RGA Labs, Inc.
Advanced Engineering & Technology

Beacon POWER

SmartBox – Flywheel Hybrid Energy Storage and MicroGrid Forming System for Commercial, Industrial, Utility, and Defense Applications

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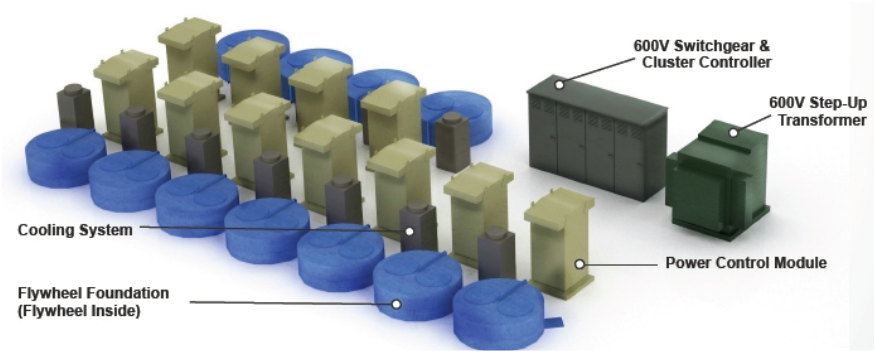
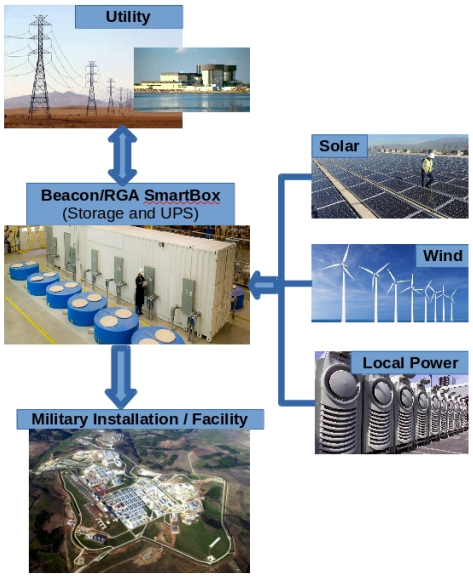
Figure 1 - Typical SmartBox Installation



1. System Summary

1.1 What is SmartBox?

SmartBox is a durable, reliable (>>N+2), ultra-high speed, smart, flexible electric MicroGrid power storage and delivery system typically installed between the utility and commercial, industrial, or defense applications. SmartBox is a hybrid system created using ultra-high speed magnetically levitated flywheel energy storage, power electronics, grid forming inverters, batteries, and powerful computers and software. It can provide clean emissions free power, capacity management, execute energy arbitrage, manage renewables, and perform regulation services in real time for the benefit of both the utility and the customer simultaneously.



SmartBox integrates various sources of storage and energy supply (e.g. storage; renewables – hydro, PV and wind; utility grid; and diesel and gas generator) into a composite, regulated, dispatchable, protected supply to the utility AND the customer. Renewables such

as PV and wind are not dispatchable and have high variability in output. SmartBox provides a buffering solution that creates a reliable power supply to the customer and utility which can be easily regulated. Energy can be stored on a short term or diurnal basis for peak shaving and energy / power arbitrage. SmartBox provides the grid forming, grid reference, and spinning reserve capability for non-rotating assets such as PV.

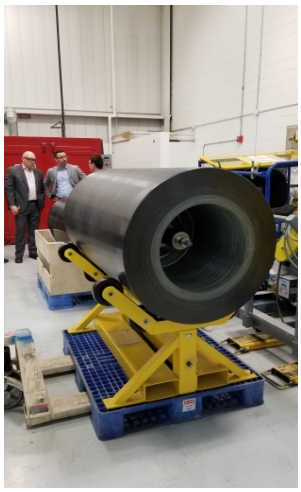


Figure 2 - Beacon FES carbon flywheel

SmartBox MicroGrid utilizes flywheel energy storage (FES) as the front end energy storage and power supply. These systems are extremely fast, 4-quadrant switching at <<0.1 cycle, and have very high power capability to supply stabilizing power/load for quenching grid transients. In addition to supplying high power, the FES can also absorb at symmetrically high power rates providing voltage and frequency protection when large loads are connected/disconnected from the utility's system. Extended storage is provided by high performance Reserve Batteries which are protected from life limiting transients by the front end FES.

