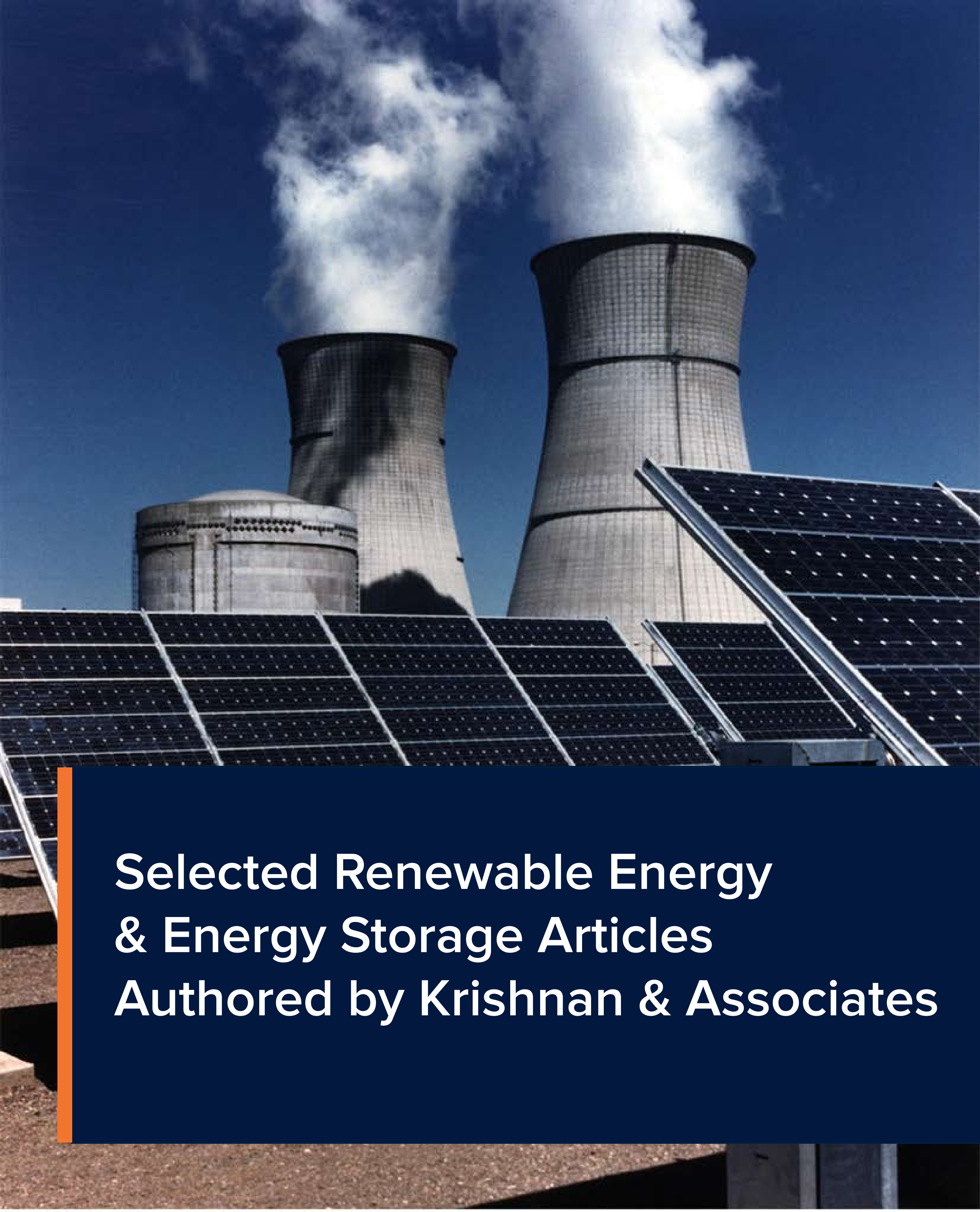

Selected Renewable Energy & Energy Storage Articles Authored by Krishnan & Associates

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CMI's MiRIS pilot project: batteries (both Li-ion and flow) are included

CMI Energy, well known as a global player in steam generation, has diversified into renewables, in particular CSP, and is now taking steps into the battery storage area with completion of the MiRIS facility at CMI Group's international headquarters in Seraing (Belgium). The aim of the MiRIS (Micro Réseau Intégré Seraing) pilot plant, which incorporates a microgrid and PV, is to look at a range of battery options and their integration with renewables. **Ravi Krishnan**, Krishnan & Associates*

Renewable energy has many environmental and economic benefits, but intermittency of solar and wind resources is by far the most formidable technical barrier to widespread system integration. Wind and solar generation are not dispatchable thus grid operators must wrestle with transmission and distribution system upgrades in addition to grid capacity constraints, spinning reserve margins, and frequency regulation to offset the effects of intermittency. Duplicate fossil-fired resources are often constructed to backstop renewables when the wind doesn't blow or the sun doesn't shine. The elegant solution to each of these problems is energy storage.

Small-scale energy storage projects are typically used in either high power, short duration applications such as frequency regulation or in low power, long duration applications such as time shifting of energy (kWh) and demand (kW) within a facility or local grid. Time shifting is the process of storing energy produced by an intermittent generating resource and releasing it at a later time when the energy and/or demand reduction is needed, typically during costly on-peak hours. Unfortunately, most energy storage technologies are unable to perform well in both roles.

There are many other economic advantages available to facilities with excess capacity to adopt energy arbitrage practices by storing low cost, off-peak energy for resale to the grid during on-peak hours at a premium price. A properly designed energy storage system may supply valuable grid ancillary services, such as grid voltage support, frequency regulation, and spinning reserve to the grid in some regions. This option is especially attractive for facilities with self-generated renewable energy that have with surplus capacity at certain times during the day.

As an alternative, energy storage may allow a facility with essential services to avoid the cost of expensive conventional backup power equipment.

Figure 1. The MiRIS pilot plant is under construction at CMI Group's international headquarters in Seraing (Belgium). The facility is expected to be completed in late 2018. Source: CMI Energy

* A global energy industry marketing firm, www.krishnaninc.com. Ravi can be reached at ravi@krishnaninc.com

Figure 2. PV panels, part of CMI Energy's MiRIS project. MiRIS will be integrated with the CMI Group's international headquarters complex, allow its engineers to perform detailed analysis of renewable integration with energy storage. Source: CMI Energy

From boilers to batteries

CMI Energy, part of CMI Group, a well established player in steam generation (notably HRSGs, as well as industrial and LNG boilers), is also active in renewable energy system design and integration, particularly concentrated solar power with thermal storage. The natural extension of that experience is battery energy storage, particularly when integrated with intermittent renewable energy resources, on either side of the meter. CMI Energy also acts as an EPC integrator within the energy storage sector, providing optimised solutions depending on each customer's specific needs and the best available technical-economic features.

