How Advances in Long-Duration, Low-Cost Energy Storage are Making Possible the Creation of Self-Sufficient, High-Resilience Micro-Grids

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Background

For many decades, the Federal Government has made use of the U.S. national electric grid (or "grid" as we will call it) as its primary power source for most of its offices, facilities, and installations. Power from the grid was cheap and reliable, and threats to the grid were not considered a serious concern. For the small percentage of mission critical Federal sites that could not tolerate any grid down time, local power generation using diesel generators was (and still is) used to provide backup power in the face of primary grid outages. Although relatively expensive, diesel generator backup was considered an adequate approach because outages were relatively infrequent and of short duration.

This "electric grid + diesel backup" approach was quite successful for most of the 20th century, as the reliability and resilience of the grid was deemed quite high and the threat to the grid was deemed quite low. However, this has all changed since 9/11. Since that time, the number and magnitude of threats to the grid has grown substantially. The assumption that grid outages are infrequent and of short duration is no longer valid. The Federal government has identified many substantial threats to the grid including: Cyber Attacks, Physical Attacks, Electro-Magnetic Pulse (EMP), Directed Energy Weapons, Geo-Magnetically Induced Currents, and Severe Weather. With this growing awareness of grid vulnerability, the U.S. government has recognized the importance of hardening the grid against these new threats, as well as improving the self-sufficiency and resilience of mission critical Federal facilities and installations that rely on the grid.

Over the past 16 years since 9/11, substantial effort has gone into hardening mission critical Federal facilities and installations against grid vulnerabilities. The primary approach to addressing grid outages has been to set up mission critical Federal facilities and installations as microgrids[1] (so they can operate independently of the main power grid) and to expand the use and scale of diesel generators to provide backup. The purpose of this paper is to present a compelling alternative to this current approach. This new approach takes advantage of the recent dramatic technical and economic advances in battery technology and stationary energy storage systems. This paper will discuss how a combination of new long-duration, low-cost batteries, when combined with low cost renewable energy sources (solar and/or wind), can enable mission critical Federal facilities and installations to become fully energy self-sufficient for extremely long periods of time - greatly enhancing their mission survivability in the face of major disruptions to the national electric grid.

Electric Energy Resiliency Today: Microgrids and Diesel Generators

Today almost all mission critical Federal facilities and installations protect themselves against grid disruptions by a creating a local microgrid and employing diesel generators for backup power. An example of a diesel based microgrid is shown in Figure 1. It consists of a Point of Common Coupling (PCC) device, an internal electrical distribution system, a local backup power source, the local loads being serviced, and a local control system for managing the microgrid.

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[1] A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. It can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.

- DOE: Office of Electricity Delivery & Energy Reliability

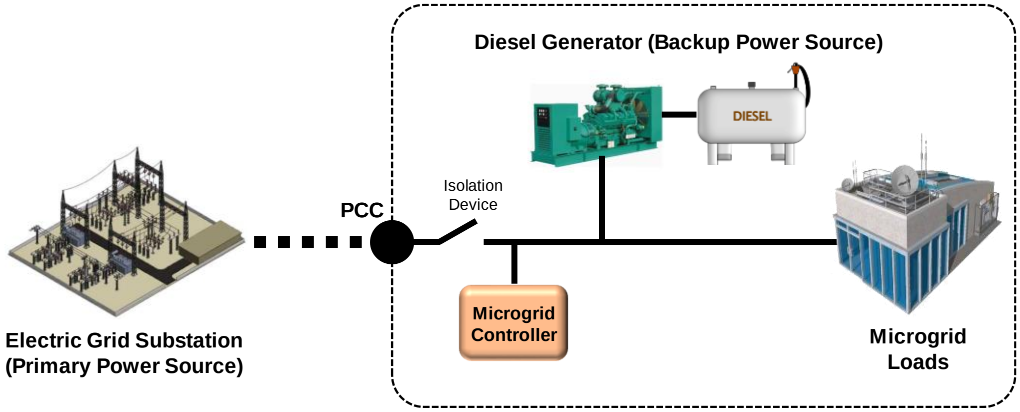


Figure 1. An Example of a Microgrid Today that uses Diesel Generators for Backup Power.

Central to the microgrid concept is a local source of energy that can provide alternative power when the microgrid is disconnected from the main grid. In this case the alternative power source is the backup diesel generator. As a backup power source, diesel generators are a very dependable and low risk option, however, they do have many disadvantages. Diesel generators are extremely noisy, produce large amounts of smoke and fumes, have a high carbon footprint, and most importantly require ongoing deliveries of fuel (which may not be possible under some of the most disruptive scenarios such as EMP and cyber-attacks). In addition, diesel backup systems are relatively expensive with operating costs of approximately 50¢/kWh (in some cases higher) vs. 5¢-10¢/kWh for commercial utilities. Despite these disadvantages, the diesel backup approach has been the preferred option for many decades because until now there haven't been any viable alternatives.