SmartBox provides unmatched grid regulation services because of its 4-quadrant ultra-high-speed switching capability. This provides the application with voltage, current, and frequency regulation services to maintain Area Control Error (ACE) at a minimum. Because SmartBox can switch across all 4 quadrants at full power in much less than one cycle, its regulation value is many times that of much larger generation and battery storage devices. These features provide grid stability and capability to quench grid transients.

Figure 3 - FES power control

With the SmartBox FES, rotating stored energy can provide continuous synchronous condenser VAR (reactive power) support for the utility while it is simultaneously performing the features described above. SmartBox provides an uninterruptable electrical supply to the customer providing reliable power during all operating modes, including complete failure of the utility grid supply. Because SmartBox MicroGrid provides its own frequency standard which is locked to utility grid, SmartBox MicroGrid can transfer from off-grid mode back to normal utility supply seamlessly and without interruption. This addresses the issues of islanding and provides the ability to assist with utility black start of the grid and other generation resources when returning from a major grid segregation and interrupt, such as recovery from storms and hurricanes. Because SmartBox is typically installed local to the customer / load, it provides secure, continuous, reliable power when the grid is not available.

Figure 4 - FES rotor package

SmartBox MicroGrid is fully automated and fully monitored and can be deployed in the most remote and extreme environments. Its software allows SmartBox to operate autonomously. And since SmartBox MicroGrid is a hybrid comprised of multiple components, it is not subject to the single mode failure limitation of traditional systems.

SmartBox MicroGrid systems can be ganged together to supply large projects (>100 MW) using standardized systems and components. This also provides the opportunity in large systems for taking subsystems out of service without degrading the performance of the entire system.

1.2 How SmartBox Works

SmartBox MicroGrid is a software controlled hybrid set of integrated systems.

System	Function
SmartLink/SmartBox control computers and software	Overall autonomous control of SmartBox systems, including the use of AI.
Main Power Inverter with high speed power switching	4-quadrant interconnection to the grid and regulation of power / storage assets
Beacon high performance flywheel energy storage (FES)	High speed / high frequency storage and generation as well as rotating synchronous condenser capability
High capacity reserve battery storage	Longer term storage for multi-hour and diurnal capability
Integral interconnects for power generation sources	(e.g. Photo-Voltaic, Wind, Hydro, Gas/Diesel reciprocating or turbine)
Connections to the utility ACE and dispatch information	Real-time dispatch and grid control
Health monitoring and protection	Fire protection, maintenance management, and remote engineering support

The SmartBox system starts with Beacon Power's high performance Flywheel Energy Storage (FES) system as the front end onto which batteries may be added for extended storage. Prime power, such as solar and wind (or other renewable, diesel, or gas turbine) can then be added to the SmartBox universal power bus. These components are all integrated together for seamless control and switching with continuous monitoring.

The FES provides the initial storage, up to 15 minutes at full power. FES is extremely fast and well suited to high frequency switching and deep discharge/charge without suffering wear and shorting component life. Longer term storage (> 15 minutes) is provided by the battery bank which has lower cost and higher capacity. The FES front end protects the batteries from the high frequency switching which substantially shortens the battery life. This hybrid design makes SmartBox unique in the industry and provides the longest component service life with lowest lifetime costs.

