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NATIONAL RENEWABLE ENERGY LABORATORY

# Recent updates to the System Advisor Model (SAM)

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9th PV Performance Modeling Workshop

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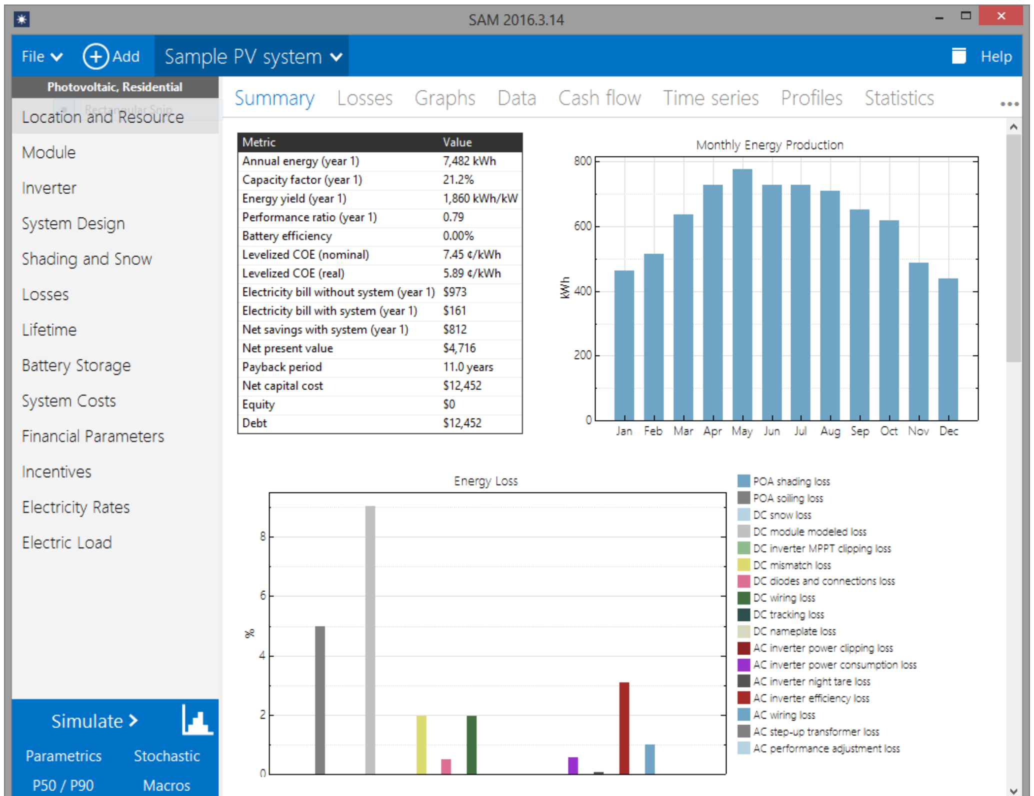
# System Advisor Model (SAM)

Free software that combines detailed performance and financial models to estimate the cost of energy for systems




http://sam.nrel.gov/download

**Offerings**

Desktop application

Scripting

Software Development Kit (SDK)

Open source code

**Technologies**

Photovoltaics (detailed & PVWatts)

