The Value of Battery Energy Storage Systems (BESS) in Microgrids

Eric Gallant
Director of Business Development
GS BATTERY (U.S.A.) INC.

Introduction

For decades, electrical grids have relied on fairly straightforward design; large, centralized power generation facilities manufacture electricity and transmission networks distribute that electricity down to end user consumers. This power system architecture was designed to send power in one direction; from the central power generation facility down to the end user.

In recent years, growing concerns about grid reliability and the limits of grid capacity have spurred a rethinking of the centralized power generation paradigm. In addition, environmental and geopolitical concerns have sparked interest in electrical infrastructure that is less dependent on the consumption of fossil fuels. These trends have caused the rapid growth and maturation of new power generation strategies including wind, photovoltaic (PV), biomass, fuel cell and micro-turbines. These new means of power generation are typically smaller in scale than the power stations of the traditional grid. In contrast to the centralized power generation scheme that characterized the traditional grid, these new energy resources are generally distributed across the electrical transmission and distribution (T&D) grid and closer to the point of power consumption.

When properly applied, these new, distributed generation units (DG) offer significant benefit to the grid and to end users. However, merging DGs into the traditional grid is not without technological challenges. The traditional electrical grid was not designed for power generation sources distributed near the ends of the T&D grid. The successful integration of DG power sources requires the single-direction grid architecture of the past transition to a smarter and more agile bi-directional grid. As DGs continue to gain traction in the electrical market, new thinking and new strategies around power generation, distribution and consumption will continue to emerge.

One of the increasingly common tactics for merging DGs into the larger electrical grid is a new twist on an old electrical architecture known as the microgrid. Microgrids are areas of the grid that can operate as part of the larger macrogrid or operate autonomously as a standalone system. The microgrid systems help facilitate the integration of DG assets into the larger electrical grid. Further, when properly implemented, microgrids can unlock a wide array of stacked values for grid operators and electrical consumers.

Fortunately for the battery industry, energy storage technologies have a central and vital role in successful microgrid deployments and in the capability of the macrogrid to meet the demands of a changing electrical landscape. Due in part to the projected growth of DGs and microgrids, industry analysts are forecasting that the annual U.S. energy storage market will cross the 1-gigawatt mark in 2019 and by 2020 will be an astounding 1.7 gigawatt market valued at $2.5 billion.

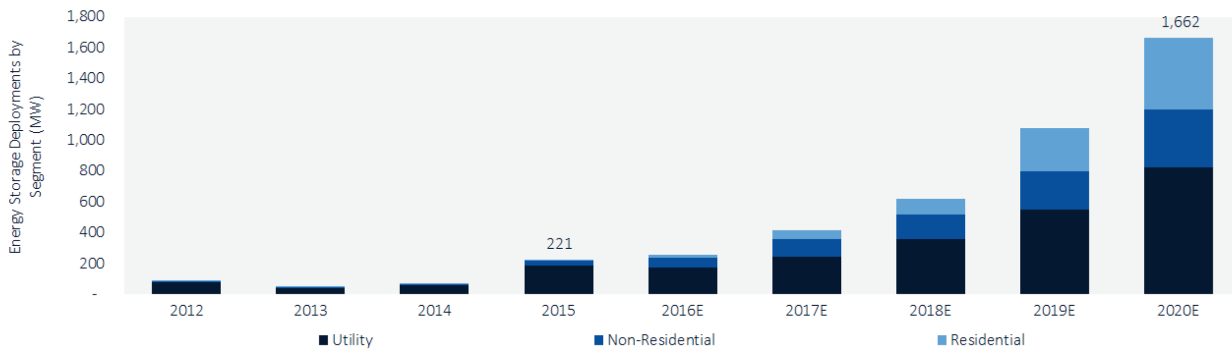

Figure 1. Annual US Energy Storage Deployments (MW) 2012-2020[i]

What is a microgrid?

