



Photovoltaic Systems in SAM 2020.2.29

Paul Gilman
2020 SAM Webinars
August 5, 2020

SAM Webinars for 2020

Introduction to SAM Workshop July 22

PV Systems in SAM 2020.2.29 Aug 5

Batteries in SAM 2020.2.29:

Focus on Battery Technology Aug 19

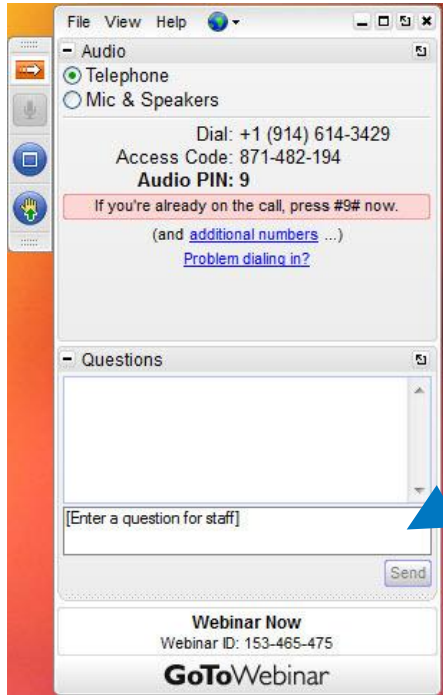
Behind-the-Meter Systems Sep 2

Front-of-Meter Systems Sep 16

Register for free at: <https://sam.nrel.gov/events.html>

This webinar will be recorded and posted on the SAM website at
<https://sam.nrel.gov/>

Questions and Answers



Desktop application



Instant Join Viewer

We will either type an answer to your question or answer it at the end of the presentation.

Outline

- 1 Detailed design steps for a residential PV system**
- 2 String sizing with the System Sizing macro**
- 3 Utility scale system: Tracking and self-shading**
- 4 Shading, soiling, snow, and other losses**
- 5 P50/P90 simulations with NREL NSRDB data**
- 6 Importing data from other models**
- 7 Questions and answers**

What is SAM?

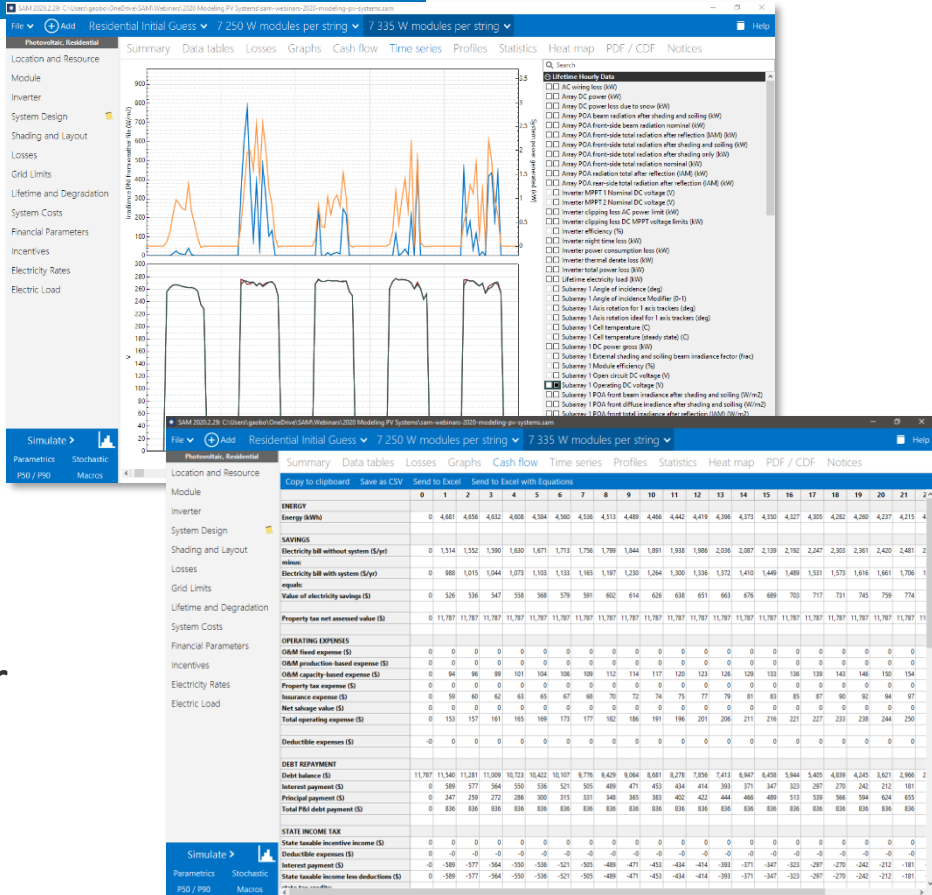
The System Advisor Model

Free computer software developed and distributed by the U.S. Department of Energy's National Renewable Energy Laboratory

Calculates:

- A power system's energy output over one year
- A power project's cash flow over years of operation

"Introduction to SAM 2020.2.29"
<https://sam.nrel.gov>



Residential PV system

Installed, owned, operated by a residential homeowner.

Power from system reduces homeowner's monthly electricity bill.

Is a project economically feasible given its cost and energy production?



“Electricity Rates and Bill Savings for Residential and Commercial Projects”
<https://sam.nrel.gov/financial-models/residential-and-commercial>

**Neighborhood PV
system in Portland,
Oregon**



First, choose a performance and financial model

Performance model calculates power produced by PV system

- Get weather data
- Choose module and inverter
- Design the system

Financial model calculates electricity savings and project cash flow

- Get load and rate data
- Define financial parameters
- Define system costs

SAM 2020.2.29

Choose a performance model, and then choose from the available financial models.

- ▼ Photovoltaic
 - Detailed PV Model
 - PVWatts
 - High Concentration PV
 - > Battery Storage
 - > Concentrating Solar Power
 - > Marine Energy
 - Wind
 - Fuel Cell-PV-Battery
 - Geothermal
 - Solar Water Heating
 - Biomass Combustion
 - Generic System
- > Power Purchase Agreement
- ▼ Distributed
 - Residential Owner
 - Commercial Owner
 - Third Party Owner - Host
 - Third Party - Host / Developer
 - Merchant Plant
 - LCOE Calculator (FCR Method)
 - No Financial Model

Next, download a weather file

Type a street address, location name, or latitude longitude pair, like:

- “golden, co”
- “15013 Denver West Parkway Golden, CO”
- “39.74,-105.18”

SAM downloads weather files from the National Solar Radiation Database

- Typical meteorological year (TMY) suitable for long term cash flow model
- Single year when load data is available for a particular year
- Multiple files for P50/P90 analysis

Download Weather Files

The NSRDB is a database of thousands of weather files that you can download and add to your solar resource library: Download a default typical-year (TMY) file for most long-term cash flow analyses, or choose files to download for single-year or P50/P90 analyses. See Help for details.

