

Beacon Power Flywheel Energy Storage Systems



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.

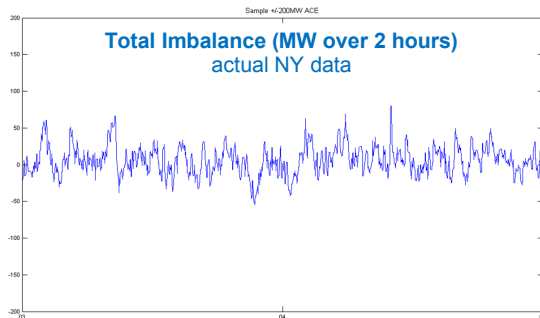
The world's electric systems are going through a dramatic transformation driven by advances in technology, societal demand for cleaner generating resources and an increasingly independent-minded customer base. Utilities are considering new business models, new ways to optimize asset utilization, and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



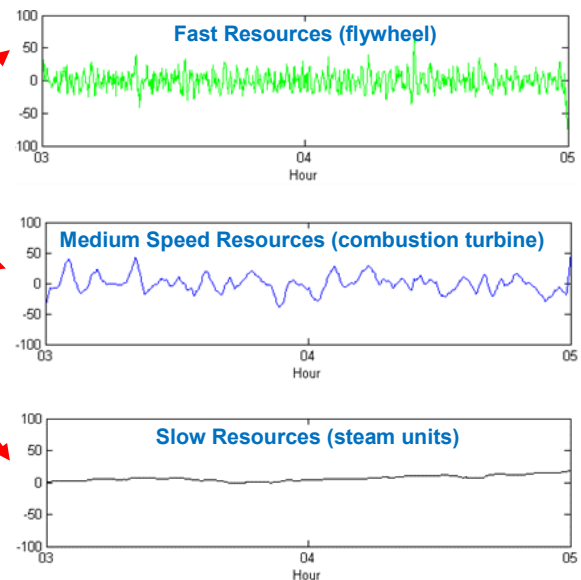
Short-duration storage provides a ‘smart’ buffer, giving grid operators critically important flexibility in system design.

Challenge: Supply/Demand imbalance in MW



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.

Solution: Break into pieces and add fast storage



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 support these constant power system fluctuations.

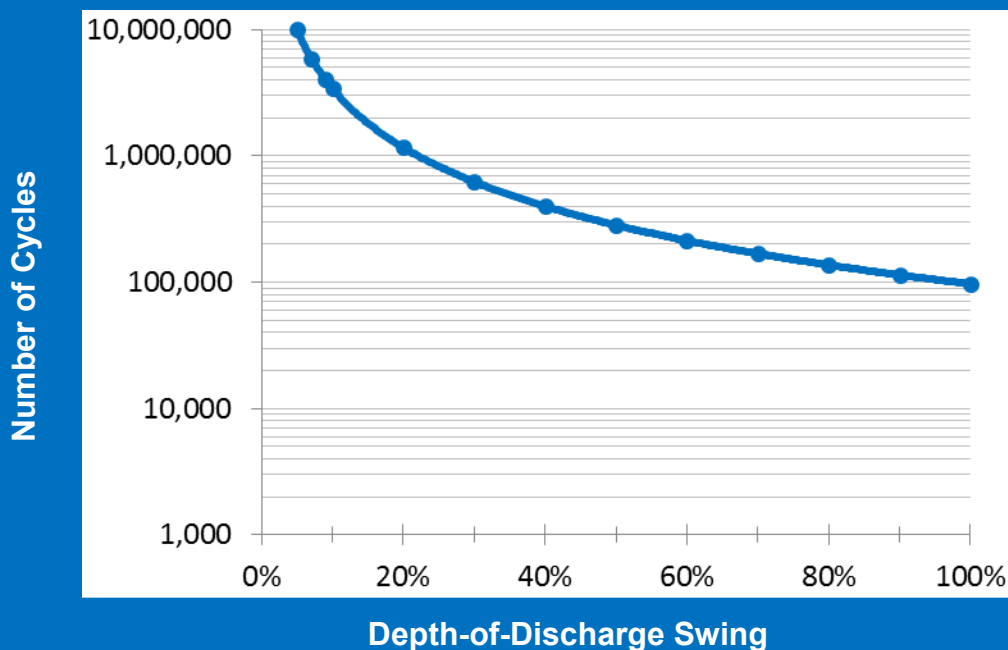
Beacon flywheel storage systems have much faster ramp rates than traditional generation and can correct imbalances sooner with much greater accuracy and efficiency. In fact, Beacon flywheels can ramp to full power nearly instantaneously. This fast response makes flywheels an ideal resource to provide 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 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. Our 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 enables grid operators to confidently integrate more renewable power.

