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Grid support stability for reliable, renewable power

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Understand why energy storage is fundamental to large-scale solar projects

Executive summary

Renewable energy is intermittent by nature. The sun does not shine on demand, and to maximize renewable energy generation, we need to make the most of what we get. As renewable energy penetration continues to expand, finding the best ways to store energy is increasingly important to accommodate those cloudy, rainy days. This is true for both the utilities that deliver electricity and the organizations investing in photovoltaic (PV) solar.

Integrated, grid-tied storage is helping to make solar energy a dependable, on-demand power that is deliverable with controllable power ramp rates. Selecting the right energy storage system is key to optimizing price per performance—maximizing energy production and minimizing grid impact for utilities.

The key considerations for choosing the type of storage to integrate with inverters hinges on defining the following:

- The prime purpose of the system—this can include peak-power shaving time-of-use shifting, limiting rate of power change, and others
- The power size is required—both continuous and peak power
- Quantifying how much energy is required for the task

Energy storage devices have been available for well over two centuries; Alessandro Volta is credited with inventing the battery in 1800. Yet batteries did not go into mass production until a century later, with the advent of the modern automobile. Since then, energy storage devices have evolved to meet various demands required in many commercial and industrial applications.

As more and more renewables come online, energy developers and utilities need to consider various forms of stored energy to fully harvest the potential of renewable resources. Additionally, energy storage helps to maintain line parameters that may otherwise be compromised without energy damping. Energy harvest from large-scale PV systems has variations that do not match up with utility loads, and energy storage devices can help match up generation to load while maximizing energy production and help maintain frequency and voltage tolerances.

Role of energy storage in large-scale PV systems

Clear, sunny days produce a smooth arc of power production that peaks at midday. In this case, power production changes relatively slowly and well within utility power ramp rate specifications.

On cloudy days, power production is not smooth and can change rapidly, so that power ramp rates exceed utility specifications. Large and fast changes in power result in voltage and frequency regulation issues. The impact from these power irregularities is greater with larger plants or penetration of PV with relation to grid size. This problem is typical for island applications.

When the cloud cover rolls away, adjusting the power ramp rate of the PV inverter can control the power surge. But this will not help make up for the shortfall in power when the clouds roll in. To keep PV production under the maximum ramp rate, algorithms reduce the power production to below production valley levels; however, they fall short in harvesting the full potential of PV production for the array.

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Fast-acting energy storage tied to the PV plant can act as an energy damper or a system shock absorber, producing smooth power output to the grid at the required utility ramp rate. This is shown in **Figure 1**, where the blue line indicates power production from a PV array, the yellow line indicates power delivered and absorbed from the array, and the red line indicates power delivered to the grid.

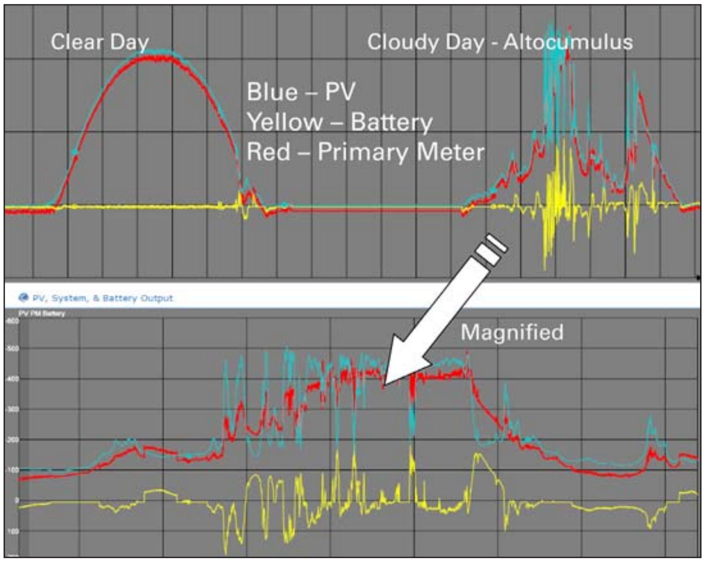

Figure 1. Solar Power During a Cloudy Day, with Energy Storage Reducing Power Rate of Change to the Grid[1]

The energy storage systems (ESS) required in these ramp rate control applications generally use a high power-to-energy ratio with storage capabilities in the 15-minute to half-hour range at full power.

Shaping and curtailment capture

Output power shaping is also useful for utilities because it helps with peak demands. Output power shaping involves storing PV power that is generated during the early and midday periods and releasing it later in the day, during peak demand, as shown in **Figure 2**.