CMI Energy is currently constructing the MiRIS (Micro Réseau Intégré Seraing) facility, Europe's largest industrial energy storage pilot, located adjacent to the CMI Group's international headquarters in Seraing (Belgium) (Figure 1). The purpose of the full-scale pilot plant is to demonstrate advanced integration of intermittent renewable energy resources with battery-based energy storage thereby producing a fully dispatchable renewable energy resource.

MiRIS, scheduled for completion in late 2018, consists of renewable power generation and energy storage systems. The renewable portion of the project includes a 2 MWp 1.75 GWh/y photovoltaic system consisting of 6500 roof top panels (Figure 2) and carports, and 36 inverters. The energy storage portion of the demonstration project includes two types of flow battery systems plus a lithium-ion battery system for a combined total of 4.2 MWh of storage capacity. The technology showcase will interconnect with the building's electrical network and its DSO 15 kV distribution service connection. The CMI complex consumes approximately 1.3 GWh/y.

CMI Energy plans to use the MiRIS project to investigate the interoperability of renewables and different energy storage technologies for a variety of energy user energy profiles, particularly with respect to renewable energy time shifting and energy resale to the grid. Another important goal is to demonstrate off-grid or "islanding" operation of the MiRIS microgrid. Potential ancillary services that may be provided to the local grid will also be evaluated as well as the impact of user demand response.

Jean-Michel Gheeraerdts, president of CMI Energy spoke to the importance of MiRIS when announcing the project: "We now have ways of use green energy sources that eradicate their major flaw: intermittent production. Energy storage and management can be applied in a number of fields as an alternative to diesel generators for unconnected regions, as a way of deferring investment in parts of the network, as a means of optimising existing photovoltaic or wind systems, and as an enabler of participation in the primary or secondary reserve markets."

Smart energy management

A single energy management system (EMS) ensures optimal energy flows within the MiRIS microgrid thus maximising the profitability of the overall system while contributing to its safe and reliable operation (Figure 3).

The EMS performs data management, modelling of alternative operating scenarios, as well as facility energy and demand forecasting. In addition, the EMS can evaluate the most economic combination of operating variables, electricity market signals, and weather projections in real-time to optimise the operation of the entire facility and its grid interconnection. CMI Energy developed the EMS in close collaboration with the University of Liège in Belgium.

The EMS is uniquely capable of adapting to a variety of different applications by employing a suite of sophisticated and innovative algorithms. System optimisation considers various inputs, such as forecast PV panel electricity production, expected loads, current and expected electricity tariffs, and grid constraints to derive optimal control decisions for each component, with both grid-tied and off-grid operation of the micro grid. Among the grid-tied applications are behind-the-meter segments, such as energy price arbitrage for consumer bill optimisation, self-consumption and peak shaving, including participation in reserve and capacity markets. The EMS will be enriched with added capabilities as experience is gained with operation of MiRIS.

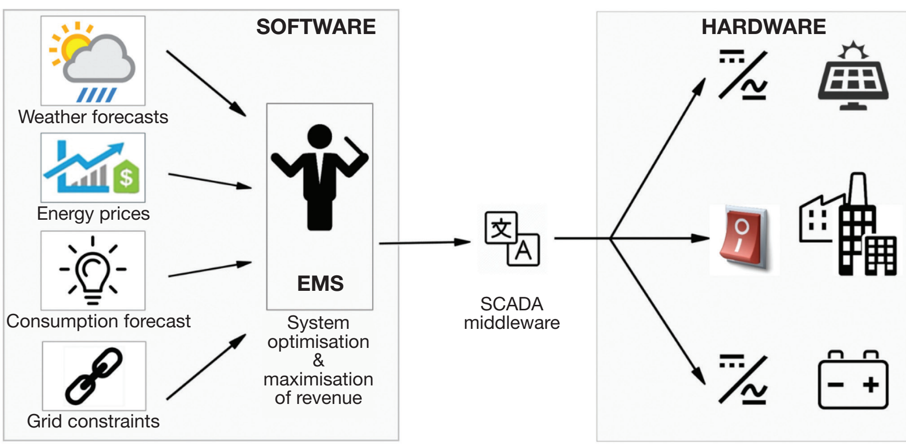
Lithium-ion battery option

Most energy storage projects today rely on packaging very large numbers, often tens of thousands, of individual lithium-ion (Li-ion) cells to meet a project's energy storage requirement. Li-ion batteries, commercialised in the early 1990s, have found many commercial and residential uses. Lithium-ion batteries have been the preferred energy storage technology for much of the past decade, particularly due to scale and manufacturing efficiencies from electric car production. Li-ion batteries are currently used in applications ranging from small-scale residential systems to grid-connected containerised battery systems that supply ancillary services.

The operation of a Li-ion battery, is in principle, the same as a conventional battery. However, instead of metallic electrodes and an acid-based electrolyte, lithium ions are injected into the structure of the electrode materials and lithium ions flowing between the electrodes produce current. The typical Li-ion battery used for energy storage applications uses a lithiated metal oxide positive electrode and a carbon negative electrode (Figure 4).

Modern Li-ion cells are generally available in different formats, such as prismatic and cylindrical. Depending on a project's energy density requirements, individual batteries are grouped into multi-cell modules in series/parallel arrays to form a battery string that will produce the desired voltage and capacity. Each string is usually controlled by a battery management system. Battery strings are then combined to provide the required amount of energy storage (kWh). For the MiRIS project, 1260 kW/1340 kWh of Li-ion batteries packaged within a single shipping container will be used.

Figure 3. The different roles of the energy management system. Source: CMI Energy



Two flow battery options

As an alternative to Li-ion, CMI Energy determined that flow batteries exhibit the best combination of life cycle cost, expected near-term economies of scale, and reasonable technology risk for bulk energy storage.

Navigant Research recently released a Leaderboard Report that examined the "strategy and execution" of 13 companies offering non-lithium-ion battery technologies for grid energy storage. The two companies judged to be market leaders were Sumitomo Electric Industries (Sumitomo vanadium redox flow battery) and ViZn Energy Systems (ViZn zinc-iron redox flow battery).

For the MiRIS project, CMI Energy concluded strategic partnership agreements in late 2017 with Sumitomo and with ViZn for the supply of flow batteries for the MiRIS and future projects.

Sumitomo Electric's redox flow battery (600 kW/1.75 kWh) uses vanadium dissolved in sulphuric acid as its electrolyte, with inert graphite electrodes.

The ViZn flow battery (400 kW/1200 kWh) uses a zinc-iron (hybrid) solution as its electrolyte.

Flow battery technology is distinctly different from conventional batteries. A flow battery stores energy in the electrolyte, unlike conventional lead-acid or Li-ion batteries, which store energy in the electrodes.

Modern flow batteries use two dissolved chemical components to form liquid electrolytes, positively or negatively charged, as energy carriers. The electrolytes are simultaneously pumped through two half cells separated by an ion-selective exchange membrane. The thin exchange membrane between the cells prevents the electrolytes from mixing but allows specific ions to pass through to complete the redox (reduction-oxidation) reaction and thus produce a flow of electric current.