Long-duration, Low-cost Energy Storage – The Game Changer

An attractive alternative to diesel generator backup power that is now emerging is the use of renewable energy sources - particularly solar. Renewable energy sources are quieter, more environmentally friendly, more convenient, and less expensive (approximately 8¢/kWh for solar and 15¢/kWh for wind vs. 50¢/kWh for diesel). More importantly, renewable energy sources have a huge benefit over diesel because there is no logistics tail for providing fuel. The lack of a fuel logistics tail is a convenience and cost benefit for less severe outages, but can be a game-changer for true national emergency scenarios such as a major cyber-attack or an EMP event. In these more severe cases, Federal facilities and installations may have to go weeks or even months without being able to obtain additional fuel for diesel generators. Renewable power sources do not have this logistics challenge.

The primary problem with moving to renewable power sources as an alternative to diesel is the intermittent availability nature of their power. (Solar doesn't provide power at night or in cloudy weather. Wind doesn't provide power when the wind isn't blowing.) Renewable power sources by themselves are fine to supplement the main grid, but to work disconnected from the grid for extensive periods of time, they require significant energy storage capabilities to cache energy for use during conditions when the renewable source can't be providing power.

Up until now, the lack of cost effective battery systems precluded the employment of renewable energy sources as an alternative to diesel power generation for mission critical Federal facilities and installations. But now this is all changing. Recent breakthroughs in the long-duration, low-cost battery capabilities are making it feasible to use renewable energy sources as either primary or backup power sources. Major investments by the commercial world has resulted in tremendous technical advancements in grid storage capabilities while at the same time driving down costs. The battery community has already driven the cost of electricity storage down to the range of 5-10¢/kWh. And with projected advancements energy storage costs are expected to be lowered to the 2-4¢/kWh range by 2020. At these price points, the cost of stationary energy storage systems is "grid parity" - below the 5-10¢/kWh cost of purchasing electricity from the grid – enabling many cost effective scenarios. Long-duration, low-cost energy storage is a major game-changer and provides the last element needed to create and deploy self-sufficient, high-resiliency microgrid solutions for mission critical Federal facilities and installations.

Self-Sufficient, High-Resilience Microgrid Solutions

We define self-sufficient, high-resilience microgrids as a specific type of microgrid that uses a combination of renewable energy and long-duration, low-cost energy storage to enable a facility or installation to operate disconnected from the main electric grid for very long periods of time (weeks, months, or even indefinitely). An example of a self-sufficient, high-resilience microgrid is shown in Figure 2. It has the same basic design as today's diesel-based microgrid solutions, but uses a combination of local renewable power and local energy storage to provide long-duration, reliable power. Solar panels and batteries can be aggregated to achieve the needed power and storage capacity to meet the self-sufficiency and high-resiliency mission requirements of individual Federal customers. Where necessary, higher levels of self-sufficiency and high-resiliency can be achieved by including additional renewable power and battery systems. The number of power and storage devices can also be adjusted to account for other variables such as solar or wind energy technical potential. The result: self-sufficient, high-resiliency microgrid solutions are no longer just technically feasible, they are now economically feasible.

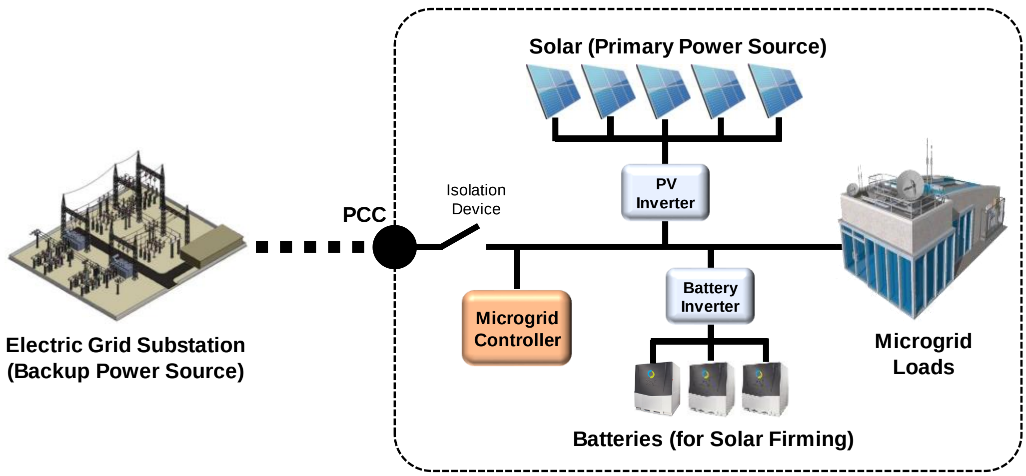


Figure 2. An example of a microgrid that uses solar and long-duration batteries to operate independently from the grid for extended periods of time.

