywheels during the other 45 outages. Ninety percent of the outages lasted for 1 second or less. With the vast majority of the outages served by the flywheel, the batteries were reported to look and perform like brand new. Sgt. Bills said they would like to get to where they just use flywheels because of the environmental concerns and costs of batteries, but they are not there yet.

### Fort Monmouth

Fort Monmouth installed a flywheel/UPS/generator system in 2002 to provide backup power and protect their exchange, Internet, and Intranet servers and server backup equipment. The addition of a generator allowed them to remove the batteries, which had previously been used to provide backup power. Without the generator, batteries would still be necessary. When an outage occurs, the flywheel kicks in immediately, then the generator fires up if the outage lasts for more than a few seconds. The UPS system meets the computer power needs, plus lighting and air conditioning. When a storm came through that knocked out electric power to the whole fort for several days, their computer system never went down.

Gindy Berkeley said that Fort Monmouth went with the flywheel/UPS system because the battery system was at the end of its useful life and the upfront cost of a new battery system was greater than the flywheel system. In addition, significant maintenance cost savings are expected. Ms. Berkeley said the flywheel is expected to require \$3,000 in maintenance every 3 years to replace the bearings. By comparison, it was costing them \$35,000 per battery bank to replace the batteries every 3 years and they had 3 to 4 banks for each computer room. They expect the flywheel to last 20 years or more with regular maintenance.<sup>6</sup>

Fort Monmouth uses the flywheel for voltage regulation as well as for outages and other electrical disturbances. The flywheel produces a smooth 480 V with 1.0 power factor. John Alexoudis noted that the flywheel is installed remotely from the computer space. It is located in an electrical vault because it can tolerate temperatures up to 100 degrees, in contrast to batteries, which must be kept in air-conditioned space.

### Dallas VA Medical Center

The VA Medical Center in Dallas has also installed a flywheel/UPS/generator system. This 2-year-old, 300 kVA system was installed to ensure continuous power for a cardiac catheterization patient care facility. This facility experienced small power disturbances that were causing the catheterization unit to shut down. This would leave surgeons "blind" to cardiac conditions for 8 minutes, while the catheterization unit was restarted.

The flywheel/UPS/generator system is oversized compared with the load it protects, but facility personnel wanted to ensure they could ride out any outages until the generators came on-line. Rick Hart notes they also have a battery-backed 225-kVA UPS system protecting another critical load that fills a whole room. On the other hand, the

flywheel/UPS system is about the size of two refrigerators and is installed in an unconditioned electrical room. The Medical Center went with the flywheel rather than another battery-based system because of the lower maintenance costs of the flywheel system.

### Case Study

Fort McPherson is a U.S. Army Forces Command (FORSCOM) installation located in Atlanta, Georgia. Building 200 at the Fort houses FORSCOM Headquarters and contains equipment that must be kept up and running on a 24/7 basis.

Grid power was previously backed up by a UPS system incorporating wet-cell batteries and diesel-fired generators. While the diesel generators could reliably come on line within 10 seconds, the existing battery system was becoming increasingly unreliable and expensive to maintain. Annual battery maintenance was approximately \$30,000.

The existing UPS system consisted of four 500-kVA units operating in parallel, each with its own wet-cell battery string. The UPS and battery system was about 15 years old, which is well beyond expected battery life, even for wet-cell batteries. (Wet-cell batteries last longer, but are more expensive initially, than VRLA-type batteries.) In fact, one of the battery strings had already failed, which created a hazardous condition for maintenance personnel, as well as significantly impairing system capability and reliability.

The battery strings occupied a 2400-square-foot room adjacent to the UPS room. Although the batteries would have fit into a space about one-half this size, the existence of the batteries essentially precluded other useful functions in the room.

