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# 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**

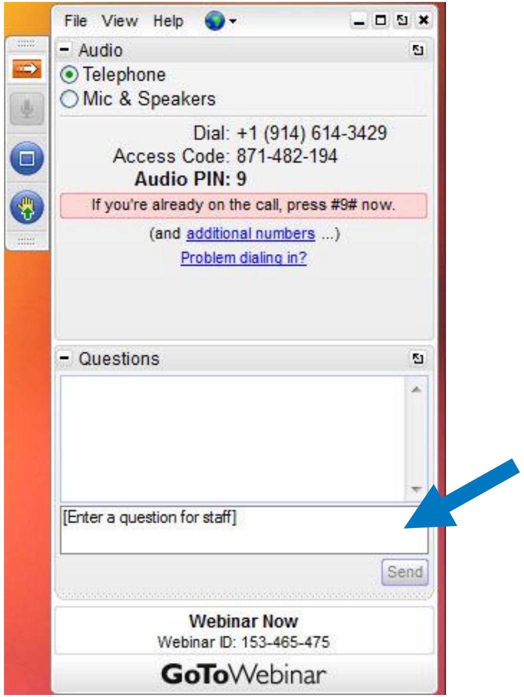
Batteries in SAM 2020.2.29:

- 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?

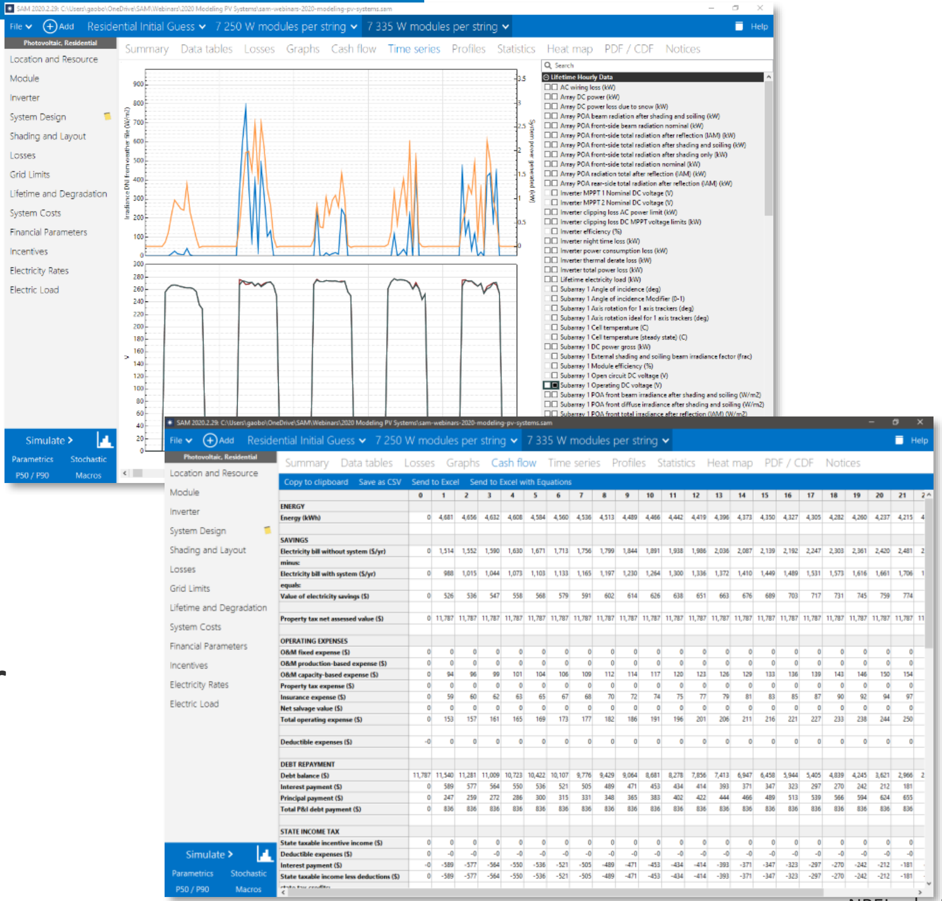
The System Advisor Model

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

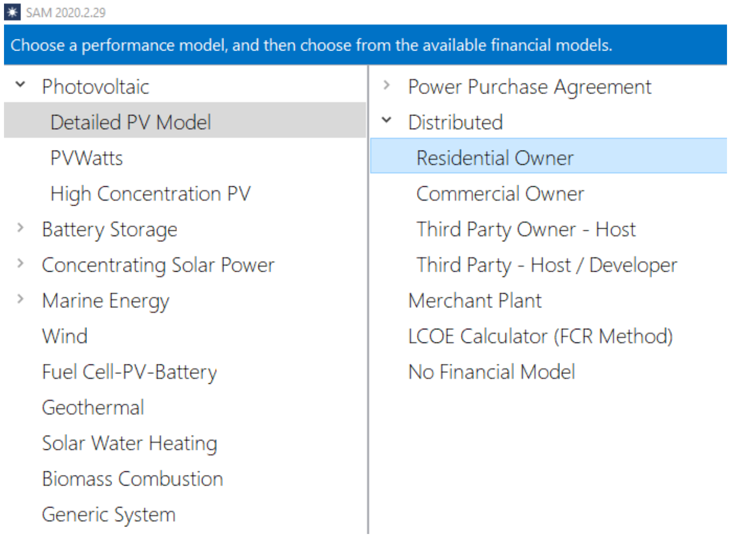
# First, choose a performance and financial model