Efficient and Durable. Real Savings.

Cycle Life Curve (100 kW flywheel)



Longest Life. Greatest Value.

Beacon Power 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.

Grid operators and utilities want to deliver the lowest lifetime cost of service for equipment in heavy workload utility system environments. Beacon flywheels can handle heavy duty high-cycle workloads without the ongoing degradation that shortens the life of other technologies. The full 100% depth-of-discharge range is available for regular use. There is no need to limit depth-of-discharge to specific ranges to manage cycle life or to oversize the storage capacity. Unlike some other technologies, charge and discharge rates are symmetrical, meaning the units recharge as quickly as they discharge which enhances their operational effectiveness. The flywheel is designed with the power-to-energy ratios needed for grid stabilizing and renewable power smoothing. With a lifespan of over 20 years in demanding high-cycle applications, the typical lifetime cost of a flywheel storage system is significantly less than competitive solutions.

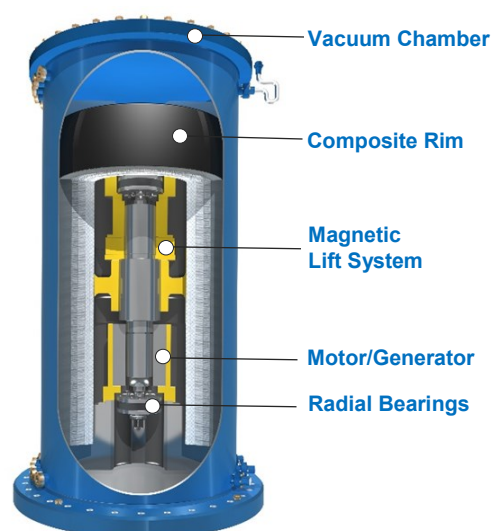




Trusted. Beacon has 30 MW in commercial operation providing up and down regulation service equivalent to 60 MW of conventional generation and our flywheels have accumulated over 5 million operating hours.

Beacon has the highest energy flywheel in commercial operation.

- Approximately 7 feet tall, 3 feet in diameter
- 2,500 lb rotor mass
- Spinning at up to 16,000 rpm
- Lifetime throughput is over 4,375 MWh
- Capable of charging or discharging at full rated power without restriction
- Beacon flywheel technology is protected by over 60 patents



Four Key Elements Make Our Flywheels Unique & Effective:

Patented composite rim – a mix of carbon fiber and fiberglass, optimizing mass, strength and cost to provide energy storage safely and at the best price.

Vacuum chamber – the sealed chamber provides a near frictionless environment eliminating exposure to oxygen and moisture, extending the life of the internal components.

Magnetic lift system – uses a non-contacting magnetic field to lift and support the rotor,