One location Multiple locations

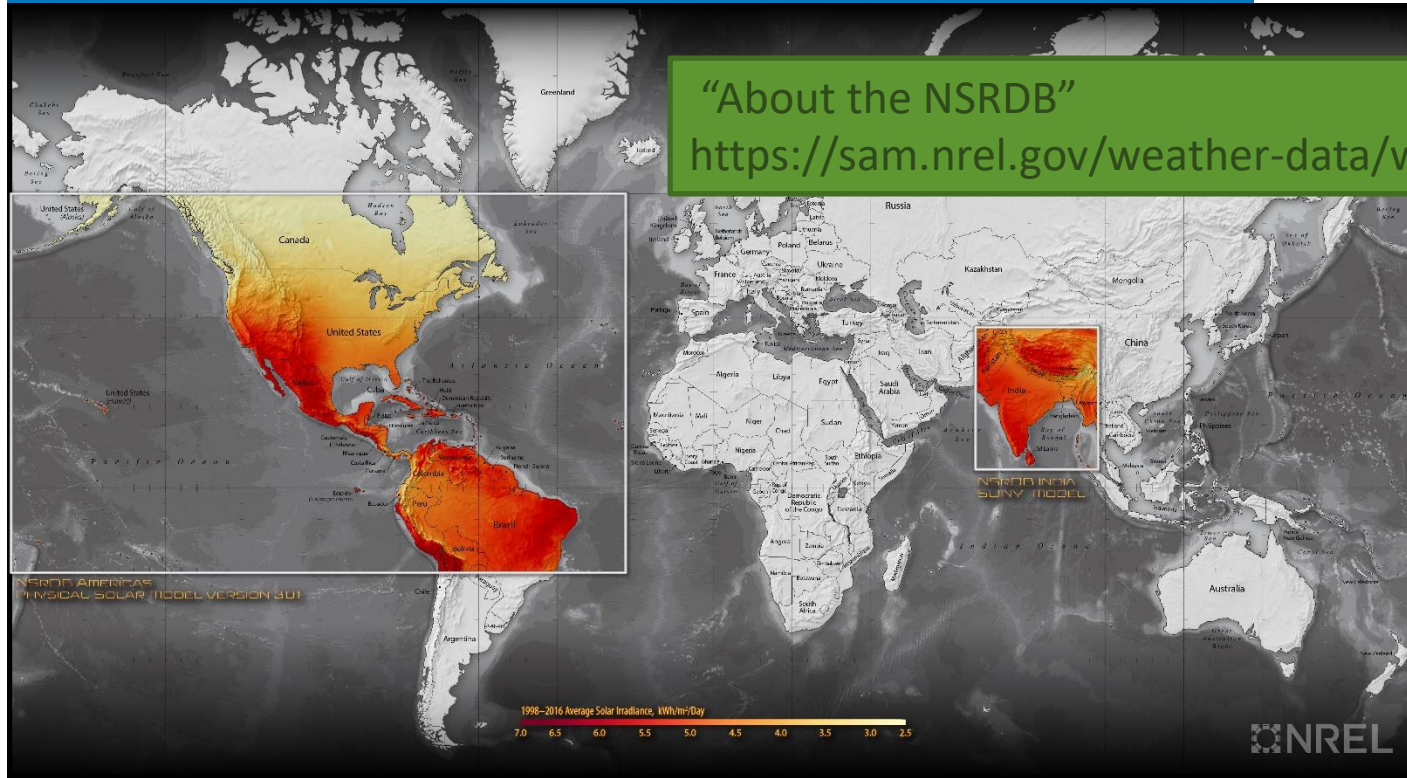


[For locations not covered by the NSRDB, click here to go to the SAM website Weather Page for links to other data sources.](#)

NSRDB Coverage Map

“About the NSRDB”

<https://sam.nrel.gov/weather-data/weather-data-videos>



For other sources of data, see <https://sam.nrel.gov/weather-data>

When the download finishes, SAM automatically adds the file to your solar resource library, which is a list of the weather files on your computer.

Solar Resource Library

The Solar Resource library is a list of weather files on your computer. Choose a file from the library and verify the weather data information below.

The default library comes with only a few weather files to help you get started. Use the download tools below to build a library of locations you frequently model. Once you build your library, it is available for all of your work in SAM.

Filter:

Name ▼

Name	Latitude	Longitude	Time zone	Elevation	Station ID	Source
fargo_nd_46.9_-96.8_mts1_60_tmy	46.9	-96.8	-6	274	14914	TMY2
imperial_ca_32.835205_-115.572398_psmv3_60_tmy	32.85	-115.58	-8	-20	72911	NSRDB
phoenix_az_33.450495_-111.983688_psmv3_60_tmy	33.45	-111.98	-7	358	78208	NSRDB
tucson_az_32.116521_-110.933042_psmv3_60_tmy	32.13	-110.94	-7	773	67345	NSRDB
golden_co_39.749672_-105.216019_psm3_60_tmy	39.73	-105.22	-7	1934	145808	NSRDB

SAM scans the following folders on your computer, click Add/remove Weather File Folders to use weather files stored on your computer.

C:\Users\gaobo\SAM Downloaded Weather Files

Click Add/remove weather file folders to add other files to your library.

Add/remove weather file folders...

Refresh library

“Downloading Solar Resource Data”

<https://sam.nrel.gov/weather-data/weather-data-videos>

Design the system

System Size

Choose Inverter

Choose Modules

String Size

Number of Strings

Array Orientation

Design the system: System size

Use roof area to determine maximum system capacity:

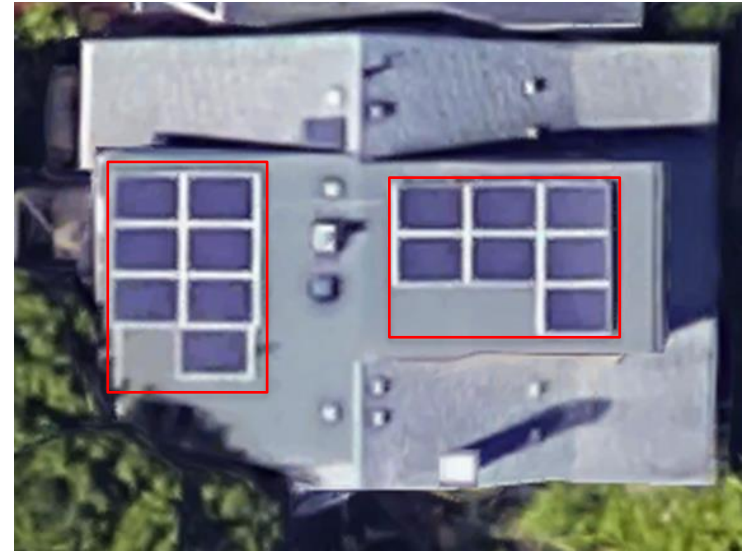
$$\text{Array Capacity (W)} = \text{Roof Area (m}^2\text{)} * \text{Module Efficiency} * 1,000 \text{ W/m}^2$$

$$35 \text{ m}^2 * 0.15 * 1,000 \text{ W/m}^2 = 5,250 \text{ W}$$

Assume about 1,000 W/m² of sunlight available on a clear sunny day at noon based on Standard Test Conditions (STC).

About 17 x 12 feet available on each surface:

$$\begin{aligned} &17 \text{ ft} * 12 \text{ ft} \\ &= 204 \text{ sq ft} * 2 \\ &= 408 \text{ sq ft} \\ &\approx 35 \text{ m}^2 \end{aligned}$$