Battery storage

Concentrating solar power

Wind

Multiple other technologies

**Financials**

Behind-the-meter

Power purchase agreements

Simple LCOE calculator

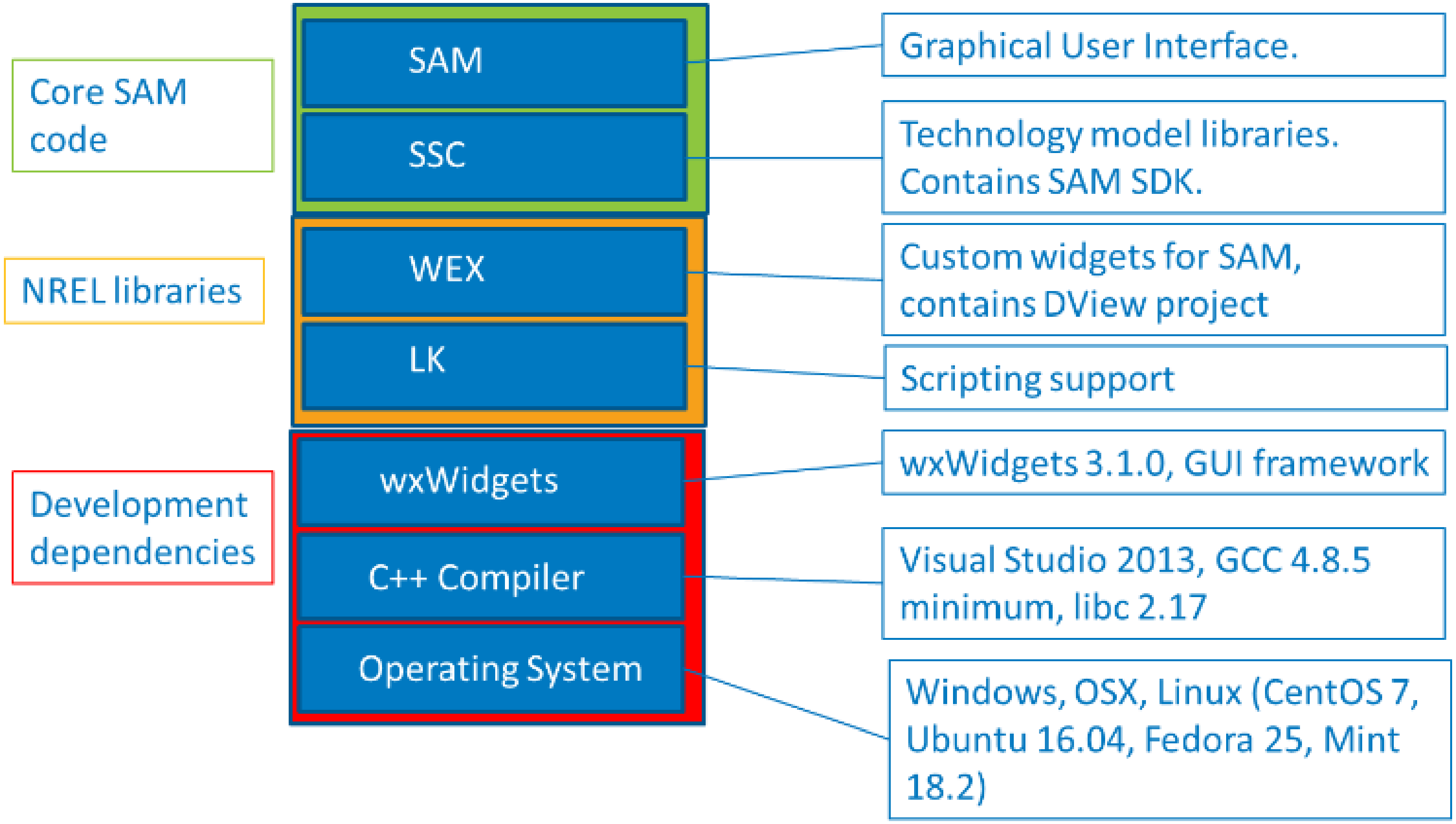
**Platforms**

Windows, Mac OSX, Linux

# Open Sourcing SAM

- NREL open sourced the SAM code in August 2017 on GitHub
- Permissive corporate license.  Non-profits must keep code changes publicly available.
- NREL still actively developing and supporting official releases
- This is the newest in the many ways to interact with SAM, including scripting, the SDK, etc.
- Increased transparency, flexibility, and collaboration opportunities.
- We are excited to continue working on SAM and fostering a new community of contributors.