## 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



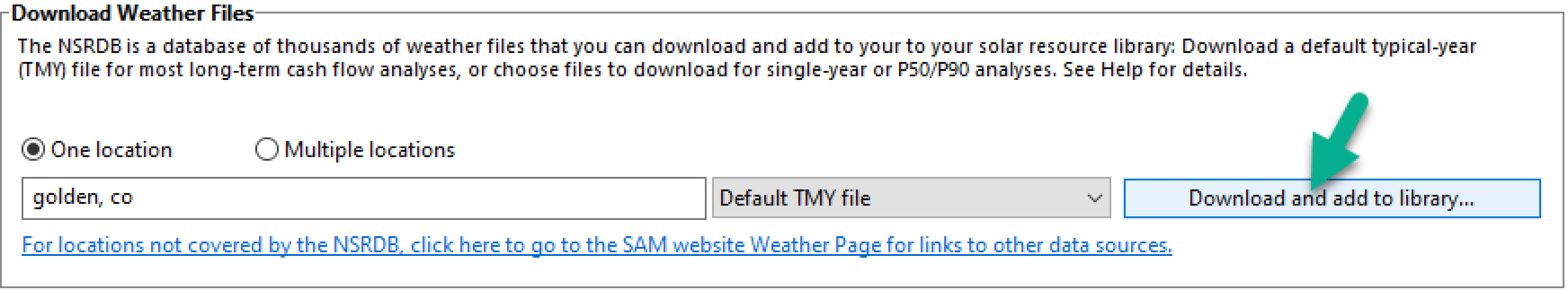
# Next, download a weather file

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

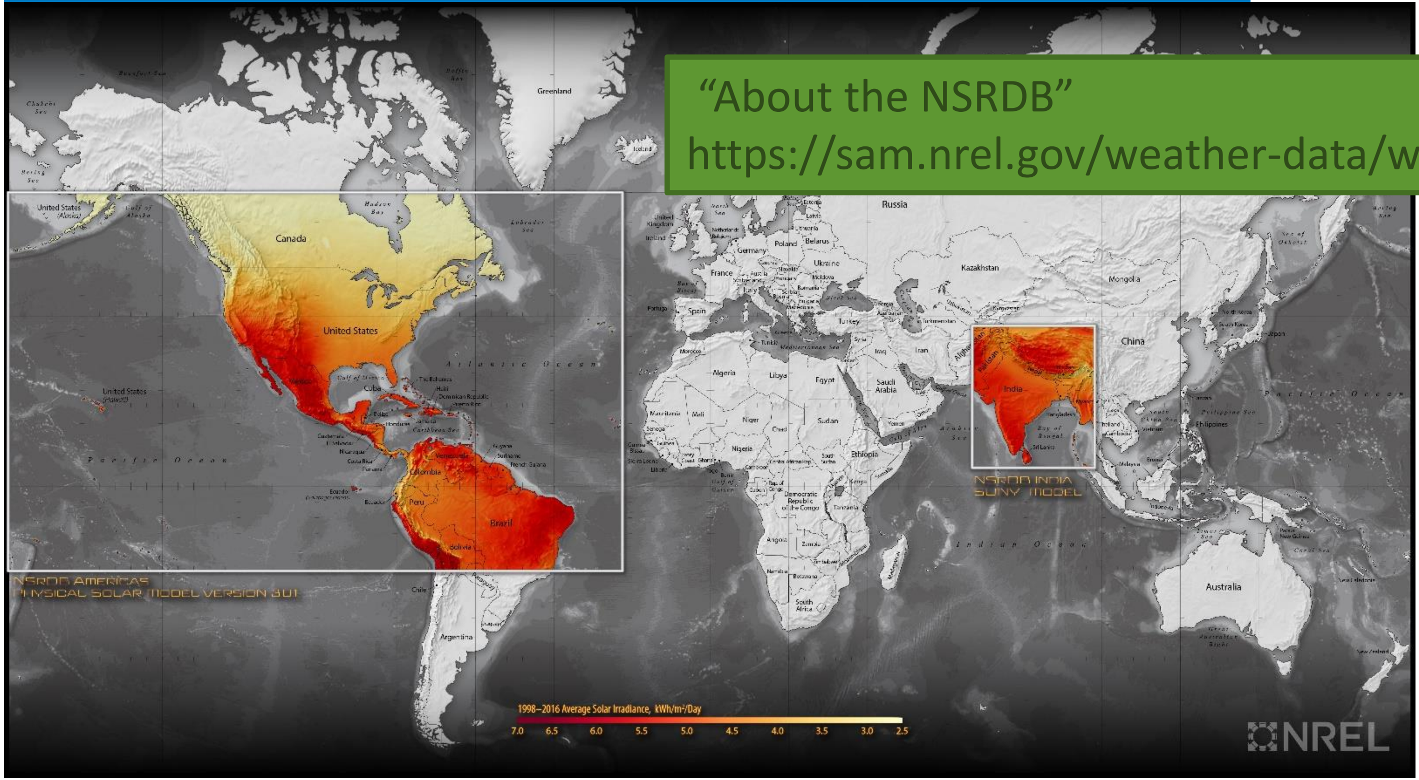
- "golden, co"
- "15013 Denver West Parkway Golden, CO"
- "39.74,-105.18"