The concept of a microgrid dates back to Thomas Edison's very first electrical power distribution strategies of the 1880's. Edison established the world's first power generation station at Pearl Street in Manhattan in 1882. In the 4 years that followed, Edison Illuminating Company set up more than 50 direct current (DC) microgrids. The Pearl Street Station produced **direct current** (DC) power. At the voltage used by Edison, DC power could only be transmitted a limited distance. However, Edison argued that DC provided the benefit of allowing his customers to seamlessly connect batteries to their electrical systems and greatly improve the reliability of their electrical service. The Pearl Street Power Station and the microgrids that it fed eventually lit 10,164 lamps for 508 customers in Manhattan.[ii]

Power generation and distribution eventually shifted from Edison's DC power to the **alternating current** (AC) power promoted by rival inventor Nicolai Tesla and business tycoon George Westinghouse. As a result, Edison's DC microgrids were eventually replaced by AC systems and the national electrical grids that we see today standardized around AC voltages.

Despite being rendered largely obsolete by Westinghouse, Edison's DC microgrids offered a few key advantages over AC distribution. Most importantly, DC energy can be stored in batteries (as chemical energy). This capability allows systems that are equipped with batteries to continue to operate even after the primary source of power generation is offline. Additionally, with a DC system, multiple power generation sources can be paralleled by simply matching voltages. AC systems on the other hand, require matching, voltage, frequency and phase angle. Ironically, these qualities of DC systems are becoming increasingly relevant to 21st century microgrids.

Today, the US Department of Energy defines a microgrid as,

> *"A group of interconnected loads and distributed energy resources (DERs) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode."*[iii]

The first component that is required to meet the definition of a microgrid is, "A group of interconnected loads…with clearly defined electrical boundaries". The phrase "group of interconnected loads" is a deliberately imprecise phrase. This imprecision leaves room in the microgrid definition for load groupings that include any number of loads and any type load. Therefore, microgrid can exist in at any scale and can be utilized for nearly any application.

For example, a single family residence may have electrical loads that include a few lights, an assortment of household appliances and a climate control system. This group of loads are interconnected by virtue of all being powered by the house's electrical panel. From an electrical load perspective, a single family house could easily comprise a microgrid provided it meets the other requirements of the definition.

Likewise, a large university campus with multiple buildings including libraries, laboratories, physical plants, dormitories, dining halls and sporting arenas could also be considered a group of interconnected loads for the purpose of a microgrid. In many cases, the utility grid that serves a university campus will have an established and clearly defined electrical boundary for the campus for the purposes of service and billing.

Even a town or community with thousands of inhabitants and a wide array of residential, commercial and industrial loads can be established as a microgrid as long as the loads are interconnected and a clear electrical boundary is defined. A number of communities in New York State that were devastated by Hurricane Sandy have investigated community scale microgrids as a means to improve electrical resilience and reduce costs to their populations. To spur further innovation in this area, the New York State Energy and Research Development Authority (NYSERDA) launched the Long Island Community microgrid project, a competition to reward the cleanest and most innovative local energy grids.[iv]

Although the loads within a microgrid can be numerous and of a wide variety of types, microgrid loads are generally classified into two types; **fixed and flexible.**[v] Fixed loads are loads that are required to be serviced at all times. For example, life safety, telecommunication and IT loads are usually considered to be mission-critical, fixed loads. A well designed microgrid would not interrupt these loads during islanding or for cost saving purposes. Flexible loads, on the other hand, can be curtailed or delayed based on economic or electrical conditions. These can be controllable or "responsive" loads may include industrial or commercial processes that can be scheduled to coincide with favorable electrical rate periods or non-critical loads that can be shed during islanding periods.

The second feature of a microgrid described in the definition is **distributed energy resources (DERs)**. DERs can include a wide variety of technologies. However, for the purposes of a microgrid, DERs generally fall into one of two general types; they either generate or store electricity.

The devices that generate electricity are known as **distributed generation units (DG)** and include:

- Combined heat and power systems (CHP)
- Fossil fuel engine based generators
- Solar power (PV)
- Wind power
- Small scale Hydroelectric
- Biomass
- Waste to energy
- Fuel cells

DERs within the microgrid also include devices to store electricity. These **energy storage systems (ESS)** are vital to the benefit and performance of a microgrid. ESSs are electrically connected to the microgrid and thus are within the clearly defined boundaries of the microgrid.

