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Maximizing the Impact of an Energy Storage Project

J. M. WOMBLE, D. R. KARSEBOOM, R. P. DOWNS, D. A. NELSON
MPR Associates, Inc.
USA

SUMMARY

The need for grid-scale energy storage is becoming more apparent as penetration of renewable generation sources continues to increase. Without storage, electricity must be consumed the moment it is produced, thus presenting two challenges associated with additional renewables. First, as exhibited by the ubiquitous CAISO duck curve, solar generation follows a daily pattern that does not align with the daily power demand pattern. Second, renewable sources are variable and create an imbalance in supply and demand when the wind stops blowing or a cloud passes over.

Grid-scale energy storage can help solve these problems. However, with the exception of pumped hydro, the energy storage industry is in its infancy. Due to the cost of storage and the limitations of the revenue streams currently available, careful planning is required to ensure success and economic profitability of a storage project.

As with any new undertaking of significance, energy storage pioneers have encountered challenges along the way. Many storage projects in recent years have fallen short of expectations for project cost and schedule, as implementers and construction firms struggle to implement first-of-a-kind designs. Some older storage assets are no longer viable, either because technology did not perform as expected, or because an equipment provider has gone out of business, leaving the customer with an unsupported, and therefore unusable, battery. Consideration of these and other examples reveals several best practices for project definition, design, and implementation. Incorporation of the practices outlined in this paper will help ensure that a new storage asset provides maximum value to society, the end customer, and project stakeholders.

Each stage of project development is discussed. Project success begins with development of a viable business case. Storage technology, storage system parameters, and tie-in location are selected to best fit the business case. System design is performed to determine optimal capacity, reduce project costs, simplify installation, and optimize system efficiency. Project implementation is conducted to incorporate lessons learned and provide maximum value to the customer and project stakeholders.

jwomble@mpr.com

KEYWORDS

Energy Storage, Solar plus Storage, Distributed Resources, Lithium-ion, Transmission and Distribution, Peak Shaving, Frequency Regulation, Merchant Power, FERC Order 841, FERC Order 845, Best Practices, Lessons Learned

1.0 Introduction

The need for grid-scale energy storage is becoming more apparent as penetration of renewable generation sources continues to increase. Without storage, electricity must be consumed the moment it is produced, thus presenting two challenges associated with additional renewables. First, as exhibited by the ubiquitous CAISO duck curve, solar generation follows a daily pattern that does not align with the daily power demand pattern. Second, renewable sources are variable and create an imbalance in supply and demand when the wind stops blowing or a cloud passes over.

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2.0 Develop the Business Case

An essential first step in planning a storage project is to develop a viable business case. While the practical value of a storage asset may be obvious to those who study the power industry, development of the business case can be challenging. The business reasons for the project must be clearly articulated to energize the investor base and raise capital.

An energy storage facility is a unique grid asset that can provide value to ratepayers, generators and grid operators in a variety of applications. In many ways it behaves like a generating station and it is often compared to a generating asset when determining how it will be compensated for the value it provides. However, business cases for storage projects are somewhat unique, given some of the fundamental differences between storage and generation facilities:

- Energy rating – Because generation facilities are capable of continuous operation, their power rating, typically in MW, is the primary parameter of concern. On the other hand, a storage asset must also be defined in terms of its energy rating (MWh), or by the amount of time it can discharge at its power rating (30-minute facility, 2-hour facility, etc.).

- Power source – Generating facilities receive their input power from an energy source external from the grid (coal, natural gas, nuclear power, wind, sunlight, etc.). Storage facilities are powered by the same grid, or local power network, that they serve. Further, power conversion processes within storage facilities are not 100% efficient, making them a net consumer of electricity.

- Essence of value provided – The value provided by generating facilities is that they power the grid. A limitation to this power is that it must be consumed the instant that it is produced. The value of the storage facility is that it provides the flexibility to consume excess power and save it for re-production at a later time.

These unique aspects of storage projects yield a variety of potential use cases. Use cases are typically categorized as either peak leveling or as one of a number of ancillary services:

- Peak leveling – This is the most obvious application for energy storage. Excess energy produced throughout the day is saved for use in peak demand hours. This use case is frequently discussed as relating to areas of significant penetration of renewables, where solar production (peaking in mid-day) and wind production (peaking at night) rarely aligns with customer demand (peaking in early evening). However, the need for peak leveling has existed for decades, as conventional baseload plants have been required to support a demand curve that changes throughout the day. Peak leveling applications often require energy storage assets that are sized for 4 to 6 hours of discharge.