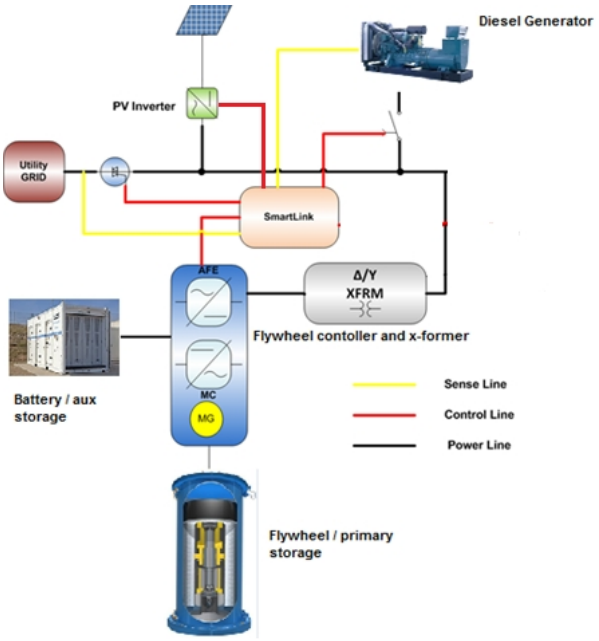


Figure 5 - SmartBox MicroGrid typical configuration

The SmartBox MicroGrid has onboard software which continually monitors and meters both the utility's and customer's demand and power requirements, along with the power generation and storage of local power generating assets. In addition, the SmartLink controller has information about the utility's energy supply cost structure and thus the SmartBox MicroGrid can react appropriately and nearly instantaneously to optimize the facility's revenues. Additional software provides continuous link to the utility allowing the utility to access the facility's power/energy when needed. The SmartBox MicroGrid hybrid design reduces the total cost to the utility and the customer through a variety of protective, performance, energy efficiency, space reduction, carbon reduction, and cable reduction features.

Figure 6 provides an example of the SmartBox system in regulation services mode. Note the high frequency switching from 20 MW to -20 MW. Batteries by themselves exposed to this type of switching would be damaged and their life severely shortened. Regulation services and system transient management typically requires less than 10 minutes of storage, thus FES is well suited to this type of service.

SmartBox is fully modular, typically constructed in 160 to 360 kW modular units or 1.6 / 3.6 MW modular blocks. Each unit is comprised of a strengthened container package with all controls, batteries, and support systems, and modular ground mounted or building mounted, external flywheels. SmartBox is compact and space efficient, and can be installed in a variety of different environments including both urban and rural applications. The system is fully enclosed providing a safe and clean installation, with zero emissions. Figure 1 on the first page demonstrates what a typical defense scale, multi-MW installation looks like. Note the blue ground mounted FES storage units in the foreground. While this system is shown in an outdoor installation, it can also be installed either entirely or partially interior to a building structure.

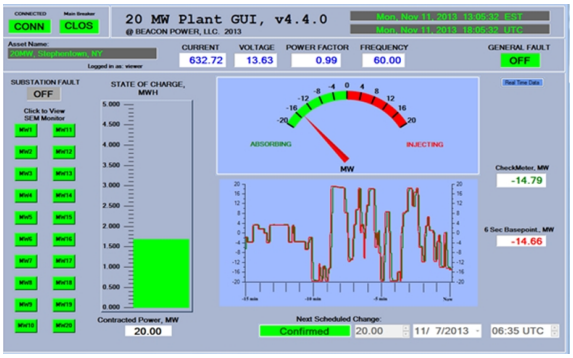


Figure 6 - Beacon Power System Regulation Interface

Because SmartBox systems have a low vertical profile, they can be co-located on the same site with PV and wind assets. This maximizes the land utilization for the developer and limits the visual impact to the surrounding land owners.

1.3 Ease of Installation and Service

SmartBox systems are designed to be installed as simply as a pad mount transformer. Typically installation requires only one day with little advance site preparation. Tools, equipment, and required permits are all standard for typical electrical systems. Rotor systems can be installed completely below grade in areas such as parking spaces to efficiently utilize land area, particularly in dense urban areas.

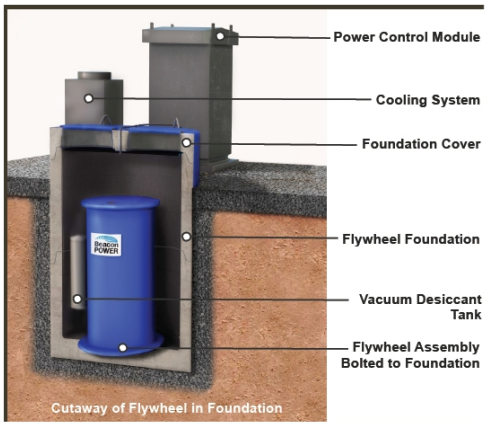


Figure 7 - Typical SmartBox PCM and Flywheel installation

1.4 Energy Arbitrage and Capacity Capability

Electric power prices change on a minute-by-minute basis as shown typically in Figure 8. Prices often swing wildly and can range from -10 cents/kW-hr to more than +40 cents/kW-hr during more severe weather.

