

Beacon Power Flywheel Energy Storage Systems



Continuously Working to Improve
Grid Performance

Message from Barry Brits, President & CEO



The availability of a wide range of new technologies is enabling smarter, cleaner, more reliable production and delivery of electricity. These long overdue developments in the electric power sector impact users around the world – from large balancing systems to small island grids, across utilities and system operators of all sizes. In communities and boardrooms, industry stakeholders are discussing the demands of high renewable power penetration, increased energy security, and changing business models.

I learned long ago that using the right tool for a job is the best way to ensure a successful project. Beacon Power flywheels are the ideal tool for managing unpredictable, real-time changes in the electric power grid. Our systems have been proven over millions of operating hours in large and small-scale utility applications. The simple truth is that mechanical flywheels are far more agile and durable than competing energy storage technologies. They work continuously to precisely absorb and inject energy, providing flexible, cost-effective, low-maintenance grid support.

As our industry evolution progresses we look forward to working with you and becoming an integral part of your power system. When you team with Beacon Power, I'm confident you'll discover that both our technology and our people can be trusted to meet challenges and deliver reliability.

Barry Brits
President and CEO
Beacon Power, LLC

Technology Overview



New Challenges. New Solutions.

The world's electric systems are going through a dramatic transformation driven by advances in technology, societal demand for cleaner generating resources and an increasingly independent-minded customer base. Utilities are considering new business models, new ways to optimize asset utilization, and new ways to predict and manage balancing of generation and load.

Customers and regulators are demanding more flexibility and reliability. Storage will play a key role in enabling the grid to meet those demands and foster the next generation of improvements. Many consumers are familiar with storage's capability for long-duration energy shifting but short-duration storage plays a critical role in delivering flexibility and reliability to the system. Beacon Power flywheels have the durability, agility and precision to address sudden grid stability problems and improve grid performance.

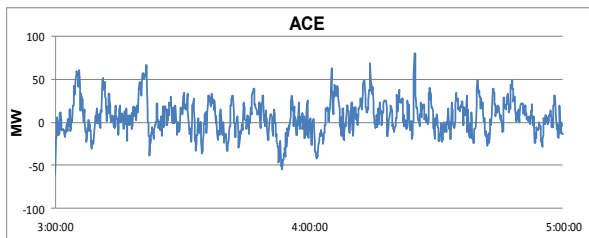


Flywheels Do More Work, More Efficiently, Than Traditional Generators

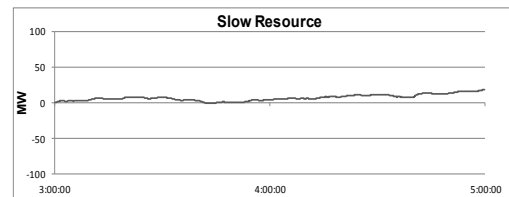
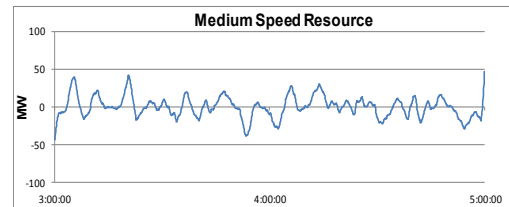
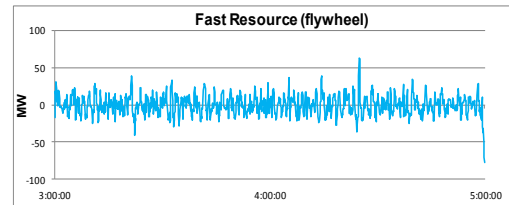
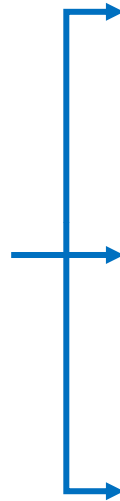
Challenge:
Supply/Demand imbalance in MW

Solution:
Break into pieces, add fast storage

**Total Imbalance (MW over 2 hours):
actual NY data**



DNV/KEMA modeled grid systems and estimates that fast-responding storage is 2 to 3 times more effective at managing grid stability than a conventional combustion turbine.



Short-Duration Storage is Essential to the Modern Grid.