There are a number of useful energy storage technologies that can be found in successful microgrid environments. The most common include:

- Pumped Hydro
- Compressed Air
- Thermal energy storage
- Rechargeable (Secondary) Batteries

The final group of infrastructure required to meet the definition of a microgrid is the control and automation components. These systems include a central microgrid master controller with a user interface that provides monitoring and control over the DGs, the controllable microgrid loads and ESSs. In order to effectively control devices within the microgrid, the master controller utilizes a variety of smart switches, communication interfaces, monitoring points and protective devices. These devices taken together enable a flexible, agile and responsive electrical system.

Microgrids are capable of operating in a number of modes based on real time conditions. Under normal conditions the microgrid operates synchronized with the larger electrical grid in order to take advantage of the resilience and economies of scale provided by the macrogrid. However, if physical and/or economic conditions are unfavorable for connection to the macrogrid, the microgrid can detach from the macrogrid and operate in islanded mode. When islanded the microgrid operates completely autonomously; creating, storing and distributing its own energy.

The ability of a microgrid to detach from the utility based on real time conditions unlocks a wide variety of benefits for both the macrogrid and to the microgrid end user. Importantly, each of these benefits are either greatly enhanced by or only possible through the application of a battery or other energy storage technology. These microgrid benefits may be broadly grouped into three key areas:

- Energy security
- Power quality
- Energy management.

Energy Security and Energy Independence

As noted earlier, one of the trends that has spurred the emergence of distributed generation and microgrid systems is the concerns regarding the reliability of the larger electrical grid. Unfortunately, the early part of the 21st century has been marked by a slew of catastrophic events that have left large populations without power for long periods of time. Hurricanes Sandy and Katrina in the US, earthquakes and tsunamis in Asia and the Caribbean and widespread, cascading electrical failures throughout the world seem to occur with tragic regularity.

In the United States, the rate and impact of events that result significant losses is clearly increasing. The US National Oceanographic and Atmospheric Administration (NOAA) National Centers for Environmental Information lists 10 weather and climate related disasters in 2015 with economic losses that exceed $1B.[vi] Ten events is a staggering number considering that that 1980-2015 annual average is only 5.2 events per year (CPI adjusted). Further, the types of disasters that are resulting in this economic impact are increasingly diverse. In 2015, the US endured five distinct types of billion dollar disasters:

Disaster Type	Dates	Location
Western Drought	Entire Year	Southwest
Tornados	May 6-10	Midwest-Oklahoma
Flooding	May 23-26	Texas-Oklahoma
Tornados and Flooding	December 26-29	Texas
Severe Weather	April 18-20	South Southeast
Severe Weather	April 7-9	Midwest Ohio Valley
Flooding	October 1-5	South Carolina
Winter Storm	February 14-20	Central Eastern
Severe Weather	June 21-25	Central Northeast
Wildfires	Summer-Fall	Western and Alaska

Figure 2. Billion Dollar Disasters in 2015

The concept of improving energy security and resilience to these types of events through the application of distributed generation is not new. A wide variety of commercial, industrial and residential sites are backed up by fossil-fuel engine based emergency power generation capability. In addition, most hospitals, data centers and other mission critical facilities routinely use a combination of engine support and stored energy to ensure maximum uptime.

Modern microgrids make use of the traditional mission-critical facility tactics of incorporating distributed generation and battery backup and then build on that platform with additional capabilities. Similar to datacenters, microgrids are capable of detaching from the utility in the event the grid becomes unstable or unavailable. For a microgrid, the control and automation features typically include smart switches located at the point of common coupling (PCC) that will open the connection to the macrogrid. Detaching from the grid and going to islanded mode provides a clear benefit of power reliability to the microgrid. In addition, the macrogrid gains a benefit from the microgrid going to autonomous operation. Without the load represented by the microgrid, it becomes easier for grid operators to stabilize the grid, isolate or mitigate sources of disturbances and restore power to the remainder of the grid.

