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Grid Tied PV Battery Systems

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ABSTRACT

Grid tied PV energy smoothing was implemented by using a valve regulated lead-acid (VRLA) battery as a temporary energy storage device to both charge and discharge as required to smooth the inverter energy output from the PV array. Inverter output was controlled by the average solar irradiance over the previous 1h time interval. On a clear day the solar irradiance power curve is offset by about 1h, while on a variable cloudy day the inverter output power curve will be smoothed based on the average solar irradiance. Test results demonstrate that this smoothing algorithm works very well. Battery state of charge was more difficult to manage because of the variable system inefficiencies. Testing continued for 30-days and established consistent operational performance for extended periods of time under a wide variety of resource conditions. Both battery technologies from Exide (Absolyte) and East Penn (ALABC Advanced) proved to cycle well at a Partial state of charge over the time interval tested.

Technical Background

The PV output from a grid connected array can change rapidly because of the movement of overhead clouds. In some cases, for example when a large PV system is connected to a relatively small grid or at the end of a weak feeder, rapid output power change can make it difficult to regulate voltage and frequency. The response time of steam turbines and other forms of generation can be too slow to mitigate the power fluctuations. It is possible to locally mitigate the effects of PV output variability using onsite energy storage. Effective PV energy smoothing requires an energy storage system that is integrated into the inverter and control system that will source and sink energy as the PV array power fluctuates according to the available solar resource. This mode of operation requires the energy storage system to operate at a partial state of charge (PSOC). The PV energy smoothing system described in this paper and shown in Figure 1 uses the battery at about 50% state of charge (SOC) and the energy in and out of the battery is determined by the average solar irradiance over a 1h time interval.

Project Goals

The intent of the energy smoothing algorithm is to reduce the rate and amount of fluctuations from the output PV power to meet utility requirements. Specifications for the 1.2 MW PV system at Lana'i in Hawaii require ramp rates of less than 6 to 60 kW/s depending on the time of day. Modeling and Laboratory testing at Sandia National Laboratories Distributed Energy Technologies Laboratory (DETL) has shown that the ramp rates can easily exceed these values.

Results

PV Smoothing Algorithm

The PV energy smoothing system described in this paper uses the battery at about 50% state of charge (SOC) and the energy in and out of the battery is determined by the average solar irradiance over a 1h time interval. On a clear day the solar energy sold to the grid will be offset by about 1h. On a variably cloudy day the power curve will be smoothed based on the average solar irradiance and the battery capacity will be returned to the same state of charge at the end of the day as at the beginning of the day. Because battery energy is only used to smooth the PV array output, battery capacity can be relatively small. In this case model calculations indicate that battery capacity can be as low as 143 Ah at 48 volts for 3.5 kW of PV assuming a maximum DOD of 25%.

Inverter Output Watts = $(I_r \times K_t) + (C_l - C_{50\%}) \times K_s$

I_r = Running Average Irradiance in W/m2
K_i = Constant (Irradiance Scale Factor)
C_l= Measured Battery Charge Level in Wh
$C_{50\%}$ = Battery Charge at 50% in Wh
K_s = Constant (Battery Charge Scale Factor)