Correcting momentary imbalances in generation and load is critical to maintaining a stable power grid. However, achieving this balance in real-time has always been a challenging task due to the time it takes conventional power generators to ramp their power output up or down to react to these constant power system fluctuations.

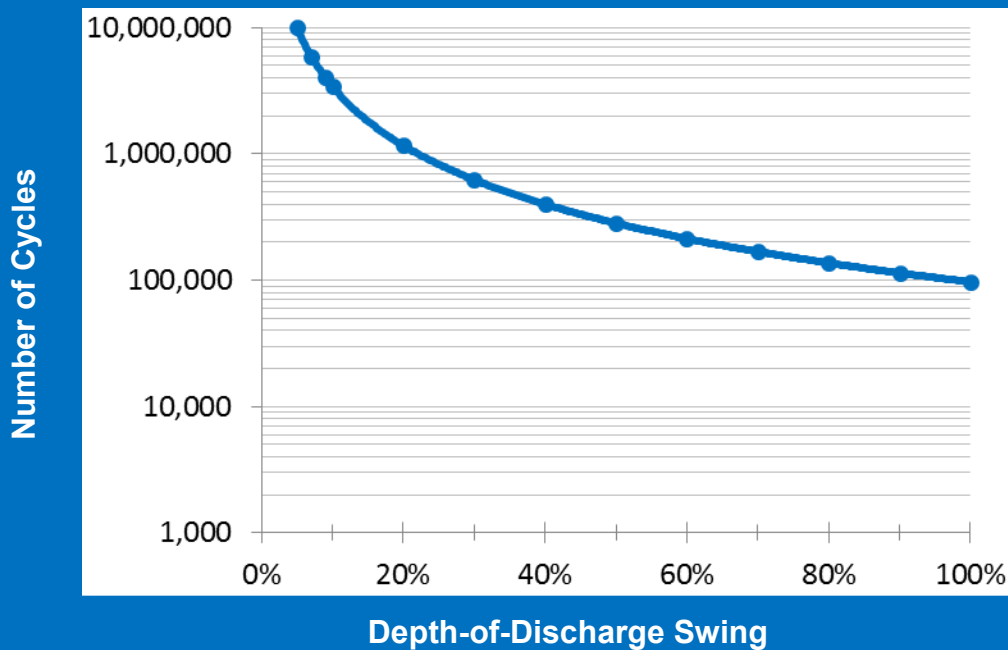
Beacon flywheel storage systems have much faster ramp rates than traditional generation and can correct imbalances sooner with much greater accuracy and efficiency. In fact, Beacon flywheels can inject or absorb full power nearly instantaneously. This range and fast response makes flywheels an ideal resource to provide regulation services thus freeing up thermal generators to service the energy market and operate at higher output levels, improving fuel efficiency and reducing emission rates. The steadier operation also reduces generator wear and tear and associated system operation and maintenance costs.

Smart short-duration storage devices allow grid operators to provide a much more granular split of the Automatic Generation Control signal by allocating the heavy-duty workload to fast-responding and durable systems. Beacon flywheels are currently providing grid balancing services dependably and accurately to NYISO, PJM and ISO-NE. Beacon's fast response and accurate flywheels allow conventional generation to operate more efficiently. The principle of applying the technology to the problem it is best suited to address unleashes efficiencies throughout the entire system.

Constantly available frequency regulation resources are becoming more critical to maintaining grid reliability, especially as intermittent generation increases alter the dynamics of the generation supply stack. Fast, accurate energy storage resources are already changing the way frequency regulation is being delivered. The efficiency and reliability offered by these resources enable grid operators to confidently integrate more renewable power.

Efficient and Durable. Real Savings.

Cycle Life Curve (100 kW flywheel)



Longest Life. Greatest Value.

Beacon flywheels experience 1,700 to 4,000 full depth cycles per year in utility grid stability operations.

Beacon Flywheels Deliver the Lowest Lifetime Cost Per Unit of Work.

- Beacon flywheels excel at handling heavy duty high-cycle workloads with no degradation, ensuring a consistent power and energy output over the 20 year design life.
- At all times, the full 100% depth-of-discharge range is available for regular use and state-of-charge (simply a function of rotational speed) is accurately known to deliver more useable range, precision, and value.
- There is no need to limit state-of-charge to specific ranges or to oversize storage capacity/duration to manage cycle life.
- Charge and discharge rates are symmetrical, meaning the units recharge at the same rate as they discharge which enhances operational effectiveness.
- Beacon's flywheel configurations deliver the high power-to-energy ratios most effective for grid stabilization and renewable power smoothing.
- With a lifespan of at least 100,000 full depth-of-discharge cycles, a flywheel storage system has a very high lifetime energy throughput (a direct measure of work performed) and thus, lifetime costs that are much less than competitive solutions in high-cycle applications.