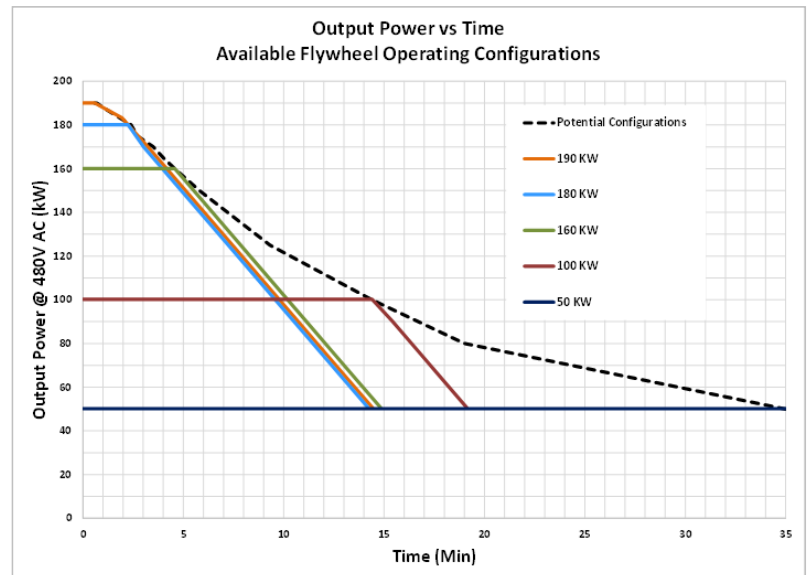
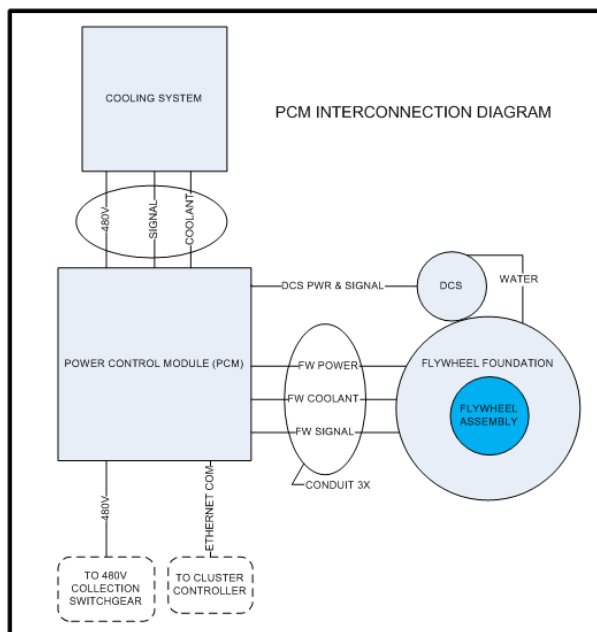
further eliminating wear and extending the life of the parts while minimizing friction. Beacon's patented bearing system is used to ensure the spinning rim maintains its axis of rotation with low bearing loads, resulting in a long life.

Brushless motor / generator – efficiently converts the electrical energy into mechanical energy when the flywheel is charging, and back to electrical energy when discharging.

Power Control Module (PCM)

The PCM is the connection interface of each flywheel storage unit, controlling the flow of power between the flywheel and electricity collection and feeder system. It also controls and monitors the status of critical flywheel operating parameters. Along with flywheel connectivity, the PCM interfaces with the other subsystems that support flywheel operation, such as cooling and power control.

Beacon's Power Control Module is an outdoor-rated, pad-mounted electronics 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 like Alaska. Beacon flywheel systems are designed to require low maintenance and our modular architecture allows units to be self-contained so service issues have minimal system impact.