Many microgrids include a fossil fuel engine generator for backup. However, there is an increasing trend to minimize the use of this type of power generation. Diesel fuel generation in particular has become recognized as a potential energy security vulnerability. Victims of Katrina, Sandy and Fukushima disasters, learned that fossil-fuel based energy assets are susceptible to failure; often with catastrophic effect. Engine based backup systems are only effective if they are properly maintained, protected from damage and (importantly) fueled. In addition, dependence on fossil fuels opens up the door to being subject to the volatility of fossil fuel prices and the environmental impact of carbon emissions.

As a result, most microgrids will incorporate renewable energy DGs in place of more traditional fossil fuel based sources. Establishing a microgrid for the expressed purpose of displacing fossil fuel sources and avoiding the operational and environmental costs associated with these sources is increasingly common. When the operational and capital costs associated with fossil fuel backup are combined with tax and regulatory pressure from state and federal governments in many locations the cost of renewable energy based distributed energy is already less than traditional fossil fuel generation. The cost of renewable energy based DG (specifically PV) continues to drop and renewables are becoming a more cost effective means of producing energy than fossil fuel backup.

Power Quality

Battery backup or an Uninterruptible Power Supply (UPS) used in a mission critical facility provides two key functions:

- bridge power to sustain critical loads between the loss of main power source and the availability of alternate sources and,
- improved power quality for sensitive critical loads

In a microgrid the ESS performs similar functions. The stored energy provides essential ride-through time needed to bridge the gap between the availability of grid and DG power sources. In addition, energy storage performs a similar task to a UPS in regards to power quality.

One of the inherent weakness of renewable energy is **intermittence**. Solar panels and windmills only provide output when the sun is shining or the wind is blowing. For example, clouds passing over a PV will dramatically reduce the amount of power generated by that array and obviously during days with no sun and at night a solar array will produce no power. In addition, the amount of sunlight and the amount of wind that a PV or wind plant receives will also vary based on the time of year. Even small scale hydroelectric may also be subject to seasonal variability based on rainy and dry seasons. Furthermore, PV and wind system performance will vary greatly based on geography. The intermittence of PV, wind and hydro due to daily, seasonal and geography variations presents an operational and reliability challenge to microgrid operators.

When comparing various forms of power generation, analysts often refer to the capacity factor (CF) of the production type. The net capacity factor of a power plant is the ratio of its actual output over a period of time to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time. CF is a useful metric to demonstrate how the intermittency and seasonal variability inherent to a renewable energy source effects the plant output.

Power Source	Capacity Factor (2009)
Nuclear	90.3%
Coal	63.8%
Natural Gas	42.5%
Hydroelectric	39.8%
Renewables (Wind)	33.9%
Renewables (Solar)	19.0%

Figure 3. Capacity Factor by Power Sourcevii

Clearly, renewables trail the pack when it comes to ability to deliver nameplate rating on a 24 x 7 basis. However, it should be noted that the capacity factor of PV continues to climb as panel efficiency improves. Meanwhile, the CF of nuclear has stalled and coal is decreasing as an increasing number of coal plants are idled. However, low CF remains a central challenge for renewables and will remain so for the foreseeable future.

Fortunately, the problem of renewable energy intermittence can be greatly improved by incorporating energy storage into the microgrid. The ESS has the effect of stiffening renewable energy DGs as a power source and provides a power quality benefit known as renewables smoothing. This fact is one of the key reasons that the paring of renewable energy DG and energy storage in microgrids is so attractive. Energy storage has the net effect of providing more full power sun or wind hours and drives renewable energy CF to parity with fossil fuels.

Energy Management

Energy independence and power quality are key benefits that are driving the increased attention to microgrids. However, without a valid financial case with relatively short returns on investment and demonstrable bankability, few of these projects would ever see the light of day. Fortunately, when batteries are included in microgrids, access to extremely powerful energy arbitrage tactics are unlocked that can save microgrid operators significant amounts of their annual energy spend.