Trusted. Beacon has 40 MW in commercial operation providing up and down regulation service equivalent to 80-120 MW of conventional generation and Beacon flywheels have accumulated over 7 million operating hours and a throughput of more than 265,000 MWh.

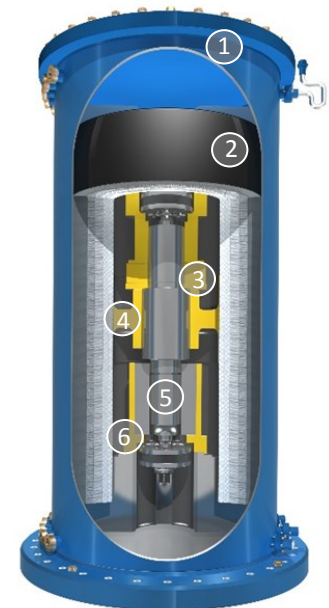


Beacon's high-energy, high-power flywheel has been in commercial operation for over 6 years.

- Approximately 7 feet tall, 3 feet in diameter
- 2,500 lb. rotor mass
- Spinning at up to 16,000 rpm
- Lifetime energy throughput is over 5,000 MWh
- Capable of charging or discharging at full rated power without restriction
- Beacon flywheel technology is protected by over 60 patents

• **U.S. Patents**

6,614,132; 6,710,489; 6,747,378; 6,817,266; 6,824,861; 6,852,401; 6,884,039; 6,959,756; 7,034,420; 7,174,806; 7,365,461; 7,679,247; 8,314,527 (other U.S. and international patents pending).



Key Elements Make Beacon Flywheels Unique & Effective

- 1. Vacuum Chamber:** A strong vacuum provides a near frictionless environment and the containment protects all components from the atmosphere and contamination. This eliminates deterioration of the internal components.
- 2. Patented Composite Rim:** A rotating carbon and fiberglass composite cylinder stores the energy. It also optimizes mass and strength to provide energy storage safely and at the best price.
- 3. Magnetic Lift System:** A non-contacting magnetic field lifts and supports the rotor, further eliminating wear and extending the life of the parts while minimizing friction. Beacon's patented bearing system ensures the spinning rim maintains its axis of rotation with low bearing loads, resulting in a long life.
- 4. Hub:** Aluminum forging connects the rotating shaft and rim.
- 5. Shaft:** Steel forging rotates and maintains the rotor centerline.
- 6. Brushless Permanent Magnetic Motor / Generator:** Efficiently converts the electrical energy into mechanical energy when the flywheel is charging, and back to electrical energy when discharging.

Beacon Series 400 Flywheel Systems

Product Name	400	400 Modular	450 XP
Grid Output/Supply Voltage	480 V _{ac}	480 V _{ac}	600 V _{ac}
Real Power Output /Discharge Times	100 kW for 15 min	160 kW for 5 min to 50 kW for 35 min	360 kW for 4 min to 70 kW for 30 min
Usable Energy at Full Charge	25 kWh	30 kWh	36 kWh
Product Enhancements	Grid Scale Implementation	Individual Power Control Module	Composite Hub
Year Available	2011	2014	2016

Power Control Module (PCM)

The PCM and its 2-stage power electronics control the flow of power between the flywheel and the project's collection system that ties to the AC grid. Each PCM also controls and monitors the status and state-of-health of critical flywheel operating parameters and interfaces with the other subsystems that support flywheel operation, such as cooling and power control.

Beacon's PCM is an outdoor-rated, pad-mounted package. Design criteria include reliable operation in extreme conditions found in hot desert environments like the Mojave in California, hot-humid locations like Puerto Rico or arctic conditions such as in Alaska. Beacon flywheel systems are designed to require low maintenance and their modular architecture allows units to be self-contained so service issues have minimal system impact.