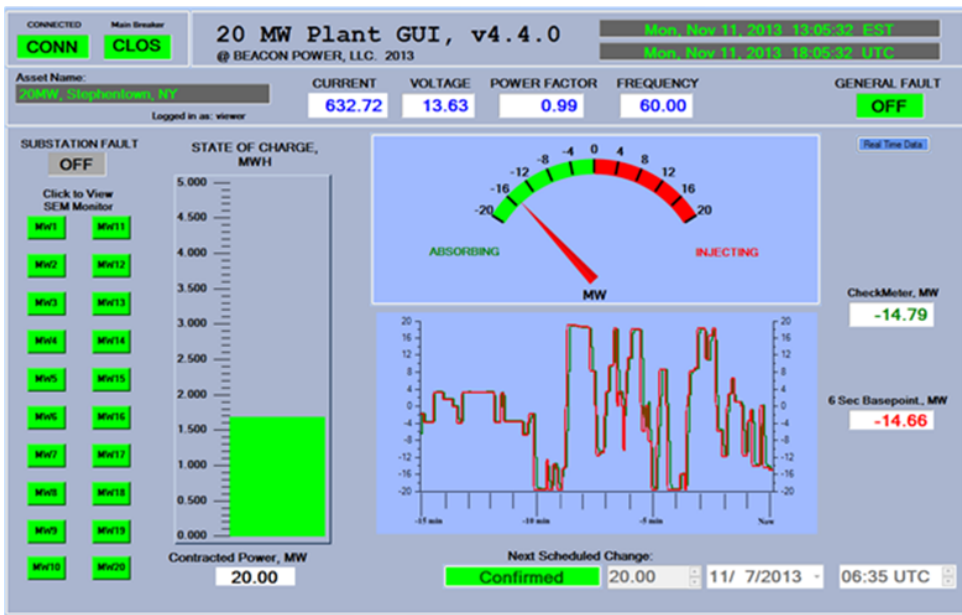
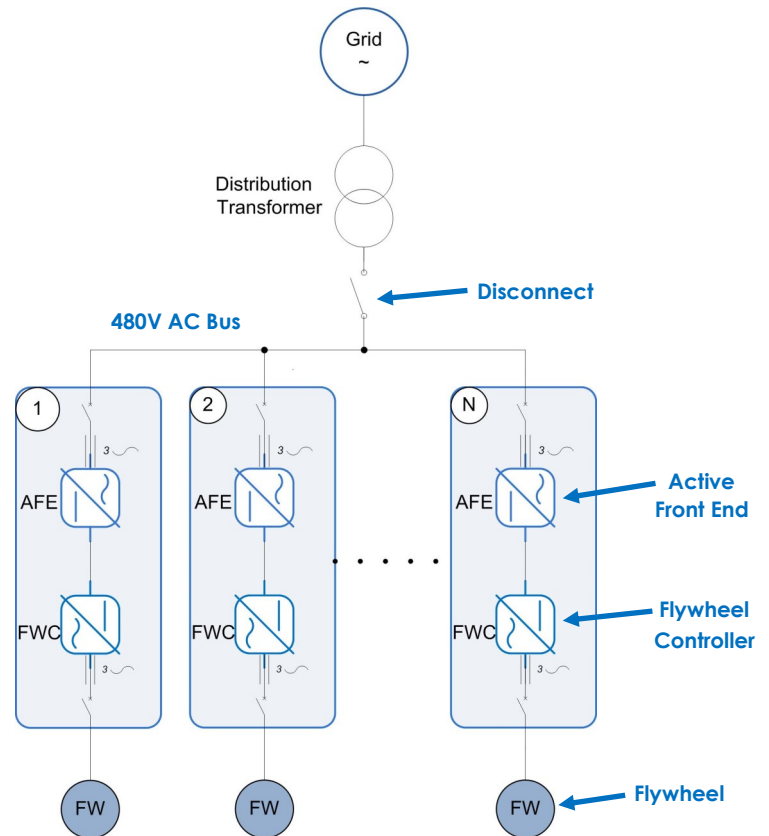


Adaptable & Flexible

- The 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 DC or AC electricity and to effectively utilize the full capability of the flywheel.
- Each flywheel has a power output rating up to 190 kW at 480V AC and the ability to provide energy storage for over 30 minutes depending on rated power injected into the grid.
- The power and energy transmission 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 20 to 30 minutes to match longer duration system variances such as managing wind power generation ramping.
- At any state-of-charge the throughput is constant and the device will recharge as quickly 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.
- The PCM allows flywheel stored energy to be coupled seamlessly to the grid and enables instantaneous response and maximum operational flexibility.

Control System

Each flywheel storage system is managed by a Master Controller that translates control signals from the grid. The Master Controller distributes signals to power blocks of up to 2 MW based on the operational readiness and state-of-charge of the storage system. At the 2 MW block level, a Cluster Controller further distributes the signal to command individual flywheels to perform based on the specific real-time status of each flywheel module. In the event of a maintenance-related issue, the Cluster Controller can take any individual flywheel module offline and redistribute the commands so the remaining modules respond to the desired control signal. This fully distributed modular architecture results in high availability and optimizes performance.



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. Beacon developed a proprietary algorithm to balance state-of-charge across a group of flywheels so no energy is wasted while balancing is accomplished.