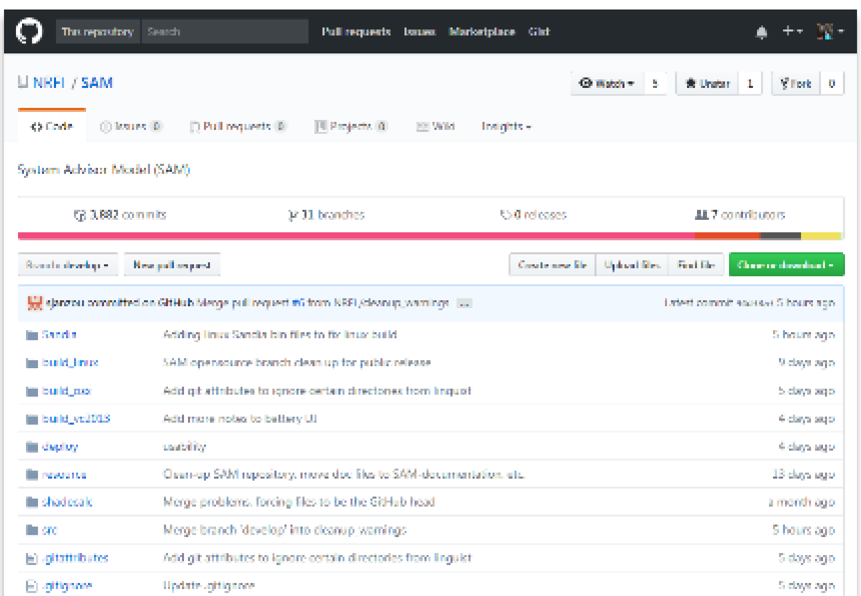
# Open Source Code




- Open-sourced all four NREL repositories
- Comprehensive build instructions

# Code Locations

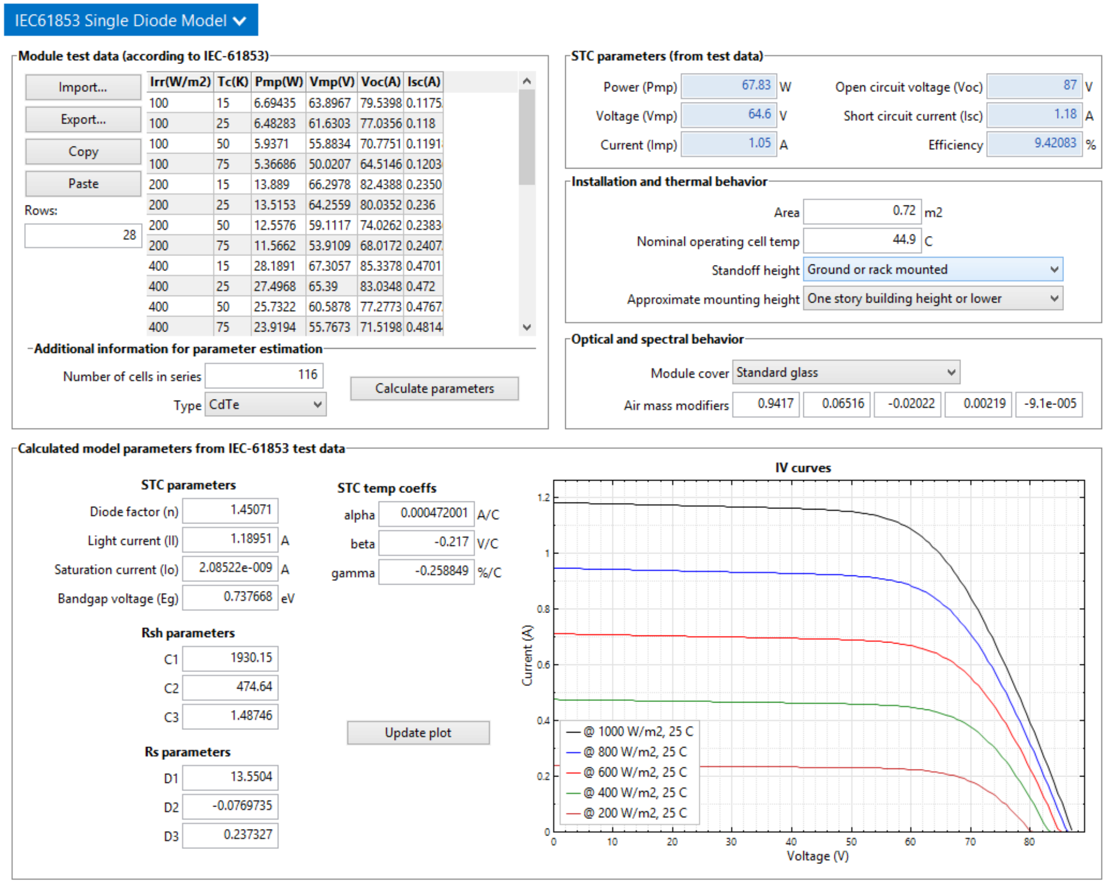
| | |
|---|---|
| **wxWidgets** | https://www.wxwidgets.org/downloads/ |
| **GoogleTest** | https://github.com/google/googletest |
| **LK** | https://github.com/NREL/lk |
| **WEX** | https://github.com/NREL/wex |
| **SSC** | https://github.com/NREL/ssc |
| **SAM** | https://github.com/NREL/SAM |