Design the system: Inverter

System Size

~5 DC kW, 1.2 DC/AC ratio

Inverter

$5,000 \text{ DC W} / 1.2 = 4166.7 \text{ AC W} \approx 4200 \text{ AC W}$

Module

String Size

Number of Strings

Array Orientation

Inverter: 5 DC kW / 1.2 ≈ 4.2 AC kW

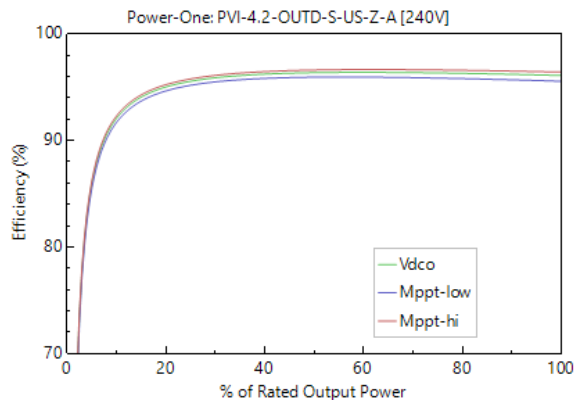
Inverter CEC Database ▾

Filter: Name ▾

Name	Paco	Pdco	Pso	Pnt	Vac	Vdco	Vdco	Mppts	Mppts	C0	C1	C2
ABB: PVI-4.2-OUTD-S-US-Z-M-A [240V]	4200	4369.962...	27.734...	1.26	240	480	340	480	100	-4.06E-06	-0.000024	-0.000
ABB: PVI-4.2-OUTD-US [240V]	4200	4369.962...	27.734...	0.2	240	480	340	480	100	-4.06E-06	-0.000024	-0.000
Power-One: PVI-4.2-OUTD-S-US-Z [240V]	4200	4369.962...	27.734...	0.2	240	480	340	480	100	-4.06E-06	-0.000024	-0.000
Power-One: PVI-4.2-OUTD-S-US-Z-A [240V]	4200	4369.962...	27.734...	0.2	240	480	340	480	100	-4.06E-06	-0.000024	-0.000
ABB: PVI-4.2-OUTD-S-US [277V]	4200	4347.116...	29.07288	0.2	277	480	395	480	100	-3.35E-06	-0.000034	-0.000

Click column heading to sort by maximum AC power (Paco)

Efficiency Curve and Characteristics



Number of MPPT inputs

CEC weight

European weight

Click row in table to choose an inverter

-Datasheet Parameters

Maximum AC power	<input type="text" value="4200"/>	Wac
Maximum DC power	<input type="text" value="4369.96"/>	Wdc
Power use during operation	<input type="text" value="27.7345"/>	Wdc
Power use at night	<input type="text" value="0.2"/>	Wac
Nominal AC voltage	<input type="text" value="240"/>	Vac
Maximum DC voltage	<input type="text" value="480"/>	Vdc
Maximum DC current	<input type="text" value="12.8528"/>	Adc
Minimum MPPT DC voltage	<input type="text" value="100"/>	Vdc
Nominal DC voltage	<input type="text" value="340"/>	Vdc
Maximum MPPT DC voltage	<input type="text" value="480"/>	Vdc

-Sandia Coefficients

C0	<input type="text" value=""/>	
C1	<input type="text" value=""/>	
C2	<input type="text" value="-6.3e-05"/>	1/Vdc
C3	<input type="text" value="-0.000598"/>	1/Vdc

Note voltage ratings

Note: If you are modeling a system with microinverters or DC power optimizers, see the Losses page to adjust the system losses accordingly.

-CEC Information

CEC name

CEC type

CEC date

Design the system: Module

System Size

5 kW, 1.2 DC/AC ratio

Inverter

4200 AC W Power-One PVI-4.2

Module

Initial guess: 250 W modules, 5,000 W array / 250 W module = 20 modules

String Size

Number of Strings

Array Orientation

Module: 5 DC kW / 20 modules = 250 DC W module

CEC Performance Model with Module Database

Filter: trina

Name

Filter by name.

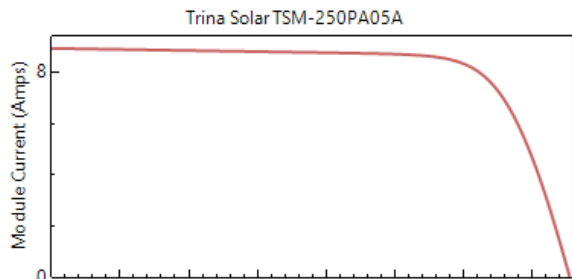
Sort by STC power rating.

Name	Manufacturer	Technology	Bifacial	STC	PTC	A_c	Length	Width	N_s	I_sc_ref	V_oc_ref	I_mp_ref	V_mp_ref	a
Trina Solar TSM-250PA05.30	Trina Solar	Multi-c-Si	0	249.86	227.5	1.618	1.643	0.985	60	8.55	37.6	8.06	31	0
Trina Solar TSM-250PA05.38	Trina Solar	Multi-c-Si	0	249.86	227.5	1.618	1.643	0.985	60	8.55	37.6	8.06	31	0
Trina Solar TSM-250PA05.xy2	Trina Solar	Multi-c-Si	0	249.86	227.5	1.618	1.643	0.985	60	8.55	37.6	8.06	31	0
Trina Solar TSM-250PA05A	Trina Solar	Multi-c-Si	0	250.1	229.1	1.618	1.643	0.985	60	8.9	37.8	8.2	30.5	0
Trina Solar TSM-250PA05A.08	Trina Solar	Multi-c-Si	0	250.1	229.1	1.618	1.643	0.985	60	8.9	37.8	8.2	30.5	0
Trina Solar TSM-250PA05A.10	Trina Solar	Multi-c-Si	0	250.1	229.1	1.618	1.643	0.985	60	8.9	37.8	8.2	30.5	0
Trina Solar TSM-250PA05A.18	Trina Solar	Multi-c-Si	0	250.1	229.1	1.618	1.643	0.985	60	8.9	37.8	8.2	30.5	0
Trina Solar TSM-250PD05	Trina Solar	Multi-c-Si	0	249.86	227.5	1.618	1.643	0.985	60	8.55	37.6	8.06	31	0

Choose module.

Module Characteristics at Reference Conditions

Reference conditions: Total Irradiance = 1000 W/m², Cell temp = 25 C



Nominal efficiency	15.4574	%	Temperature coefficients		
Maximum power (Pmp)	250.100	Wdc		-0.430	-1.075
Max power voltage (Vmp)	30.5	Vdc			
Max power current (Imp)	8.2	Adc			
Open circuit voltage (Voc)	37.8	Vdc		-0.330	-0.125
Short circuit current (Isc)	8.9	Adc		0.050	0.004

Note ratings.

-Bifacial Specifications-

Module is bifacial

“Preview of SAM’s New Model for Bifacial PV Modules”
<https://sam.nrel.gov/photovoltaic/pv-videos>

Design the system: String size

System Size

5 kW, 1.2 DC/AC ratio

Inverter

4200 AC W Power-One PVI-4.2

Module

250 DC W Trina Solar TSM-250

String Size

Inverter Maximum Voltage / Module Voc

Maximum modules per string: $480 \text{ VDC} / 37.8 \text{ VDC} = 12.7 \approx 12$

Minimum modules per string: $100 \text{ VDC} / 37.8 \text{ VDC} = 2.65 \approx 3$

Number of Strings

Array Orientation

**Array divided into
two strings facing
East and West**

Use 2 inverter MPPT inputs
because subarrays have
different orientations



Design the system: Number of strings

System Size

5 kW, 1.2 DC/AC ratio

Inverter

4200 AC W Power-One PVI-4.2

Module

250 DC W Trina Solar TSM-250

String Size

10 modules

Number of Strings

2 strings, 2 inverter MPPT inputs

Array orientation

Two subarrays, 10 degree tilt, E-W facing

One inverter, two strings of 10 modules. E-W facing subarrays

Number of inverters

- Photovoltaic, Residential
- Location and Resource
- Module
- Inverter
- System Design
- Shading and Layout
- Losses
- Grid Limits
- Lifetime and Degradation
- System Costs
- Financial Parameters
- Incentives
- Electricity Rates
- Electric Load

AC Sizing

Number of inverters
DC to AC ratio

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration

Sizing Summary

Nameplate DC capacity	<input type="text" value="5.002"/> kWdc	Number of modules	<input type="text" value="20"/>
Total AC capacity	<input type="text" value="4.200"/> kWac	Number of strings	<input type="text" value="2"/>
Total inverter DC capacity	<input type="text" value="4.370"/> kWdc	Total module area	<input type="text" value="32.4"/> m ²