**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



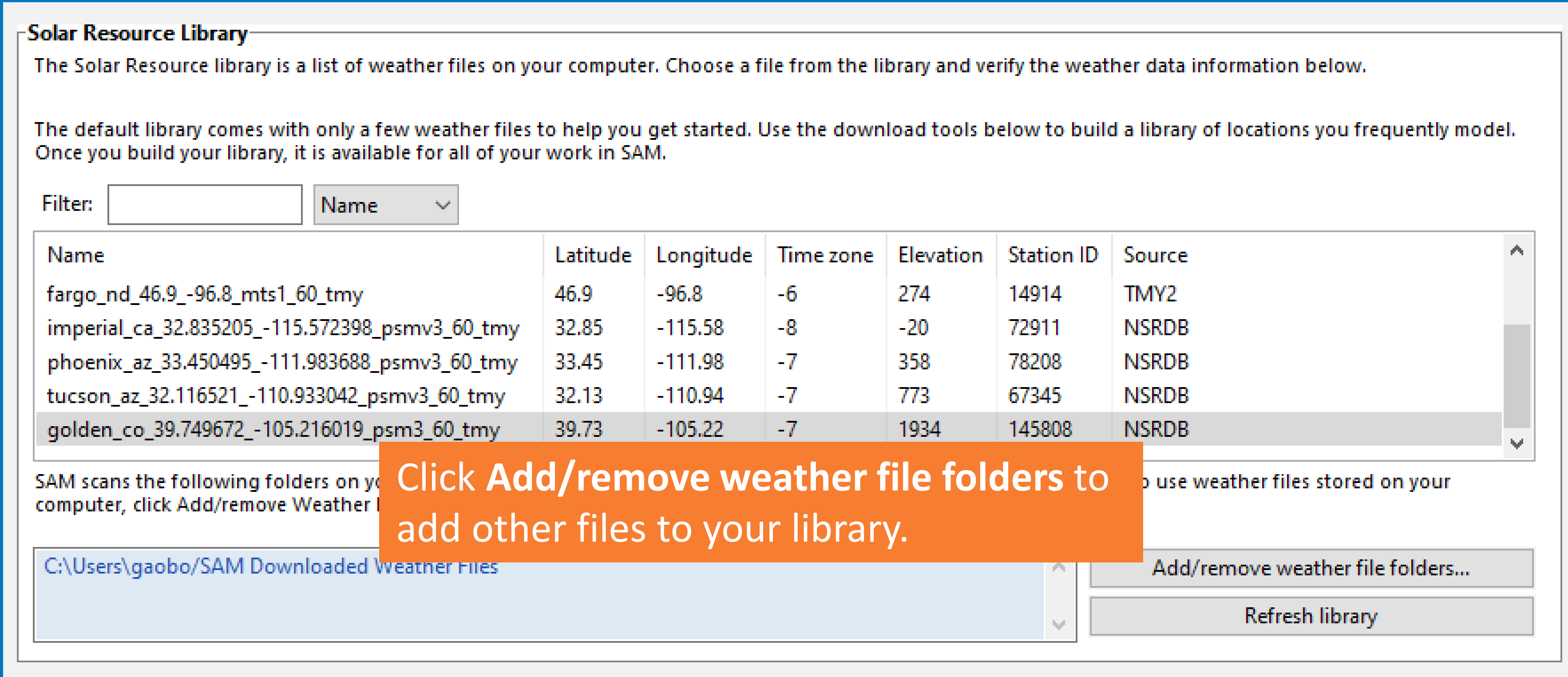
# NSRDB Coverage Map




“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.




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

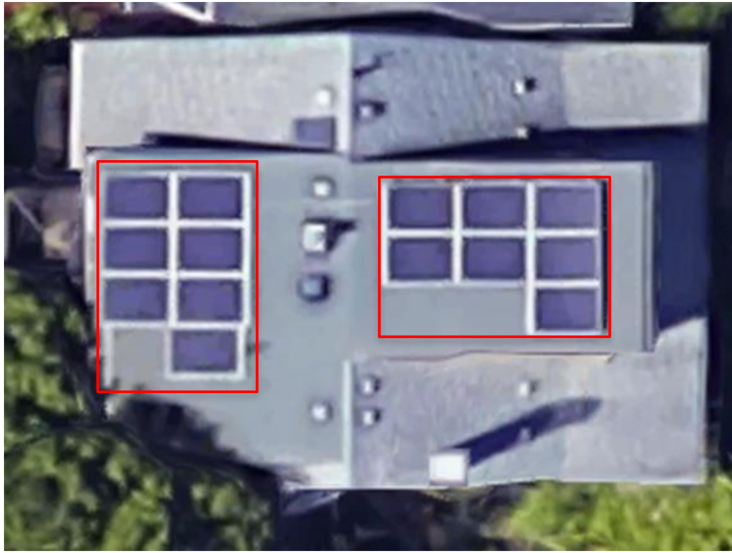
# Design the system: System size

Use roof area to determine maximum system capacity:

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

35 $m^2$ * 0.15 * 1,000 $W/m^2$ = 5,250 W

*Assume about 1,000 $W/m^2$ 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:*