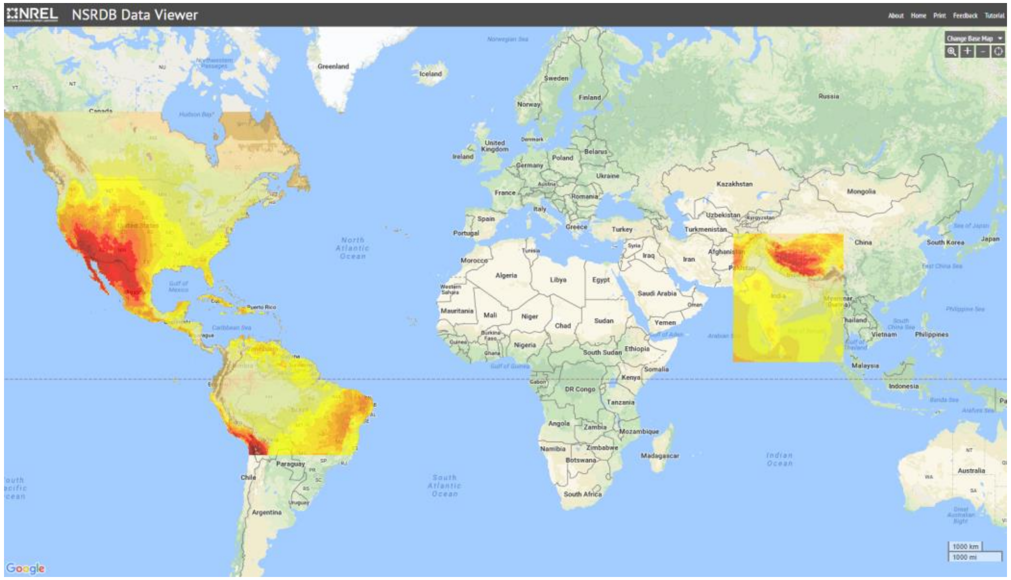

If you are new to Git and GitHub, please checkout: [https://guides.github.com/](https://guides.github.com/)

# Detailed photovoltaic model

- ★ **Irradiance**
  - Transposition using Isotropic, HDKR, or Perez
  - Measured plane of array (POA) input
- **Shading**
  - Irregular obstruction shading from 3D scene
  - Self-shading for regularly spaced rows
  - External input from SunEye, Solar Pathfinder
  - Snow cover loss model
- **Module**
  - Simple efficiency model
  - Single diode model (CEC database or datasheet)
  - Extended single diode model (for IEC-61853 tests)
  - Sandia PV Array Performance Model
- **Inverter**
  - Sandia/CEC grid-tied inverter model
  - Datasheet part-load efficiency curve
- **System**
  - ★ Sizing wizard or electrical layout
  - Multiple subarrays
  - Fixed, 1 axis, backtracking, azimuth axis, 2 axis
  - ★ Battery storage
- **Degradation**
  - Extrapolated single year
  - Lifetime simulation of all years
- **Simulation**
  - 1 minute to 1 hour time steps