For example, in Sumitomo's vanadium flow battery, the battery reactions change the valence of the vanadium in both the positive and negative electrodes (Figure 5). The valence change moves protons through the membrane, charging or discharging the battery. In a similar fashion, ViZn uses a zinc-iron electrolytic solution for its flow battery design.

The power rating (kW) of a flow battery is determined by the size, number, and configuration of electrodes in the cell stacks. A bipolar design describes cells stacked in a sandwich configuration so that the negative plate of one cell becomes the positive plate in the next cell. The voltage of a single cell is approximately 1.4 V. To obtain the design voltage, multiple layers of cells are connected in series to form a cell stack. The energy storage rating (kWh) is determined by the amount of electrolyte in the two electrolyte tanks (see Figure 5).

Figure 4. Basic operation of a lithium-ion battery. Source: BYD

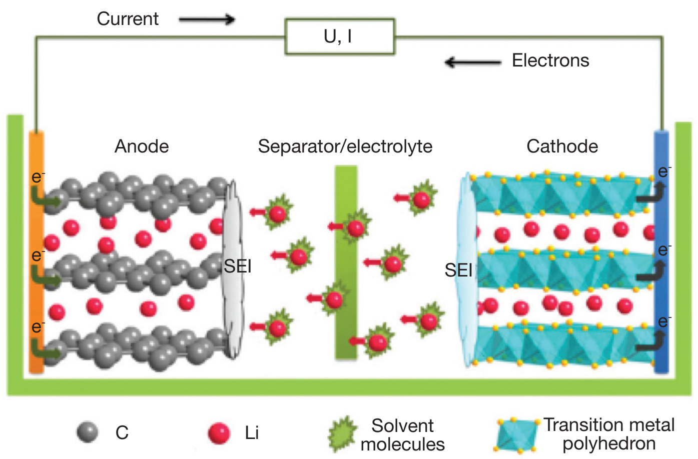
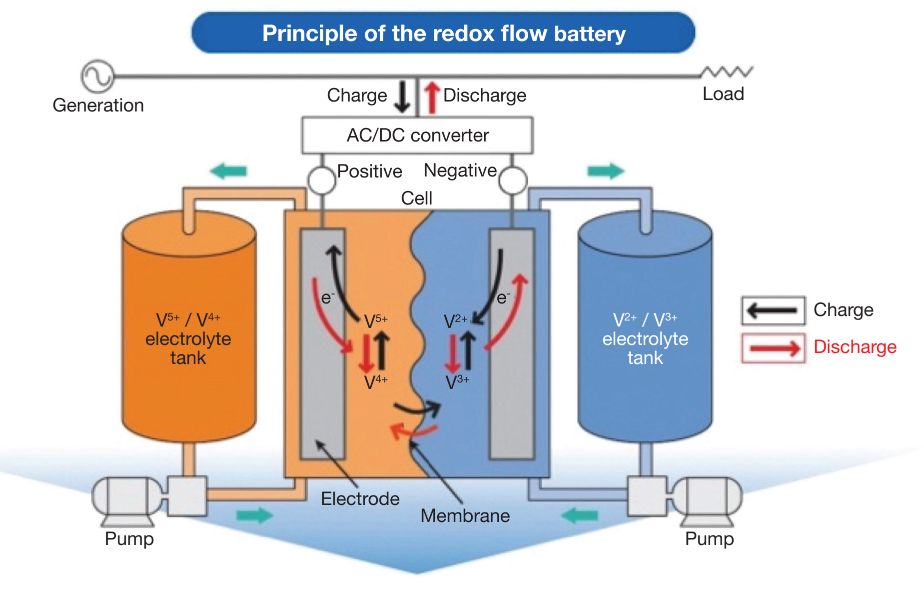


Figure 5. Flow batteries are an important technology option for grid-connected energy storage systems. Source: Sumitomo Electric Industries, Ltd.



Unlike Li-ion batteries, redox batteries can be fully discharged with no impact on the life of the battery. Redox batteries are characterised by very high power output, capable of deep discharge and fast recharging of spent electrolyte, can undergo complex charge/discharge cycles (particularly attractive for remotely controlled grid ancillary services), very quick ramp rates, and have a long life because the electrolyte can be replaced. The electrolytes are also incombustible. ViZn's electrolyte has the added advantage of being globally abundant, non-toxic, and easily recycled. The output and capacity of a redox flow battery is expected to remain close to 100% of rated capacity for the first 20 years of operation. Li-ion batteries typically lose storage capacity with age and the charge/discharge cycles must be carefully managed in order to maximum battery life. Conversely, flow batteries are much more complex that conventional Li-ion batteries (except for the battery management system) and have a much lower energy density.

The capacity of a redox flow battery is also easily expandable as the power output (kW) and the energy storage capacity (kWh) may be independently specified because the number of cell stacks determine power output and the energy storage capacity is a function of available electrolyte (the size of the storage tanks). Flow batteries are also uniquely capable of providing both rapid, high-power discharges as well as long-duration low-power releases, ideal for grid-connected applications. In merchant applications, for example, flow batteries can provide two daily charge/discharge cycles and millisecond switching for wholesale grid regulation services, which are substantial economic advantages over conventional batteries.

Future plans

In the immediate future, CMI Energy will complete MiRIS and begin developing a deep understanding of how to economically optimise renewable energy sources coupled with energy storage for a range of users and demand load profiles. An added complexity in assessing the economics is the impact of grid interoperability (purchases, sales, and supply of ancillary services), which is site specific. Once these design and engineering hardware and EMS issues are well in hand, CMI Energy plans to expand its MiRIS project in the future by incorporating further energy storage and management innovations.

Author
Lou Lambruschi is Marketing Services and E-Business Manager for Parker Hannifin Corporation's Energy Grid Tie Division.

Integrating Energy Storage

BY LOU LAMBRUSCHI

California may soon become the U.S. leader in energy storage spurred by the 2013 California Public Utility Commission (CPUC) mandate that the state's three largest public utilities have 1,325 MW of electricity storage in service by 2024. These projects are necessary in order for the state to meet its goal of having 50 percent of its electricity produced by renewables by 2030. The goal is ambitious and does have its risks.

"Advancing and Maximizing the Value of Energy Storage Technology: A California Roadmap," was released on Dec. 31, 2014. It is the result of the collaboration of the California Independent System Operator, the CPUC, and the California Energy Commission plus the input of over 400 stakeholders to identify those priority issues "…that need to be addressed include[ing] refining existing [energy storage] products and driving new ones to market; reducing costs of metering and connection; and creating a predictable and transparent process for commercializing and connecting storage projects."

The Roadmap includes a long list of policy and tariff structure issues that must be resolved if manufacturers and developers are to invest adequately to achieve the state's renewable goal at the scale and prices required. The time for California, as well as other ISOs, to adopt energy storage as a means for managing grid operations, particularly to mitigate the impact of intermittent renewable (solar and wind) generation resources, has arrived.