Performance is tracked on 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 dozens of system and flywheel health parameters. The GUI together with an O&M alarm feature 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

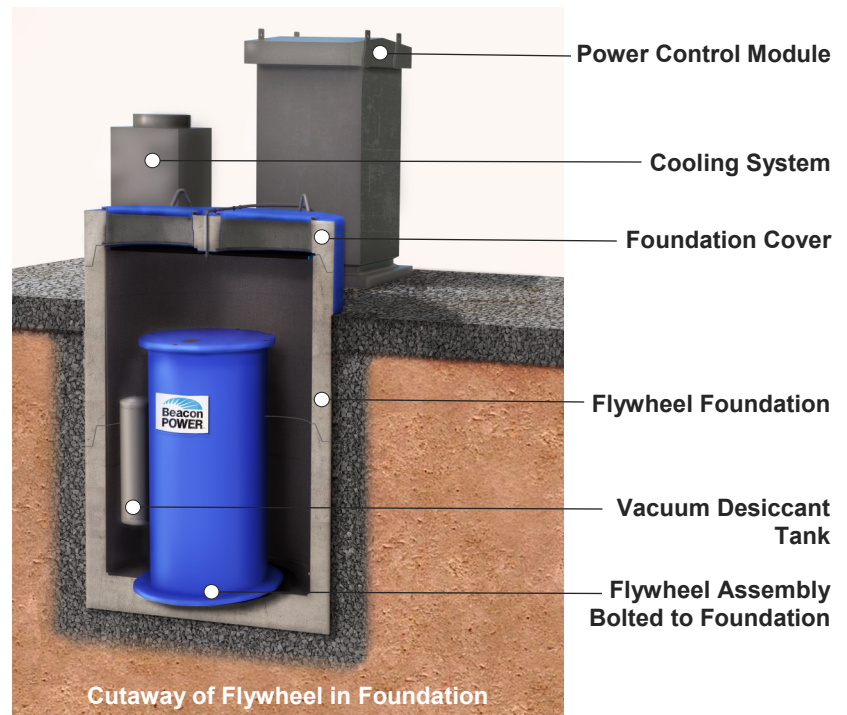


Hazle, PA, 20 MW
Initial COD Q3 2013

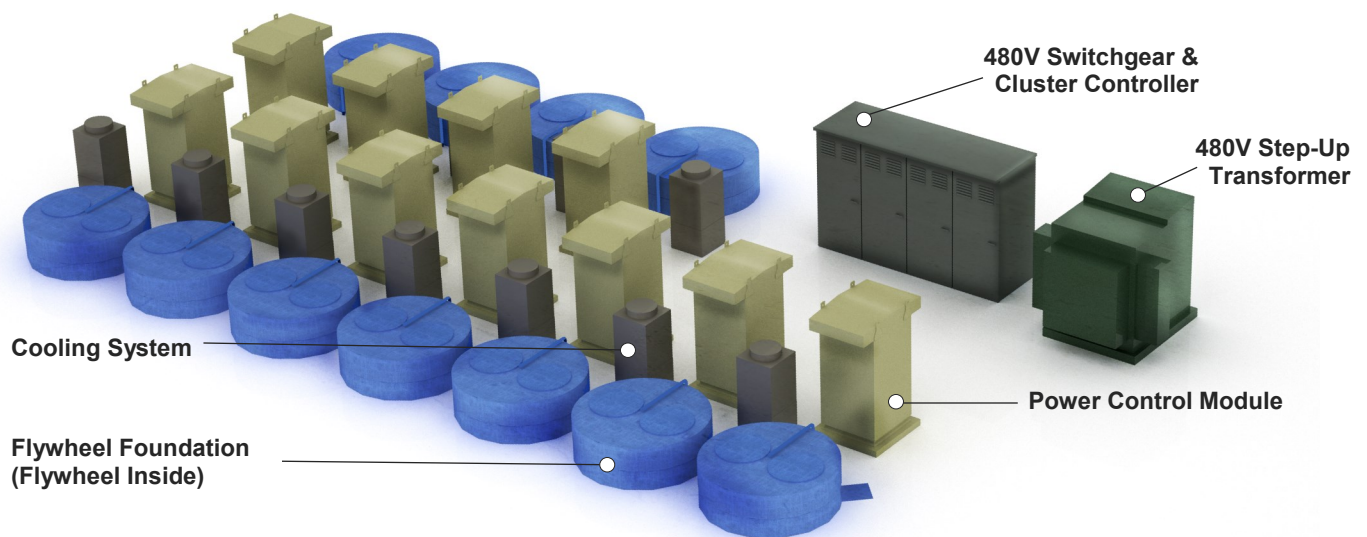
Beacon has three commercial plants, operating in three different ISO markets, responding with high accuracy to three different control signals. In the NYISO market, the project is about 10% of regulation market capacity but provides over 30% of the Area Control Error correction, doing so with over 95%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