Energy arbitrage is an energy management tactic that takes advantage of variations in the rates that utilities charge for power. For example, most utilities have daily and seasonal peak periods during which the cost of energy (per kw/hr.) for their commercial and industrial customers increases dramatically. In many areas of the country, the difference between on-peak and off-peak rates can be double, triple or more. This difference in electrical rates provides a great opportunity for microgrids with energy storage. Through **demand response and time of use (TOU) shifting**, microgrids can shift all or a portion of their flexible and fixed loads to battery power during periods when utility rates are highest. Later, when rates are lower (usually at night) microgrids can take advantage of the lower off peak rates to charge up batteries. Alternately, microgrids with both renewable energy DG and ESS can charge their batteries from renewable sources and further reduce their operating expenses related to energy.

Another energy arbitrage tactic that is unlocked for microgrids by energy storage is **Peak Demand Reduction**. Not only do utilities charge more during certain peak times of day, they also charge more if their customers exceed certain demand thresholds. The demand curve for most commercial and industrial consumers of electricity varies throughout the day. For example, many industries will operate two or three shifts during a 24 hour period. Each of those shifts will have a period of time when the rate of energy use is at its absolute maximum. Utility providers sets threshold rates for these customers. If their power exceeds a threshold during one of their daily peaks, the utility will increase the rate for the entire billing period. This is a bit like having a credit limit on a credit card. If you exceed your credit limit the card issuer will bump you up to a higher interest rate. Even if you pay your credit card down later the same day, you are still stuck at that higher interest rate.

Through management of peak demand, microgrid customers can note when they are approaching a peak demand threshold and shift a portion of their demand to stored energy from their batteries. A recent report from GTM Research[viii] concluded that the typical Commercial/Industrial customer in California can reduce their monthly power bill by up to 40% by eliminating peak demand charges through use of stored energy.

Finally, the US Department of Energy (DoE)[ix] lists "facilitation of demand side energy management" as one of the key benefits of microgrids. Once a microgrid master controller and automation control for flexible loads is in place, additional opportunities to reduce overall energy spend are often revealed. In short, when end users become more engaged in the production, storage and distribution of their own energy they naturally become more inclined to address energy efficiency opportunities.

Case Study: Shetland Islands

At the northernmost reaches of the United Kingdom lie the Scottish isles of Shetland. The Shetland Islands are positioned 400 miles south of the Arctic Circle and are bracketed by the open Atlantic Ocean to the west and the rugged North Sea to the east. This small archipelago is ruggedly beautiful, with deep green windswept hills and rocky shores circled by fierce currents. The Shetland Islands are around 120 miles from the Scottish mainland and are not connected to the national electrical grid that serves the remainder of the United Kingdom (UK). Fortunately for the Shetlands, they have access to abundant local energy resources.

The first modern energy resources to be developed in the Shetlands were fossil fuels. In the late 1960s, massive offshore oil and natural gas fields were discovered in the North Sea and the East Shetland Basin. Shetland was the natural landing point for the oil from these reserves. Between 1975 and 1981 a terminal was constructed along the Sullom Voe inlet between the islands of North Mainland and Northmavine. The terminal at Sullom Voe quickly became one of the largest oil terminals in Europe. By 2008, this facility had handled a staggering 8 billion barrels of oil.[x]

To support oil terminal operations, an electrical power generation facility was also constructed at Sullom Voe. This 100 MWe gas turbine power station features four 25 MW General Electric Frame 5 gas turbines and is capable of delivering an actual power output of approximately 80 MWe. During the most productive years at the terminal, the majority of the power generated at Sullom Voe was used by the terminal. However, the peak drilling years in the North Sea have passed and terminal activity has significantly scaled back. This scaling back has made the Sullom Voe power generation capacity available as a resource for the rest of the Shetland electrical grid. Sullom Voe currently supplies about 20MWe to the Shetland Island grid.

The principal power supply for the Shetland Islands is a diesel generator power station located near the island's main port of Lerwick. The Lerwick Power Station was established in 1953 and features a variety of diesel engine generators and waste heat recovery turbines. Lerwick has a total nameplate electrical generation capacity of 66 MWe. However, some of the original diesel generators have been retired in place and much of the remaining infrastructure is aging. As a result, plans for construction of a new power generation facility have been approved and a new site chosen.