- Frequency regulation (ancillary service) – The frequency of the grid is nominally 50 or 60 Hz, and changes to frequency are representative of changes in the amount of generation and load connected. The grid has significant inertia, as it is primarily a network of rotating machinery (generators) that supply an assortment of loads. The supply of power from the generators is balanced by the demand of power from the electric loads. When an imbalance develops between generation and load, the difference in energy manifests as a change to the angular momentum of all rotating machines, resulting in a change to the speed of rotation, which translates directly to grid frequency. An energy storage system can monitor grid frequency for variations and counter short-term imbalances, helping to maintain frequency and support grid stability. It can also perform this function by responding to an external regulation signal.

- Spinning reserve (ancillary service) – Spinning reserve is on-line reserve generation capacity that is synchronized and ready to meet demand in a short period of time. This service is needed to maintain system frequency stability during emergency operating conditions or unforeseen load swings.[1] Most battery energy storage assets are well-suited to this task, as they are able to transition from idle mode to full power within seconds.

The varied use cases, in turn, result in range of business cases that can be developed for a given storage project. Some of the most common business cases include:

- Energy arbitrage – The storage unit buys and sells power on the wholesale market based on real time market prices. A merchant participant purchases cheap off-peak energy and stores it to be discharged when prices are higher, earning revenue from the price spread between the lower energy purchase price and the higher energy sale price.

- Participation in ancillary services markets – The storage resource participates in one of the ancillary services markets described above. The most commonly-referenced market for frequency regulation is the PJM interconnection, where storage units are ideally suited to follow the volatile RegD signal. In 2016, PJM had 265 MW of grid-connected storage assets, with an additional 700 MW planned or under construction.[2] The energy storage unit may earn revenue based on a per-MWh capacity basis, a performance basis, or a combination of both.

- Revenue stacking of arbitrage and ancillary services – A storage asset maximizes its revenue by participating in more than one market. For example, a storage unit may participate in the frequency regulation market as its primary source of revenue, and then use arbitrage to return the battery to 50% state of charge (SOC). This practice of "value stacking" will be further enabled by RTO/ISO implementation of the recent FERC Order 841, which requires that markets allow a storage resource to provide all of the services it is technically capable of providing. The California Public Utilities Commission is enforcing similar rules for Multi-Use Applications.

- Deferral of T&D improvements – A utility may use installed storage to defer more expensive transmission and distribution (T&D) upgrades. For example, if the peak load in a remote area is expected to exceed transmission capacity from a generation station to this remote area, a strategically placed storage unit can prevent or defer the need for new transmission lines. In this example of peak leveling, the storage unit is charged during the times of low demand and is discharged during times of high demand, when the transmission lines are operating at or near their capacity.

- Demand charge reduction – This is a use case for behind-the-meter storage for commercial and industrial (C&I) facilities. These customers typically pay the utility a demand charge based on the peak electricity usage during a billing period. The billing period is divided into 15-minute intervals. The peak electricity usage is determined based on the highest 15-minute interval of energy use. A behind-the-meter storage asset enables the C&I facility to reduce the peak energy provided by the utility, as storage is used to supplement power requirements in times of maximum load. Reducing the demand charge paid to the utility has the capability of substantially reducing the operating costs of a facility.

- Co-location with generating asset – Energy storage may be co-located with a generation source to improve the overall site viability. The dynamics of the power market are such that some coal and gas plants do not run continuously and are relegated to participating as peaking assets. As a result, these plants spend a significant amount of time in idle mode or shut down. During times of low demand, co-location with a storage asset would allow a plant to save on operating costs by spending time shut down rather than in idle mode. The storage asset would provide the initial minutes or hours of power when demand peaks, thereby allowing the conventional asset time to start up.

  Operational constraints limit the ramp rate of thermal power plants. This affects their capability to respond as a peaking asset from idle mode or shutdown conditions. Co-location with storage would allow the storage asset to complement the thermal plant output while ramping. This would improve the overall ramp rate of the power station, thus making it more competitive than other coal or gas plants.

  Another example is the co-location of solar power and storage. Energy produced from solar power could be stored until evening peak demand hours, when energy prices are higher.