*17 ft * 12 ft*
*= 204 sq ft * 2*
*= 408 sq ft*
*≈ 35 $m^2$*

# Design the system: Inverter

System Size

~5 DC kW, 1.2 DC/AC ratio

Inverter

5,000 DC W / 1.2 = 4166.7 AC W ≈ 4200 AC W

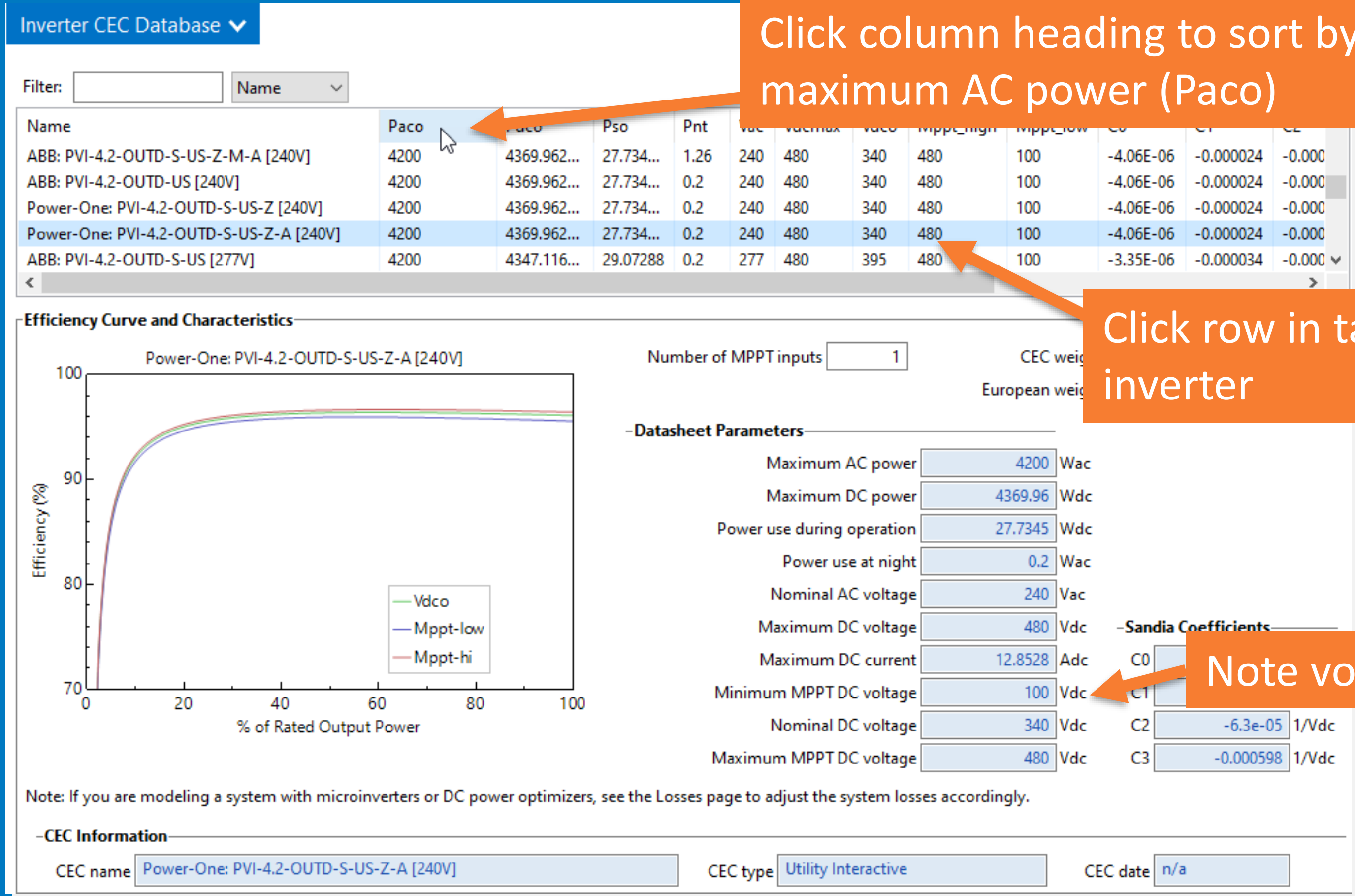
Module

String Size

Number of Strings

Array Orientation

# Inverter: 5 DC kW / 1.2 ≈ 4.2 AC kW




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

Click row in table to choose an inverter

Note voltage ratings

# 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.**

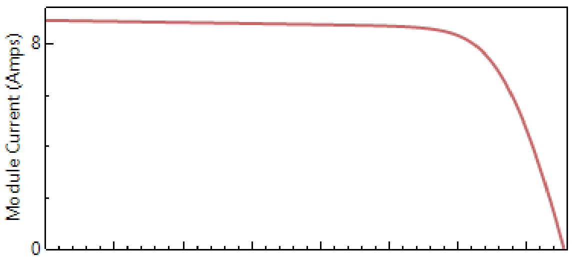
**Sort by STC power rating.**

| 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 | [illegible] | [illegible] | [illegible] |
| 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 | [illegible] | [illegible] |
| 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 | [illegible] | [illegible] |
| 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




| | | | Temperature coefficients | | | |
|---|---|---|---|---|---|---|
| Nominal efficiency | 15.4574 | % | | | | |
| Maximum power (Pmp) | 250.100 | Wdc | -0.430 | %/°C | -1.075 | W/°C |
| 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 | V/°C |
| Short circuit current (Isc) | 8.9 | Adc | 0.050 | %/°C | 0.004 | A/°C |