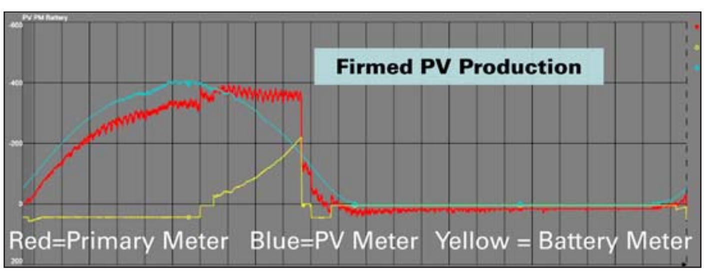

Figure 2. Power Shaping of PV Array[1]

In cases where power delivery is constrained by limits to transmission, such as small feeders, energy storage systems can be deployed to limit the power delivery input to the grid. By curtailing PV generation, power delivery is stretched out longer during the day. This allows utilities and developers to avoid or delay the large capital outlays needed to upgrade transmission lines until there is sufficient customer demand.

ESS required for power shaping and curtailment generally use lower power-to-energy ratios, with storage capabilities lasting over an hour at full power. The power-to-energy ratio is known as the storage system C factor. Depending on the total system requirements, energy storage, power, and C factor must be defined before selecting an optimum energy storage technology.

In addition to ramp rate control and power shaping, other auxiliary services of an ESS can be capitalized. These services include frequency regulation, grid healing, emergency power, and peak power shaving.

Frequency regulation requires quick response by the ESS, generally within seconds of a utility SCADA command or a frequency change event. In the event of a frequency drop, the ESS can be used to assist with frequency changes, by pushing or pulling power into the grid to accommodate for frequency drops or surges. An inverter-based ESS can deliver this kind of support because of its inherent step response capabilities. Coupled with fast responding storage devices like flywheels, advanced lead acid, or lithium-ion batteries, the ESS can respond usually within a cycle of receiving such a command.

A similar benefit of grid-tied inverters is the ability to deliver lagging or leading reactive power or volt-ampere reactive (VAR) for voltage control. Additional VAR support can be provided in conjunction with existing PV inverters. However, an inverter-based ESS can deliver full 360-degree power and reactive power support with fast response.

The ESS can help provide grid healing with both low voltage ride-through (LVRT) and high voltage ride-through (HVRT) capabilities. When a grid short circuit occurs, it is to the utility's advantage to have large grid-tied inverters stay online to help clear the fault for at least the prescribed period established by the North American Electric Reliability Corporation's (NERC) requirements for voltage ride-through (outlined in **Figure 3**). Conversely, when large loads are dropped, voltage surges can occur. Staying online and running ESS inverters in lagging VAR mode helps to bring the voltage within normal values.

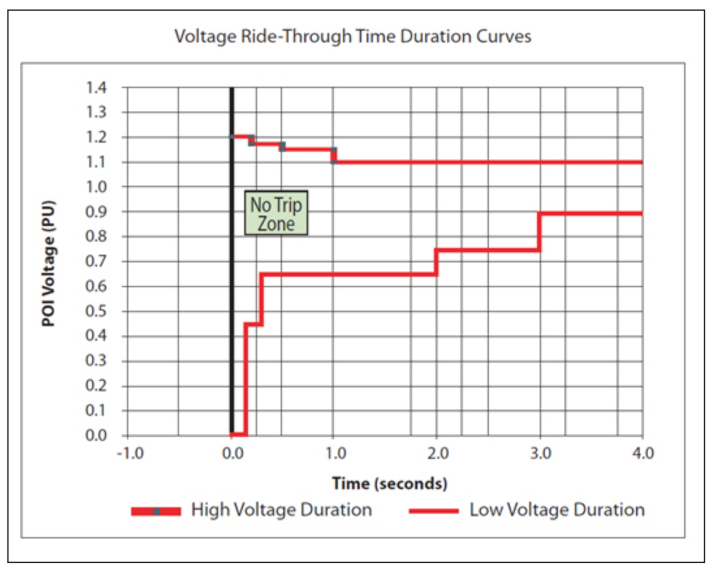

Figure 3. NERC Requirements for Voltage Ride-Through[2]

Selecting storage systems

So, which ESS system is best for PV applications? The answer depends on a number of site-specific conditions. There are various energy storage systems and each has strengths that can be assessed by defining:

- System power rating
- System stored energy
- Fast or slow system response
- Required cycling
- Space considerations

Each of these parameters must be defined for the installation before an analysis of storage can occur. For example, ramp control requires more power than energy, a fast system response, and numerous charge-discharge cycles per day as shown in **Figure 1**. Conversely, energy power curtailment requires higher energy-to-power ratios, generally does not require a fast system response, and is operated with fewer cycles per day.