# Integration with NSRDB data




## National Solar Radiation Database

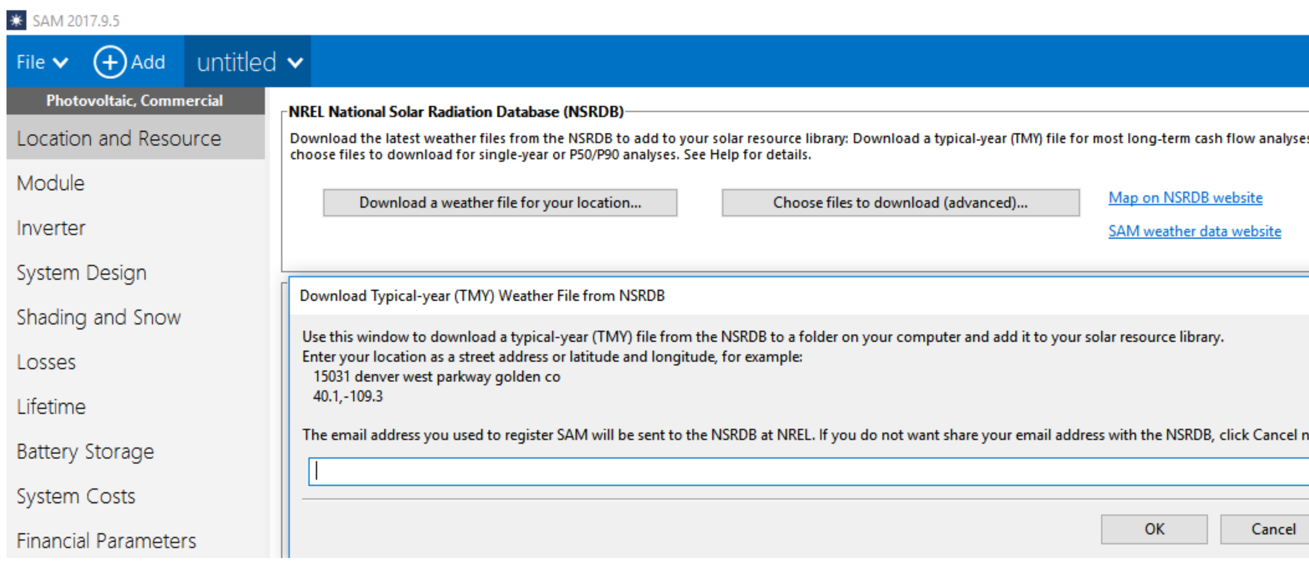
- Collection of hourly and half-hourly solar irradiation and meteorological data
- U.S data – 4x4 km spatial resolution, 30 minute temporal resolution from 1998-2014. Older data available.
- **International data – available in Mexico and Central and South America, South Asia.**

## SAM Integration

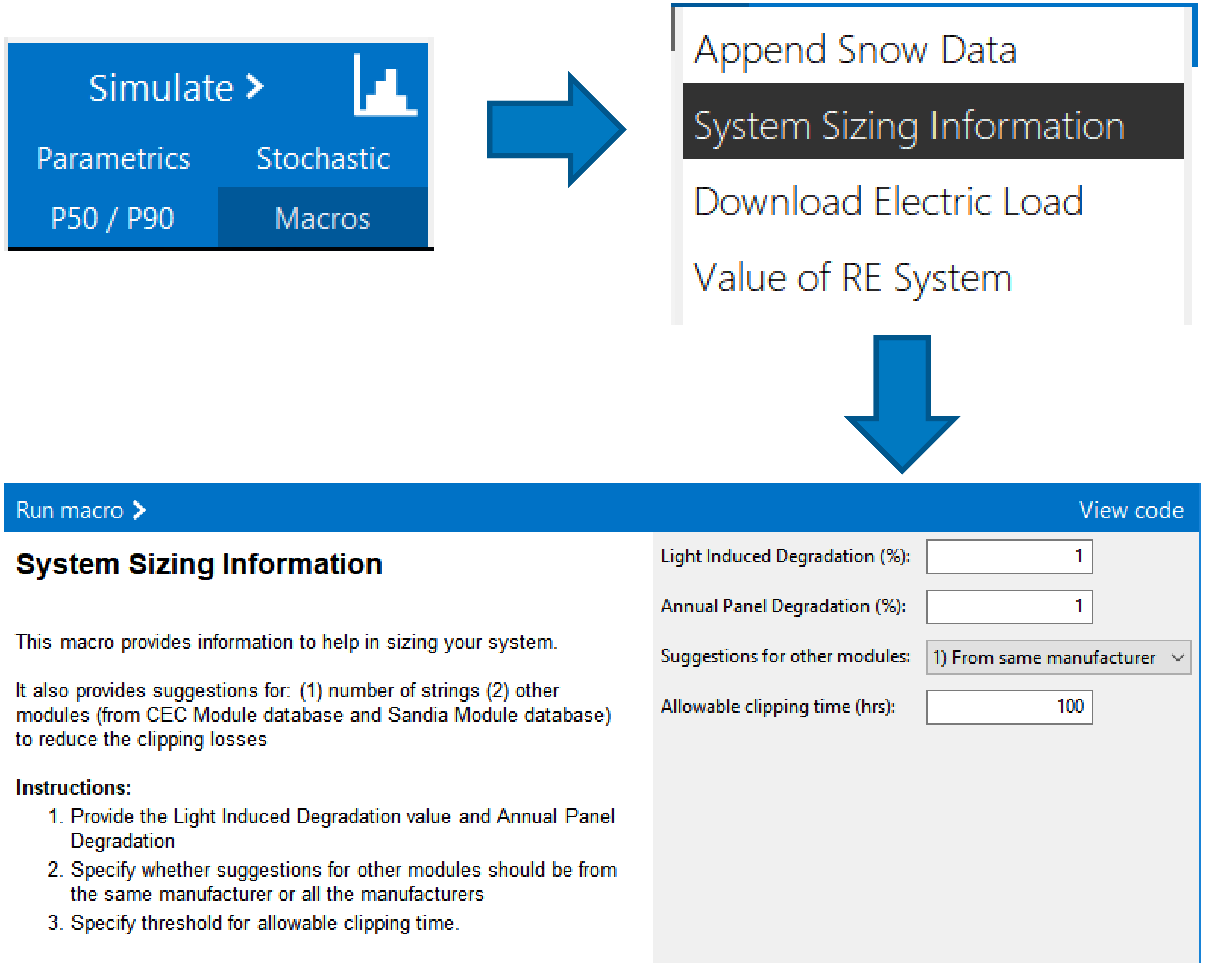
- Simple interface
- Options for choosing specific data sets