Adaptable & Flexible

- Beacon flywheels and bundled power electronics are designed in a custom configuration to cost-effectively convert the variable-speed / high-inertia motor output into a clean and stable source of AC electricity (with a DC option) and to effectively utilize the full capability of the flywheel.
- The PCM allows flywheel stored energy to be coupled seamlessly to the AC grid and enables

instantaneous response and maximum operational flexibility.

- The current Series 400 Modular product has a maximum power output rating of 160 kW at 480 V_{ac} and offers a flexible range of power ratings and charge/discharge durations. Beacon's 450 XP is the next evolution of the Series 400 line introducing a higher power motor and a composite hub increasing the maximum power output rating to 360 kW at 600 V_{ac}.
- The power and energy duration settings can be changed on the fly, injecting or absorbing high power for a few seconds to address immediate frequency response needs or tailored to release energy over a longer period of 30 minutes to match longer duration system variances such as managing wind power generation ramping.
- At any operator selected power output level, the throughput is constant and the device can charge at the same rate as it discharges providing maximum flexibility.
- The flywheel system is a 'smart device' capable of operating based on Automatic Generation Control signals or sensing and responding to the activity on the grid. In addition to its active power flexibility, full four-quadrant inverters can deliver reactive power continuously.

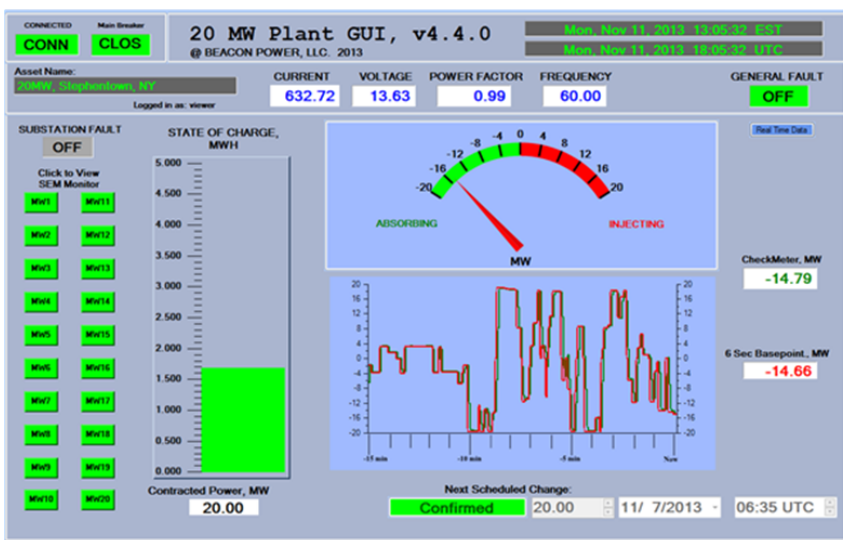
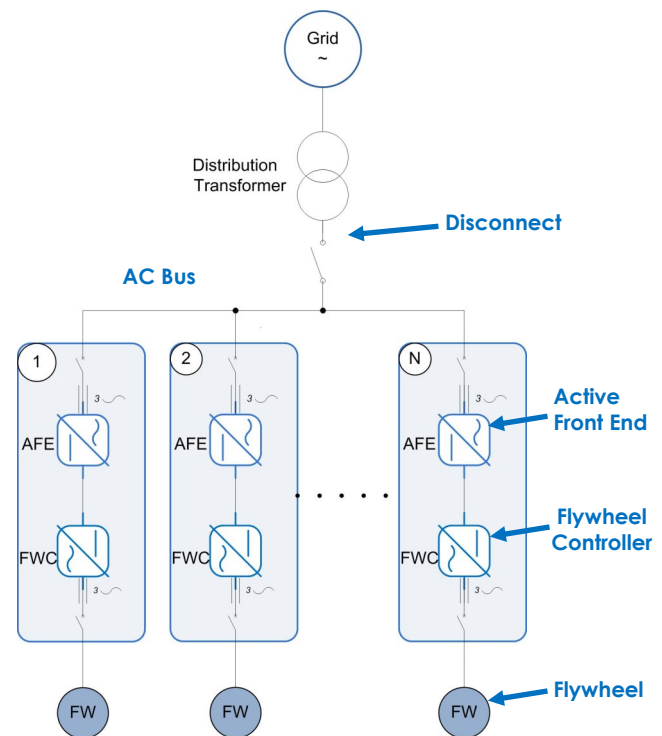
Beacon Control System

Each flywheel storage system is managed by a Beacon-designed Master Controller that receives inputs and signals from a grid system operator or directly from the local grid depending on the application. Operating modes available include frequency response, frequency regulation, renewable smoothing, VAR support, and custom applications.