**Note ratings.**

**Bifacial Specifications**

“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 VDC / 37.8 VDC = 12.7 ≈ 12
- Minimum modules per string: 100 VDC / 37.8 VDC = 2.65 ≈ 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

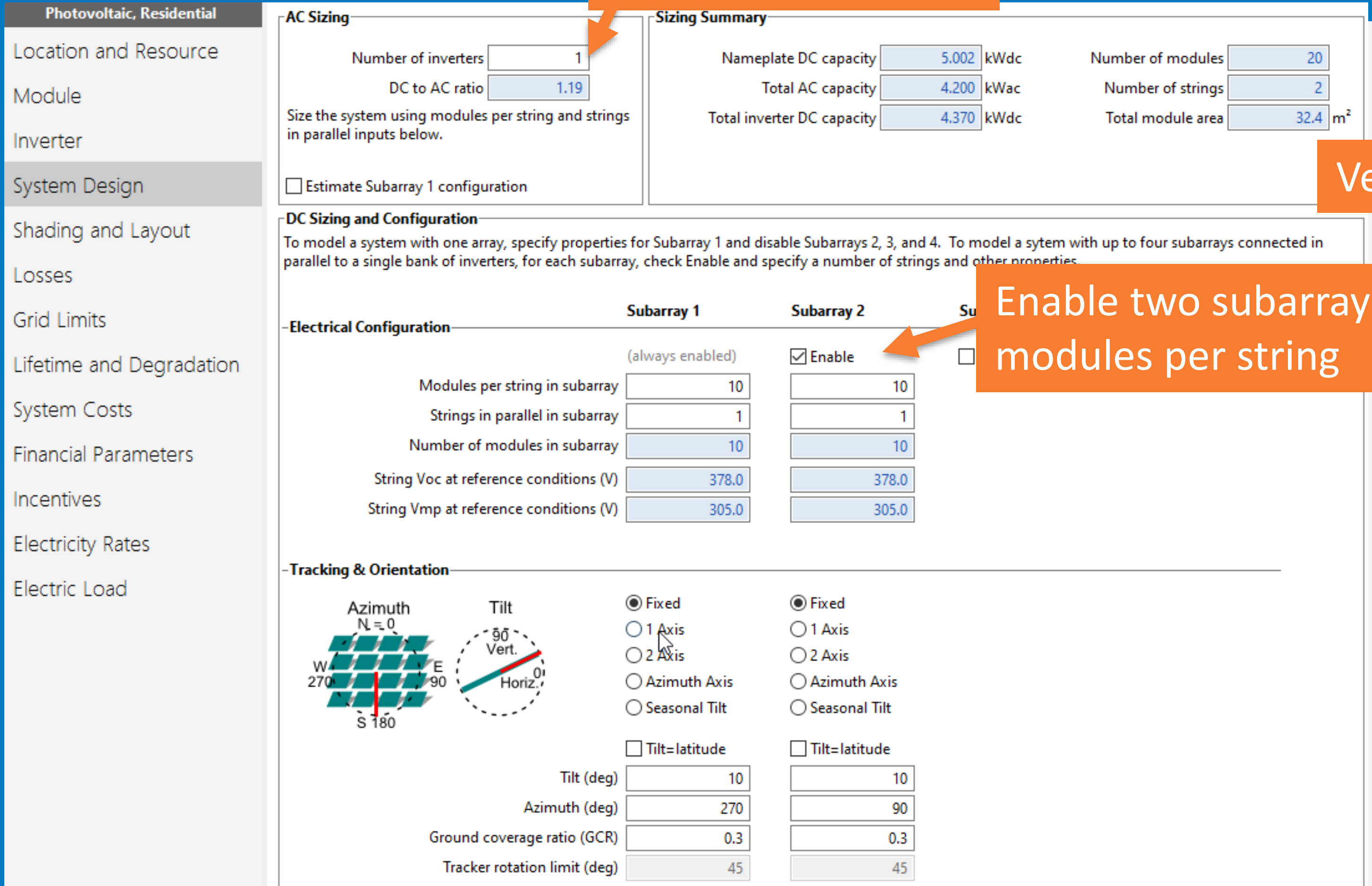
Two subarrays, 10 degree tilt, E-W facing