  These types of applications are supported by FERC Order 845, which will enable an existing generating station to add storage to its portfolio without a new interconnect agreement, with the requirement that the original nameplate capacity of the station not be exceeded.

- Regulatory compliance – A public utilities commission (PUC) may mandate that utilities install storage assets to level peaks in areas of high renewable penetration. The utility may be required to install storage in lieu of a new substation or a new peaking plant. In this case, the utility purchases a storage unit from a developer, or enters into a power purchase agreement with a merchant participant.

The graph in Figure 1 depicts the total revenue available to an energy storage asset with value stacking, compared to the profit margin available based on the levelized cost of storage (LCOS). Most of the potential business cases will become more attractive over the next two to five years as costs continue to decrease, the feasibility of grid-scale (tens and hundreds of MWh) projects are demonstrated, RTO/ISO market rules are adjusted to allow storage participation and value stacking, and as public utility commissions continue to mandate installation of storage facilities.

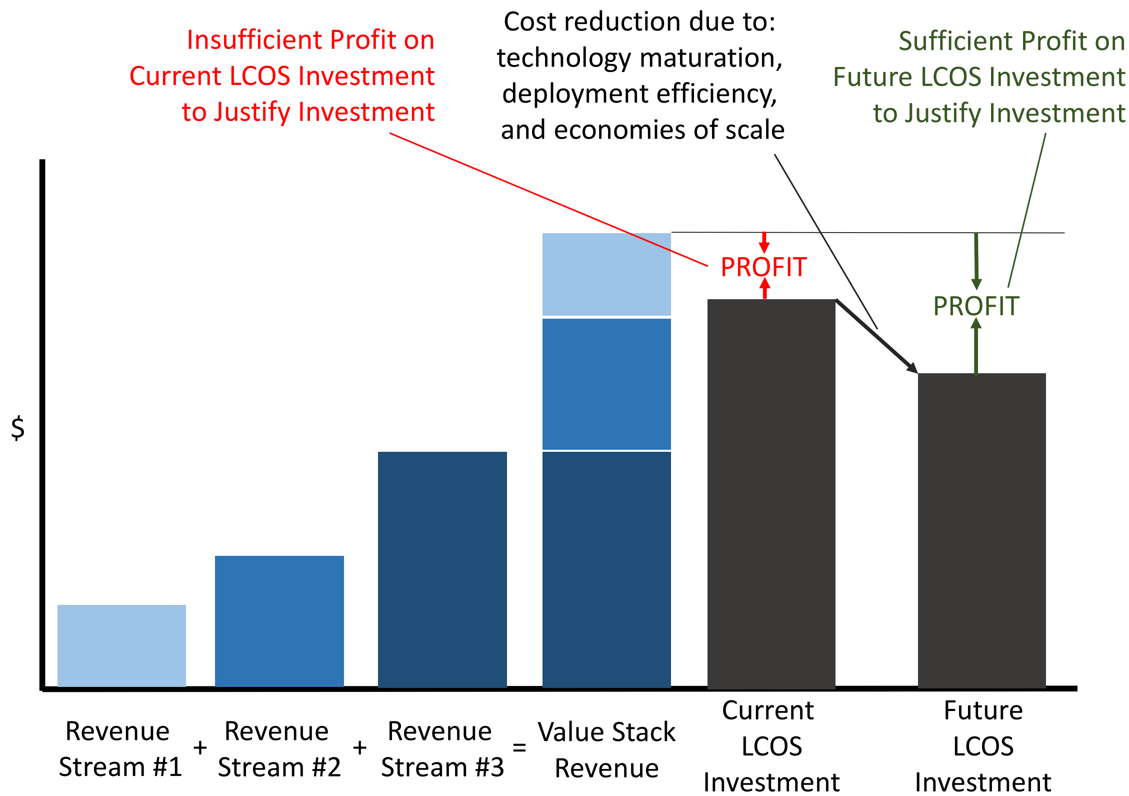

Figure 1. Value and Cost of a Storage Asset

3.0 Define the Project

In addition to determining the business case, the developer must define the project size, select a storage hardware technology and provider, and determine the project location. Many of these projects aspects are interrelated to each other.