The Master Controller processes inputs, applies the operating mode logic and priorities in effect, and then directs the flywheel system to absorb or inject real and reactive power accordingly. It allocates the work between clusters consisting of up to 2 MW of flywheels and aggregates the state-of-charge and state-of-health information from the clusters. Operating modes and set points can be changed throughout the day and over the life of the system to meet evolving customer system needs.

At the 2 MW cluster level, a Cluster Controller commands individual flywheels based on the Master Controller instructions and the real-time status of each flywheel module. State-of-charge and state-of-health are determined for the cluster. In the event of a maintenance issue, the Cluster Controller can take any individual flywheel module offline and redistribute the commands to the remaining modules. This fully distributed modular architecture results in high availability and optimizes performance.

Beacon's control system can receive signals in any standard protocol or type of communication medium, typically via a fiber or TCP/IP connection.



Graphic User Interface (GUI)

System operators are always able to monitor the exact state-of-charge of Beacon's flywheel systems, enabling efficient resource management and dispatch as well as maximum economic value. Beacon utilizes a proprietary algorithm to balance state-of-charge across a group of flywheels so no energy is wasted while balancing is accomplished.

Flywheel system operations and performance is tracked and controlled via a Beacon-designed GUI that can be displayed on owner and operator SCADA systems, computers, tablets or even smart phones. The GUI monitors and reports instantaneously on high level system performance and state-of-charge information as well as dozens of system and flywheel state-of-health parameters. Together with operations and maintenance alarm and notification features, the GUI enables flywheel storage facilities to operate without on-site personnel.

Proven. Beacon flywheel energy storage systems are the result of more than 15 years of product development and have been in commercial operation since 2008.