Unfortunately, the exact role of the new power generating facility at Lerwick remains unresolved. A 550MW high voltage direct current (HVDC) connection between Shetland and the Scottish mainland has been proposed. The construction of the new power station is closely tied to the fate of the Shetland HVDC Connection. Until technical, routing and funding issues around the Shetland HVDC Connection are resolved, new construction at Lerwick is delayed.

Fortunately, the energy resources of the Shetland Islands don't end with fossil fuel based power generation. The subarctic climate of the islands and their position at the boundary of the Atlantic and North Seas, leads to consistently strong winds that perpetually sweep the islands. In the early 2000s, the Shetlands began to tap these rich, natural wind resources. The 3.68MW Burradale windfarm was established in the hills near Lerwick. Burradale immediately began producing energy at a consistently high rate. Since opening in 2000, the Burradale wind turbines have had an average capacity factor of 52%. In 2005, Burradale established a world record CF benchmark of 57.9%. This remarkable CF exceeds the average CF of hydroelectric and natural gas and approaches the capacity of a typical coal plant.

Based on the phenomenal success of Burradale, additional wind farms have been proposed. The Viking Wind Farm received planning permission in 2012 and is scheduled to deliver 370MW. However, the project has been delayed by a variety of environmental concerns and is dependent on the completion of the Shetland HVDC Connection to the UK mainland.

Figure 4. Burradale Wind Farm

In addition to abundant wind resources, the Shetlands are also blessed with significant tidal energy resources. The Islands currently boast one of the world's first community owned tidal power turbines. The Nova Innovation 30 tidal turbine is located on the seabed of Bluemull Sound, a straight between the islands of Unst and Yell. The turbine began exporting 30kw of power to the Shetland grid via undersea cable in 2014. The success of the Nova 30 led to the approval of a larger scale tidal array at the Bluemull Sound location. The Shetland Tidal Array is expected to be complete in 2017 and will feature five 100kw tidal turbines. The first of the 100kw tidal turbines was placed in March of 2016. Finally, the Shetland Islands power profile includes a fuel cell based wind-to-hydrogen energy initiative and a significant waste-to-energy management program.

Due to the abundance of rich tidal and wind resources, this area of Scotland has often been referred to as the "Saudi Arabia of renewable energy". The proposed Shetland HVDC Connection is evidence of the untapped renewable energy potential of the area. The objective of that connection to the UK national electrical grid is not to bring increased electrical capacity, reliability and availability to the remote Shetlands. Rather, the connection is planned to allow the UK electrical grid to import energy from the abundant, renewable resources found in the Shetlands.

Integrating this diverse portfolio of energy resources in a reliable and efficient manner is not without technical challenges. Challenges include; how can the emerging wind and tidal resources be harvested to their maximum potential? How can these new resources be integrated with existing electrical infrastructure without sacrificing power quality and reliability? How can the inherent intermittence of renewable energy resources be managed? How can the renewable energy resources be applied such that reliance on fossil fuels is directly reduced? The fundamental solution to each of these questions is the establishment of energy storage enabled microgrid.

In 2010, the Scottish Hydro Electric Power Distribution (SHEPD) launched the “1MW Battery, Shetland” project to address some of these technical challenges. The primary intent of the project was to reduce peak demand on the Lerwick Power Station by installing a battery that could cycle efficiently to meet the needs and profile of the islands’ generation and demand. Secondary project objectives included:

- Renewable generation constraint avoidance
- Reduction of power station fossil fuel consumption
- Stability control including SVC functions
- Provision of ancillary services

In addition, as the first grid-scale energy storage project in the UK, the project planners hoped to gain valuable experience and knowledge regarding the design, procurement, construction, installation, commissioning and safety factors involved in grid scale energy storage projects. The collection of these knowledge items would be useful throughout the UK Distribution Network Operators community as energy storage projects becomes increasingly common.

The basic building block of the energy storage system installed at Lerwick Power Station is a 2-volt advanced lead acid battery manufactured by GS Yuasa. The battery characteristics are as follows.

