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Technology Advisory

Energy Storage Use Case:
PV Smoothing

This Technology Advisory is one of a series by NRECA's Renewable and Distributed Generation work group, providing Use Case studies of various aspects of Energy Storage. The series may be found on NRECA's: Energy Storage topic page on cooperative.com, and Renewable and Distributed Generation page on nreca.coop.

*Note: As a **Use Case**, this document provides description and recommendation of applying Energy Storage to the given market scenario; this is not a **Case Study** of a particular deployment of the technology.*

Defining the Use Case

PV Smoothing

Energy from a photovoltaic (PV) system is inherently variable, since the sun itself is often blocked by clouds. If the clouds are moving rapidly in an otherwise clear sky, the change in output of the system can vary dramatically over a short period of time, both when the cloud cover progresses over the array and as the array is uncovered. This change in system output is one form of "ramping" encountered in PV systems. Another form is when the sun goes down in the evening. The output of the system is reduced over a couple of hour period from near full output to zero.

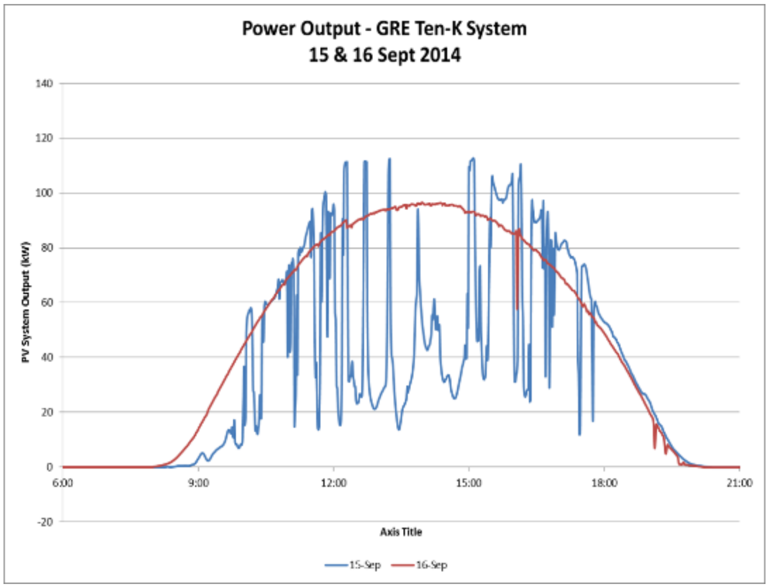

Figure 1. PV system output on a clear day and a high variability day

The variability in output can cause rapid fluctuations in the grid voltage, potentially causing problems, such as consumer voltage excursions outside the acceptable voltage range or causing excessive cycling of voltage control devices (e.g. capacitors, voltage regulators, and load tap changers). In the example shown in Figure 1, there are 96 excess ramping events on the given day with the high variability. As a result, standards have been proposed to regulate the amount of variability that can be allowed to be tolerated from a PV system. The Puerto Rico Electric Power Authority, for example, includes a requirement to limit PV system ramping to 10 percent per minute.[1] For the purpose of the use case, it will be assumed that this is defined as 10 percent of the rated alternating current (AC) capacity of the system.

An energy storage system (ESS) can compensate for this intermittency with an effectively instantaneous source of energy to offset the change in PV output. If the system ramps from 100 percent to zero over 1/6th of an hour, the amount of energy is equal to the area of a right triangle of height equivalent to the rated power of the array, 10 minutes wide. The maximum amount of energy to compensate for a single ramp event (from full power to zero power instantaneously, or the reverse) is then 8.33 percent of the MW rating of the array, the area of the right triangle[2]. For a 1.0 MW-AC PV array, an ESS with at least 83.3 kWh of storage could mitigate the intermittency.

However, a ramp can operate in either direction. If using a battery-based ESS, the battery would typically be maintained somewhere around a 50 percent state-of-charge (SOC), so that it could either supply 83.3 kWh or absorb 83.3 kWh. This would make the nominal capacity 167 kWh, or 16.7 percent of the PV power rating. Due to inefficiencies of the battery and the possibility of multiple ramping events in quick succession, an installed system would probably require a system with a useable energy capacity of 25 to 33 percent of the AC size of the PV array. The power of the system must be equal to the output of the array, so the ESS must be capable of three times the energy capacity of the battery – "**3C**" (if 33 percent capacity) or "**4C**" (if 25 percent of capacity) – charge and discharge.

The ESS would also have to have a very high cycling capability. Although not every day has the extreme variability shown in Figure 1, it is safe to assume that a typical month might have 1,000 to 2,000 cycles or more. Continuing with the system as described, the maximum ESS cycle would be 33 percent of the rated capacity. This means that a typical ESS might experience 12,000 to 24,000 cycles over a ten-year lifetime, with cycle depth ranging from 1 to 33 percent.

Specifications of ESS for PV Smoothing

Energy Capacity: Useable energy capacity should be 25 to 33 percent of the power rating of the PV array. For example, a 1 MW PV array should have an ESS rated at 0.25 to 0.33 MWh minimum. It is important to note that this is the "useable capacity" of the energy storage device. If a specific technology specifies a maximum depth-of-discharge of 80 percent, the useable energy would actually be 80 percent of the rated energy capacity.

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[1] http://energy.sandia.gov/wp-content/gallery/uploads/Lave_SAND2013-4926C_PVSC39.pdf

[2] This assumes a uniform ramp down over time. The formula is 0.5(P_{max})*Hours. For 1 MW ramp of 10 min., it would be (0.5((1 MW)*(10 min/60 min/H)) =.0833 MWH or 83.3 kWh.

