Recent Improvements in PV+Battery Modeling in NREL's System Advisor Model

Brian T. Mirletz and Darice L. Guittet
National Renewable Energy Laboratory, Golden, CO, 80401, USA

Background

NREL's System Advisor Model is free, open-source technoeconomic analysis software that facilitates decision-making for people in the renewable energy industry.

Desktop software: https://sam.nrel.gov/

Open-source code:
https://github.com/NREL/SAM/

The PV+Battery model in SAM combines SAM's detailed PV performance model with a nonlinear generic electrochemical battery model. The PV can be AC or DC coupled to the battery model. The following configurations are also available:

- PVWatts-Battery
- Generic System-Battery
- Stand-alone Battery

The technology models can be used with utility scale, front of meter systems and PPA or merchant plant revenue, or behind the meter systems which offset utility bills.

The generic electrochemical battery model includes the following subcomponents:

- Cell Capacity
- Lifetime Fade
- Voltage Curves
- Thermal Effects

The battery can be dispatched with various heuristic options, or a custom (potentially optimized) timeseries can be provided.

References:

Fregosi, Daniel, Pilot, Nicholas, Bolen, Michael, and Hobbs William B., "An analysis of storage requirements and benefits of short-term forecasting for PV ramp rate mitigation". Journal of Photovoltaics Under Review

Mirletz, Brian T., and Darice L. Guittet. "Heuristic Dispatch Based on Price Signals for Behind-the-Meter PV-Battery Systems in the System Advisor Model." 2021 IEEE PVSC

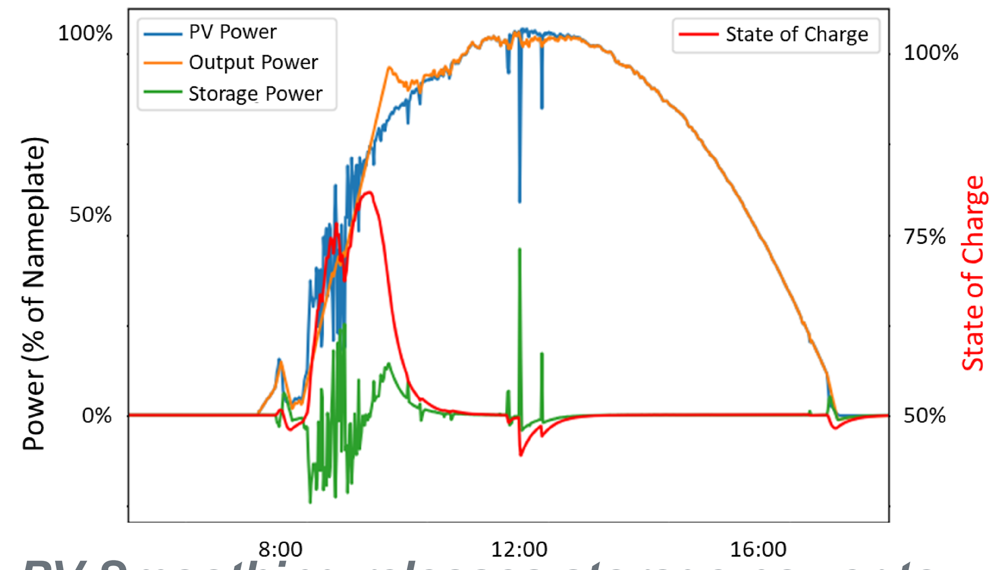
Guittet, Darice, Brian Mirletz, and Matthew Prilliman. What's New in the Battery Model for the System Advisor Model. No. NREL/PR-7A40-80862. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2021.

Smith, Kandler, et al. "Life prediction model for grid-connected Li-ion battery energy storage system." 2017 American Control Conference (ACC). IEEE, 2017.