3.1. Determine the Optimal Project Size

The following two parameters are required to size a project:

- Power rating (kW or MW) – The power rating of a storage asset is the maximum amount of real power and reactive power that the asset is rated to produce. This rating is familiar to most people in the electric power industry, as it is consistent with the rating of a generating asset. For battery projects, the power rating is determined by the size and number of power conversion systems (PCSs) that can convert power on the DC battery bus into AC power for the grid. PCSs are commonly referred to as inverters, although this term describes conversion from DC to AC power and neglects rectification of AC to DC power.

- Energy rating (kWh or MWh, sometimes expressed in terms of time at rated power) – The energy rating is the total amount of energy that a storage unit can provide without consuming additional electricity. Some people tend to neglect this rating when discussing storage assets. The energy rating of a storage asset is determined by the capacity of the storage hardware, such as the size and number of battery modules.

For ancillary services such as frequency regulation, the power rating is more important because it measures the instantaneous effect that the storage asset can have on the grid. Storage units that will primarily perform ancillary services are typically rated to operate at full power for 1 hour or less because they are designed to alternate between charging and discharging for short increments of time. The marginal benefit of additional energy does not typically justify ratings of more than 1 hour for these systems.

A storage asset that will perform peak reduction requires a large energy capacity, as there are typically several consecutive hours of high demand in the late afternoon and early evening. This phenomenon is more pronounced in areas of significant solar production when the hours of peak renewable generation have limited or no overlap with the following hours of high demand. Storage assets that will be used for peak leveling are typically sized for 4 or more hours of full-power operation to discharge continuously over the peak demand duration.

Some storage assets may use a hybrid of these two approaches by operating PCSs at less than 100% of the rated output. A storage unit rated for 2 hours of full-power operation may be well-suited for high-power frequency regulation participation, and also capable of performing peak leveling at 50% power for 4 hours of discharge.

3.2. Select a Storage Technology and Hardware Provider

Selecting storage technology and a storage hardware provider begins with development of a usage profile. A typical profile for a peak shaving application is one full charge/discharge cycle per day for the life of the project. For ancillary services, the usage profile is not as straightforward, but can be developed through modeling that was previously performed to justify the anticipated use case. The usage profile is particularly important for Li-ion batteries, because the life of the battery is significantly impacted by the manner in which it is used. Hardware providers may add extra battery capacity to ensure that the nameplate rating is met throughout the warranty period. A comprehensive usage profile will enable the developer to work with potential storage hardware providers to properly size the hardware, and will help ensure that the optimal price and performance is obtained.

The recent substantial investment in the research and development of new storage technologies demonstrates the recognition of the clear need to develop this industry. A wide variety of storage technologies have been conceived, and are in various stages of development. Some examples include:

- Lithium-ion (Li-ion) batteries are high-density, rechargeable batteries which are used extensively in home electronics and electric vehicles. A variety of materials have been developed as the electrodes in the battery cells. Individual battery cells are wired together to make a battery pack or battery module.

- Flow batteries consist of a central cell with electrodes, and two physically separate tanks which each hold an electrolyte. The electrolytes are pumped through the cell to drive the electrochemical reaction, either in a charging mode or discharging mode. The power is a function of the surface area of the electrodes in the cell, while the energy is a function of the volume of the electrolyte tanks.

- Lead-acid batteries were the first rechargeable batteries to be developed. Lead-acid battery cells consist of two electrolyte plates (lead), separated by an insulator, and submersed in an electrolyte (acid). These batteries are used significantly in automobiles and as backup control power systems in industrial applications.

- Pumped-hydro energy storage systems are similar to hydroelectric power stations in that they consist of a reservoir of water that can be discharged through a turbine to create electricity. The pumped-hydro system turbine is reversible and can also be used as a pump to store water in the reservoir, converting it back to a source of potential energy. This storage technology has been used in grid-scale applications for more than 80 years.

- Compressed-air energy storage (CAES) involves the compression of gas to store energy, and the expansion of the same gas to produce energy. A constant volume, variable pressure application may use a large chamber for air storage, such as underground caverns created by solution mining. A constant-pressure application may use an expandable storage vessel that is situated underwater at a prescribed depth.

- Flywheels store rotational mechanical energy and are typically attached directly to motor/generator sets. Reducing friction is critical to these systems. This may be accomplished with special bearings or by enclosing the machine in a vacuum.