Tyngsboro, MA, 0.5 MW
Operating since 2008



Stephentown, NY, 20 MW
Operating since Q1 2011

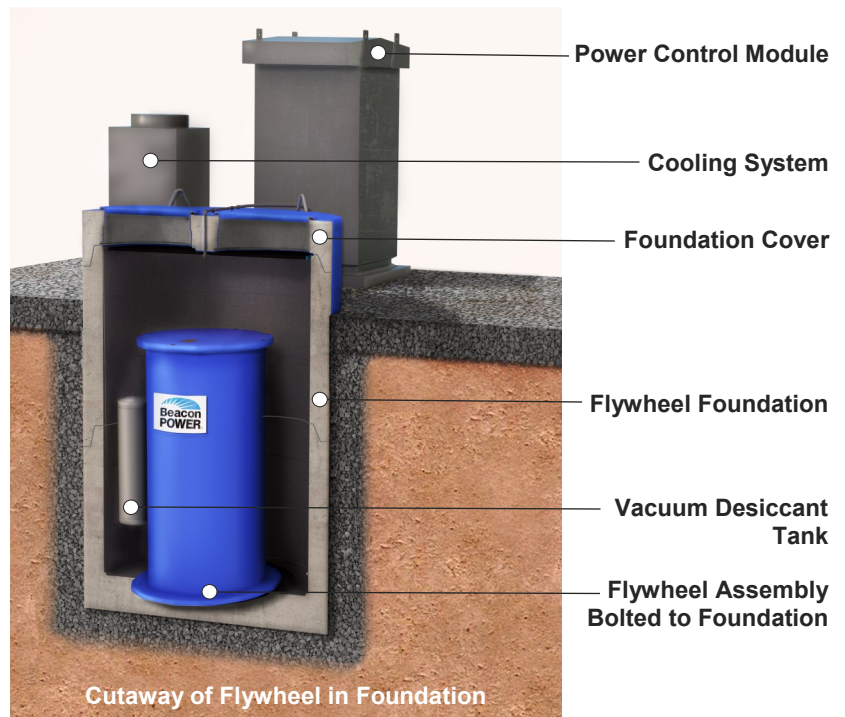


Hazle, PA, 20 MW
Operating since Q3 2013

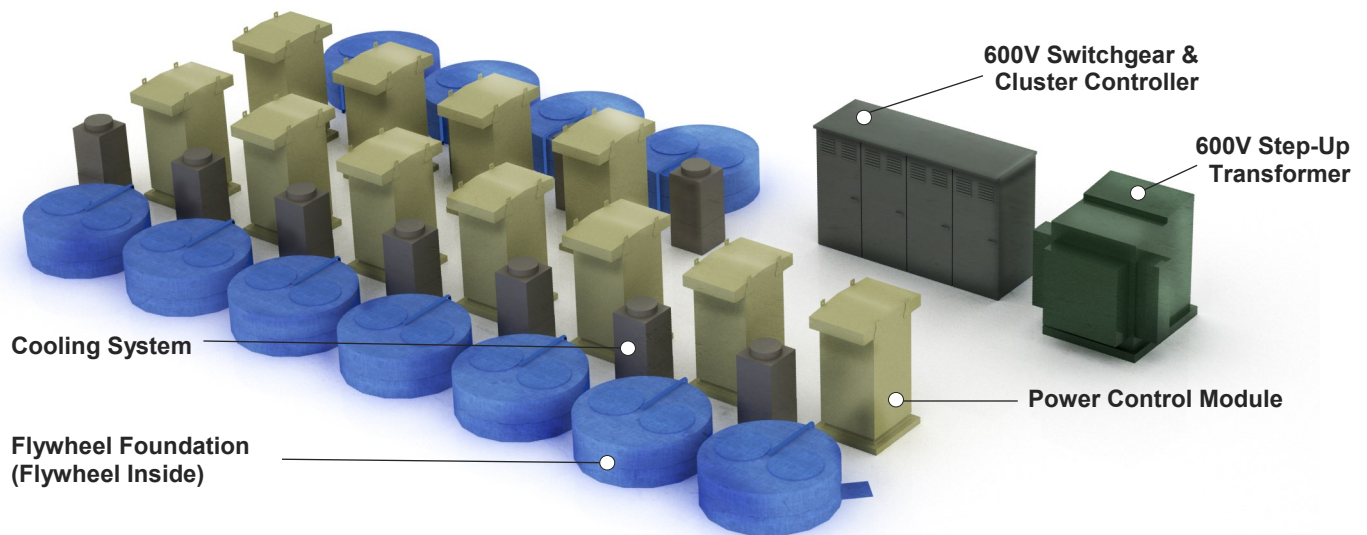
Beacon has three commercial plants, operating in three different ISO markets, responding with high accuracy to three different control signals. In the NYISO market, the project is about 10% of regulation market capacity but provides over 30% of the Area Control Error correction, doing so with over 95% accuracy.

Easy Installation

The flywheel is mounted to a cement base buried underground to ensure a stable platform that will support the high-velocity spinning mass. During construction, 8-foot deep holes are dug and a crushed stone base added and leveled. Three-piece, pre-cast concrete flywheel foundations (similar in construction to highway storm drains) are installed in the ground, leveled, and surrounded by crushed stone. Concrete pads are built for the PCM, cooling systems and switchgear. Underground conduit is placed to run power and signal cables between components.



Representative Flywheel Energy Storage Module

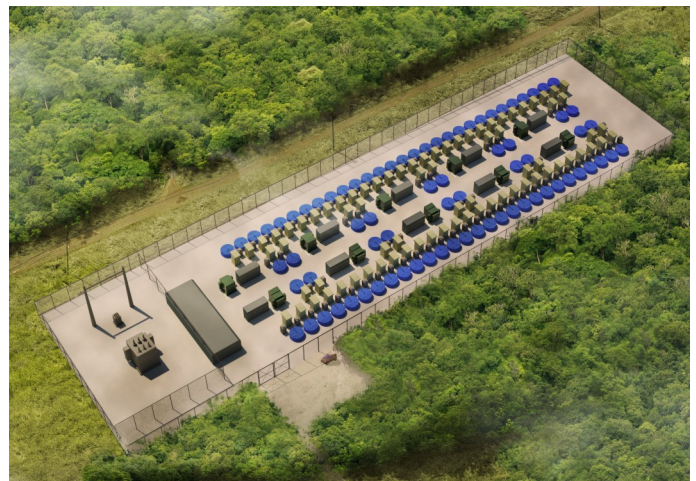


Modular Design

Beacon flywheel storage systems are modular, providing flexibility in power capacity, energy duration, and siting. Each module is a stand-alone unit, requiring just 480 or 600 V_{ac} power and communication connections to operate. A storage module consists of a flywheel, power control module, flywheel foundation, cooling system, and the necessary mounting and support connections.