It was clear to Fort McPherson personnel that the existing batteries needed

<sup>6</sup>Note that routine maintenance costs for flywheels and batteries, discussed elsewhere in this Federal Technology Alert, are not included in the figures provided by Ms. Berkeley. The flywheel will also need to have its vacuum pump replaced at a cost of about \$1,500 once every 10 years.

to be replaced. Their options were to purchase either new VRLA or wet-cell batteries, or flywheels. Reductions in power demand since Building 200 was constructed reduced the requirement to two 500-kVA units operating in parallel, with either unit able to meet the building's critical power demand. The two parallel units were judged to be necessary to meet overall system reliability requirements.

Fort McPherson personnel decided to install a flywheel (actually two flywheels, one for each 500-kVA UPS unit) instead of replacement batteries for the following reasons.

- A wet-cell battery would cost approximately the same as a flywheel, but would probably have a shorter life and was expected to incur higher annual maintenance costs.
- A VRLA battery would cost about half as much as a flywheel initially, but would have to be replaced several times over the life of the flywheel and was also expected to incur higher annual maintenance costs.
- Using a flywheel would allow the Fort to reclaim the 2400-square-foot room currently dedicated to the battery strings. Depending on the specific future use, room ventilation and cooling costs could also be reduced.
- The diesel generators could reliably come on line within 10 seconds, which minimized the value of the longer backup period provided by batteries. Overall, the flywheels were judged to provide equal or better reliability than the batteries.
- Environmental and safety issues associated with batteries were eliminated.

One of the flywheels installed at Fort McPherson is shown in Figure 9. Although the Fort has experienced problems (unrelated to the flywheel) with the 15-year-old UPS electronics, the flywheels have performed flawlessly since being installed in early 2002, according to Luke Wyland, the energy manager at Fort McPherson.



Photo courtesy of Pacific Northwest National Laboratory

**Figure 9.** Luke Wyland with flywheel at Fort McPherson.

### Life-Cycle Cost Comparison

In general, flywheels will cost more than batteries initially, but require less maintenance and will last much longer. Thus, a flywheel will generally be much less expensive on a life-cycle cost basis. Consider a situation where a 250-kW UPS system is backed up by a reliable generator that can come up to full power in 10 seconds. Backup power for the interim period could be provided by either batteries or a flywheel.

The comparison developed in the text box is based on a low-rpm flywheel with a life of 20 years and a VRLA battery with a life of 4 years. As previously noted, battery life will vary significantly depending on the operating conditions, principally the load duty and ambient temperature seen by the batteries. A typical lifetime of 4 years is assumed in this comparison. In addition, the batteries are assumed to have the capability to provide power for 10 minutes. The cost estimates shown in the text box were developed using these assumptions and the rules-of-thumb provided earlier.

These cost estimates were entered into the NIST BLCC 5.1-02 life-cycle cost model (see Appendix A). The resulting present value of life-cycle costs was \$248,129 for the battery option, but only \$105,572 for the flywheel option, or a savings of \$142,557 or about 60%. Although the batteries are initially less expensive to install, the extremely short battery life compared with flywheel life results in much greater life-cycle cost for the battery option. The details of the life-cycle cost results are presented in Appendix B.

#### Battery Costs

Purchase cost = \$13/kWm * 250 kW * 10 minutes =	\$32,500
Installation cost = \$30/kW * 250 kW =	\$7,500
Total initial capital cost =	\$40,000
Capital replacement cost every 4 years =	\$40,000
Annual maintenance cost = \$2.25/kWm * 250 kW * 10 minutes =	\$5,625
Annual floor-space cost = 0.22 ft <sup>2</sup> /kW * 250 kW * \$10/ft <sup>2</sup> =	\$550
Annual standby power consumption cost = 250 kW * 8760 hours * 0.01% * \$0.063/kWh =	\$14