The recent growth of the electric vehicle industry has increased the worldwide production of Li-ion batteries. This has increased availability and driven down costs. This supply-side inducement combined with the Li-ion's compact footprint, high round-trip efficiency, and cycle ratings measured in the thousands, has resulted in the recent trend that most new grid-scale storage projects today use Li-ion batteries. However, the following factors should be considered prior to selecting an energy storage technology:

- Li-ion batteries are susceptible to thermal runaway, a condition where a thermal event, caused by short circuit or other means, initiates a chain reaction by heat propagation to adjacent cells. Therefore, Li-ion batteries represent a fire safety hazard if there are manufacturing defects or if they are not operated in accordance with manufacturer recommendations.

- Flow batteries have an advantage over Li-ion batteries in that they can be operated at full power and over their entire state-of-charge range without exhibiting significant degradation. However, flow batteries require a significantly larger footprint than Li-ion, and they have not enjoyed the same rate of price reduction, making the economics and business case challenging.

- Lead acid batteries are used extensively in C&I applications. This solution is a more mature, less hazardous technology, with a reasonable cost. However, compared to lithium-ion, lead acid batteries have a larger footprint, and their capacity is diminished at high power, making their implementation impractical for T&D scale.

- According to July 2018 data in the DOE Global Energy Storage Database, pumped hydro storage accounts for 94% of the world's total storage capacity.[3] However, most of the ideal hydro power locations in the United States have already been developed. A new pumped storage facility would likely require a significant amount of land, earth movement, and permitting, which challenge the economics of future development.

- Compressed-air storage, flywheels, and other alternative technologies have shown promise in limited applications, but they are not yet mature enough for commercial implementation.

The best practices and lessons learned in this paper will focus on Li-ion batteries, as this technology represents most of the new capacity currently in development.

3.3. Locate the Project

Locating the project requires selection of a site that supports tie-in to the desired point on the electric grid as well as an appropriate physical location for the asset. Determining the grid tie-in point is closely related to the business case and may include the following considerations:

- Transmission and distribution network modeling and growth projections – The loading of each conductor on the grid varies seasonally and with time of day. Growth projections are used by utilities to determine future loading of each network. A strategically-placed storage system can relieve peak loads and eliminate or delay the need for new wires and/or substations.

- Locational marginal price (LMP) of electricity – The LMP reflects the wholesale value of energy at the specific location and time it is delivered. Congestion on the grid will raise the LMP where the electricity is delivered. For example, in the PJM Interconnection, LMPs are posted every five minutes and "take into account electricity demand, generation costs, and the use of and limits on the transmission system."[4] Therefore, a developer that intends to use storage in an arbitrage application will seek to locate the asset in an area with a highly variable LMP. By definition, this will also be a location with high congestion during peak loads, and the storage asset will therefore reinforce reliability of the grid near the tie-in point.

- Behind-the-meter applications – As the name implies, behind-the-meter applications tie into the electrical distribution system on the customer side of the revenue meter. This applies to C&I customers seeking a demand charge reduction. It also applies to residential customers implementing solar plus storage solutions to reduce their reliance on the grid, or using storage to reduce their electricity bills in regions where time-of-day metering is implemented. Another example of a behind-the-meter application is a generating station that adds storage to their portfolio in accordance with the provisions of FERC Order 845.

Determining the physical location includes considerations of its own. In addition to locating sufficient real estate near the grid tie-in point, public safety must be considered. Li-ion projects do pose a fire hazard, and should have sufficient clearance from nearby structures.

4.0 Design Considerations

Development of the storage system design is an opportunity to reduce project costs, simplify installation, and improve system efficiency. As developers, storage companies, and EPC firms gain experience, standardized designs will become more common.

4.1. DC System Aggregation

Li-ion battery modules for use in utility-scale storage systems are typically sized in the range of 2-10 kWh. Modules are wired together in series to form strings with a voltage range appropriate for the PCS AC voltage, then strings are aggregated on a DC bus to provide the desired energy rating (kWh) for the system.

The PCS is sized to provide the desired power (kW) rating and runtime at full load. Grid-scale energy storage PCSs are available at sizes from less than 100 kW up to 2200 kW. Multiple PCSs can be integrated in parallel to increase the power throughput to/from the grid.

When selecting the level of DC aggregation, consider that:

- Fewer battery modules per PCS results in a more modular system and minimizes the impact of the loss of a single PCS or battery rack.

- Aggregating at a higher power level (fewer PCSs per MW) reduces project complexity and the number of power conductors and communication connections. This reduces project cost and improves the return on investment.