Verify capacities

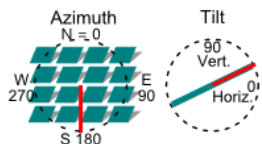
DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

	Subarray 1	Subarray 2	Subarray 3
Electrical Configuration	(always enabled)	<input checked="" type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="10"/>	<input type="text" value="10"/>	<input type="text" value="10"/>
Strings in parallel in subarray	<input type="text" value="1"/>	<input type="text" value="1"/>	<input type="text" value="1"/>
Number of modules in subarray	<input type="text" value="10"/>	<input type="text" value="10"/>	<input type="text" value="10"/>
String Voc at reference conditions (V)	<input type="text" value="378.0"/>	<input type="text" value="378.0"/>	<input type="text" value="378.0"/>
String Vmp at reference conditions (V)	<input type="text" value="305.0"/>	<input type="text" value="305.0"/>	<input type="text" value="305.0"/>

Enable two subarrays, 10 modules per string

Tracking & Orientation



- | | |
|--|--|
| <input checked="" type="radio"/> Fixed | <input checked="" type="radio"/> Fixed |
| <input type="radio"/> 1 Axis | <input type="radio"/> 1 Axis |
| <input type="radio"/> 2 Axis | <input type="radio"/> 2 Axis |
| <input type="radio"/> Azimuth Axis | <input type="radio"/> Azimuth Axis |
| <input type="radio"/> Seasonal Tilt | <input type="radio"/> Seasonal Tilt |

Tilt=latitude Tilt=latitude

Tilt (deg)	<input type="text" value="10"/>	<input type="text" value="10"/>
Azimuth (deg)	<input type="text" value="270"/>	<input type="text" value="90"/>
Ground coverage ratio (GCR)	<input type="text" value="0.3"/>	<input type="text" value="0.3"/>
Tracker rotation limit (deg)	<input type="text" value="45"/>	<input type="text" value="45"/>

Two inverter MPPT inputs, configure on System Design and Inverter input pages

- Photovoltaic, Residential
- Location and Resource
- Module
- Inverter
- System Design
- Shading and Layout
- Losses
- Grid Limits
- Lifetime and Degradation

Inverter CEC Database

Filter: Name

Name	Paco	Pdco	Pso	Pnt	Vac	Vdcmx	Vdco	Mppt_high	Mppt
ABB: PVI-3.8-OUTD-US [240V]	3800	3950.148...	26.980...	1.14	240	480	340	480	100
ABB: PVI-3.8-OUTD-US [277V]	3800	3931.927...	29.742...	1.14	277	480	395	480	100
ABB: PVI-4.2-OUTD-S-US [208V]	4200	4393.078...	24.648...	0.1	208	480	310	480	100
ABB: PVI-4.2-OUTD-S-US [240V]	4200	4369....							100
ABB: PVI-4.2-OUTD-S-US [277V]	4200	4347....							100

Efficiency Curve and Characteristics

ABB: PVI-4.2-OUTD-S-US [240V]

Number of MPPT inputs

2 MPPT inputs

Sizing Summary

Nameplate DC capacity

Total AC capacity

Total inverter DC capacity

Number of inverters

DC to AC ratio

DC Sizing and Configuration

To model a system with parallel to a single bank

Estimate Subarray 1

Electrical Configuration

Set subarrays for multiple MPPT (always enabled)

	Subarray 1	Subarray 2
Modules per string in subarray	<input type="text" value="10"/>	<input type="text" value="10"/>
Strings in parallel in subarray	<input type="text" value="1"/>	<input type="text" value="1"/>
Number of modules in subarray	<input type="text" value="10"/>	<input type="text" value="10"/>
String Voc at reference conditions (V)	<input type="text" value="378.0"/>	<input type="text" value="378.0"/>
String Vmp at reference conditions (V)	<input type="text" value="305.0"/>	<input type="text" value="305.0"/>
Inverter MPPT input for subarray	<input type="text" value="1"/>	<input type="text" value="2"/>

Tracking & Orientation

Azimuth Tilt Fixed Fixed

Assign each subarray to an inverter input

“Modeling PV Systems with Multiple MPPTs”
<https://sam.nrel.gov/photovoltaic/pv-videos>

Design the system: Array orientation

System Size

5 kW, 1.2 DC/AC ratio

Inverter

4200 AC W Power-One PVI-4.2

Module

250 DC W Trina Solar TSM-250

String Size

10 modules

Number of Strings

2 strings, 2 inverter MPPT inputs

Array orientation

Two subarrays, 10 degree tilt, E-W facing

Orientation for two East-West facing subarrays at 10° tilt

Photovoltaic, Residential

Location and Resource

Module

Inverter

System Design

Shading and Layout

Losses

Grid Limits

Lifetime and Degradation

System Costs

Financial Parameters

Incentives

Electricity Rates

Electric Load

AC Sizing

Number of inverters

DC to AC ratio

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration



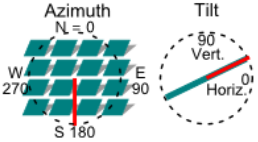
Sizing Summary

Nameplate DC capacity	<input type="text" value="5.002"/> kWdc	Number of modules	<input type="text" value="20"/>
Total AC capacity	<input type="text" value="4.200"/> kWac	Number of strings	<input type="text" value="2"/>
Total inverter DC capacity	<input type="text" value="4.370"/> kWdc	Total module area	<input type="text" value="32.4"/> m ²

DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Electrical Configuration				
	(always enabled)	<input checked="" type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="10"/>	<input type="text" value="10"/>		
Strings in parallel in subarray	<input type="text" value="1"/>	<input type="text" value="1"/>		
Number of modules in subarray	<input type="text" value="10"/>	<input type="text" value="10"/>		
String Voc at reference conditions (V)	<input type="text" value="378.0"/>	<input type="text" value="378.0"/>		
String Vmp at reference conditions (V)	<input type="text" value="305.0"/>	<input type="text" value="305.0"/>		
Tracking & Orientation				
	<input checked="" type="radio"/> Fixed	<input checked="" type="radio"/> Fixed		
	<input type="radio"/> 1 Axis	<input type="radio"/> 1 Axis		
	<input type="radio"/> 2 Axis	<input type="radio"/> 2 Axis		
	<input type="radio"/> Azimuth Axis	<input type="radio"/> Azimuth Axis		
	<input type="radio"/> Seasonal Tilt	<input type="radio"/> Seasonal Tilt		
	<input type="checkbox"/> Tilt=latitude	<input type="checkbox"/> Tilt=latitude		
Tilt (deg)	<input type="text" value="10"/>	<input type="text" value="10"/>		
Azimuth (deg)	<input type="text" value="270"/>	<input type="text" value="90"/>		
Ground coverage ratio (GCR)	<input type="text" value="0.3"/>	<input type="text" value="0.3"/>		
Tracker rotation limit (deg)	<input type="text" value="45"/>	<input type="text" value="45"/>		



System design

System Size

5 kW, 1.2 DC/AC ratio

Inverter

4200 AC W Power-One PVI-4.2

Module

250 DC W Trina Solar TSM-250

String Size

10 modules

Number of Strings

2 strings, 2 inverter MPPT inputs

Array orientation

Two subarrays, 10 degree tilt, E-W facing

Run a simulation, refine the design

- Check System Design page for sizing messages.
- Read any simulation messages.
- Use Losses tab to identify potential sizing issues
 - Excessive clipping losses
 - Module-related losses

Use System Sizing macro to find alternate designs

- Generates a report of design and operating voltages based on simulation results and conventional design rules.
- Generates a list of modules that work given the system design.
- Try changing number of modules per string, or choosing different modules and inverters and compare macro results to find best design.