#### Flywheel Costs

Purchase cost = \$200/kW * 250 kW =	\$50,000
Installation cost = \$30/kW * 250 kW =	\$7,500
Total initial capital cost =	\$57,500
Bearing replacement cost every 5 years = \$10/kW * 250 kW =	\$2,500
Vacuum pump replacement every 7 years = \$5/kW * 250 kW =	\$1,250
Annual maintenance cost = \$5/kW * 250 kW =	\$1,250
Annual floor-space cost = 0.08 ft <sup>2</sup> /kW * 250 kW * \$10/ft <sup>2</sup> =	\$200
Annual standby power consumption cost = 250 kW * 8760 hours * 1% * \$0.063/kWh <sup>a</sup> =	\$1,380

<sup>a</sup>Average cost per kWh for Federal buildings in FY01.

## The Technology in Perspective

As indicated elsewhere in this report, a few hundred DC flywheel energy storage systems have been installed with approximately a dozen of these known to be installed at federal facilities. The earliest of these installations dates back to 1998 while most have been in the last 2 years. The experiences to date have been good. All of the federal installation representatives contacted provided positive descriptions of their flywheel systems to date. Still, the number of existing installations is relatively small compared to the number of potential applications.

## The Technology's Development

Flywheels have been around for centuries and are not new to the power quality market either. Motor-generator pairs have been used for years as a means to isolate electric loads from electricity supply disturbances. Flywheels were incorporated into these devices to increase rotary inertia, hence the tolerable disturbance period. However, such directly integrated devices used only a small fraction of the kinetic energy stored in a flywheel and generally provided at most a second of ride-through capability.

More effective use of flywheel technology in power quality applications required some means of disconnecting the kinetic energy stored in its rotating mass from the electric energy demands of the load being served. The addition of variable speed drive, rectifier, and inverter components to the above system provided a technological solution, but was cumbersome and/or too expensive. Advances in electronic power conversion and control technology, coupled with innovative integration of the components noted above, have been keys to the technology's development.

The superior energy storage density of flywheels compared to batteries is widely recognized. Much of the flywheel development occurring in recent decades has been oriented toward potential applications in vehicles and satellites, where mass

and volume constraints are more rigorous than for UPS applications. The focus of flywheel development for these applications has been toward increasing the rotor speed to maximize energy density. Such speeds require the use of magnetic bearings, which are now used in some moderate rpm flywheels as well.

## Relation to Other Technologies

As indicated throughout this Federal Technology Alert, DC flywheel energy storage systems are an alternative or supplement to lead-acid batteries. Batteries have the advantage of providing backup power for a period measured in minutes rather than seconds, but this advantage has limited value if reliable backup generators are available. Batteries will usually have lower first costs, but their significantly shorter life and greater maintenance requirements compared to flywheels generally makes the latter more life-cycle cost effective.

## Technology Outlook

Six companies currently offer DC flywheel energy storage products. Another half dozen or so are developing products they expect to bring to market within the next few years. Still others offer products where the flywheel is an integral part of the UPS system rather than being a direct substitute for batteries.

The current array of available DC flywheel energy storage products includes low-speed, unenclosed steel rotors with conventional bearings at one end of the spectrum and high-speed, composite material rotors operating in a vacuum with magnetic bearings at the other end of the spectrum. Intermediate products with elements of these two endpoints also exist. It is not clear yet whether the UPS application will move toward one end of the technology spectrum or the other. Different design approaches may each find their niche within the UPS application market.

Although currently developed DC flywheel energy storage systems offer significant advantages over batteries, the

number of companies currently offering products, and an equal or greater number developing products, suggests that further product development and enhancement is likely to occur. Coupled with seemingly ever-increasing needs for more reliable, higher quality power, the long-run prospects for flywheel energy storage in UPS applications looks good.

## Manufacturers

Manufacturers of flywheels for application in UPS systems were primarily identified via searching Internet web sites. This search was conducted during fall 2002. Although the focus of this Federal Technology Alert is on stand-alone DC flywheel energy storage systems that could substitute or supplement batteries in a UPS system, this list also includes manufacturers that offer flywheels as an integral part of a UPS system. Also included are developers who intend to have a DC flywheel energy storage system on the market within the next few years.