## PVWatts Integration

- Upcoming
- Will replace TMY2 as standard dataset



# PV System Sizing




## Sizing goals

- For current system, optimize the number of modules per string and strings in parallel to reduce clipping losses
- Allowable clipping is user-specified

# PV System Sizing Results

Inverter Sizing Results

*String Sizing Information*

Sizing information reported for case: Sizing Macro

**Tips for system design**

The maximum voltage produced by the array under open circuit condition is **831.387 V**

- This is ok as it is below the inverter's maximum voltage rating.

*You have **12** modules per string. The maximum number of modules per string should be **14** for the given case.*

***1401.18 kWh** is being clipped.*

**Suggestions for reducing clipping time.**

**1. By reducing number of strings:**

*The number of strings should be reduced by **7** to reduce clipping losses*

**2. By changing the modules used in string**

*Module suggestions to reduce clipping loss*

- SunPower PL-SUNP-SPR-305

**DC-AC Ratio**

The effective Year 25 DC-AC ratio is computed after light-induced degradation and annual m

| | |
|---|---|
| Nameplate DC-AC Ratio | 1.22279 |
| Effective DC-AC Ratio, Year 1 | 1.21057 |
| Effective DC-AC Ratio, Year 25 | 0.941603 |

**First Year Inverter Clipping Losses**

| | Power Limiting | MPPT Voltage Limiting |
|---|---|---|
| Number of Hours Clipped | 195 | 919 |
| Total kWh (AC) lost | 1401.18 | 348.693 |
| % of AC Power lost | 0.335863 | 0.0837934 |
| % of DC Power lost | 0.32962 | 0.069696 |