4.2. Buildings vs Containers

Recent grid-scale projects have been located in either a dedicated, manned building or in a conglomeration of outdoor-rated containers and enclosures. The recent trend has been towards outdoor-rated containers and enclosures for the following reasons:

- Many of the grid-scale PCSs (500 kW and greater) are built in outdoor-rated enclosures with an integrated cooling system. Housing these units in a climate-controlled building adds capital costs due to the additional floor space required and operating costs due to the unnecessary heat load on the building HVAC.

- The PCS produces a significant amount of heat as a byproduct of the power conversion process, and is typically the largest heat source. The PCS components are relatively insensitive to temperature, and therefore can tolerate a high ambient temperature. The chemistry of Li-ion batteries, in contrast, require lower temperatures and tighter control of temperature to maintain battery performance and satisfy the manufacturer’s warranty requirements. Implementing a design that separates the PCS and the battery module enclosures reduces the energy consumed by HVAC equipment in maintaining battery temperature. This improves the operational profitability by reducing the cooling costs.

- An essential characteristic of a storage asset is its round-trip efficiency. Energy input always exceeds energy output due to power conversion inefficiency and parasitic loads such as HVAC and lighting. Round-trip efficiency gauges the productivity of the energy storage system by the ratio of the energy output over the energy input:

$$Round\ Trip\ Efficiency = \frac{Energy\ Provided}{Energy\ Consumed} * 100\%$$

  Round-trip efficiency is typically determined by charging and discharging the system around a reference battery state of charge (SOC), an effective measure of the energy available within the battery. By starting at a low reference SOC, charging to a high SOC, and then discharging to the same low reference SOC, the energy available within the system remains unchanged. Round trip efficiency is calculated based on the total amount of energy consumed and provided by the system during the test.

  Reducing the cooling requirements helps to improve round trip efficiency, as the energy consumed is reduced. A properly-designed Li-ion system can achieve round trip efficiencies in excess of 90%.

- Locating energy storage hardware in outdoor, unmanned enclosures allows the enclosures to be considered equipment from a regulatory perspective. This limits some of the facilities, systems, and permitting that would be required for a manned building, reducing development costs and improving the project economics.

Another option entering the market is the plug-and-play containerized storage unit. This product includes storage hardware, a PCS, and HVAC equipment in an integrated unit. Due to the weight of the batteries compared to shipping limitations the size of these integrated units is typically limited to less than 1500 kWh. These units are well-suited for behind-the-meter C&I applications.

4.3. Solar Plus Storage

Co-locating a storage project with solar adds another variable: Both PV and batteries are DC sources, so the two assets can either be coupled via a shared DC bus or via separate inverters on an AC bus. A depiction of an AC-coupled system is provided in Figure 2, and a depiction of a DC-coupled system is provided in Figure 3. Points to consider include:

- The peak output of PV panels is only achieved for a portion of the day, and sizing solar inverters for this peak output is not economical. In typical solar installations, inverters will be purposely undersized, and will “clip” the peak PV output. The revenue lost at the peak output is balanced against the reduced cost of the inverter.

  Combining a solar installation with the battery via a shared DC bus allows the energy typically lost at peak PV output to be captured and stored in the battery. The inverter can therefore be undersized effectively, and the output of the installation averaged over a longer duration.