In automotive applications, space is at a premium and weight needs to be minimized; lithium-ion batteries are the norm. Size and weight are generally not a concern for large PV installations. This makes other storage devices, such as advanced lead acid, liquid-metal batteries, and others, attractive because of cost and performance. There are also economies of scale for larger ESSs that open the viability to systems requiring balance of plant, which would be prohibitive in smaller energy storage applications. This becomes evident in **Figure 4**, which shows an energy, power, and time duration comparison of the application of various energy storage systems.

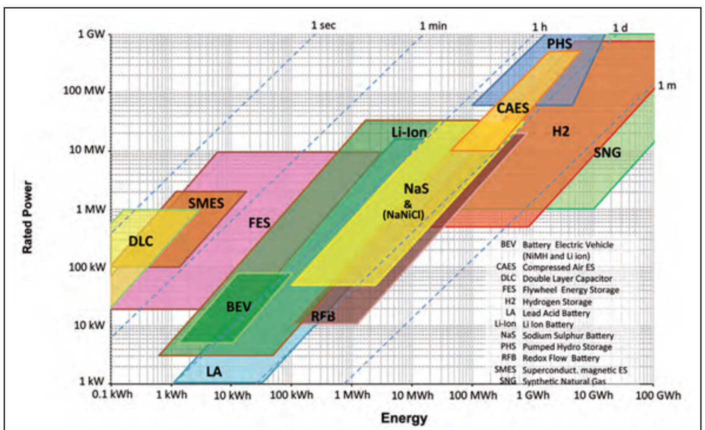

Figure 4. Energy Storage System Ratings[3]

For large-scale solar, technologies including lithium-ion, sodium sulfur, lead acid, flywheels, and flow batteries are all viable candidates. The technologies shown with shorter time capabilities are better suited to ramp control, whereas technologies in the higher time range are better suited to firming, shaping, and curtailment applications. Most renewable applications to date have used lithium-ion and advanced lead-acid technologies, given the system sizes, time duration, system response, cycling capability/life, and commercial availability. New batteries not shown in this figure, such as liquid-metal types, are planning commercial availability and show promise in renewable energy applications.

Capital cost is certainly an important economic factor, but the total ownership cost must be calculated. For example, the capital cost of traditional lead-acid batteries is relatively low, yet they may not be the least expensive option for ramp control because of their relatively short lifespan for this type of cycling application.

Round-trip efficiency also plays an important factor in the evaluation of an ESS over the life of the installation, especially in high cost energy domains like islands, where energy in the form of hydrocarbon fuels must be imported. Electrochemical capacitors are a good example of a high efficiency ESS; these are also known as super-caps or ultra-capacitors. Unfortunately, their high power, low energy ratings presently do not make them cost-completive against the slightly less efficient lithium-ion type system for large renewable applications.

Table 1. Energy Storage Comparison[4]

Storage Technology	Main Advantage (Relative)	Disadvantage (Relative)	Power	Energy
High-speed flywheels	High power	Low energy density	Compatible	Not feasible or economical
Electrochemical capacitors	Long life	Very low energy density	Compatible	Not feasible or economical
Lead acid	Low capital cost	Limited cycle life	Compatible	Feasible but not practical
Advanced lead acid	Low capital cost	Low energy density	Compatible	Compatible
Sodium sulfur	High power and energy density	Cost and high temperature operation	Compatible	Compatible
Liquid metal	High power and energy density	High temperature operation	Compatible	Compatible
Lithium-ion	High power and energy density	Cost and increased control circuit needs	Compatible	Reasonably Compatible
Zinc bromine flow battery	Independent power and energy density	Medium density	Reasonably Compatible	Compatible
Vanadium redox flow battery	Independent power and energy density	Medium density	Reasonably Compatible	Compatible
Compressed air energy storage	High energy, low cost	Special site requirements	Not feasible or economical	Compatible
Pumped hydro	High energy, low cost	Special site requirements	Not feasible or economical	Compatible

- Compatible
- Reasonably Compatible
- Feasible but not practical
- Not feasible or economical

Summary

Energy storage technologies continue to evolve, as do the economics of such systems. Reducing costs and increasing performance are driving this evolution.

System analysis is critical to determine storage requirements such as power, energy, and charge/discharge cycles. This will help determine the best storage system based on:

- Capital cost
- Cycling life / operating costs
- Vendor bankability

Select the energy storage system that is beyond demonstration and from a reputable, bankable vendor that will service the equipment for the long term. In addition to the storage system itself, a vendor must also provide the technical and application expertise to support the project in the short and long term.

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