Pushing Self-Sufficient, High-Resilience Microgrid Solutions into the Real-World

In the past few years there has been a large amount of work done to test and harden emerging self-sufficient, high-resilience microgrid technologies and solutions. Many pilot demonstrations have been underway involving a wide range of solution providers taking this capability out to mission customer sites for testing and validation. At Primus Power, we have conducted three such pilots using our first generation long-duration EnergyPod® batteries[2] (see Table 1). These piloting efforts have demonstrated the feasibility of implementing self-sufficient, high-resiliency microgrids.

Table 1. Primus Power microgrid piloting efforts with the first generation EnergyPod® System.

Customer	Piloting Activity
U.S. Marine Corps Air Station at Miramar	Primus Power integrated a 1 MWh EnergyPod system to an existing 280 kW solar PV array. Raytheon provided the control system (see Figure 3). The system enabled the critical facilities at building 6311 to operate when disconnected from the main power grid. This effort received the 2016 ESTCP project of the year and the 2017 Federal Energy and Water Management Award.
Microsoft – Redmond Campus	Primus Power installed and tested an EnergyPod at a Microsoft data center that demonstrated the ability to support the data center completely from stored energy.
Samruk-Energy – Kapchagay solar farm	Samruk-Energy used an EnergyPod at a remote, 2 MW solar PV facility and successfully demonstrated the ability of batteries to enhance the resiliency of the power provided by the solar PV.

[2] The EnergyPod® is Primus Power's first generation flow battery. It provides 20 kW of peak power and 72 kWh of total energy storage capacity.

Figure 3. A high-resilience microgrid implemented at the Marine Corps Air Station at Miramar that employs a Primus Power 1 MWh battery system to firm solar power.

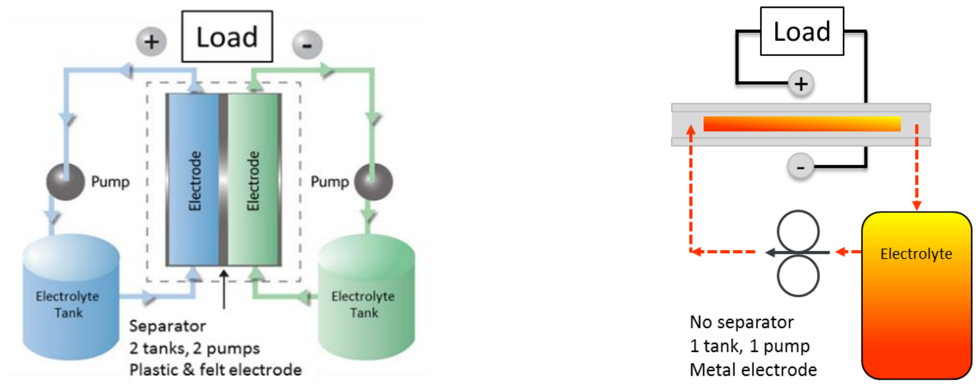
With the great success of these initial piloting efforts, commercial and Federal customers are moving from piloting and experimentation with self-sufficient, high-resilience microgrids, to full scale production and product delivery to mission customers. At Primus Power, we have developed a second-generation flow battery (EnergyPod 2) that is now in production and being delivered to a diverse set of mission-critical customers for current real-world applications (see Table 2). As these activities demonstrate, long-duration, low-cost batteries are now ready for real world applications across a wide range of mission use cases.

Table 2. Primus Power EnergyPod 2 Systems being Supplied to Mission Customers.