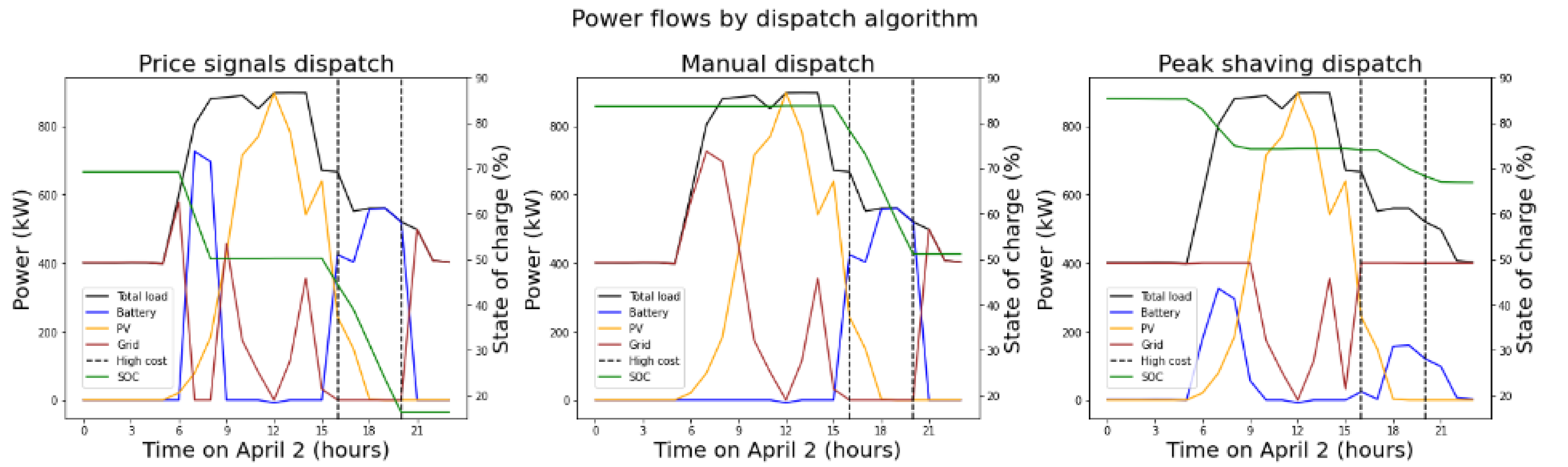
Dispatch Algorithms

New PV Smoothing algorithm (right) provides front of meter PV+Battery systems with the ability to smooth their output to avoid ramp-rate violations in relevant markets.

New Price Signals dispatch algorithm (bottom) considers utility rates in addition to PV and load forecasts to minimize utility bills while considering battery degradation.



PV Smoothing releases storage power to "overshoot" PV power



Price Signals (left) compared with prior dispatch methods. Price signals does better peak shaving than manual dispatch and shifts more grid use outside of the high-cost evening period when compared to peak shaving dispatch.

Grid Outage Analysis

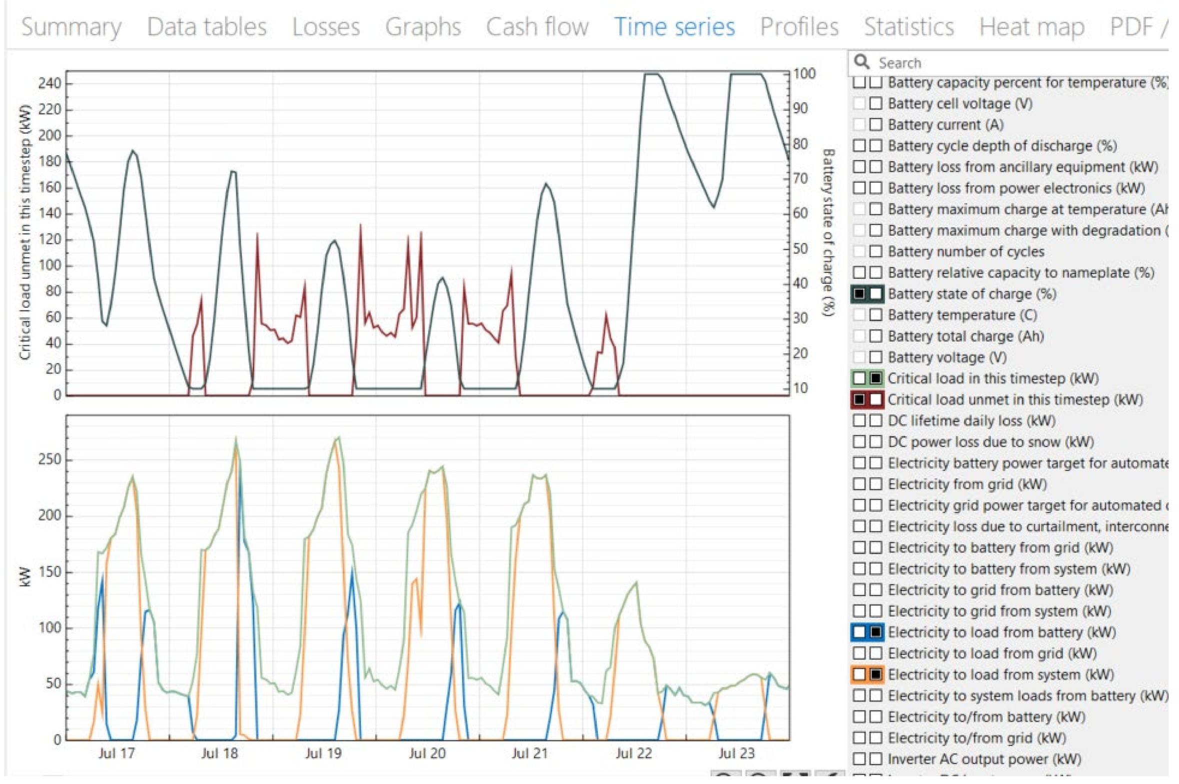
New support for outage analysis in behind the meter models, which affects battery performance. Users can now specify:

- Critical load
  - Percent of load or time series
- Time steps of the outage (could be entire analysis period for off-grid)

Outage analysis can be run two ways, which can be combined:

- Calculate hours of autonomy for a hypothetical outage
- Meet the critical load during the outage, which affects the state of charge and economics

Outputs include the critical load (met and unmet) as well as the performance of the system. The electricity bill is zero during an outage, so caution should be used interpreting financial results from off-grid simulations. Future work will include value of lost load.



Top: Critical load unmet (red) and battery state of charge (dark blue)

Bottom: Electricity to load from battery (blue) and PV (yellow), with total critical load (green)

The critical load is fully met by the system on the first day, Jul 17th, but not on the 2nd night. The next several days have unmet critical load at night, but the decrease in load on July 22nd allows the system to meet the load and recharge the battery.

Levelized Cost of Storage

$$LCOS\left[\frac{\$}{MWh}\right]=\frac{Investment\ cost+\sum_{n}^{N}\frac{O\&M\ cost}{(1+r)^{n}}+\sum_{n}^{N}\frac{Charging\ cost}{(1+r)^{n}}+\frac{End\text{-}of\text{-}life\ cost}{(1+r)^{N+1}}}{\sum_{n}^{N}\frac{Elec_{Discharged}}{(1+r)^{n}}}.$$

- Metric for comparing storage technologies
- Presented in addition to full-system LCOE
- SAM accounts for dispatch strategy, charging costs, replacement costs, etc.
- Charging cost for PV charging is based on PV LCOE
- Charging cost for grid charging is either market price or retail rate

	Peak Shaving & PV Charging Example	
	LCOS (cents/ kWh)	LCOE (cents/ kWh)
NMC/Graphite	69.15	7.07
LMO/LTO	69.03	7.06
LFP/Graphite	69.03	7.06
Lead Acid	149.11	14.21
Vanadium Flow	69.35	7.11

Varying battery chemistry with the same installed costs. LCOS shows high replacement costs for Lead Acid.

	Price Signals Dispatch Example			Peak Shaving Dispatch Example		
	LCOS (cents/ kWh)	LCOE (cents/ kWh)	Battery Cycles (yr 1)	LCOS (cents/ kWh)	LCOE (cents/ kWh)	Battery Cycles (yr 1)
San Diego Hospital PV Only Charging	50.21	7.10	331	69.15	7.07	387
San Diego Hospital Grid Charging	39.67	20.04	504	76.32	14.32	499