Battery Specification Data	
Batteries voltage	2VDC
Cells per battery	1
Battery type	Sealed Valve Regulated Lead Acid (VRLA)
Battery chemistry	Advanced (Carbon Enhanced) Lead Acid, AGM
Battery AH rating	1000AH @10HR
Battery Cycle Life	3000 cycles at 50% DOD

Figure 5. Lerwick Power Station Battery Specification Data

The power conversion platform used at Lerwick requires a DC voltage of approximately 500VDC. In order to reach the required DC voltage, the batteries were arranged into strings of 264 batteries each for a nominal DC voltage of 528 VDC. 12 strings in this configuration were installed in order to provide 3MWh of available stored energy.

Battery System Configuration Data	
Batteries per Rack	24
Racks per String	11
Cells per String	264
Nominal Voltage	528VDC
Parallel Strings	12
Total cell count	3168
System Power	1MW
System Energy	3MWh

Figure 6. Lerwick Power Station BESS System Configuration

Figure 7. Battery Room at Lerwick Power Station

Power Infrastructure Data	
Transformer Room	11kV grid connection
Power Conversion Room	2x 500kW AC-DC converters
Battery Room	1MW/3MWh VRLA storage
Store Room	Fire suppression and spares

Figure 8. Lerwick Power Station BESS Power Infrastructure Dataxi

Following the initial battery charging, commissioning and testing, attention turned to the objective of reducing peak demand at the Lerwick Power Station. SHEPD engineers identified points on the Shetland demand curve where demand peaked. Due to the nature of commercial and industrial activities on the islands, there are three distinct peaks that appear consistently each day.

Grid operators set the battery to discharge in 15 minute intervals at the beginning of each upswing in the demand curve. This strategy provided an optimum 3MWh discharge schedule and effectively lowered the demand curve during each of the peak demand periods. Prior to the installation of the battery, meeting these demand peaks required starting of additional diesel generator sets. By reducing these peak demand periods, Lerwick Power Station operators were able to eliminate up to three generator engine starts per day. This reduction in generator starts and run hours will extend the life of the diesel generator, facilitate more renewable integration, and reduce the amount of carbon produced.

Charging of the batteries was set to occur near the bottom of the daily demand curve which typically occurs during the overnight hours. The charging schedule was set with a large enough 'window' to fully charge the batteries and provide periodic equalization charges as required. During overnight hours the base load on the Shetland Power grid is substantially less than during daylight hours. As a result, battery charging can be accomplished without requiring the start of additional fossil fuel power generation assets.

In addition to the regularly scheduled off peak battery charging period, grid operators are able to charge the batteries using power generated at the Burradale wind farm. Prior to the installation of the battery, if the demand on the grid was insufficient to consume the power generator by the wind farm, the wind farm would be curtailed. Grid curtailment is a process where the output of a power generation asset is reduced below what that generator is capable of producing. In case of fossil fuel power generation, curtailment results in lower fuel consumption rates and the consequences of curtailment are essentially offset. However, with wind generation, curtailed energy is lost energy. Now that the Lerwick battery is in place, energy that would have previously been curtailed can be directed into the battery and stored for later use. This has the net effect of improving the wind capacity factor and system efficiency.