Representative Flywheel Energy Storage Module



Modular Design. Beacon's flywheel storage systems are modular, providing flexibility in power capacity, energy duration, and siting. Each module is a stand-alone unit, requiring just 480V 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, 10 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 Voltage/Fault 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 will be 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.

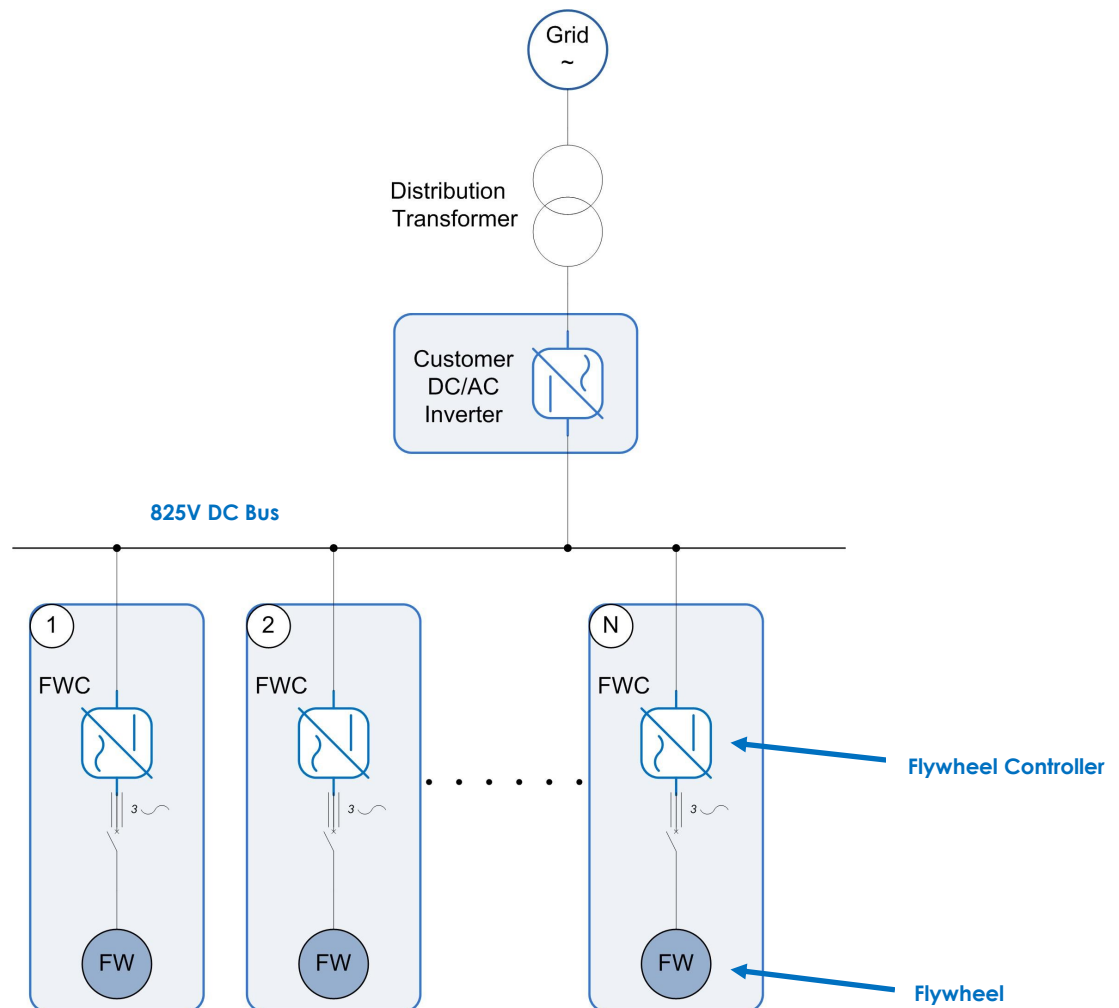
Technical Data Sheet

AC Product	Flywheel with PCM
Design Life	
160 kW configuration	20 years or 175,000 full depth-of-discharge cycles
100 kW configuration	20 years or 100,000 full depth-of-discharge cycles
Specifications	
Nominal supply voltage	3 Phase, 480 VAC
Supply frequency	50/60 Hz
Response time — normal operations	<1 second to full power
Ramp rate	Up to 190 kW/second
Response time — system event	100 milliseconds to full power
Under-voltage fault ride through	Yes
Output short circuit protection	Yes
Paralleling of units	Yes
Unbalanced current	Optional
Technical Data	
Nominal output rating	Up to 190 kVA
Reactive power	Four-quadrant operations up to full rating
Output power and corresponding charge/discharge times	Configurable from 190 kW for 0.5 minutes to 50 kW for 35 minutes. Configurations can be changed during an operating day. See Output Power vs Time Plot (Appendix)
Usable energy (@ full charge)	~30 kWh depending on power vs time configuration
Idling losses	3 kW per hour under typical conditions
Round trip efficiency	> 85%
Environmental	
Temperature range	-35C to +40C (without derating)
Humidity	Up to 95% (above which a heater may be installed)
Altitude (above sea level)	<1200 m (without derating)
Flywheel installation	Below ground in concrete foundations
Seismic capability	Sds 1.0g Per IBC 2012
Communication	
Supported protocols	Modbus, TCP/IP, CAN
Monitoring	Internet-based in compliance with NERC standards
Data storage	Full trending and analysis; data stored locally and offsite
Dimensions	
Flywheel dimensions	82 in (208 cm) height x 47 in (120 cm) diameter
Power Control Module	40 in (101 cm) x 40 in (101 cm) x 60 in (152 cm)

