Grid Tied PV System Energy Smoothing

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ABSTRACT

Grid tied PV energy smoothing was accomplished 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.

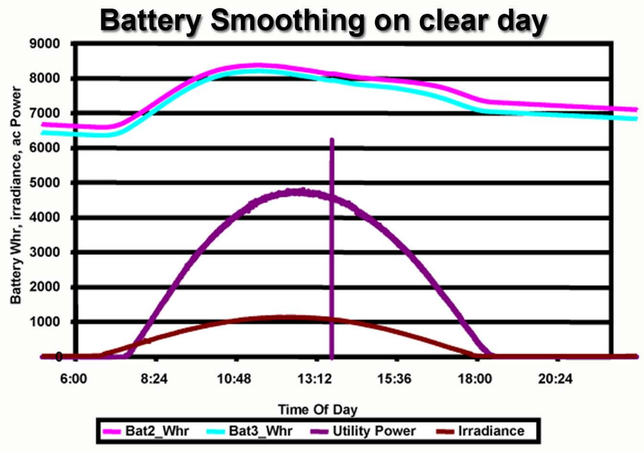
Grid tied PV energy smoothing system.

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 a clear day.

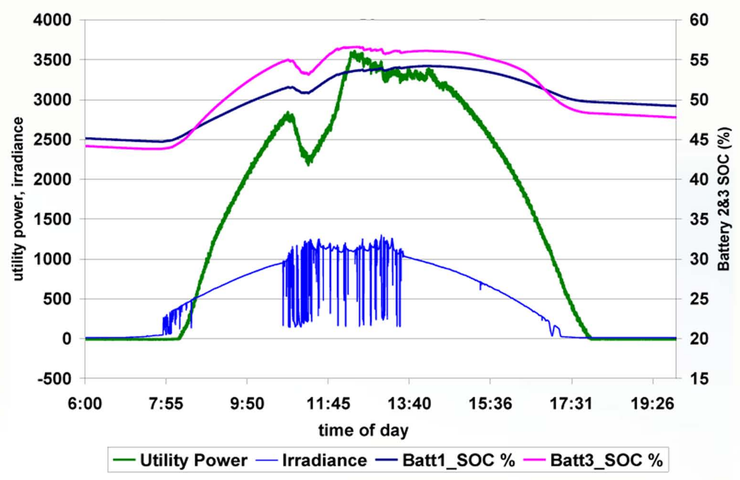
PV Smoothing Algorithm

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%.

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

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)

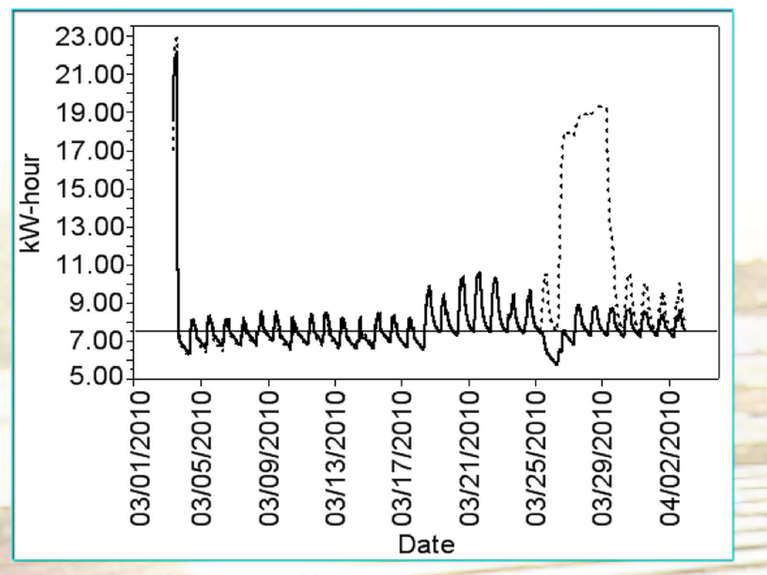
Grid-Tied PV energy smoothing results



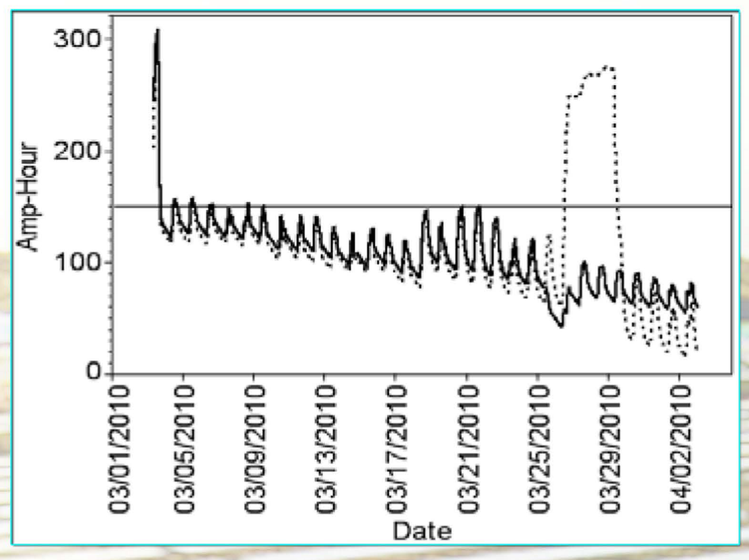
Battery Technology

The PSOC mode of battery operation is potentially very damaging to conventional valve regulated lead-acid (VRLA) batteries because of the formation of hard sulfation on the battery plates. In this test two battery types, the Absolyte from Exide and the carbon enhanced advanced VRLA from East Penn were used to evaluate their performance. The carbon enhanced VRLA technology has only recently been made available as a result of the Advanced Lead-Acid Battery Consortium (ALABC) development work directed at designing lead-acid batteries for use in hybrid electric vehicles. The ALABC battery technology is now available through East Penn Manufacturing in a large industrial VRLA format. The Absolyte battery technology has a long history in cycling solar and utility applications.

Energy smoothing algorithm operation during partly cloudy day.



Battery Wh capacity over 30-day test period for both batteries.



Battery Ah capacity over 30-day test period for both batteries.

SUMMARY

The work presented in this paper has demonstrated that all of the basic components of a grid tied PV energy smoothing system are available and can be implemented to construct the system. The biggest obstacle to overcome will be the integration of the energy control algorithm into the inverter and the battery management functions required to operate the energy smoothing system.

Test and model results have shown that the irradiance averaging algorithm has worked well and requires only a relatively small battery to accomplish it's function. In addition, the new cycling VRLA batteries from East Penn and Exide have proven to cycle well with a slight capacity gain if only for one month of operation. This is an indication that battery life may be good for many years. Based on the above initial results, PV grid tied energy smoothing looks very achievable and at a reasonable cost.

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