Conventional electric power systems (diesel/UPS/transfer switch) provide no value in capturing this arbitrage potential while consuming capital and maintenance resources. SmartBox's on-board predictive intelligence and network system connections provide the ability to capture and store low cost energy and deliver this energy to BOTH the customer and the utility during high-cost periods.

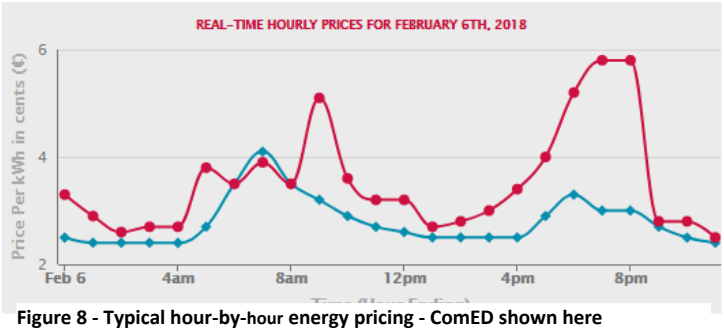


Figure 8 - Typical hour-by-hour energy pricing - ComED shown here

Renewables connected to SmartBox are also properly sequenced and dispatched to maximize the value of their capacity and energy production. This power management reduces the costs to BOTH the customer and the utility.

SmartBox's automated net metering capability and automated sell/buy capability allow the customer to utilize previously unused real estate (e.g. roof area) as revenue producing space with renewables such as solar.

1.5 Remote and Defense Applications, Security, and Cyber Security

SmartBox is a fully autonomous grid-forming system allowing remote and fully secure installations. In areas where the utility capacity is limited, a remote installation of SmartBox can provide significantly increased power capacity without any upgrade of the utility connection.

For defense and field applications, SmartBox has full grid-forming capability providing completely independent (island) and secure grid quality power when paired with generation such as solar, wind, diesel, small modular nuclear reactors, etc.

Figure 9 - Beacon FES Stephentown, NY, 20 MW, Operating since Q1 2011

Because SmartBox's flywheel front end is fully magnetic, its instantaneous power capability is not limited by battery chemistry, making it an excellent platform for powering impulse loads common in defense applications. This includes rail gun, electromagnetic aircraft launch systems (EMALS) and electromagnetic aircraft recovery systems (EMARS), energy and beam weapons, and high power radar systems.

Because SmartBox has extremely high transient response speed (< 1 ms), it can respond and quench grid and micro-grid upsets such as electro-magnetic pulse (EMP) effects. SmartBox systems can be fully protected from EMP because their systems are fully self contained and can operate completely autonomously without outside control in the event of being cut off from any grid or internet connections. This also provides black start capability.

SmartBox systems are equipped with strong cyber security features, operating with an independent intranet, that is fully resistant to cyber attack. In applications where additional security is required, such as nuclear installations, SmartBox systems can operate complete autonomously without any internet connection, making them complete immune from cyber attack.

1.6 Operational History

SmartBox MicroGrid is constructed from systems, modules, and components which have extensive in-field operation and experience. All of the major subsystems have successful operational experience and market performance.

Figure 10 - Beacon FES Hazel, PA, 20 MW, Operating since Q3 2013

The FES units have an unmatched performance record of service and deployed in multiple locations throughout the world. Notably, Beacon FES systems have been deployed for regulation service at two locations in Stephenstown, NY and Hazel, PA. Both installations are 20 MW 4-quadrant resources for the utility, connected at 138 KV to the grid. These units have an excellent service record and essentially 100% service capacity since installation. Beacon rotors have more than 2,800 rotors years of successful operating experience.

The total SmartBox installation size is essentially unlimited. Units are modular and installed as needed by the application. There is no upper limit to the project size and thus >>100 MW installations are possible.

1.7 SmartBox Partners and Project Development

SmartBox is designed and constructed with field proven technology and industry experience in delivering projects. The SmartBox Team will work with the site/project owner, the local utility, and local contractors to best configure a profitable SmartBox system. Components and supplies are sourced from American suppliers where possible, and every effort is made to utilize minority and veteran owned suppliers.

Figure 11: Two modular Beacon FES systems installed in Ireland for Schwungrad Energy as a renewable / battery hybrid demonstration.