Other states, such as New York, Texas, and Washington have or are in the process of removing similar regulatory barriers, often by redefining energy storage as a qualified energy generation technology and requiring inclusion of energy storage in utility integrated resource plans. At the national level, the Federal Energy Regulatory Commission's Order No. 792 has clarified that devices "for storage for later injection of electricity" as Small Generators, and included them into its fast track interconnection procedures, which will help standardize energy storage interconnections to the grid.

> "The time for California, as well as other ISOs, to adopt energy storage as a means for managing grid operations has arrived."

In Canada, the Government of Ontario's Long Term Energy Plan calls for a total of 50 MW of storage capacity but for a slightly different reason than California. According to the National Resource Council Canada (NRC) Energy Storage for Grid Security and Modernization initiative, Canada wishes to use energy storage technologies to help defer the costs of transmission and distribution system renovation while also stabilizing the intermittent nature of renewable energy and enabling peak shaving and arbitrage.

ENERGY STORAGE OPTIONS

Energy storage technology providers can optimize the economic value of their investment by providing multiple services, supported with a suitable tariff and revenue streams. A single energy storage facility might provide and be compensated for a combination of applications including:

1. Renewables integration. Stored electricity may be dispatchable in order to offset the effects of highly intermittent renewable generation by providing ramp-rate control for "smoothing, firming, and time-shifting output, principally of wind and solar, while avoiding system level integration costs," according to a CPUS staff study (CPUC Rulemaking 10-12-007).

2. Ancillary Services. Ancillary services are required to maintain grid stability and security. They include such things as frequency control, reliability controls, and spinning reserves. Traditionally power plant generators have provided these services, but generators are often to slow to react to changes in the grid, and are less efficient when compared to a BESS.

- Frequency Regulation. The BESS may be used to ensure that the grid frequency stays within a specified range. The frequency provided by the electrical grid moves due to a mismatch between electricity demand and power generation. The utility will send a signal (typically every four seconds) to the BESS, asking the BESS to either charge or discharge, bringing the frequency back to its nominal value.
- Reactive Power and Voltage

POWER Engineering

Control. Reactive power can be used to compensate for voltage drops, but must be provided closer to the load to increase the advantage of lower currents, and improved efficiencies.

- Spinning Reserve. This represents a reserve capacity used to help maintain output during a generator failure or unexpected transmission loss, which might otherwise cause power reductions to customers. Keeping generator capacity online but unloaded wastes fuel and causes unwanted air emissions. A BESS can be made available in microseconds, and can take the place of conventional spinning reserve generation and improve system efficiency.

3. Peak Shaving. Energy storage on the customer's side of the meter can be used to flatten demand spikes by charging during off-peak periods, and discharging during periods of peak demand lowering utility demand charges for the facility. .

4. Energy Arbitrage. A BESS may be used to purchase of electricity during low purchase cost periods and resell the stored electricity during high-cost periods, allowing the storage owner to profit from the difference in price.

5. Black Start. A BESS can provide balance of plant power needed for a plant restart.

Technology suppliers and system developers view the ability to provide multiple services from a single plant as a huge benefit and an economic opportunity. For example, a BESS might supply ancillary services to the wholesale market at other times providing reliability services to the local grid or peak shaving services for a large end user. The challenge for the market is to define the true economic benefit, and if possible, get paid for it.

The technology is available but electric utilities don't have the modeling tools that fully value the contribution that energy storage systems offer to the wholesale market, nor do they know how to price the true benefits of these services to the rest of the system. It's difficult to participate in an energy market when the market rules haven't been fully understood or established or written, but this is changing and now a focus.

Writing tariffs that address the multi-use potential of BESS and how the operation of a BESS might be economically optimized is complicated. Each project must address site-specific needs as well as conform to the requirements of the local energy markets so conflict in priorities is to be expected. For example, a BESS may earn a higher economic return with energy arbitrage during periods of extremely high demand instead of providing desperately needed ancillary services. Proper tariff design and interconnection constraints are perhaps the only real impediment remaining to the rapid expansion of BESS installations

ENERGY STORAGE IN ACTION

The 98MW Laurel Mountain Wind Farm, owned by AES Energy Storage LLC and located on a mountain top, near Belington, West Virginia, is an example of a multi-use BESS. The 32MW/8MWh grid-connected BESS and AES uses its Storage Operating System (sOS) to optimize electricity sales into the market. The plant also supplies frequency regulation and grid stability services to the PJM market, which adds an important second revenue stream to the owners. The plant can also moderate the ramp rate of the plant electricity production.

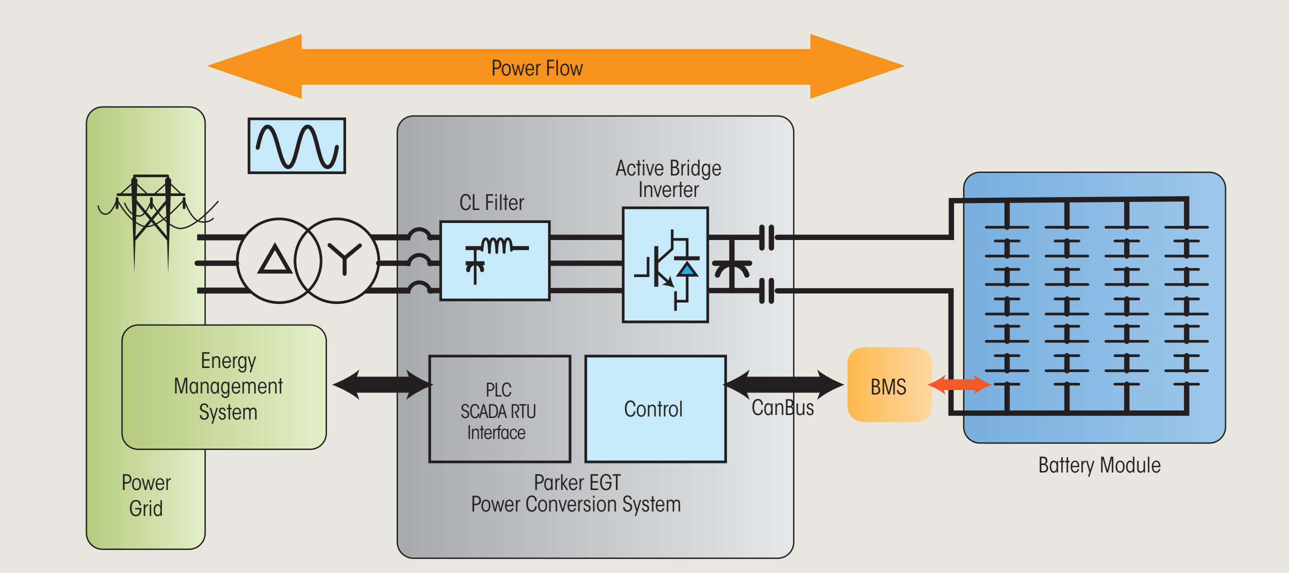
Laurel Mountain thus far has operated with over 95 percent availability and has been consistently the low cost provider of regulation service in the region. The project is a collaboration of AES Wind Generation, AES Energy Storage, battery manufacturer A123 Systems, and power conversion system (PCS) supplier Parker Hannifin Energy Grid Tie Division (Parker). Power generated by the facility is sold to PJM.