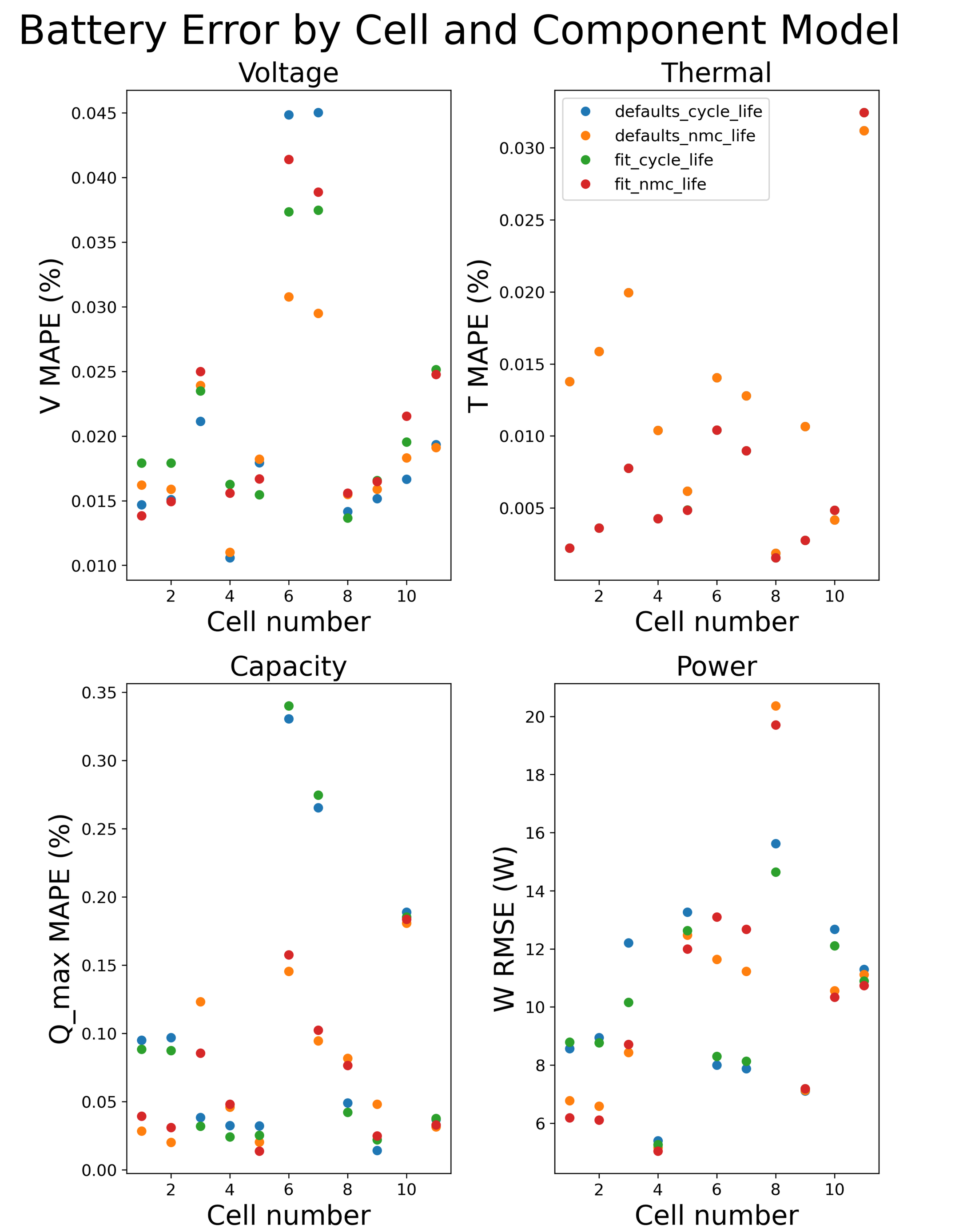
Varying dispatch and charging options for the NMC/Graphite Chemistry.

Battery Validation

Preliminary results from a comparison of SAM's battery model to 10 second measured data over a year of cycles for NMC/Graphite cells from Smith et al. 2017.

The maximum output power of the cell is 270 W, so mean power error is within 8%, and in the room-temperature cases (cells 1 and 2), within 2.5%.

Cell	Parameters		
	Temperature	DOD	Dis/charge rate
1,2	23°C	80%	1C/1C
3	30°C	100%	1C/1C
4	30°C	80%	1C/1C
5	30°C	Storage	N/A
6,7	0°C	80%	1C/0.3C
8	45°C	Storage	N/A
9	45°C	80%	1C/1C
10	45°C	Storage	N/A
11	55°C	Storage	N/A



Component model accuracy for 11 cells under different conditions. Accuracy is lowest at non-room temperature conditions.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

2022 PV Performance Modeling Workshop
Salt Lake City, UT
August 23-24, 2022
NREL/PO-7A40-83677