1.8 Advantages

SmartBox MicroGrid provides a host of advantages to the developer, the utility, and the customer including:

1. Lower total installed cost than traditional diesel/ UPS w/integrated packaging
2. Lowest total life cycle cost and revenue producing
3. Application in both remote and urban areas
4. Survivability under the most extreme conditions
5. Significantly improved power quality and reliability than traditional systems
6. Projects can expand capacity incrementally
7. Diurnal and minute-by-minute arbitrage energy pricing utility price response
8. 100% power factor correction and peak utility demand reduction, reducing customer capacity charges
9. Essentially instantaneous response performance maximizing value
10. Lower cost batteries, longer battery life - environmental credit. Lower labor hours.
11. Fire safe batteries with no thermal runaway risk
12. More environmentally friendly battery chemistry
13. Lower carbon emissions from less primary drive (generator) cycling
14. Lowered parts count from traditional diesel/UPS/transfer switch systems
15. Maximum renewable utilization – lower cost to connect renewables using less hardware
16. Standardized inverter topology creating high reliability
17. Fully monitored in real time from both local and remote locations
18. Reconfigurable to adjust for utility's / customer's changing needs
19. System service can be performed modularly while maintaining overall site capability – 100% capacity factor.
20. Reduced cabling customer costs due to integrated transfer switching
21. No utility service upgrade is required for installation -- Customer can expand capacity without the need for service upgrade
22. Full backup power capability, replacing traditional diesel/UPS/transfer switch systems – i.e. diesel / fossil power system may be eliminated in certain applications.
23. 30% smaller primary power diesel/turbine requirement where primary power is required.
24. Utility and customer share SmartBox values simultaneously.
25. Can be configured for small space / high density installations.

Figure 12: Beacon factory assembly area in Tyngsborough, MA

2. Attachments and Supporting Data

Table 1 - Typical SmartBox 400-160 MicroGrid block specifications – 10 x 160 kW FES Unit Group (motor drives available from 10 kW – 400 kW)

Continuous Power Rating	1.6 MW
Peak Power Rating	3.0 MW
2 hour power rating	2.5 MW
Number of units ganged together	>500
Discharge/charge cycles	Unlimited – continuous cycling duty
Input Voltage	480 VAC / 60 HZ / 3 phase – user selectable
Output Voltage	480 VAC / 60 HZ / 3 phase – user selectable
Input voltage range	400 – 510 VAC
Full load efficiency / part load efficiency	96% / 95%
FES rating per rotor	160 KW / 300 KW / 35-40 KW-hr
Number of rotors	10
FES minutes of storage @ 500 KW	15 minutes / 1.6 MW
Battery minutes of storage @ 500 KW	2 hours / 1.6 MW – longer with additional battery packs
Voltage Regulation	Better than +/- .25%
Voltage THD	Less than 1% (100% nonlinear load); Less than 1% (100% linear load)
Transient Response	Full absorb to full delivery in < 0.1 cycles, full recovery within 0.1 cycles (<< 0.0017 seconds)
Reactive Power Capability	Fully 4-quadrant symmetric
Frequency Regulation	+/- 0.005 Hz
Frequency Slew Rate	>>100 Hz/sec. (grid tied)
Control system interface	Ethernet / TCP/IP
Monitoring	Internet with encryption
Data storage and metering	Full trending and analysis available; data stored locally and offsite. Milli-second data resolution. Revenue quality metering on all connections to SmartBox.
Ratings:	UL 1778 ; CUL CAN/CSA C22.2NO.107.1-M91 ; EN 50091-1; All Cabinets provide seismic mounting features, potential for DC ground fault detection capability
Design lifetime	>25 years

Available modes as of 1/1/2019

Model	Useable Stored Energy	Installation	Available Power Drives (also available in custom sizes)	SmartBox / SkyNet Software	Typical Applications	
200 (prev: BHE-2)	2 KW-hr	Direct burial or vault/closet	1/2/3 KW Micro-grid forming	YES	Tele-communications, computer networks, municipal infrastructure	
300 (Prev: BHE-6)	6 KW-hr	Direct burial or vault/closet	2/6/15 KW Micro-grid forming	YES	Tele-communications, computer networks, commercial, municipal infrastructure	
400	Up to 35 KW-hr	Buried Vault	10/25/50/100/160/ 300/360 KW Micro-grid forming +1 MW superconducting (available 2020)	YES	Data centers, utilities/grid, defense, industrial, nuclear	

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