Technical Data Sheet

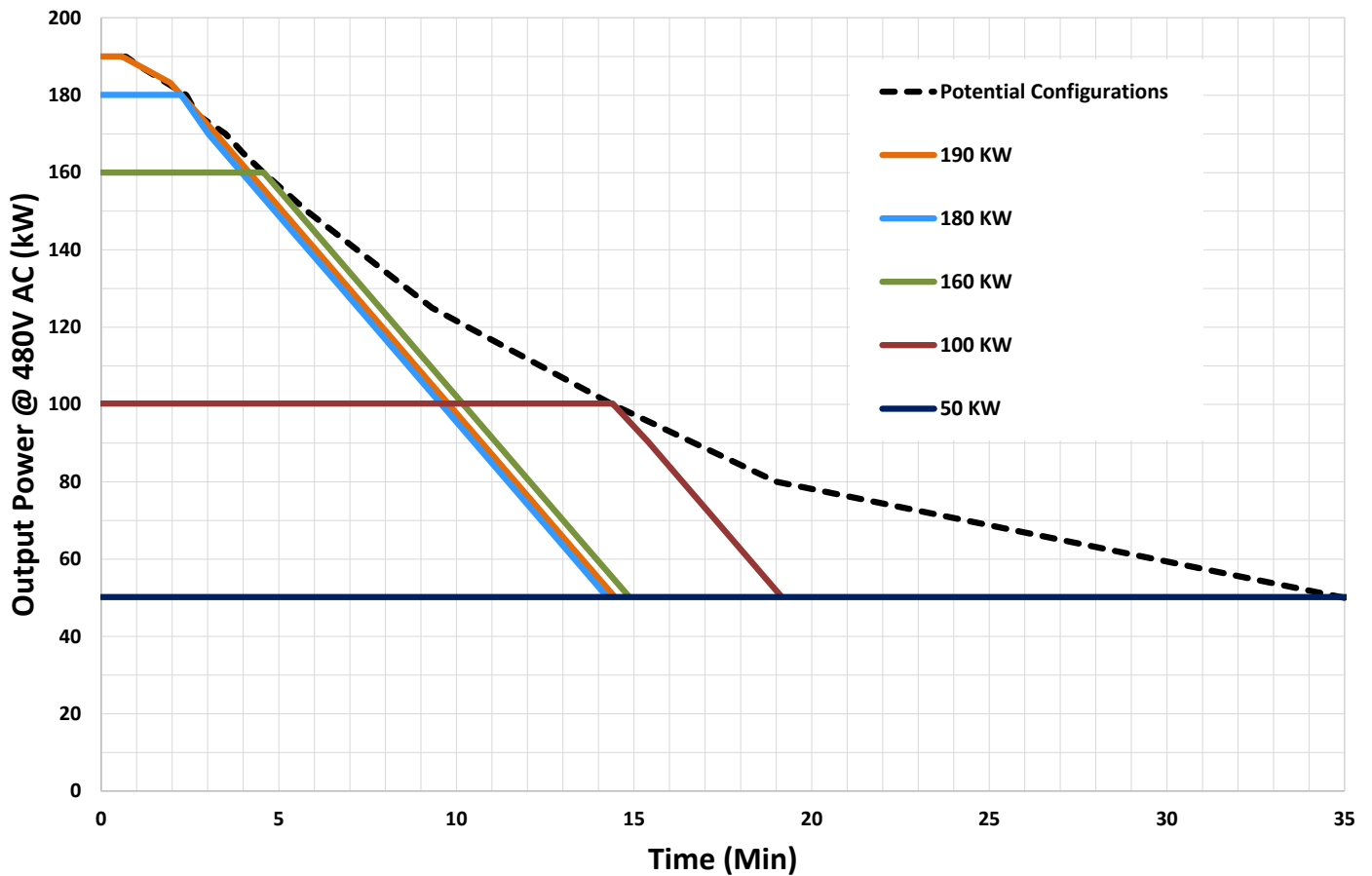
DC Product	Flywheel with PCM (DC Output)
Electrical Interface	
DC Bus Voltage	825 VDC
Input / Output Power	Up to 195 kW continuous power (single unit)
One Way Efficiency	>93 %

Flywheel systems can be configured for DC integration, enabling system integrators to incorporate flywheel storage capability into an existing system, or one optimized around different controls and AC conversion technologies. Below is a one-line configuration diagram along with flywheel performance specifications at the DC bus.



Appendix

Output Power vs Time
Available Flywheel Operating Configurations



Typical Operating Modes*	Max Power (kW)	Time at Max Power** (min)	Total Operating Time (min)	Total Energy Injected (kWh)
Max Power: Frequency Response	190	0.5	14.4	30.4
Power Mode: Solar Smoothing	180	2.3	14.4	30.1
Grid Support & Frequency Regulation	160	4.6	14.8	30.0
Energy Mode: Wind Smoothing	100	14.5	19.0	30.0
Energy Mode: Reserves	50	35.0	35.0	29.0

*Operating modes can be selected and changed as needed throughout an operating day.

**Max charge and discharge rates are equal.

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.

Durability: 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 5 million high-cycle operating hours. The lifetime and capability of the flywheel is a matter of basic materials science; it's a spinning machine similar to a gas turbine but operates in a vacuum without any significant thermal stress or friction. As a mechanical energy storage device, the performance of the Beacon flywheel energy storage system does not degrade with cycling, depth-of-discharge, time or temperature.

Agility: 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 as fast as they discharge and do not need to operate within limited state-of-charge ranges.

Precision: The response time and modularity of the Beacon flywheel energy storage system enables 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 seconds and at a 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.

Safety: Beacon's flywheels have an excellent safety record. Beacon has over 300 flywheels installed and in commercial operation and has accrued over 5 million operating hours with no significant safety issues or events. Safety starts with the system design, and our 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. This also provides an additional layer of system control and safety protection as it will isolate units containing system energy to ensure 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 Power flywheels are in operation today continuously working to improve grid performance and are a trusted resource ensuring grid reliability.

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