Despite our efforts, it is practically impossible to ensure that all manufacturers of DC flywheel energy storage systems have been identified. To those we missed, we extend our apologies. This list is provided as a service for those interested in obtaining information on specific flywheel products for UPS applications. No endorsement or other judgment regarding qualification of any manufacturer listed is given or implied.

### Acumentrics Corporation

14 Southwest Park  
Westwood, Massachusetts 02090  
Contact: Gary Genet  
Phone: 404-713-0364 or 781-461-8251  
Fax: 781-461-1261  
ggenet@acumentrics.com  
www.acumentrics.com  
Products: Flywheel-based UPS; DC flywheel energy storage; under development as of fall 2002

### Active Power, Inc.

2128 West Braker Lane, BK-12  
Austin, Texas 78758  
Contact: Stephen Burke  
Phone: 512-836-6464 Fax: 512-836-4511  
sburke@activepower.com  
www.activepower.com  
Product: Flywheel-based UPS; DC flywheel energy storage

## **AFS Trinity Power Corporation**

6724D Preston Avenue  
Livermore, California 94551  
Contact: Gerald Starr  
Phone: 925-455-7231 Fax: 925-455-7993  
gstarr@afstrinity.com  
www.afstrinitypower.com  
Product: DC flywheel energy storage;  
under development as of fall 2002

## **Beacon Power Corporation**

234 Ballardvale Street  
Wilmington, Massachusetts 01887  
Contact: John Jesi  
Phone: 978-661-2081 Fax: 978-694-9127  
jesi@beaconpower.com  
www.beaconpower.com  
Product: DC flywheel energy storage,  
Flywheel-based UPS

## **Caterpillar, Inc.**

100 N.E. Adams St.  
Peoria, Illinois 61629  
Phone: 800-947-6567 or 309-675-1000  
www.CAT-ElectricPower.com  
Product: Flywheel-based UPS

## **Designed Power Solutions International**

2348 Meyers Avenue  
Escondido, California 92029  
Contact: Mike Dean  
Phone: 760-480-0760 Fax: 760-480-0780  
miked@designedpower.com  
www.designedpower.com  
Products: Flywheel-based UPS with  
generator; Flywheel-based UPS; DC flywheel  
energy storage

## **Flywheel Energy Systems, Inc.**

25C Northside Road  
Nepean, Ontario Canada K2H 8S1  
Contact: Dean Flanagan  
Phone: 613-596-0856 Fax: 613-596-6052  
fesi@magma.ca  
www.magma.ca/~fesi  
Product: DC flywheel energy storage;  
under development as of fall 2002

## **GE Digital Energy**

2018 Powers Ferry Road, Suite 500  
Atlanta, Georgia 30339  
Contact: Mark Klaiber  
Phone: 678-627-0954 Fax: 678-627-0986  
mark.klaiber@indsys.ge.com  
www.gedigitalenergy.com  
Product: Flywheel-based UPS with generator

## **Indigo Energy, Inc.**

535 Westgate Drive  
Napa, California 94558  
Contact: Chris Gabrys  
Phone: 707-254-9302 Fax: 253-981-0243  
info@indigoenergyinc.com  
www.indigoenergyinc.com  
Products: Flywheel-based UPS; DC flywheel  
energy storage; under development as of fall 2002

## **Optimal Energy Systems**

2560 W. 237th Street  
Torrance, California 90505  
Contact: Dwight Swett  
Phone: 310-257-0301 Fax: 310-257-0303  
sales@optimalenergysystems.com  
www.optimalenergysystems.com  
Products: Flywheel-based UPS; DC flywheel  
energy storage; under development as of fall 2002

## **Pentadyne Power Corporation**

20750 Lassen Street  
Chatsworth, California 91311  
Contact: Chandler Williamson  
Phone: 818-350-0370, ext. 207  
Fax: 818-350-0385  
info@pentadyne.com  
www.pentadyne.com  
Product: DC flywheel energy storage;  
under development as of fall 2002.