Batteries 1

The 98MW Laurel Mountain Wind Farm uses battery energy storage to optimize energy sold into PJM and to provide regulation services.

Source: AES Energy Storage LLC

A Grid-Connected BESS With Batteries 2



A typical grid connected BESS with batteries and bidirectional PCS inverters to manage the effects of high peak demand, grid instability, and the unpredictable nature of renewable resources is illustrated.

Source: Parker Hannifin, Energy Grid Tie Division

When commissioned in Oct. 2011, it was the largest lithium-ion BESS in the world **(Figure 1 on page 25).**

Prior to this installation, Parker supplied AES Energy Storage with a PCS for a 12 MW BESS installation at AES Gener's Norgener plant, the Los Andes Substation that provides critical backup services to the electric grid in northern Chile. The backup service was installed to provide grid stability services to the mining operations in the region. Grid operator CDEC-SING has recognized Los Andes as one of the best performing spinning reserve units in the region. The plant is used both as a generation and a grid stability resource.

"As one of the largest power generators in Chile, we're consistently looking for ways to unlock [the] value of our existing plants while maintaining grid reliability and flexibility," said Felipe Ceron, CEO of AES Gener. "Since 2009, we've been working with AES Energy Storage to free up generating capacity at our Norgener plant by employing a battery-based installation to meet the power system's obligations for spinning reserve." Los Andes has been in commercial operation for nearly three years.

THE BRAIN OF BESS

The battery energy storage system consists of two main parts: battery modules and the accompanying Battery Management System (BMS), and a PCS used to enable the interface of the batteries to the grid. Individual battery cells are connected in a series/parallel arrangement in order to obtain the desired nominal voltage for highest efficiency and required storage capacity. The PCS is a bidirectional power conversion device (inverter), enabling AC power from the grid to be converted to DC to charge the batteries in a controlled manner, and discharge DC battery power to feed AC power onto the grid (**Figure 2**).

The PCS must produce electricity that can be synchronized with the grid frequency and have a stable output, in effect disguising itself to the grid as a stable synchronous generator. It must also be capable of performing a smooth transition when used as a power backup system. Other components within the PCS are responsible for physically connecting to the grid and battery system, as well as for protection, detection, power quality, safety, and interfacing with the (SCADA) signaling to and from the utility. Integral harmonic filters are used to deliver pure sine wave power well within IEEE519 guidelines for total harmonic distortion. The PCS provides automated sequenced shutdown and disconnection under power loss in compliance with IEEE 1547 guidelines or can be configured to function in island mode, providing backup power for an isolated microgrid plant.

In addition to simply charging and discharging batteries, many systems provide an important extra benefit–providing both real and reactive power (VAR support). This capability provides the ability for the BESS to grid support and voltage regulation. Firmware and programmability in the PCS allows for flexibility of control and operating autonomy. If PCS contains the algorithms

Power Conversion System 3

The Parker 890GTS/GTB is used on solar as well as BESS energy storage systems. The enclosure houses the PCS and thermal management systems for a BESS size up to 2 MW.

Source: Parker Hannifin, Energy Grid Tie Division

for real and reactive power management, it can eliminate or reduce the responsibility of external site management by the utility. A well-designed PCS will also include robust LVRT (low voltage ride-through), HVRT (high voltage ride-through), and FRT (frequency ride-through) support over a wide range of operating conditions during critical events.

BESS DESIGN FEATURES

A BESS is often installed outdoor in remote and environmentally hostile regions, like those installed in the deserts of Chile or in the salt spray of a coastal area. In these environments, thermal protection and modular designs are important considerations. An energy storage system only produces revenue for its user when it is on line and providing its intended services, whether that is frequency regulation, VAR support, power backup, arbitrage, or used as a Microgrid.

Heat is the enemy of electronics. The key to a reliable installation is good thermal management in order to protect inverters, batteries, and ancillary components. Cooling system design in grid-tie inverters traditionally has relied on air or liquid water-glycol cooling. Air-cooling has low heat exchange efficiency and can consume a lot of energy. Chilled water-glycol requires a substantial volume of liquid to be pumped through the system, which consumes significant space and power, and raises concerns about corrosion and other maintenance issues.

A better option is closed-loop evaporative cooling. In this type of system a refrigerant such as R134a is circulated at low pressure through the thermally critical components inside the PCS. As heat from the components transfers to the refrigerant, it partially evaporates, with the resulting vapor sent to a condenser. Using outside air, the vapor then condenses to a liquid form and returns to the holding reservoir, where it is again pumped through the components. This method of cooling has proven to be very efficient, requiring much less liquid flow than in a water/glycol system. This allows for a higher power density, and lower auxiliary power requirements, and longer system life. Real-time temperature monitoring at crucial points throughout the PCS provides preemptive notification of thermal issues. This form of system cooling has a tremendous advantage over more traditional air or liquid cooling systems. Using this design, Parker has reduced the enclosure size to two thirds compared to its competition (**Figure 3**).

The modular design approach chosen by Parker includes other benefits; the two most valuable are scalability and system redundancy. Scalability allows for the expansion of a base system for future state conditions. In some cases, a small trial system has been installed, which is easily expanded once the concept is demonstrated and proven. In others, availability of funding has dictated building in stages. Also, additional systems can be added to respond to the need for additional grid stability and VAR support. Another advantage is when tariffs are established in the future for new services, additional modules could add new revenue streams at existing plants.

Modular design on the inside of the PCS also offers the benefit of maximum up-time by virtue of low MTTR (mean time to repair). Interchangeable spare phase modules containing power semiconductors and all related circuitry can be stocked on site, where plant technicians can quickly diagnose a failure and replace a module without requiring a service call from the factory. Redundant fan motors and cooling pumps mean one component can fail, while allowing the system to continue to function. pe

AES Energy Storage's Laurel Mountain, US lithium-ion battery energy storage system
Credit: Parker Hannifin, Energy Grid Tie Division

Options for integrating energy storage

Energy storage offers solutions for many of the issues faced by today's power producers and network operators, and its grid-connected technologies can be delivered at a reasonable cost, writes Lou Lambruschi

California may soon become the US leader in energy storage, spurred by the 2013 California Public Utilities Commission (CPUC) mandate that the state's three largest public utilities have 1325 MW of electricity storage in service by 2024.

These projects are necessary in order for the state to meet its goal of having 50 per cent of its electricity produced by renewables by 2030. The goal is ambitious and does have its risks.