Like building blocks, single flywheel modules fit together with others to build a flywheel energy storage system of any size from 100 kW to multi-MW power plants. The modular configuration minimizes site footprint and enables owners to place the exact amount of stabilizing resource in the exact location needed. The layout of the modules can be configured to maximize use of space. Depending on the specific site, 20 MW or more can

be installed per acre. Each module in a flywheel energy storage system is designed to function on a fully independent basis which results in high plant availability and optimizes performance.



Applications



Flywheel Energy Storage Systems

Offer:

- Frequency Regulation
- Frequency Response
- Voltage Support
- Renewable Power Smoothing
- Low/High Voltage Ride Through
- Low/High Frequency Ride Through
- Grid Forming and Grid Reference
- Spinning Reserves

Benefits:

- Maximize Renewable Penetration
- Ensure a Stable Grid
- Reduce Energy Costs
- Enable Independence from Fossil Fuels and Infrastructure
- Reduce Emissions
- Reduce O&M Costs
- Minimize Environmental Impact

Renewables are a critical power source in many markets driven by the desire to reduce harmful emissions and improve system economics. Many of the world's major markets are implementing aggressive renewable mandates which are alleviating critical fuel constraints but having a significant impact on grid stability. In addition, island grids isolated from major grid infrastructure are usually dependent on expensive liquid fossil fuels. Renewable energy introduces a path to escape from expensive energy generation, but at a cost to grid stability. These grids are typically smaller and less diverse than major market grids and stability cannot be effectively and efficiently managed with thermal generation alone.

Managing the variability caused by renewable energy integration has many power system operators searching for new ways to stabilize frequency and voltage. Fast-responding, durable flywheels are the perfect solution for these high-cycle applications.

U.S. Application Patents

7,834,479; 8,008,804

(other U.S. and international patents pending).

The Beacon Advantage

Beacon Power flywheels provide a new resource to help grid operators improve reliability. The durability, agility, and precision of Beacon flywheel energy storage systems makes them an extremely effective stabilizing force.

Durable: Beacon flywheels are designed for high reliability and availability. Beacon's early generation products have been spinning for more than 10 years and Beacon's utility-scale flywheels have over 7 million high-cycle operating hours. Beacon flywheels are spinning machines like gas turbines but operate in a vacuum without any significant thermal stress or friction. The performance of the Beacon flywheel energy storage system does not degrade with cycling, depth-of-discharge, time or temperature.

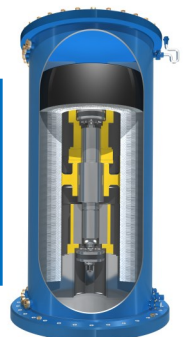
Agile: Beacon flywheel systems can respond to an Automatic Generation Control signal or sense imbalances on the grid to provide active power for over 30 minutes or reactive power continuously. They can charge at the same rate as they discharge and do not need to operate within limited state-of-charge ranges.

Precise: The response time and modularity of the Beacon flywheel energy storage system enable owners to apply the exact amount of energy in the exact place it is needed. Control signals move the output to the needed power state within milliseconds and at a high level of accuracy that is proven in grid operations. The state-of-charge and operational readiness are known at all times so grid operators have a predictable and reliable grid-stabilizing tool.

Safe: Beacon flywheels have an excellent safety record. Safety starts with the system design, and Beacon flywheel systems include numerous sensors and controls to alert operators when maintenance is needed and/or trigger an automatic controlled shutdown if required. The Beacon installation process utilizes in-ground concrete foundations to ensure a stable platform to support the high-velocity spinning mass and to isolate units and ensure that any unexpected service issues are confined with minimal system impact. Beacon flywheel storage systems use no harmful chemicals or other hazardous materials in system operations.

Proven: Beacon flywheels are in operation today continuously working to improve grid performance and are a trusted resource ensuring grid reliability. With over 400 flywheels systems installed and in commercial operation, Beacon has delivered over 7 million high-cycle operating hours.

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