## **Piller, Inc.**

334 County Rte. 49  
Middletown, New York 10940  
Contact: Travis Gerould  
Phone: 845-355-5000 Fax: 845-355-9005  
info@piller.com  
www.piller.com  
Product: DC flywheel energy storage, Flywheel-  
based UPS, Flywheel-based UPS with generator

## **Powerware**

8609 Six Forks Rd.  
Raleigh, North Carolina 27615  
Contact: Barry Needle  
Phone: 919-870-3045 Fax: 919-870-3450  
barry.needle@psd.invensys.com  
www.powerware.com  
Product: Flywheel-based UPS; DC flywheel  
energy storage

## **Precise Power Corporation**

P.O. Box 9547  
Bradenton, Florida 34206  
Phone: 888-522-1600 Fax: 941-729-4337  
info@precisepwr.com  
www.precisepwr.com  
Product: Flywheel-based UPS

## **Regenerative Power and Motion**

Contact: Dick Fradella  
Phone: 949-496-4274  
fradella@earthlink.net  
www.rpm2.8k.com  
Product: DC flywheel energy storage;  
under development as of fall 2002

## **Reliable Power Systems, Inc.**

399 Perry Street, Suite 300  
Castle Rock, Colorado 80104  
Contact: Michael Warner  
Phone: 720-733-8970 Fax: 720-733-8976  
warnermd@attglobal.net  
www.reliablepowersystems.com  
Product: Flywheel-based UPS

## **SatCon Power Systems**

835 Harrington Court  
Burlington, Ontario, Canada L7N 3P3  
Contact: Martin Valeri  
Phone: 905-631-4402 Fax: 905-639-0961  
martin.valeri@satcon.com  
www.inverpower.com  
Product: Flywheel-based UPS with generator

## **Urenco Power Technologies**

Suite 610, Watergate Building  
2600 Virginia Avenue NW  
Washington DC 20037  
Contact: Colin Davies  
Phone: 202-333-7971 Fax: 202-337-2421  
cdavies@urencoinc.com  
www.uptenergy.com  
Product: DC flywheel energy storage

## **Who is Using the Technology**

Several hundred DC flywheel energy storage systems have been installed, with about a dozen of these in federal applications. Most of the federal applications have been in the Department of Defense, but at least one system each have been installed at State Department and Veterans Affairs facilities. Contacts for the four federal applications previously described are listed below.

### **Fort McPherson**

Luke Wyland—404-469-3563  
luke.wyland@forscom.army.mil

### **Fort Monmouth**

John Alexoudis—732-532-6368  
john.alexoudis@mail1.monmouth.army.mil  
Gindy Berkeley—732-532-6171  
gindy.berkeley@mail1.monmouth.army.mil

### **Peterson Air Force Base**

Staff Sgt. (retired) Brian Bills  
719-550-8670  
brian.bills@psd.invensys.com

### **VA Medical Center, Dallas**

Rick Hart—214-857-1052  
rick.hart@med.va.gov

## **For Further Information**

Perhaps the best sources of additional information are the manufacturers' Web sites listed above. In addition to containing information about their specific products, many of the Web sites contain generic tutorials about flywheels, batteries, and other energy storage devices.

## Appendix A

### Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of \$0.10 per kWh, this fixture has an annual energy cost of \$20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes “present value of cost stream x,”  
 IC is the installed cost,  
 EC is the annual energy cost,  
 OM is the annual nonenergy O&M cost, and  
 REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative’s LCC is less than the baseline’s LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1) + PV(OM_0) - PV(OM_1) + PV(REP_0) - PV(REP_1) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,  
 subscript 1 denotes the energy cost saving measure,  
 IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),  
 ECS is the annual energy cost savings,  
 OMS is the annual nonenergy O&M savings, and  
 REPS is the future replacement savings.