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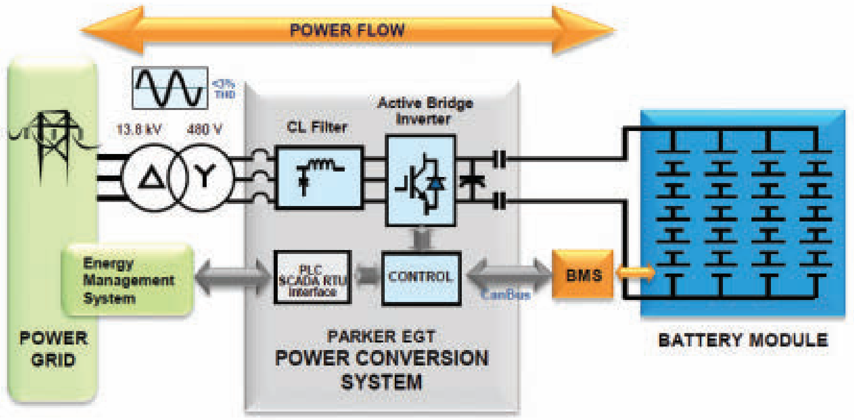
4. Energy Arbitrage. A BESS may be used to purchase electricity during low purchase cost periods and resell the stored electricity during high-cost periods, allowing the storage owner to profit from the difference in price.

5. Black Start. A BESS can provide balance of plant power needed for a plant restart.

Technology suppliers and system developers view the ability to provide multiple services from a single plant as a huge benefit and an economic opportunity. For example, a BESS might supply ancillary services to the wholesale market, at other times providing reliability services to the local grid or peak shaving services for a large end user. The challenge for the market is to define the true economic benefit and, if possible, get paid for it.



A typical grid-connected BESS with batteries and bidirectional PCS inverters to manage the effects of high peak demand, grid instability and the unpredictable nature of renewable resources
Credit: Parker Hannifin, Energy Grid Tie Division

The technology is available, but electric utilities don't have the modeling tools that fully value the contribution that energy storage systems offer to the wholesale market, nor do they know how to price the true benefits of these services to the rest of the system. It's difficult to participate in an energy market when the market rules haven't been fully understood, established or written, but this is changing and is now a focus.

Writing tariffs that address the multi-use potential of BESS and how the operation of a BESS might be economically optimized is complicated. Each project must address site-specific needs as well as conform to the requirements of the local energy markets, so conflict in priorities is to be expected. For example, a BESS may earn a higher economic return with energy arbitrage during periods of extremely high demand instead of providing desperately needed ancillary services. Proper tariff design and interconnection constraints are perhaps the only real impediment remaining to the rapid expansion of BESS installations.

Storage in action

The 98 MW Laurel Mountain Wind Farm, owned by AES Energy Storage and located on a mountaintop near Belington, West Virginia, is an example of a multi-use BESS. AES uses the 32 MW/8 MWh grid-connected BESS and its Storage Operating System (SOS) to optimize electricity sales into the market. The plant also supplies frequency regulation and grid stability services to the PJM market, which adds an important second revenue stream to the owners. The plant can also moderate the ramp rate of the plant's electricity production.

Laurel Mountain thus far has operated with over 95 per cent availability, and has been consistently the low-cost provider of regulation service in the region. The project is a collaboration of AES Wind Generation, AES Energy Storage, battery manufacturer A123 Systems, and power conversion system (PCS) supplier Parker Hannifin Energy Grid Tie Division (Parker). Power generated by the facility is sold to PJM. When commissioned in October 2011, it was the largest lithium-ion BESS in the world.

Prior to this installation, Parker supplied AES Energy Storage with a PCS for a 12 MW BESS installation at AES Gener's Norgener plant, the Los Andes Substation that provides critical backup services to the electric grid in northern Chile. The backup service was installed to provide grid stability services to the mining operations in the region. Grid operator CDEC-SING has recognized Los Andes as one of the best performing spinning reserve units in the region. The plant is used as both a generation and a grid stability resource.

"As one of the largest power generators in Chile, we're consistently looking for ways to unlock [the] value of our existing plants while maintaining grid reliability and flexibility," said Felipe Ceron, chief executive of AES Gener.

Storage containers at the Laurel Mountain facility
Credit: Parker Hannifin, Energy Grid Tie Division

"Since 2009, we've been working with AES Energy Storage to free up generating capacity at our Norgener plant by employing a battery-based installation to meet the power system's obligations for spinning reserve." Los Andes has been in commercial operation for nearly three years.

The brain of BESS

The battery energy storage system consists of two main parts: battery modules and the accompanying Battery Management System (BMS), and a PCS used to enable the interface of the batteries to the grid. Individual battery cells are connected in a series/parallel arrangement in order to obtain the desired nominal voltage for highest efficiency and required storage capacity. The PCS is a bidirectional power conversion device (inverter), enabling AC power from the grid to be converted to DC to charge the batteries in a controlled manner, and discharge DC battery power to feed AC power onto the grid.

The PCS must produce electricity that can be synchronized with the grid frequency and have a stable output, in effect disguising itself to the grid as a stable synchronous generator. It must also be capable of performing a smooth transition when used as a power backup system. Other components within the PCS are responsible for physically connecting to the grid and battery system, as well as for protection, detection, power quality, safety, and interfacing with the (SCADA) signaling to and from the utility. Integral harmonic filters are used to deliver pure sine wave power well within IEEE519 guidelines for total harmonic distortion. The PCS provides automated sequenced shutdown and disconnection under power loss in compliance with IEEE 1547 guidelines, or can be configured to function in island mode, providing backup power for an isolated microgrid plant.

In addition to simply charging and discharging batteries, many systems offer an important extra benefit: providing both real and reactive power (VAR support). This capability provides the ability for the BESS to offer grid support and voltage regulation. Firmware and programmability in the PCS allow for flexibility of control and operating autonomy. If the PCS contains the algorithms for real and reactive power management, it can eliminate or reduce the responsibility for external site management by the utility. A well-designed PCS will also include robust LVRT (low voltage ride-through), HVRT (high voltage ride-through), and FRT (frequency ride-through) support over a wide range of operating conditions during critical events.

Design features

A BESS is often installed outdoors in remote and environmentally hostile regions, like those installed in the deserts of Chile or in the salt spray of a coastal area. In these environments, thermal protection and modular designs are important considerations. An energy storage system only produces revenue for its user when it is online and providing its intended services, whether that is frequency regulation, VAR support, power backup, arbitrage, or used as a microgrid.

Heat is the enemy of electronics. The key to a reliable installation is good thermal management in order to protect inverters, batteries and ancillary components. Cooling system design in grid-tie inverters has traditionally relied on air or liquid water-glycol cooling. Air cooling has low heat exchange efficiency and can consume a lot of energy. Chilled water-glycol requires a substantial volume of liquid to be pumped through the system, which consumes significant space and power, and raises concerns about corrosion and other maintenance issues.

A better option is closed-loop evaporative cooling. In this type of system, a refrigerant such as R134a is circulated at low pressure through the thermally critical components inside the PCS. As heat from the components transfers to the refrigerant, it partially evaporates, with the resulting vapour sent to a condenser. Using outside air, the vapour then condenses to a liquid form and returns to the holding reservoir, where it is again pumped through the components.