For example, try changing string length from 10 to 7 modules to refine design for fewer modules

System Sizing Information

modules per string

Table 4: Modules from the same manufacturer that meet the inverter voltage requirements. Table displays up to 50 modules that result in the highest rated string Voc.

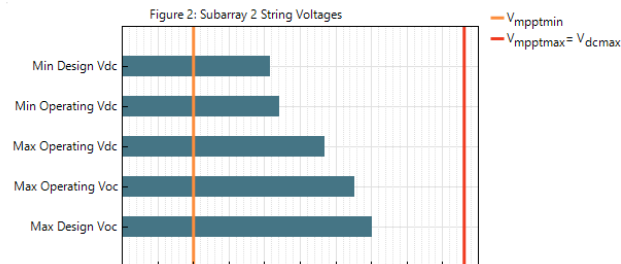
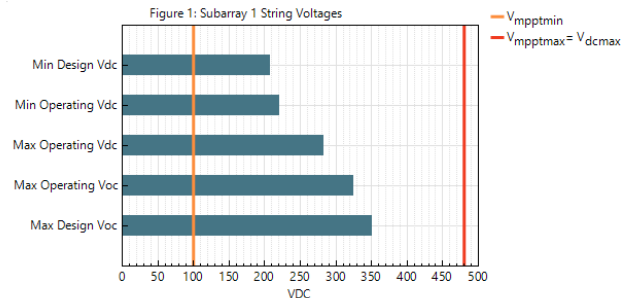
Module	Array Power (kW)	Subarray 1 String Voc (VDC)	Subarray 2 String Voc (VDC)	Nameplate DC/AC Ratio
Trina Solar TSM-335DD06M.05(II)	4.69	284.90	284.90	1.12
Trina Solar TSM-335DD06M.15(II)	4.69	284.90	284.90	1.12
Trina Solar TSM-335DD06M.18(II)	4.69	284.90	284.90	1.12
Trina Solar TSM-335DE06M.T0(II)	4.69	284.90	284.90	1.12
Trina Solar TSM-335DEG6M.20(II)	4.69	284.90	284.90	1.12
Trina Solar TSM-340DEG6M.20(II)	4.76	287.70	287.70	1.13

Table 5: Modules from different manufacturers that meet the inverter voltage requirements. Table displays up to 50 modules that result in the highest rated string Voc.

Module	Array Power (kW)	Subarray 1 String Voc (VDC)	Subarray 2 String Voc (VDC)	Nameplate DC/AC Ratio
WINAICO WSP-340MX	4.77	284.20	284.20	1.14
Hanwha Q CELLS Q.PEAK DUO BLK-G6+ 340	4.76	284.90	284.90	1.13
LG Electronics Inc. LG335N1T-V5	4.69	284.90	284.90	1.12
LONGi Green Energy Technology Co., Ltd. LR4-60HPB-355M	4.97	284.90	284.90	1.18

System Sizing Information

The figure(s) below show the inverter rated MPPT voltage range with worst case design maximum open-circuit voltage and minimum maximum-power voltage, along with the operating open circuit, minimum, and maximum voltages from the simulation results for each subarray in the system.



First macro run with 7 250 W modules per string suggests that 335 W modules would also work.

Second run with 7 335 W modules confirms that voltages are within inverter limits.

Power Purchase Agreement (PPA) Project

Installed, owned, and operated by a single owner or partnership.

Power from PV system sold to generate revenue.

Does project revenue cover installation and operating costs?



Ground coverage ratio (GCR) and self-shading

Create Detailed PV / Single Owner case: 20 MW system with 64,488 modules and 22 inverters.

Duplicate case with $GCR = 0.9$.

Compare results: They are the same.

On Shading and Layout page, enable self-shading with 2 x 12 rows.

Compare results: $GCR = 0.9$ has severe shading.

Use parametrics to plot annual energy vs. GCR.

External shading and snow losses

Import external shading data

3D Shade Calculator to generate shading data

Snow model when data available in weather file

“Modeling Shading Losses for PV Systems”
<https://sam.nrel.gov/photovoltaic/pv-videos>

Ryberg, D.; Freeman, J. (2017). Integration, Validation and Application of a PV Snow Coverage Model in SAM. National Renewable Energy Laboratory. 33 pp. TP-6A20-68705. ([PDF 3.1 MB](#))

P50 / P90 analysis

- On Location and Resource page, use Download Files for all years option to download weather files to a folder.
- Click P50/P90, and choose the folder.
- Click Run P50/P90 simulations.

Download Weather Files

The NSRDB is a database of thousands of weather files that you can download and add to your solar resource list (TMY) file for most long-term cash flow analyses, or choose files to download for single-year or P50/P90 analyses. See Help

One location

Multiple locations

15013 Denver W Pkwy, Golden, CO

Default TMY file

[For locations not covered by the NSRDB, click here to go to the SAM web](#)

Default TMY file

Choose year

Download files for all years (P50/P90)

	P10	P50	P90	P70.5	Min	Max
Annual AC energy (kWh)	7323.72	7005.48	6757.81	6894.92	6517.17	7542
Inverter clipping loss AC power limit (kWh/yr)	11.3607		5.73585	6.52786	5.59489	12.8
Inverter power consumption loss (kWh/yr)	43.0467	42.0542	40.2832	41.3369	40.164	44.02
Inverter night time loss (kWh/yr)	5.24255	5.2206	5.18918	5.21021	5.16516	5.245
Annual GHI (Wh/m2/yr)	1.75452e+06	1.68516e+06	1.61825e+06	1.64566e+06	1.55724e+06	1.79887e+06
POA front-side irradiance total nominal (kWh/yr)	44740.4	42741.6	41290	41982.8	39578.7	4628
POA front-side irradiance beam nominal (kWh/yr)	30270.7	27642.7	25531.9	26682.6	25471.5	314
POA front-side irradiance total after shading (kWh/yr)	44740.4	42741.6	41290	41982.8	39578.7	4628
POA front-side irradiance total after shading and soiling (kWh/yr)	42503.4	40604.5	39225.5	39883.6	37599.7	4397
POA front-side irradiance beam after shading and soiling (kWh/yr)	41199	39339.2	37983.1	38619.7	36405.7	4263
POA irradiance total after reflection (IAM) (kWh/yr)	41199	39339.2	37983.1	38619.7	36405.7	4263
POA front-side irradiance beam after shading and soiling (kWh/yr)	28757.2	26260.6	24255.3	25348.5	24197.9	2985
Annual DC energy nominal (kWh/yr)	8467.27	8085.03	7806.32	7937.16	7482.15	8761
Annual DC energy gross (kWh/yr)	8001.34	7657.58	7388.64	7538.15	7131.86	8240
Annual DC energy (kWh/yr)	7646.07	7317.57	7060.57	7203.44	6815.19	7874
Annual AC energy gross (kWh/yr)	7397.8	7076.35	6826.18	6964.67	6583.11	7618
Subarray 1 Gross DC energy (kWh)	8001.34	7657.58	7388.64	7538.15	7131.86	8240
Subarray 1 DC mismatch loss (kWh)	160.027	153.152	147.773	150.763	142.637	164.6
Subarray 1 DC diodes and connections loss (kWh)	40.0067	38.2879	36.9432	37.6908	35.6593	41.2
Subarray 1 DC wiring loss (kWh)	160.027	153.152	147.773	150.763	142.637	164.6
DC mismatch loss (kWh)	160.027	153.152	147.773	150.763	142.637	164.6
DC diodes and connections loss (kWh)	40.0067	38.2879	36.9432	37.6908	35.6593	41.2
DC wiring loss (kWh)	160.027	153.152	147.773	150.763	142.637	164.6
POA front-side reflection (IAM) loss (%)	3.17866	3.12353	3.05562	3.0743	3.05327	3.196
DC module deviation from STC (%)	5.91725	5.47117	4.74014	5.04983	4.68162	6.05
AC inverter power clipping loss (%)	0.15802	0.112647	0.0736202	0.0901618	0.0718418	0.1782
AC inverter power consumption loss (%)	0.600996	0.574702	0.516129	0.549691	0.510073	0.646
AC inverter night tare loss (%)	0.0729192	0.0713521	0.0667172	0.0692968	0.0659776	0.077
AC inverter efficiency loss (%)	2.57156	2.55578	2.53876	2.54719	2.53381	2.572