Levelized energy cost (LEC) is the break-even energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project’s LEC is given by

$$PV(LEC \cdot EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

## Appendix B

### NIST BLCC 5.1-02: Comparative Analysis

Consistent with Federal Life-Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: Battery

Alternative: Flywheel

#### General Information

File Name:	C:\Program Files\BLCC5\projects\Battery-Flywheel Comparison.xml
Date of Study:	Fri Jan 31 11:56:20 PST 2003
Project Name:	Battery-Flywheel Comparison
Project Location:	U.S. Average
Analysis Type:	MILCON Analysis, Energy Project
Analyst:	Daryl R. Brown
Base Date:	January 1, 2003
Beneficial Occupancy Date:	January 1, 2003
Study Period:	20 years 0 months (January 1, 2003 through December 31, 2022)
Discount Rate:	3.2%
Discounting Convention:	End-of-Year

### Comparison of Present-Value Costs

#### PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alternative
<b>Initial Investment Costs:</b>			
Capital Requirements as of Base Date	\$40,000	\$57,500	-\$17,500
<b>Future Costs:</b>			
Energy Consumption Costs	\$0	\$19,566	-\$19,566
Energy Demand Charges	\$0	\$0	\$0
Energy Utility Rebates	\$0	\$0	\$0
Water Costs	\$0	\$0	\$0
Routine Recurring and Non-Recurring OM&R Costs	\$90,200	\$21,180	\$69,019
Major Repair and Replacements	\$117,929	\$7,326	\$110,604
Residual Value at End of Study Period	\$0	\$0	\$0
Subtotal (for Future Cost Items)	\$208,129	\$48,072	\$160,057
<b>Total PV Life-Cycle Cost</b>	<b>\$248,129</b>	<b>\$105,572</b>	<b>\$142,557</b>

#### Net Savings from Alternative Compared with Base Case

PV of Non-Investment Savings	\$49,454
- Increased Total Investment	-\$93,104
<b>Net Savings</b>	<b>\$142,557</b>

## About FEMP's New Technology Demonstrations

The Energy Policy Act of 1992 and subsequent Executive Orders mandate that energy consumption in federal buildings be reduced by 35% from 1985 levels by the year 2010. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) sponsors a series of activities to reduce energy consumption at federal installations nationwide. FEMP uses new technology demonstrations to accelerate the introduction of energy-efficient and renewable technologies into the federal sector and to improve the rate of technology transfer.

As part of this effort, FEMP sponsors the following series of publications that are designed to disseminate information on new and emerging technologies:

**Technology Focuses**—brief information on new, energy-efficient, environmentally friendly technologies of potential interest to the Federal sector.

**Federal Technology Alerts**—longer summary reports that provide details on energy-efficient, water-conserving, and renewable-energy technologies that have been selected for further study for possible implementation in the federal sector. Additional information on Federal Technology Alerts (FTAs) is provided in the next column.

**Technology Installation Reviews**—concise reports describing a new technology and providing case study results, typically from another demonstration program or pilot project.

**Other Publications**—the program also issues other publications on energy-saving technologies with potential use in the federal sector.

### More on Federal Technology Alerts

Federal Technology Alerts, our signature reports, provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the FTAs have already entered the market and have some experience but are not in general use in the federal sector.

The goal of the FTAs is to improve the rate of technology transfer of new energy-saving technologies within the federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their federal sites.

The information in the FTAs typically includes a description of the candidate

technology; the results of its screening tests; a description of its performance, applications, and field experience to date; a list of manufacturers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the FTAs to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant federal-sector savings, the FTAs do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the FTAs attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the FTAs as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested federal energy and facility managers to contact the manufacturers and other federal sites directly, and to use the worksheets in the FTAs to aid in their purchasing decisions.