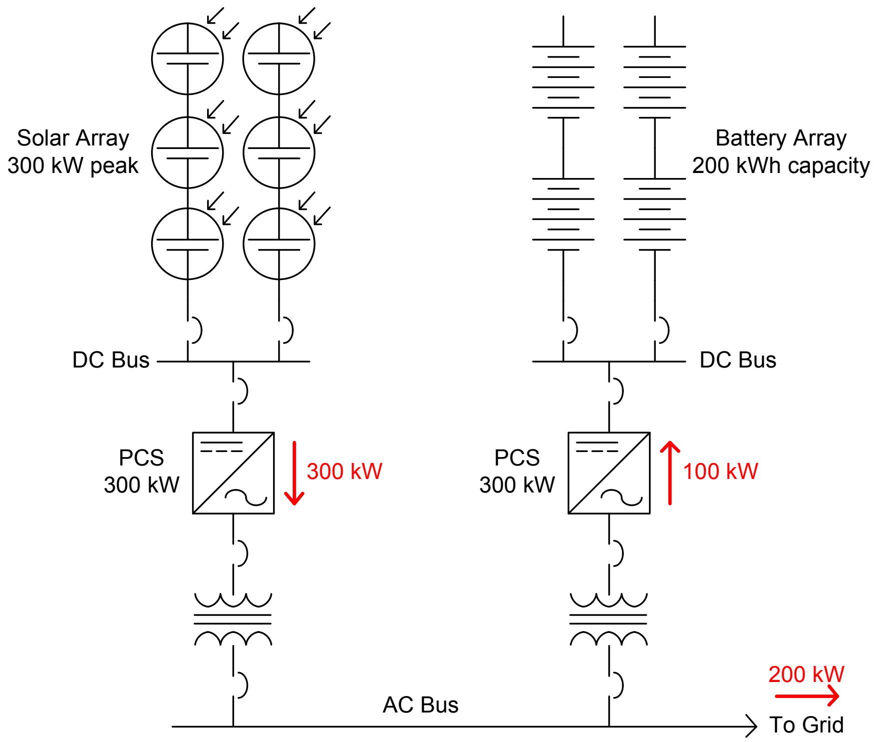

Figure 2. Solar Plus Storage – AC Coupling

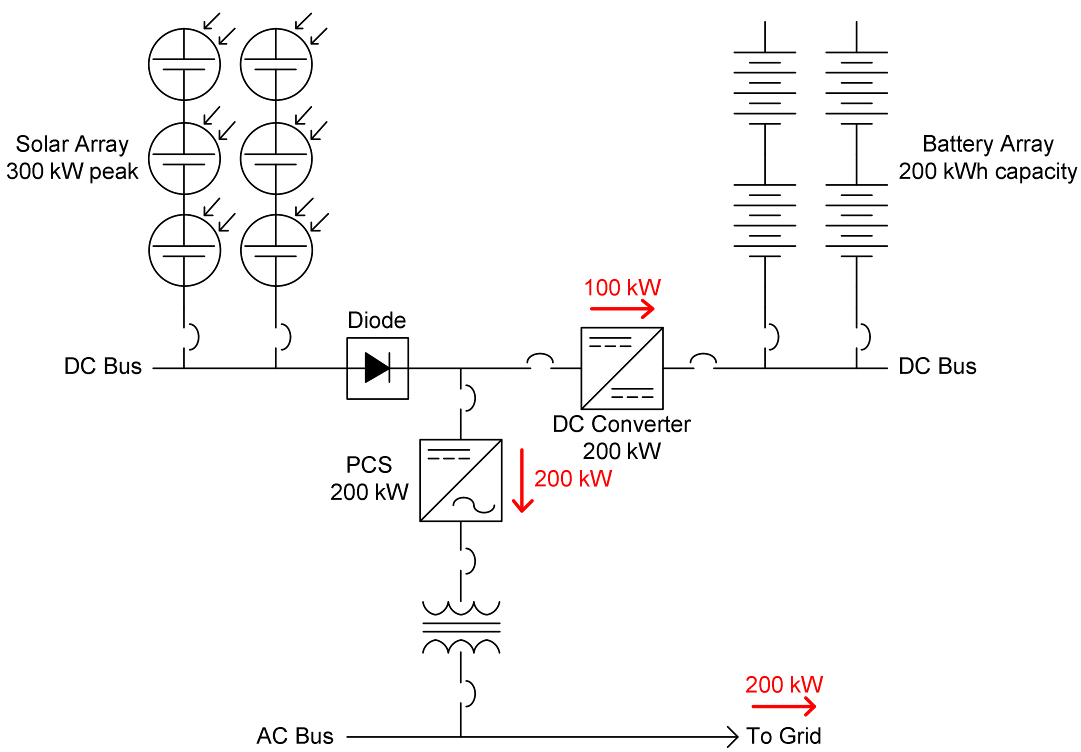

Figure 3. Solar Plus Storage – DC Coupling

- The DC-coupled system allows the solar array and battery to share an inverter, thus reducing capital costs by eliminating the storage inverter, one step-up transformer, and one set of switchgear. However, an additional DC-DC converter and a blocking diode are required at the DC interface between the solar system and the battery. The converter controls power flow across the interface and allows unequal voltages between the two sides. This permits the PV panels to be loaded near their maximum power point while battery voltage varies with SOC. The PCS and converter can both be sized for a more moderate sustained output, resulting in considerable savings compared to a dedicated inverter, transformer, and switchgear for each asset.