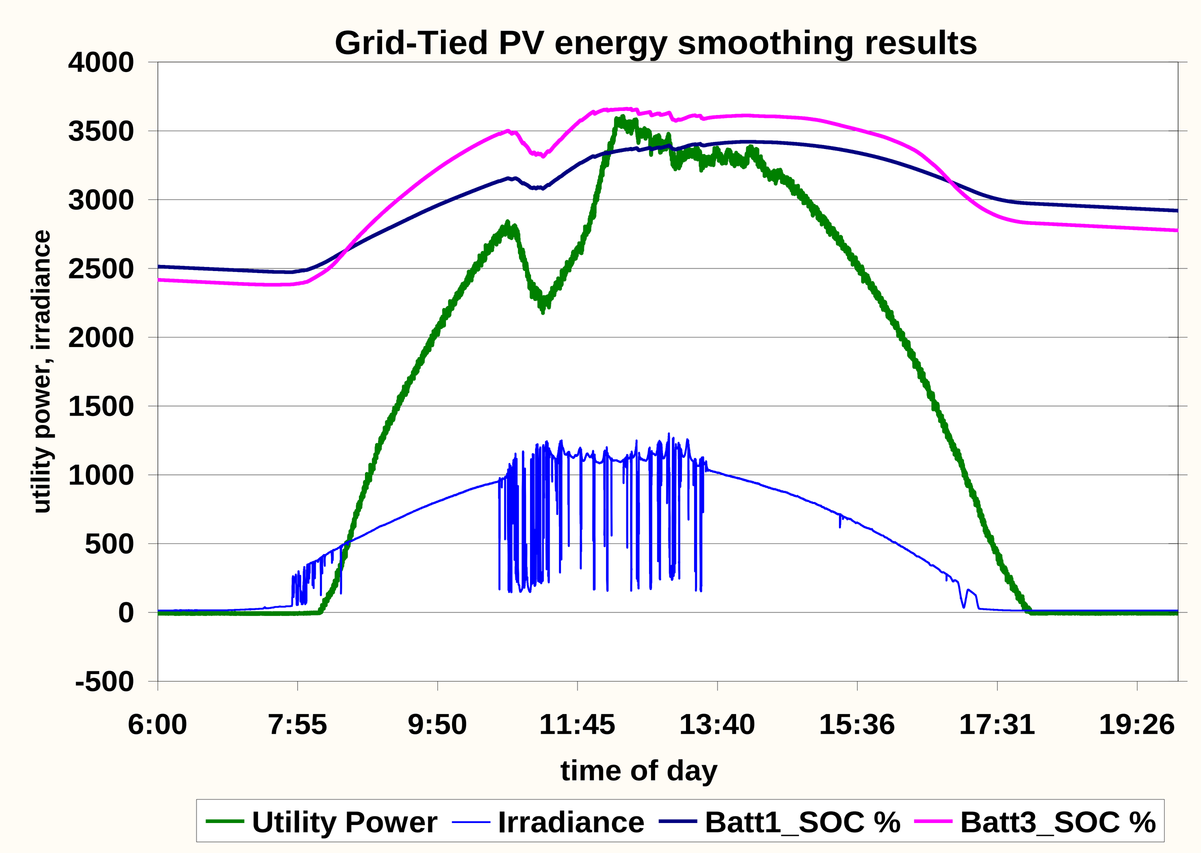
Results

PV energy smoothing model results for a 3.5 kW PV array.

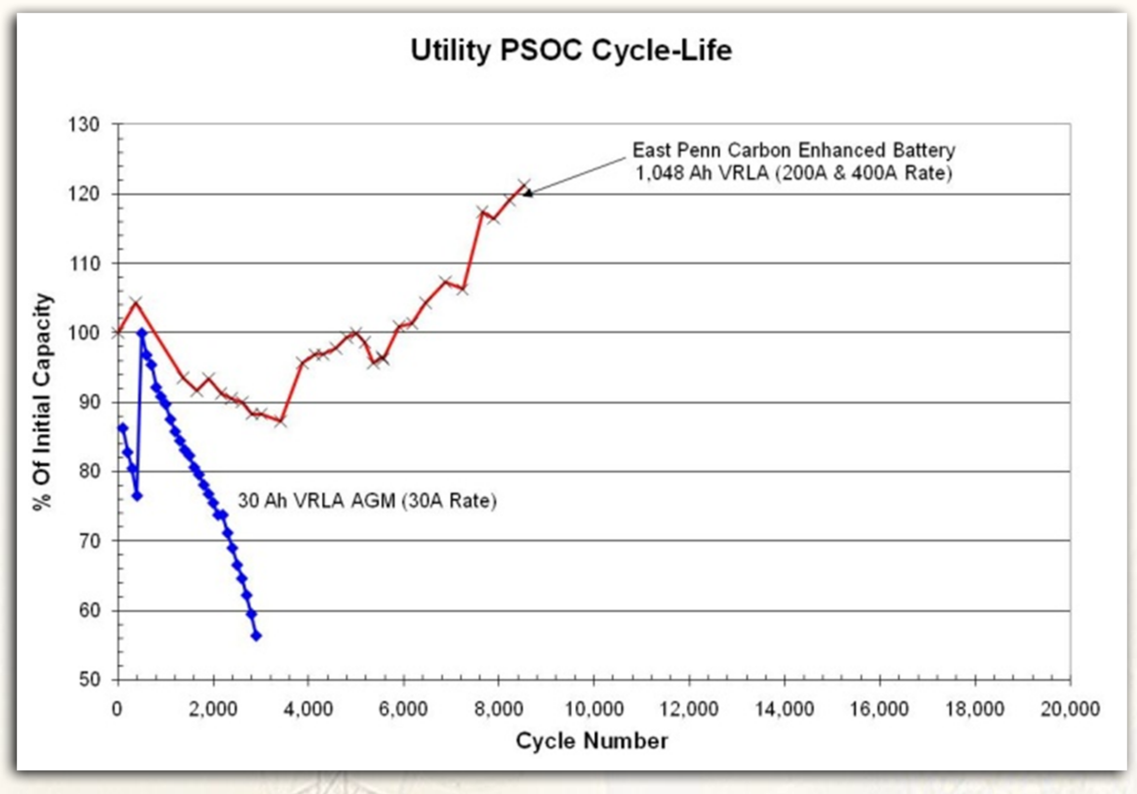
Irradiance Smoothing Interval (h)	Minimum Battery Size (Wh)	Minimum Battery Size (Ah @ 48V)	Max Power Ramp Rate (W/s)
1.00	6,840	143	0.875
0.50	3,488	73	1.75
0.25	1,756	37	3.5
0.00	NA	NA	1,575

Battery specifications and test results.

Battery	Cell#	Specification Ah @ 8h rate (43A & 48A)	Capacity Initial Ah @ 100A rate	Temp °C	Capacity Final Ah @ 100A rate	Temp °C
Absolyte Type GP #90G09	1 to 12	344	274	31	288	31
	13 to 24	344	272	31	296	31
East Penn ALABC Advanced #95-09	1 to 12	380	307	28	326	32
	13 to 24	380	291	28	330	33



Energy smoothing algorithm operation during partly cloudy day.



Carbon Enhanced battery capacity cycling at a partial state of charge.

Conclusions

The work presented in this paper has demonstrated that all of the basic components of a grid tied PV energy smoothing and/or load shifting system are available and can be implemented to construct the system. Previously one of the biggest obstacles to overcome was the energy storage. With the development of the new carbon enhanced VRLA technology from East Penn, a significant increase in battery life can be achieved vs. traditional float service VRLA batteries.

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