Power Rating: The power rating of the ESS for this application must be equal to the rated output of the PV array. For example, an ESS for a 1 MW-AC PV system must have a power rating of 1 MW-AC, which implies that its charge/discharge rate is three to four times the energy capacity of the battery, or 3 to 4C.

Required Footprint: This is the space (in three dimensions) required for the energy storage device, including offsets and required fencing. The footprint will include the battery, power, and control electronics, and if connected to a medium voltage system, the step-up transformer and associated protective switchgear. Many energy systems are being packaged in multiple 20- or 40-foot shipping containers, which can often be vertically stacked at least two high for space savings. One vendor offers a 2MW-AC/1 MWh-AC system in a 40-foot shipping container-type enclosure.

Round Trip Efficiency: Since the system is likely performing multiple cycles per day, alternating current round trip efficiency (ACRTE) is more important than in some other applications. ACRTE should be a minimum of 70 percent, and higher efficiencies will decrease the operating cost of the system.

Cycling: Cycling capability should be for a minimum of 30,000 cycles to 25 to 33 percent depth of discharge over a ten year operating period.

Equipment Life: A PV array typically has a 25-year life, so the ESS equipment should be designed to match. This may be accomplished through replacement of part or all of the ESS at regular intervals.

Controls: The ESS must be able to switch between charge and discharge frequently, often within a few milliseconds.

Energy Storage Technologies for PV Smoothing

The most critical requirement for this application is the extremely frequent cycling of the battery. A similar circumstance applies to an ESS providing frequency regulation. Because of this, a flywheel would be a reasonable technical choice. Alternatively, some of the newer lithium technologies are claiming the ability to do up to and exceeding 100,000 discharge cycles, especially if the cycles are limited in depth-of-discharge. Lead-Carbon batteries are also used in partial SOC operation for frequency regulation, that technology would be appropriate for a PV smoothing application.

Finally, this function could easily be incorporated into a longer-term battery, such as one used for demand management or energy-time-shifting. The ramp-control would be supplied simply by varying the power level of the charge or discharge process, which would be occurring anyway.

What is the Value?

The value of the ESS in this application would be the benefits gained compared to the costs of the system over the operating period. The ESS costs include the installed cost of the system, the operating and maintenance costs, and the replacement/refurbishment of components. The benefits would be the reduction in system impacts associated with the PV array.

However, the benefits of implementing ramping control are difficult to quantify. If there is a formal requirement for limited ramping, the cost of the ESS needs to be included in the overall cost of the PV system. If there is no formal requirement, but merely a perception of a problem, then a tool such as the OMF (Open Modeling Framework) could help quantify the effects of a PV system on a specific distribution system, so the benefits of mitigation using energy storage could be evaluated.

Inputs to the value determination include:

Equipment Installed Cost: This is the fully installed cost of the equipment, which meets the specifications described above. It should include land and site preparation, interconnection transformer and switchgear (if separate from the PV array), and any required monitoring and communications equipment.

Equipment operating and maintenance cost: This includes both regular maintenance tasks and labor, as well as a schedule of anticipated replacement/refurbishment costs.

Financial Variables: If the equipment is to be financed, the interest rate, term of loan, tax incentives, and other relevant financial information related to the acquisition of the equipment and the savings obtained.

Electricity Prices: These are the energy costs for both discharging and charging the system. The price for charging the system is the cost of energy production from the PV array. Depending on system configuration, the value received for discharging the battery during down-ramping is the price of the electricity at the time of discharge or, if metered at the same point of the array, the price for electricity from the array.

Cost of Associated Voltage Regulation Equipment: The impact of variable and intermittent PV on a particular feeder will have cost impacts associated with:

- Reduction in remaining life of regulating equipment and early replacement.
- Upgraded voltage regulation equipment so as to manage the additional variation.

Performing the Analysis

Cost/Benefit Analysis and Net Present Value Calculation

Although the benefits of PV smoothing are difficult to quantify, some measure of the benefit must be identified and considered when evaluating the use of an ESS to help resolve intermittency. If the goal of the project is compliance with a limited ramping requirement, then this cost must be added to the cost of the PV system itself. If required standards of ramping rate and minimum voltage range are already in place, an ESS providing PV smoothing, the existing regulating equipment to provide feeder protection would be displaced by the ESS. The benefit would then be the avoided cost of the associated alternative voltage regulation equipment.

The cost of ESS ownership would be the initial installed cost of the system and the costs of owning and operating for the assumed life of the system. Operating costs of the system consist of the sum of the operations and maintenance (O&M) costs (including refurbishment and replacement of components), the value of energy delivered when discharging the battery and the cost of energy used to charge the battery. If the costs are below the avoided cost of the alternative, the investment may be worthwhile.

For a more detailed examination, a net present value, or "discounted cash flow", analysis of the cost of owning and operating the energy storage system could be determined that includes the initial cost of the system, plus the annual costs of operation, discounted to account for the time value of money. If the system if financed, the loan payments and other financing aspects, including any tax incentives or other unique financial instruments, must be included in the cash flow. The net present value cost would be compared with the discounted cash flow of the costs of adding, replacing, or upgrading the avoided or displaced regulating equipment.

Summary

PV smoothing with an ESS may be a worthwhile investment to accommodate intermittency and assure continuity of a feeder voltage profile. The location and characteristic delivery of power from the PV system, and local system voltage requirements will be factors in consideration of this application.

There are two possible benefits for providing real-time smoothing of PV arrays using energy storage:

1) compliance with a mandated ramping limit; or
2) avoiding additional voltage regulation equipment or early deterioration of voltage regulation equipment impacted by the PV system.

In the first instance, compliance is simply a part of the project's cost. In the second case, the costs of limiting voltage excursions due to excessive ramping would be compared to the costs of adding or upgrading voltage regulation equipment or simply replacing this equipment more often.

Contact for Questions

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