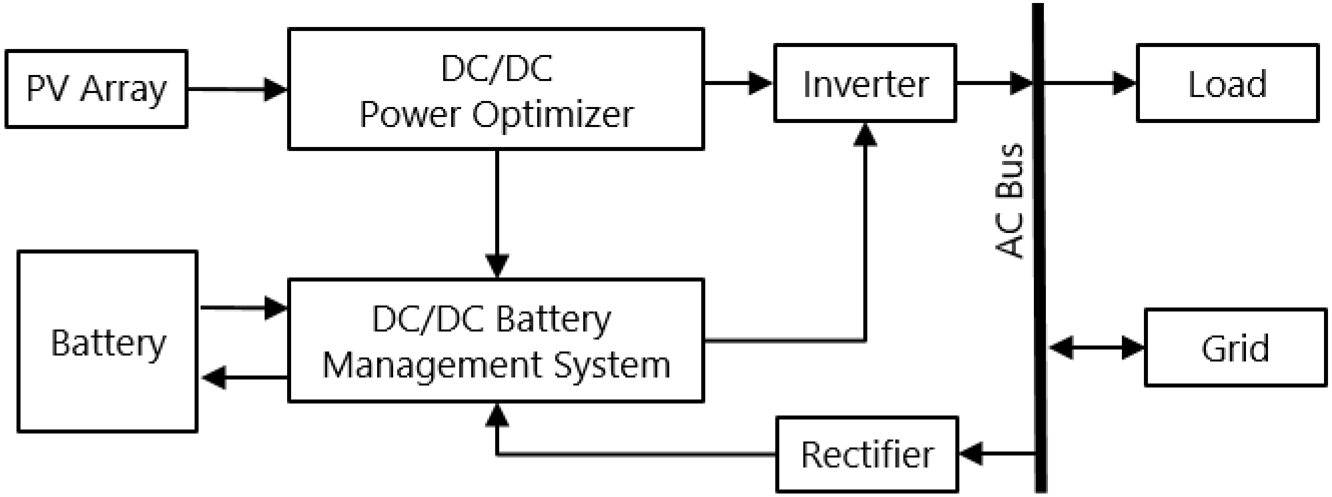
**Inverter MPPT Performance**

| Inverter Specifications | V | Actual System Voltages | Subarray 1 |
|---|---|---|---|
| MPPT Voltage Minimum | 570 | Actual Voltage Minimum | 570 |
| MPPT Voltage Maximum | 800 | Actual Voltage Maximum | 683.539 |
| Maximum Allowable Voltage | 1000 | Actual Maximum Voltage | 683.539 |

## Results summary

- Recommended layout of modules
- Options for modules that could reduce clipping
- System properties and metrics

# Photovoltaics with DC-connected batteries

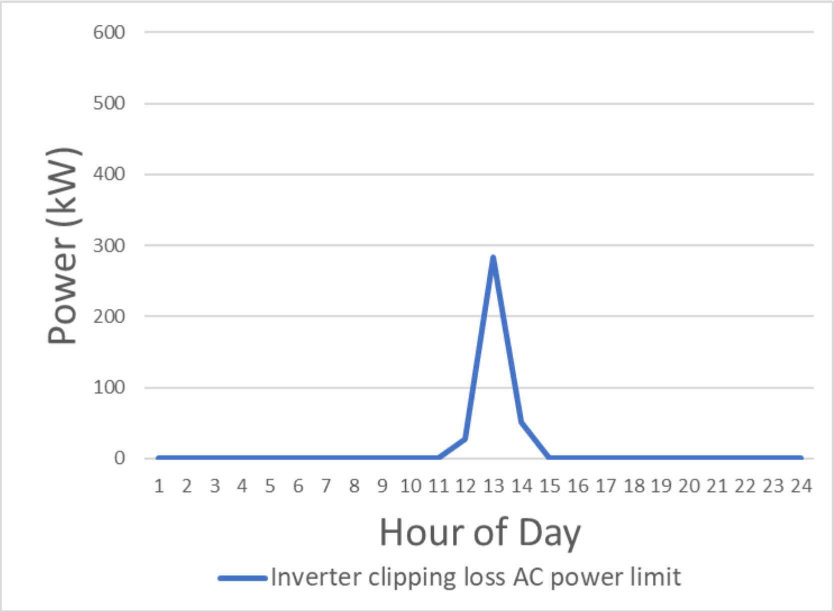



**Possible reasons for connecting battery on DC-side**

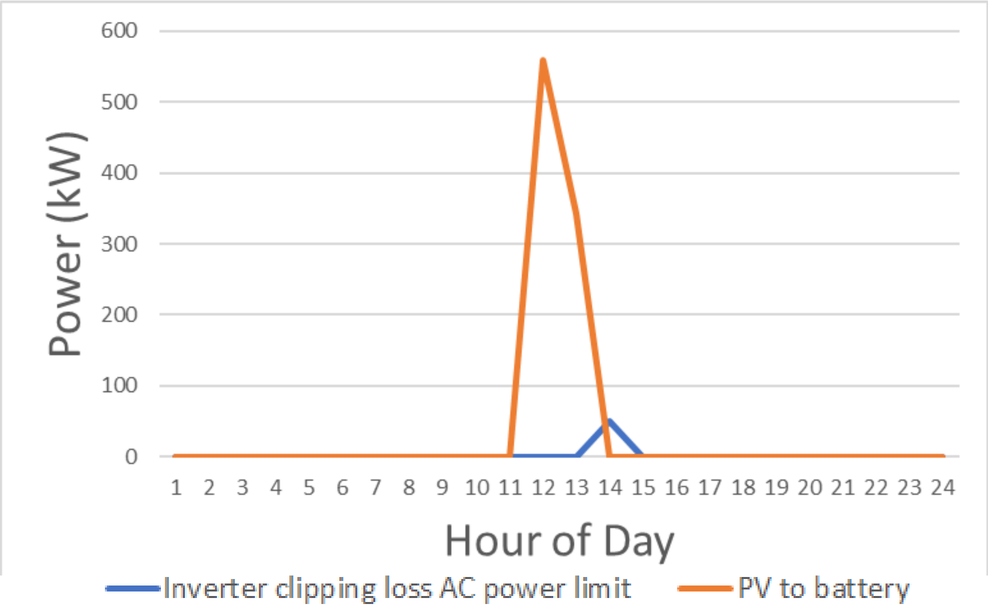
- Leverage existing PV power electronics
- Install higher DC-AC ratio systems
    - capture energy from PV array which would otherwise be clipped
    - Discharge battery during times of low PV production
- PV Grid integration in locations encouraging self consumption (no NEM).
- Powering a DC-microgrid