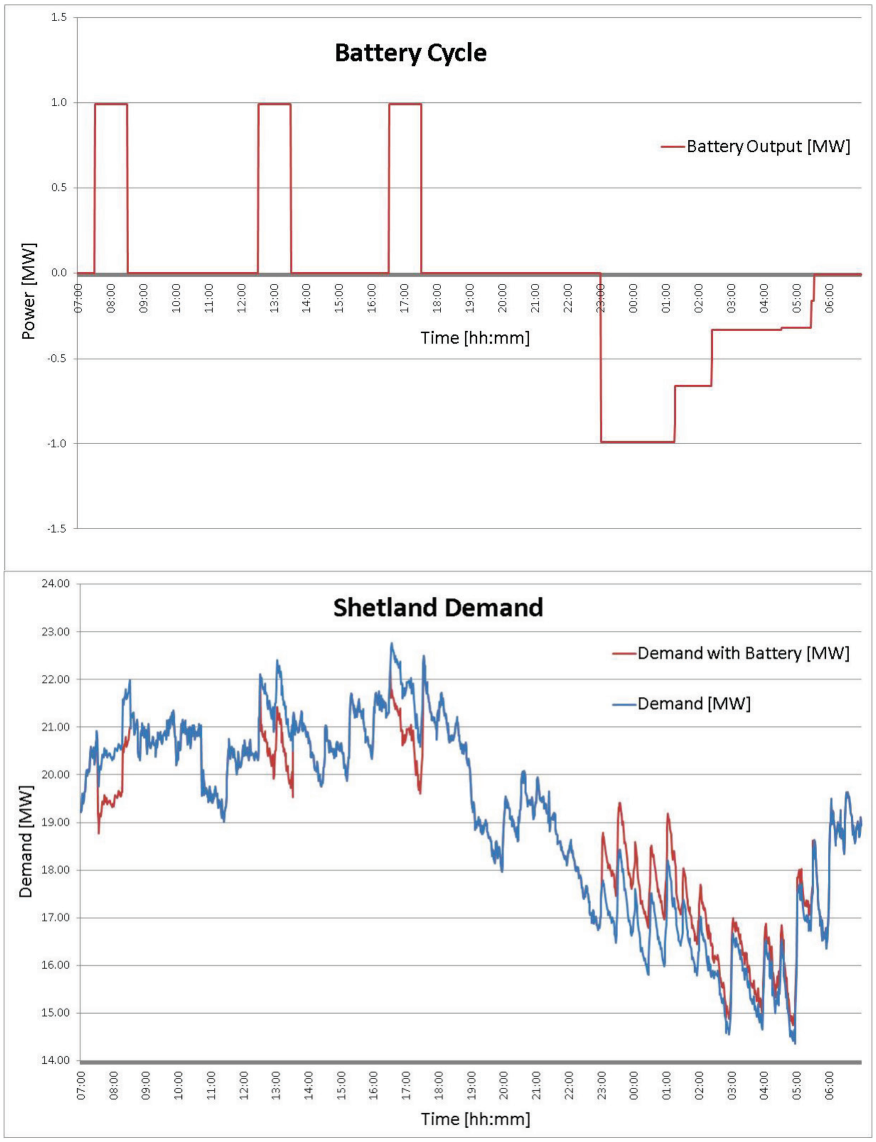

Figure 9. Shetland Island Demand Curve and BESS Usagexii

Finally, the battery at Lerwick helped stabilize the Shetland grid and smooth the effects of adding intermittent wind generation into their power generation mix. Wind power generation on Shetland is substantial compared to the overall demand curve. Adding a relatively large and essentially random power generation asset to the grid can result in a variety of power stability issues. The issues were avoided by adding energy storage capability to the Shetland grid.

Conclusions

Microgrids equipped with energy storage represent an evolutionary leap forward in grid architecture. The shift to microgrids dramatically increases the versatility and agility of electrical systems and facilitates the integration of new, cost effective and environmentally sustainable power generation sources. For the first time, electricity consumers are able to fully manage the production, storage and use of their own electrical energy and gain access to advanced energy arbitrage tactics such as peak demand reduction and time-of-use shifting. These benefits allow end users to dramatically reduce their operating expenses related to energy and ensures that the trend toward microgrids will continue.

The widespread adoption of battery enabled microgrids is further guaranteed by the fact that energy storage in microgrids provides a benefit to end users **and** to grid operators. As was seen in the Shetland Island project, energy storage provides microgrid operators with greater grid resilience and an effective tool in their arsenal to reduce peak demands, integrate renewables and control disturbances that threaten grid availability.

Perhaps most importantly, microgrids with energy storage can provide a global benefit by reducing the net consumption of fossil fuels and, as a result, reduce greenhouse gas emissions. By enabling the transition to a renewable energy economy, microgrids provide a lasting benefit to the environment and to the future of our planet.

For these reasons, energy industry analysts forecast rapid and sustained increase in demand for energy storage solutions. These new applications present a terrific opportunity for battery manufacturers that understand the value provided by their products in these systems.

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[xii] Nathan Coote, Scottish and Southern Energy Power Distribution “LCNF Tier 1 Close Down Report 1MW Battery Shetland SSET1001” July 7, 2014