Customer	Use Case
Puget Sound Energy	Puget Sound Electric is buying EnergyPod 2 systems to shave peak electrical loads thereby avoiding the build out of additional power generation facilities
Victor Valley Wastewater Reclamation Authority	Victor Valley Wastewater Reclamation Authority will use 8 EnergyPod 2 systems to improve integration of renewable solar energy, reduce GHG emissions and save water
Samruk-Energy	Samruk-Energy will use 60 EnergyPod 2 batteries to firm wind at their 45 MW wind farm in central Kazakhstan
UC Riverside	UC Riverside will use EnergyPod 2 batteries as part of a microgrid to power a Native American community center
IDEC	IDEC will use Primus EnergyPod 2 batteries to reduce utility demand charges. Expected payback time is 5 years.
Anglo American	Anglo America is buying 140 EnergyPod 2 systems to firm solar at their Mogalakwena platinum mine in South Africa.
CBRE	CBRE will use EnergyPod 2 batteries at multiple industrial facilities to reduce tenant's energy bills and provide resiliency for critical operations
EDF	EDF, the largest utility in Europe, will use EnergyPod 2 batteries as part of a microgrid test facility
Eskom	Eskom, the largest utility in South Africa, will use 4 EnergyPod 2 batteries in a series of microgrid testing applications

The Primus Power EnergyPod 2 Battery

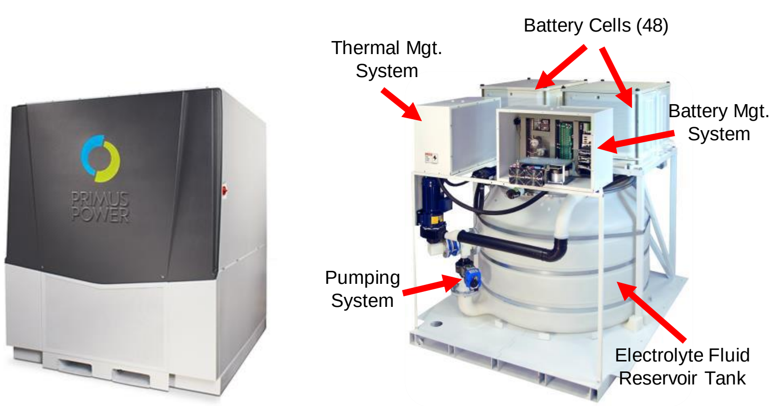
The Primus Power EnergyPod 2 is a long-duration, low cost energy storage solution intended for large scale grid storage applications. The EnergyPod 2 is a flow battery that uses the chemical reaction of a circulating electrolyte to store and release electricity. Unlike conventional flow batteries that use two flow loops interacting across a set of membranes, the EnergyPod 2 battery has a single flow loop and has no membranes – which greatly reduces both system and operating costs, and enables longer system life.



Conventional Flow Battery **Primus Power Flow Battery**

Figure 4. Unlike conventional flow batteries, the Primus Power EnergyPod 2 flow battery uses a single flow loop and no membranes – which reduces cost and adds reliability .

The EnergyPod 2 is comprised of an electrolyte tank, a pumping system to circulate the electrolyte, two stacks of 48 titanium electrodes (battery cells), a thermal management system, and a battery management system. These components are fully packaged into a self-contained NEMA 3R-rated enclosure that provides protection against weather and unauthorized access. The external dimensions of the EnergyPod is 1.8m x 2.0m x 2.1m. Six EnergyPods can fit a standard 8x40 foot ISO shipping container. The system can operate from within the shipping container, if desired, providing additional protection from the weather and allowing the batteries to be stacked – saving space. A picture of a Primus Power EnergyPod 2 Flow Battery showing both the external and internal view is provided in Figure 5.



External View **Internal View**

Peak Power	25 kW
Energy Storage	125 kWh
Lifetime Cycles	30,000
Efficiency	70%

Key Performance Parameters

Figure 5. Primus Power's EnergyPod 2 Flow Battery.

Primus Power EnergyPod 2 systems are modular and designed to scale up to large configurations. Delivered power and energy scale linearly. The Battery Management System contained within each system is configured as either a follower or a leader. When operating as a follower, the Battery Management System only controls the operations of the battery in which it resides. When operating as a leader, the Battery Management System can control a set of other EnergyPod 2 batteries that are operating in following mode. This design enables a wide range of control topologies to be constructed depending on the mission application. The Battery Management System interfaces with a higher-level microgrid controller through a published application programming interface (API).

For Additional Information

The rapid developments in long-duration, low-cost energy storage is making this an exciting time for addressing the very critical and significant problems facing mission critical users of the national electric grid. Primus Power is pleased to be part of this community. We believe our flow battery products and microgrid expertise can be invaluable to Federal mission customers that in need of self-sufficient, high-resilience microgrid solutions. For additional information about Primus Power products and capabilities, please visit us at our website, http://primuspower.com or contact:

- Brian Dillard – VP of Business Development
  Phone: 510-342-7600
  Email: brian.dillard@primuspower.com
- Robert Beaton – Federal Solutions Architect
  Phone: 703-216-7422
  Email: robert.beaton@primuspower.com