# Capturing clipped power

PV clipping with no battery




PV clipping with DC-connected battery




- Strategically discharge battery to:
  - Level off PV output
  - Reduce state-of-charge and prepare to accept clipped PV power

# Upcoming 2017 and 2018 improvements

- Addition of Sandia and NREL developed Bifacial model
- Support for multiple MPPT inputs
- Inverter thermal modeling
- Continued improvement of dispatch controllers
  - Automated dispatch for DC-connected battery storage systems
  - Integration with NREL REopt

# Questions?

- Website:
  - **sam.nrel.gov**
- Open source code:
  - **https://github.com/NREL/SAM**

# Thank You!

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# Extra Slides

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# REopt Lite: reopt.nrel.gov

Web app and upcoming API that optimizes solar plus storage combination, size, and dispatch to minimize lifecycle costs.

## Results for Your Site

These results from REopt Lite summarize the economic viability of PV and battery storage at your site. You can edit your inputs to see how changes to your energy strategies affect the results.

Edit Inputs

REopt Lite

Your recommended solar installation size

174 kW
PV size

Your recommended battery power and capacity

30 kW
battery power

117 kWh
battery capacity

| Accessing REopt | Link |
|---|---|
| Website | https://reopt.nrel.gov/tool |

API will be available in the next few months. See the REopt website to learn more.

### Technologies
Photovoltaics
Battery Storage

### Financials
Behind-the-meter

### Inputs:
Location (uses PVWatts for PV)
Electric load
Utility rate (uses URDB for rates)
Site financial information
PV and storage costs

### Outputs:
Optimal system sizes
Annual savings
Financial metrics
Optimal dispatch graph
Annual cash flow

# What kinds of things can you do with SAM open-source?

**Transparency**

- Look at the underlying code of a model that you are interested in.

**Flexibility**

- Change the way a model works for research purposes
- Change electricity rate models to be specific to your country

**Collaboration**

- Add new technology models
- Add a new battery dispatch model

We'd love to learn how you use SAM's open-source code! It helps us tailor our efforts.

# Code licenses (LK and WEX)

- Licensed under an MIT-type license.  Main restrictions:
  - Redistribution of source code or binary must reproduce copyright notice, list of license conditions, and disclaimer.
  - Neither the name of the copyright holder or the names of contributors may be used to endorse products derived from the software without prior written permission.
- See full licenses:
  https://github.com/NREL/lk/blob/develop/LICENSE.md
  https://github.com/NREL/wex/blob/develop/LICENSE.md

# Code licenses (SSC and SAM)

- Licensed under a mixed MIT-type license and GPLv3 license.
- Commercial businesses can use SSC and SAM under the MIT-type restrictions
  - You can use SSC and SAM in software you develop for your business.
- Research entities, including national labs, institutions of higher learning, and non-profits are restricted under a GPLv3-type license.
  - You can use SSC and SAM in your research, but must make your changes publicly available.

# Code licenses (SSC and SAM), continued

- Why the mixed license?
  - Want to encourage companies to use SSC and SAM as a foundation for growing their business in a fairly unrestricted way.
  - Want to encourage research institutions to share back any new innovations or make them publicly available so that the community as a whole benefits.
- Please see full license here:
  - https://github.com/NREL/SAM/blob/develop/LICENSE.md