- There is a limited experience base with DC coupling. AC coupling is less risky, as it is very similar to typical solar and storage systems that interact with other devices on the AC grid.

5.0 Implementation Considerations

Project developers, storage companies, and EPC contractors are beginning to develop an experience base for energy storage project implementation. Employment of the following best practices and lessons learned will maximize value to project stakeholders.

5.1. Fire Protection

Fire protection is an essential element to a battery energy storage project, especially Li-ion projects, as this technology is susceptible to thermal runaway. A new standard for energy storage fire protection, NFPA 855, is currently in development. The draft form of this standard is available for public viewing on the NFPA website. The final standard will help improve fire safety and will reduce project development risk by removing uncertainty from the fire protection approach.

Project success in fire protection requires early engagement with the Authority Having Jurisdiction (AHJ). Requirements will likely vary based on storage technology, project size, project location/proximity to other structures, and experience of the AHJ. A robust fire protection program will likely incorporate many of the following best practices:

- A fire hazards analysis is developed to evaluate the risks and consider the necessary protective measures. The analysis will likely be reviewed by the AHJ and issued to the local fire department for preparation in case they are required to respond to an emergency at the energy storage site.

- An emergency shutdown (E-shutdown) feature that expediently powers down and disconnects the battery modules and PCSs. Effective emergency shutdown system designs will interface with and can be triggered by other safety systems, such as fire detectors, protective relaying in switchgear, and manual pushbuttons.

- A clean agent fire suppression system (such as Halon, FM200, or Novec) may be required in each battery container to prevent cascading damage to adjacent battery containers and other buildings. Even if not explicitly required, the added protection against additional loss may be desired by the owner, operator, or insuring agent.

- If a suppression system is provided, then procurement documents should specify a room integrity test, also known as a door fan test. This test ensures that the suppression agent will remain long enough to fully extinguish a fire and not prematurely escape from the space following a discharge.

- The E-shutdown system and the integrity of the container should be tested on site prior to system energization.

5.2. Battery Loading

The process of loading batteries into storage racks also requires careful planning and engagement. Loading batteries at a construction site is difficult to coordinate with construction activities. Battery modules must only be handled in a clean environment, so the dust and debris of a construction site further complicate performing this work.

One option is to load batteries at the factory that manufactures containers. The following considerations will influence the plan for loading batteries:

- A dedicated area in a factory can provide a cleaner environment than an outdoor construction site. In addition, activities performed in a dedicated testing area at a factory are safer and easier to coordinate as compared to activities performed at a construction site, where other work may compete with battery loading.

- Loading batteries at the factory may facilitate an integrated system test, if a PCS is also shipped to the factory. Many factories that build portable electric buildings/containers have a test facility on site.

- A container loaded with batteries is heavy. Due to transportation and rigging constraints, this approach limits the size of an individual battery container.

- The battery manufacturer may require that batteries be shipped in their original packaging to maintain the warranty. If moving the batteries while they are mounted inside the container will void the warranty, then the batteries must be loaded at the construction site.

5.3. Manage Risks

In this relatively new industry, a storage project is frequently a first of a kind (FOAK) project for the developer, system integrator, and/or EPC contractor. FOAK projects and designs feature hidden risks and lack efficiency. The following practices can be implemented to limit the impact to the project:

- Begin a FOAK project with a prototype build and test of a single battery enclosure and PCS. Ideally the prototype will be tested at the container facility, prior to commencing construction site activities.

- Hire an experienced firm to perform a third party review of the system design and project implementation plan. The firm should highlight variability in development cost and schedule as well as affirm operational economics of a project ensuring the expected return of investment.

- Work towards a standardized and proven design and implementation plan as additional projects are implemented.

- Develop relationships with key partners so the entire project team is rewarded by increased return on investment through execution efficiency as they gain experience working together to improve designs and processes.

- Clearly define the scope of each firm that is providing equipment, installation support, or commissioning services.

6.0 Conclusion

Grid-scale storage has the capability to make a significant positive impact, especially as renewable assets continue to come online. Thoughtful implementation of best practices and lessons learned will help ensure the success of new projects, will drive further investment in storage, and will ultimately strengthen the resiliency of the electric grid.

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