“P50/P90 Analysis”

<https://sam.nrel.gov/weather-data/weather-data-videos>

Importing data from other models

- PVsyst OND – PAN to SAM macro imports module, inverter, and weather data from PVsyst files
- Solar Resource File Converter macro imports weather data from PVGIS 5 and SolarAnywhere
- Use Generic System model to use a generation profile from a different model as input to SAM

Thank you!

www.nrel.gov



Array Layout Examples

Supporting Slides

Layout examples are in *pv-layout-examples-2020.2.29.sam* file

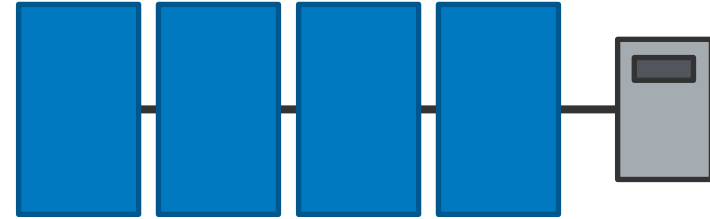
Case numbers correspond to numbers in the titles of the next few slides.

These examples use a small number of modules for clarity but the same concepts apply to large arrays with hundreds or thousands of modules.

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Number of inverters	1			
Nameplate DC capacity	3.352 kWdc			
Number of modules	10			

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Electrical Configuration	(always enabled)	<input checked="" type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	4	6		
Strings in parallel in subarray	1	1		

1: One string, one inverter, one MPPT



Photovoltaic, Residential

- Location and Resource
- Module
- Inverter
- System Design**
- Shading and Layout
- Losses
- Grid Limits
- Lifetime and Degradation
- System Costs
- Financial Parameters
- Incentives

AC Sizing

Number of inverters

DC to AC ratio

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration

Sizing Summary

Nameplate DC capacity	<input type="text" value="1.341"/> kWdc	Number of modules	<input type="text" value="4"/>
Total AC capacity	<input type="text" value="1.100"/> kWac	Number of strings	<input type="text" value="1"/>
Total inverter DC capacity	<input type="text" value="1.216"/> kWdc	Total module area	<input type="text" value="6.5"/> m ²

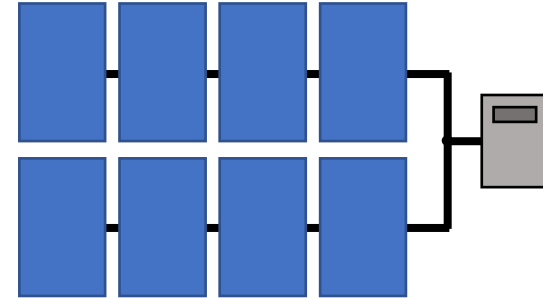
DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Electrical Configuration				
	(always enabled)	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="4"/>			
Strings in parallel in subarray	<input type="text" value="1"/>			
Number of modules in subarray	<input type="text" value="4"/>			
String Voc at reference conditions (V)	<input type="text" value="271.6"/>			
String Vmp at reference conditions (V)	<input type="text" value="229.2"/>			

2: Two identical strings, one inverter, one MPPT

“Identical strings” means both strings have same number of modules, orientation, tracking and shading, so both subarrays operate at same voltage.



- Photovoltaic, Residential
- Location and Resource
- Module
- Inverter
- System Design**
- Shading and Layout
- Losses
- Grid Limits
- Lifetime and Degradation
- System Costs
- Financial Parameters
- Incentives
- Electricity Rates

AC Sizing	Sizing Summary	
Number of inverters: <input type="text" value="1"/>	Nameplate DC capacity: <input type="text" value="2.682"/> kWdc	Number of modules: <input type="text" value="8"/>
DC to AC ratio: <input type="text" value="1.06"/>	Total AC capacity: <input type="text" value="2.530"/> kWac	Number of strings: <input type="text" value="2"/>
Size the system using modules per string and strings in parallel inputs below.	Total inverter DC capacity: <input type="text" value="2.620"/> kWdc	Total module area: <input type="text" value="13.0"/> m ²
<input type="checkbox"/> Estimate Subarray 1 configuration		

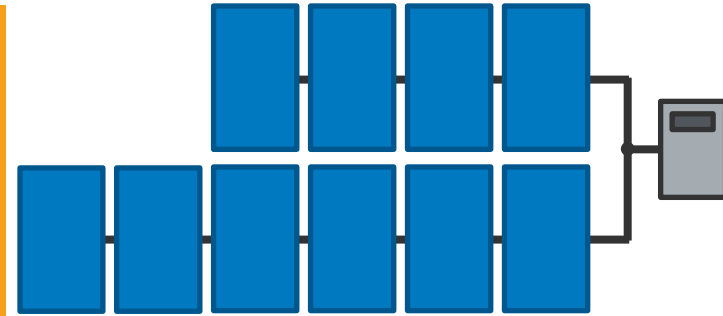
DC Sizing and Configuration
To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Electrical Configuration	(always enabled)	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="4"/>			
Strings in parallel in subarray	<input type="text" value="2"/>			
Number of modules in subarray	<input type="text" value="8"/>			
String Voc at reference conditions (V)	<input type="text" value="271.6"/>			
String Vmp at reference conditions (V)	<input type="text" value="229.2"/>			

3: Two different strings, one inverter, one MPPT

“Different strings” could have different number of modules, and/or different orientation, tracking, or shading.

Inverter DC voltage is either average of subarray voltages, or if you enable it, calculated using voltage mismatch option.



Photovoltaic, Residential

Location and Resource

Module

Inverter

System Design

Shading and Layout

Losses

Grid Limits

Lifetime and Degradation

System Costs

Financial Parameters

Incentives

Electricity Data

AC Sizing

Number of inverters

DC to AC ratio

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration

Sizing Summary

Nameplate DC capacity kWdc

Total AC capacity kWac

Total inverter DC capacity kWdc

Number of modules

Number of strings

Total module area m²

DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Electrical Configuration				
	(always enabled)	<input checked="" type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="4"/>	<input type="text" value="6"/>		
Strings in parallel in subarray	<input type="text" value="1"/>	<input type="text" value="1"/>		
Number of modules in subarray	<input type="text" value="4"/>	<input type="text" value="6"/>		
String Voc at reference conditions (V)	<input type="text" value="271.6"/>	<input type="text" value="407.4"/>		
String Vmp at reference conditions (V)	<input type="text" value="229.2"/>	<input type="text" value="343.8"/>		

PV Subarray Voltage Mismatch Option



PV Subarray Voltage Mismatch

Subarray Voltage Mismatch Calculation

When subarrays have different orientations, modules in each subarray are exposed to different levels of solar radiation and wind speed, which results in different subarray cell temperatures and maximum power point voltages (V_{mp}). The voltage mismatch causes electrical losses and an inverter input voltage less than V_{mp} . By default, SAM estimates the inverter input voltage by averaging the subarray V_{mp} values.