This method of cooling has proven to be very efficient, requiring much less liquid flow than in a water/glycol system. This allows for a higher power density, lower auxiliary power requirements and longer system life. Real-time temperature monitoring at crucial points throughout the PCS provides preemptive notification of thermal issues. This form of system cooling has a tremendous advantage over more traditional air or liquid cooling systems. Using this design, Parker has reduced the enclosure size to two thirds compared to its competition.

The modular design approach chosen by Parker includes other benefits. The two most valuable are scalability and system redundancy. Scalability allows for the expansion of a base system for future state conditions. In some cases, a small trial system has been installed, which is easily expanded once the concept is demonstrated and proven. In others, availability of funding has dictated building in stages. Also, additional systems can be added to respond to the need for additional grid stability and VAR support. Another advantage is that, when tariffs are established in the future for new services, additional modules could add new revenue streams at existing plants.

Modular design on the inside of the PCS also offers the benefit of maximum uptime by virtue of low MTTR (mean time to repair). Interchangeable spare phase modules containing power semiconductors and all related circuitry can be stocked on-site, where plant technicians can quickly diagnose a failure and replace a module without requiring a service call from the factory. Redundant fan motors and cooling pumps mean one component can fail, while allowing the system to continue to function.

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Increasing Wind Turbine Reliability Through Blade Pitch Control Upgrades

Tom Ulery and Mark Riley1.17.20

Wind power generation in the U.S. is enjoying favorable winds.

First, the cost of wind turbine installations has dropped by over one-third since 2010 as the capacity of turbines increased. Next, according to Lawrence Berkeley Labs, the average capacity of turbines installed is now 2.32MW, up more than 200% since the late 1990s. The upsizing is mainly due to a drop in the per unit cost of equipment that is of even more advanced technology.

Finally, capacity factors are also rising with an average of 42% reported over the period of 2014 to 2016, a significant increase of 31.5% reported over the period of 2004 to 2011. American Wind Energy Association (AWEA) data reports that there are now over 56,800 wind turbines representing 96,488 MW in service in the U.S., with 5,944MW installed in the fourth quarter of 2018 alone.

Repowering existing wind turbine sites with taller towers and longer blades is perhaps the most notable current industry trend. A repowered wind farm not only extends the life of the facility but leverages rising capacity factors found with modern technology along with more efficient power generation. One midwestern energy company, for example, has announced plans to spend upwards of $1 billion to repower 700 existing wind turbines with the promise of 19 to 28% more generation, depending on site. In fact, 15 repowering projects accounted for 2,136MW of the about 7,000 MW added to the grid in 2017, according to AWEA. The National

Renewable Energy Laboratory (NREL), as reported by the EIA, has predicted that investment in repowering of existing wind turbine sites has the potential to grow to $25 billion by 2030.

Not all existing wind farm owners have the balance sheet or site factors that would encourage a full or partial repowering. Instead, those owners often pursue a more incremental approach to improving the reliability and capacity factor of their wind turbines. One approach is to consider an optimized blade replacement, typically at sites characterized by low wind speeds. Development of more reliable and efficient gearboxes has also been the desire of many wind farm owners and the Department of Energy has invested heavily in their development. NREL has also helped develop many new wind turbine components for increased turbine reliability. However, turbine blade pitch control valves, well known within the industry as having a limited life, continues to weigh down wind turbine reliability and capacity factor.

Controlling Blade Pitch

Blade pitch controlled is a critical function within the overall wind turbine control system. Wind turbines operate at constant rotational speed, usually about 15-20rpm for large turbines. The gearbox increases the shaft speed to about 1,000–1,800rpm to match the generator rotational speed requirements, typically producing 60-cycle AC electricity at about 700V. The turbine controller starts the turbine when the wind reaches a given speed, usually about 8-16mph. A yaw drive keeps the turbine pointed into the wind to maximize electricity production.

The pitch control system, located within the turbine hub, rotates the three variable-pitch turbine blades in unison to precisely control the generator speed based on a feedback signal from the generator. On hydraulically controlled units there is one pitch control proportional valve per blade on a turbine so, for example, there are three valves used on a three blade turbine. The pitch system also “stalls” the blades so that there is no lift generated by the rotating blades thus shutting the turbine down when the wind speed reaches about 55mph to protect the turbine from damage (Figure 1). A brake is usually engaged when the blades cease rotation.

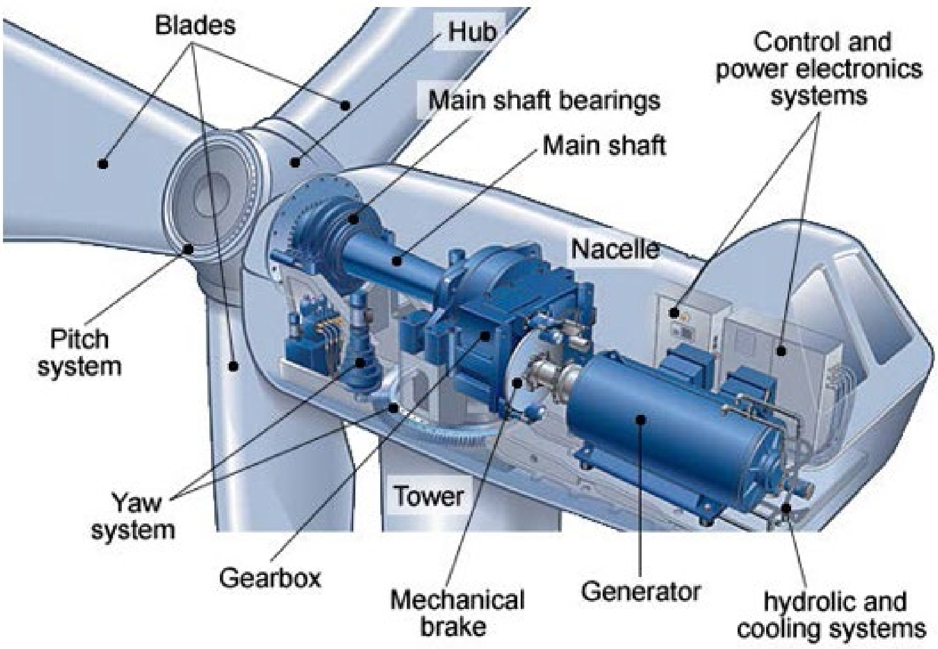

Figure 1. The anatomy of a typical wind turbine. *Source: Parker Hannifin*

The pitch control system operates in a very demanding environment and the proportional control valve, one per blade, is arguably the device exposed to the harshest operating environment. Failure of only one of the three valves will force the wind turbine out of service. Data from operators confirm this observation with many field reports of pitch control valve failure within weeks of its first operation, with an unexpectedly large number of failures occurring within six months of service. Upon failure, a maintenance technician must travel to the turbine site and replace the pitch control valve in the hub. Performing this service can take one or more days, depending on the site location, technician availability, and weather conditions. Often the cause of the failure has been traced to circuit board failure due to inadequate vibration protection or the circuit board enclosure design does not prevent dirt and moisture ingress. The cost of a replacement pitch control valve is secondary to the cost of maintenance replacement evolution and the loss of energy generation.