## Federal Energy Management Program

The federal government is the largest energy consumer in the nation. Annually, the total primary energy consumed by the federal government is 1.4 quadrillion British thermal units (quads), costing \$9.6 billion. This represents 1.4% of the primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the federal infrastructure.

Over the years, several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; the National Energy Policy Act of 1992; Executive Order 13123, signed in 1999; and most recently, Executive Order 13221, signed in 2001, and the Presidential Directive of May 3, 2001.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting new technology demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.





## A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our national energy infrastructure
- Facilitate the emergence of hydrogen technologies as a vital new "energy carrier."

### The Opportunities

#### *Biomass Program*

Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

#### *Building Technologies Program*

Homes, schools, and businesses that use less energy, cost less to operate, and ultimately, generate as much power as they use

#### *Distributed Energy & Electric Reliability Program*

A more reliable energy infrastructure and reduced need for new power plants

#### *Federal Energy Management Program*

Leading by example, saving energy and taxpayer dollars in federal facilities

#### *FreedomCAR & Vehicle Technologies Program*

Less dependence on foreign oil, and eventual transition to an emissionsfree, petroleum-free vehicle

#### *Geothermal Technologies Program*

Tapping the earth's energy to meet our heat and power needs

#### *Hydrogen, Fuel Cells & Infrastructure Technologies Program*

Paving the way toward a hydrogen economy and net-zero carbon energy future

#### *Industrial Technologies Program*

Boosting the productivity and competitiveness of U.S. industry through improvements in energy and environmental performance

#### *Solar Energy Technology Program*

Utilizing the sun's natural energy to generate electricity and provide water and space heating

#### *Weatherization & Intergovernmental Program*

Accelerating the use of today's best energy-efficient and renewable technologies in homes, communities, and businesses

#### *Wind & Hydropower Technologies Program*

Harnessing America's abundant natural resources for clean power generation

To learn more, visit [www.eere.energy.gov](http://www.eere.energy.gov)

## For More Information

### FEMP Help Desk

(800) 363-3732  
International callers please use  
(703) 287-8391  
Web site: [www.eere.energy.gov/femp](http://www.eere.energy.gov/femp)

### General Contacts

#### Ted Collins

New Technology Demonstration  
Program Manager  
Federal Energy Management Program  
U.S. Department of Energy  
1000 Independence Ave., SW EE-92  
Washington, D.C. 20585  
Phone: (202) 586-8017  
Fax: (202) 586-3000  
[theodore.collins@ee.doe.gov](mailto:theodore.collins@ee.doe.gov)

#### Steven A. Parker

Pacific Northwest National Laboratory  
P.O. Box 999, MSIN: K5-08  
Richland, WA 99352  
Phone: (509) 375-6366  
Fax: (509) 375-3614  
[steven.parker@pnl.gov](mailto:steven.parker@pnl.gov)

### Technical Contact

#### Daryl Brown

Pacific Northwest National Laboratory  
P.O. Box 999, MSIN: K8-07  
Richland, WA 99352  
Phone: (509) 372-4366  
Fax: (509) 372-4370  
[daryl.brown@pnl.gov](mailto:daryl.brown@pnl.gov)

## Log on to FEMP's Web site for information about New Technology Demonstrations

[www.eere.energy.gov/femp/](http://www.eere.energy.gov/femp/)

### You will find links to

- A New Technology Demonstration Overview
- Information on technology demonstrations
- Downloadable versions of publications in Adobe Portable Document Format (pdf)
- A list of new technology projects under way
- Electronic access to a regular mailing list for new products when they become available
- How Federal agencies may submit requests to us to assess new and emerging technologies

Produced for the U.S. Department of Energy, Energy Efficiency and Renewable Energy, by the Pacific Northwest National Laboratory

DOE/EE-0286

September 2003