If you are using the CEC or IEC 61853 module model, SAM can more accurately estimate the inverter input voltage. This option requires longer simulation times to calculate mismatch losses. This more accurate method generally results in lower system output than the default method. See Help for details.

Calculate maximum power voltage for array and associated losses due to subarray mismatch (CEC and IEC 61853 models only)

Use this option (at the bottom of the System Design page) with two or more subarrays connected to a single inverter MPPT input when the subarrays have different string lengths or orientations, and you want a more precise estimate of inverter input voltage than the average of subarray voltages.

4: Two different strings, one inverter, two MPPTs

Photovoltaic, Residential

Inverter CEC Database

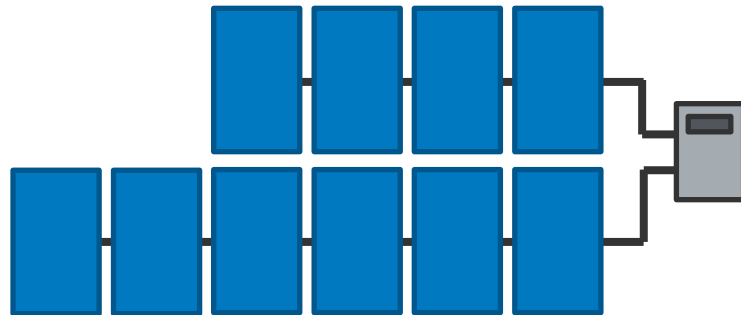
Filter: Name

Name	Paco	Pdco	Pso	Pnt	Vac	Vdcmx	Vdco	Mppt_high	Mppt_low
SMA America: SB3.0-1TP-US-40 [208V]	3030	3137.374...	26.673...	0.909	208	480	365	480	155
SMA America: SB3.0-1TP-US-40 [240V]	3040	3135.798...	27.530...	0.912	240	480	365	480	155
SMA America: SB3.0-1TP-US-41 [208V]	3028	3135.288...	26.710...	0.9...	208	480	365	480	155
SMA America: SB3.0-1TP-US-41 [240V]	3036	3131.658...	27.539...	0.9...	240	480	365	480	155
SMA America: SB3.8-1SP-US-40 [208V]	3600	3723.102...	26.851...	1.08	208	480	365	0	195

Efficiency Curve and Characteristics

SMA America: SB3.0-1TP-US-41 [240V]

Number of MPPT inputs



Photovoltaic, Residential

AC Sizing

Number of inverters

DC to AC ratio

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration

Sizing Summary

Nameplate DC capacity kWdc

Total AC capacity kWac

Total inverter DC capacity kWdc

Number of modules

Number of strings

Total module area m²

DC Sizing and Configuration

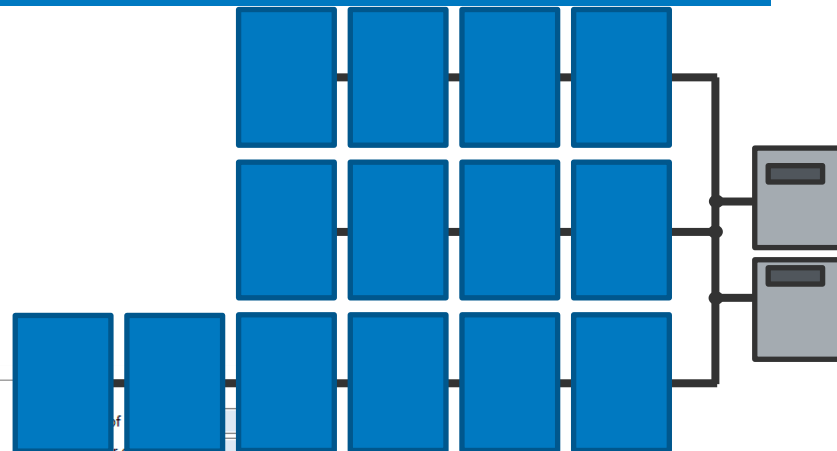
To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Set subarrays for multiple MPPT	(always enabled)	<input checked="" type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="4"/>	<input type="text" value="6"/>		
Strings in parallel in subarray	<input type="text" value="1"/>	<input type="text" value="1"/>		
Number of modules in subarray	<input type="text" value="4"/>	<input type="text" value="6"/>		
String Voc at reference conditions (V)	<input type="text" value="271.6"/>	<input type="text" value="407.4"/>		
String Vmp at reference conditions (V)	<input type="text" value="229.2"/>	<input type="text" value="343.8"/>		
Inverter MPPT input for subarray	<input type="text" value="1"/>	<input type="text" value="2"/>		

Each string operates at a different voltage.

5: Three strings (two identical), two inverters, one MPPT

Inverter DC voltage is either average of subarray voltages, or if you enable it, calculated using voltage mismatch option.



- Photovoltaic, Residential
- Location and Resource
- Module
- Inverter
- System Design
- Shading and Layout
- Losses
- Grid Limits
- Lifetime and Degradation
- System Costs
- Financial Parameters
- Incentives

AC Sizing

Number of inverters

DC to AC ratio

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration

Sizing Summary

Nameplate DC capacity kWdc

Total AC capacity kWac

Total inverter DC capacity kWdc

Number of strings

Total module area m²

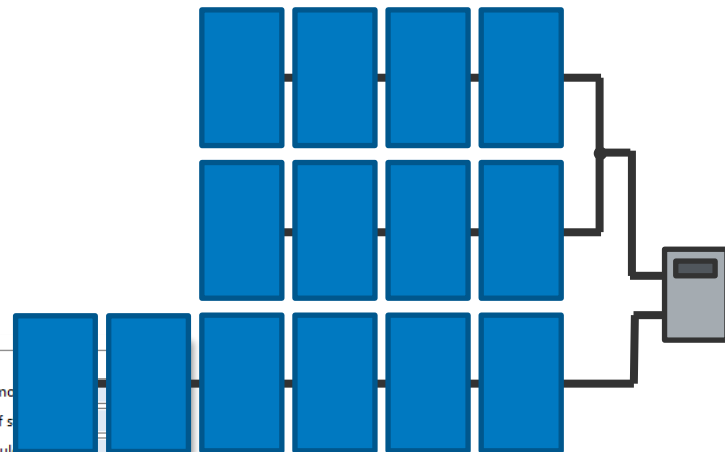
DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

Electrical Configuration	Subarray 1	Subarray 2	Subarray 3	Subarray 4
	(always enabled)	<input checked="" type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="4"/>	<input type="text" value="6"/>		
Strings in parallel in subarray	<input type="text" value="2"/>	<input type="text" value="1"/>		
Number of modules in subarray	<input type="text" value="8"/>	<input type="text" value="6"/>		
String Voc at reference conditions (V)	<input type="text" value="271.6"/>	<input type="text" value="407.4"/>		
String Vmp at reference conditions (V)	<input type="text" value="229.2"/>	<input type="text" value="343.8"/>		

6: Three strings (two identical), one inverter, two MPPTs

Both strings of Subarray 1 operate at same voltage, string of Subarray 2 operates at its own voltage.