A pitch control valve must be designed to operate 24/7 in an extremely rugged environment. First, most pitch control valves are located in the turbine ub which rotates and thus exposed to heavy vibration, shock, and rotational forces (up to 50G on three axes). The valves are also subject to lightning strikes so the valve electronics must be electrically isolated from the turbine nacelle. Also, the pitch control valve must be capable of withstanding ambient temperatures, ranging from -40C (Minnesota in the winter) to 85C (West Texas in the summer) in which wind turbines are installed. Finally, it stands to reason that the pitch control valve should be designed to comply with IP65 standards for protection against dirt, grease, and moisture **(Figure 2)**.

Figure 2. A well-designed pitch control valve will not only ensure stable turbine performance over its load range but will be designed to operate reliably in extreme cold and heat and will not allow dust or moisture intrusion, a known cause of valve failure. *Source: Parker Hannifin Corp.*

Up Your Turbine Game

One pitch control valve that has proven itself in multiple wind turbine applications is the Parker Hannifin D1FC (nominal size: NG06, 5gpm flow rate) and the D3FC (nominal size NG10, 16gpm flow rate) direct operated proportional DC valve with position feedback. The control valves receive an input signal (either 4-20ma or +/- 10VDC) from the main turbine controller based on its monitoring of the generator output. Valve flow and performance specifications have been matched to the system requirements of the turbine so as to be compatible with the existing control parameters and co-exist with valves on the other axis.

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Field service reports often cite mating connectors as the root cause of a turbine forced outage. The connectors used on OEM pitch control valves do not have locking connectors so vibration can cause the connectors to disengage. The D1FC and D3FC valve assemblies use locking mating connectors much like those found in the automotive industry that is exceptionally vibration resistant. Other important design characteristics of the D1FC and D3FC pitch control valves are illustrated in **Figure 3**.

Figure 3. The Parker Hannifin pitch control valves are designed to meet the most demanding performance specifications and are configured to be “plug and play” when replacing OEM control valves. *Source: Parker Hannifin Corp.*

Exceptional Operating Report

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There is a further advantage for cost-conscience owners: a single replacement D1FC valve may be used in conjunction with two existing OEM valves, thereby allowing an incremental replacement program. This approach may be preferable for those owners who would rather replace with upgraded components as repeated failures occur over time. Other owners may determine that changing all three valves may be most cost-effective solution when the technician labor cost for multiple repairs and lost generation costs are considered in the analysis.

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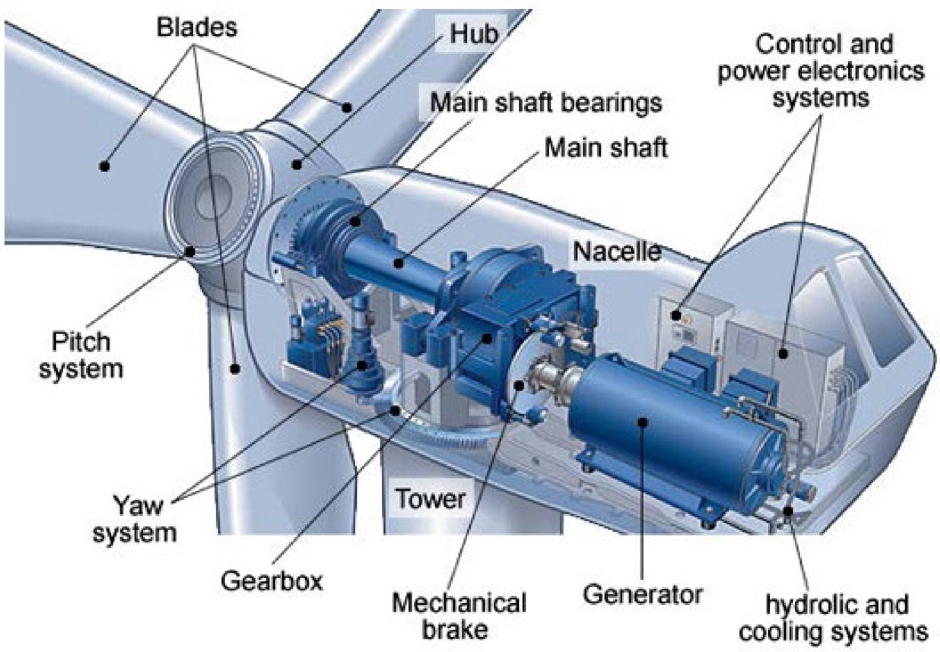

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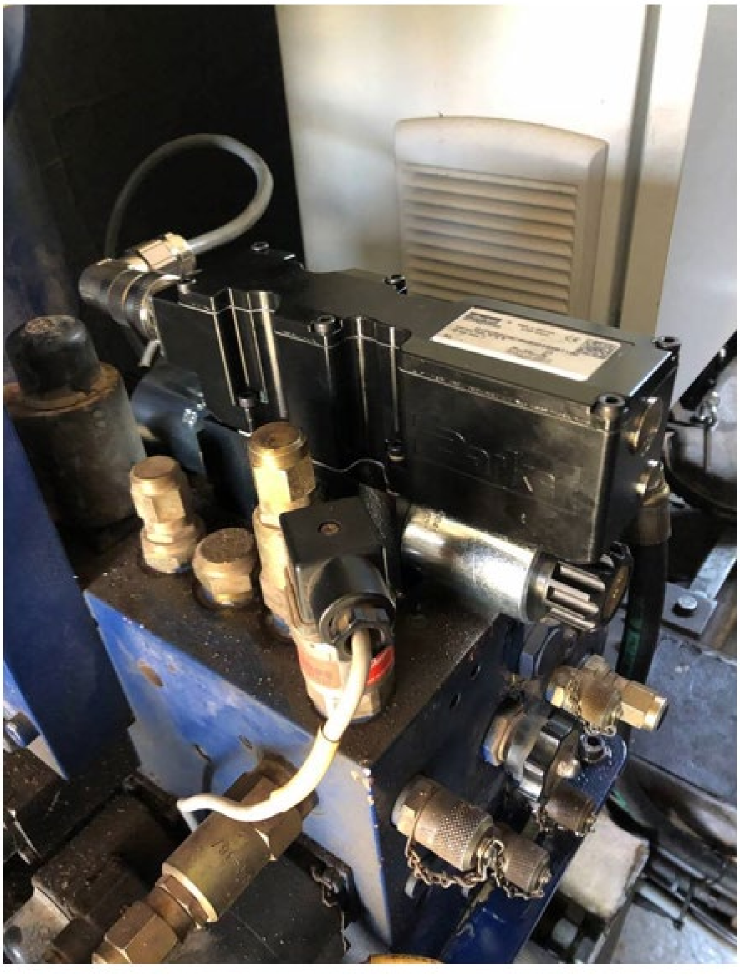

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