Photovoltaic, Residential

- Location and Resource
- Module
- Inverter
- System Design
- Shading and Layout
- Losses
- Grid Limits
- Lifetime and Degradation
- System Costs
- Financial Parameters
- Incentives
- Electricity Rates

AC Sizing

Number of inverters:

DC to AC ratio:

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration

Sizing Summary

Nameplate DC capacity: kWdc

Total AC capacity: kWac

Total inverter DC capacity: kWdc

Number of modules:

Number of strings:

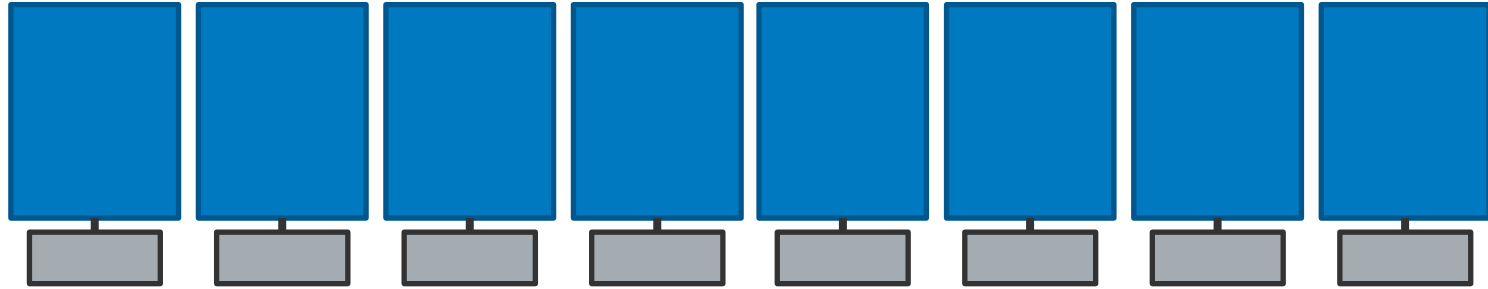
Total module area: m²

DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

Electrical Configuration	Subarray 1	Subarray 2	Subarray 3	Subarray 4
Set subarrays for multiple MPPT	(always enabled)	<input checked="" type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="4"/>	<input type="text" value="6"/>		
Strings in parallel in subarray	<input type="text" value="2"/>	<input type="text" value="1"/>		
Number of modules in subarray	<input type="text" value="8"/>	<input type="text" value="6"/>		
String Voc at reference conditions (V)	<input type="text" value="271.6"/>	<input type="text" value="407.4"/>		
String Vmp at reference conditions (V)	<input type="text" value="229.2"/>	<input type="text" value="343.8"/>		
Inverter MPPT input for subarray	<input type="text" value="1"/>	<input type="text" value="2"/>		

8: Microinverters



- Photovoltaic, Residential
- Location and Resource
- Module
- Inverter
- System Design**
- Shading and Layout
- Losses
- Grid Limits
- Lifetime and Degradation
- System Costs
- Financial Parameters
- Incentives

AC Sizing

Number of inverters

DC to AC ratio

Size the system using modules per string and strings in parallel inputs below.

Estimate Subarray 1 configuration

Sizing Summary

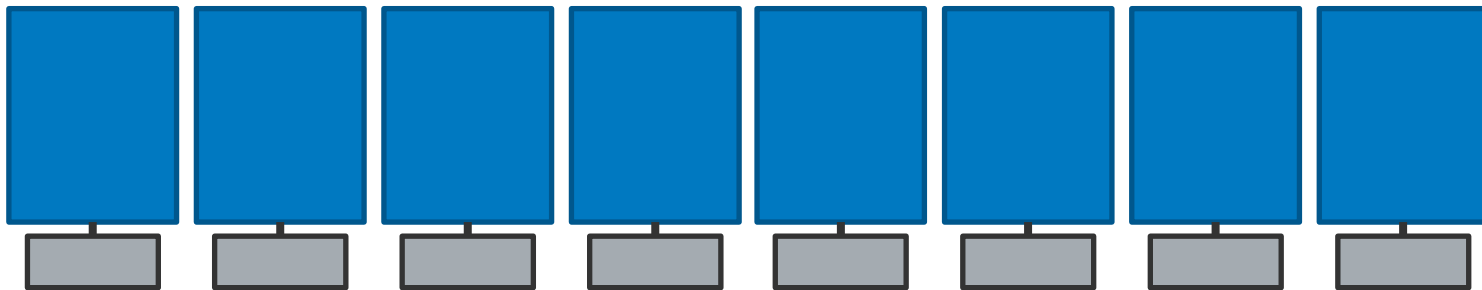
Nameplate DC capacity	<input type="text" value="2.003"/> kWdc	Number of modules	<input type="text" value="8"/>
Total AC capacity	<input type="text" value="1.920"/> kWac	Number of strings	<input type="text" value="8"/>
Total inverter DC capacity	<input type="text" value="2.005"/> kWdc	Total module area	<input type="text" value="13.1"/> m ²

DC Sizing and Configuration

To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

Electrical Configuration	Subarray 1	Subarray 2	Subarray 3	Subarray 4
	(always enabled)	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable	<input type="checkbox"/> Enable
Modules per string in subarray	<input type="text" value="1"/>			
Strings in parallel in subarray	<input type="text" value="8"/>			
Number of modules in subarray	<input type="text" value="8"/>			
String Voc at reference conditions (V)	<input type="text" value="59.6"/>			
String Vmp at reference conditions (V)	<input type="text" value="48.7"/>			

For microinverters, be sure to set module mismatch loss on Losses page



Losses

- Grid Limits
- Lifetime and Degradation
- System Costs
- Financial Parameters
- Incentives
- Electricity Rates
- Electric Load

DC Losses

DC losses apply to the electrical output of each subarray and account for losses not calculated by the module performance model.

Module mismatch (%)	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
Diodes and connections (%)	<input type="text" value="0.5"/>	<input type="text" value="0.5"/>	<input type="text" value="0.5"/>	<input type="text" value="0.5"/>
DC wiring (%)	<input type="text" value="2"/>	<input type="text" value="2"/>	<input type="text" value="2"/>	<input type="text" value="2"/>
Tracking error (%)	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
Nameplate (%)	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
DC power optimizer loss (%)	<input type="text" value="0"/>	All four subarrays are subject to the same DC power optimizer loss.		
Total DC power loss (%)	<input type="text" value="2.490"/>	<input type="text" value="2.490"/>	<input type="text" value="2.490"/>	<input type="text" value="2.490"/>

Total DC power loss = 100% * [1 - the product of (1 - loss/100%)]

-Default DC Losses-
Apply default losses to replace DC losses for all subarrays with default values.

Apply default losses for:

Financial Models

Supporting Slides

Residential PV system

Installed, owned, operated by a residential homeowner.

Power from system reduces homeowner's monthly electricity bill.

Is a project economically feasible given its cost and energy production?



Financial model overview

Power Purchase Agreement (PPA)

Sell power to generate revenue

Power price is fixed with optional escalation and time-of-delivery adjustments

Distributed

On customer side of electricity meter

Reduce customer's electricity bill

Merchant Plant

Sell power at market prices

LCOE Calculator

Calculate levelized cost of energy using simple fixed-charge-rate method.

- ▼ Power Purchase Agreement
 - Single Owner
 - Partnership Flip with Debt
 - Partnership Flip without Debt
 - Sale Leaseback
- ▼ Distributed
 - Residential Owner
 - Commercial Owner
 - Third Party Owner - Host
 - Third Party - Host / Developer
 - Merchant Plant
 - LCOE Calculator (FCR Method)
 - No Financial Model

Commercial PV System

Installed, owned, and operated by business owner.

Power from PV system reduces business owner's electricity bill.

Is a project economically feasible given its cost and energy production?



Third party ownership for projects with a developer who owns the system and a host who uses the power:

Host: Compare lease to power purchase agreement (PPA) option from the host (building owner) perspective.

Host / Developer: Calculate “host indifference point,” or PPA price that developer would have to charge to make project feasible.

Other distributed financial models

Power Purchase Agreement (PPA) Project

Installed, owned, and operated by a single owner or partnership.

Power from PV system sold to generate revenue.

Does project revenue cover installation and operating costs?