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

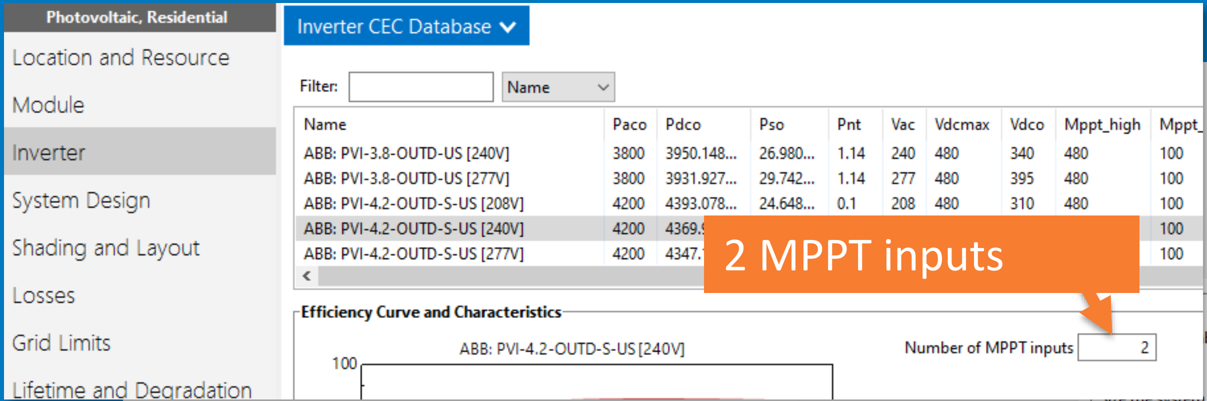
Number of inverters

Verify capacities

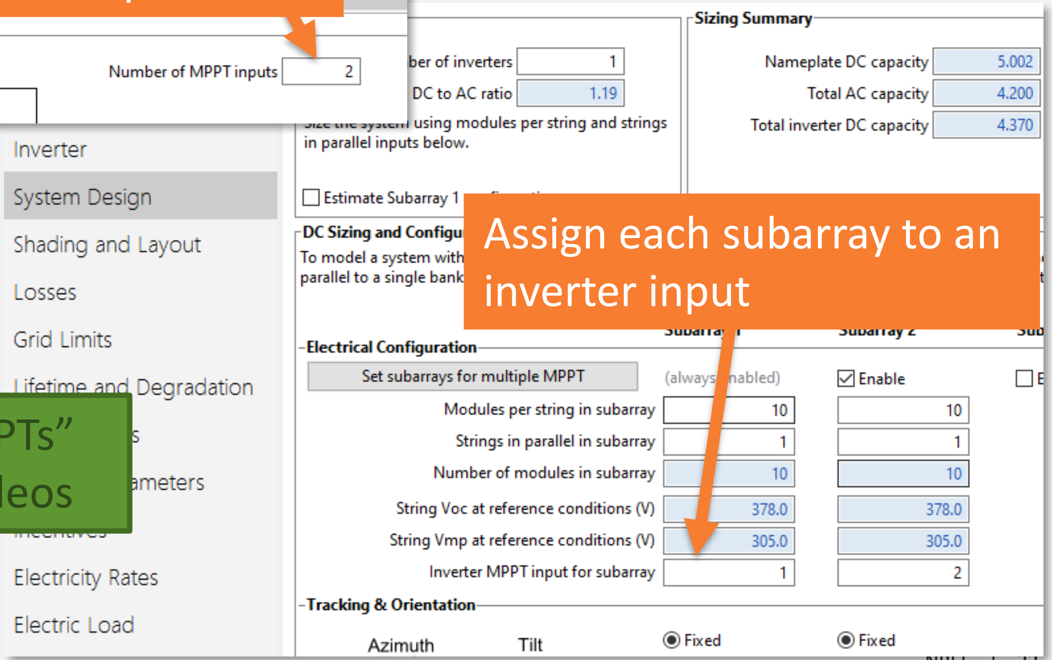
Enable two subarrays, 10 modules per string



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




2 MPPT inputs




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

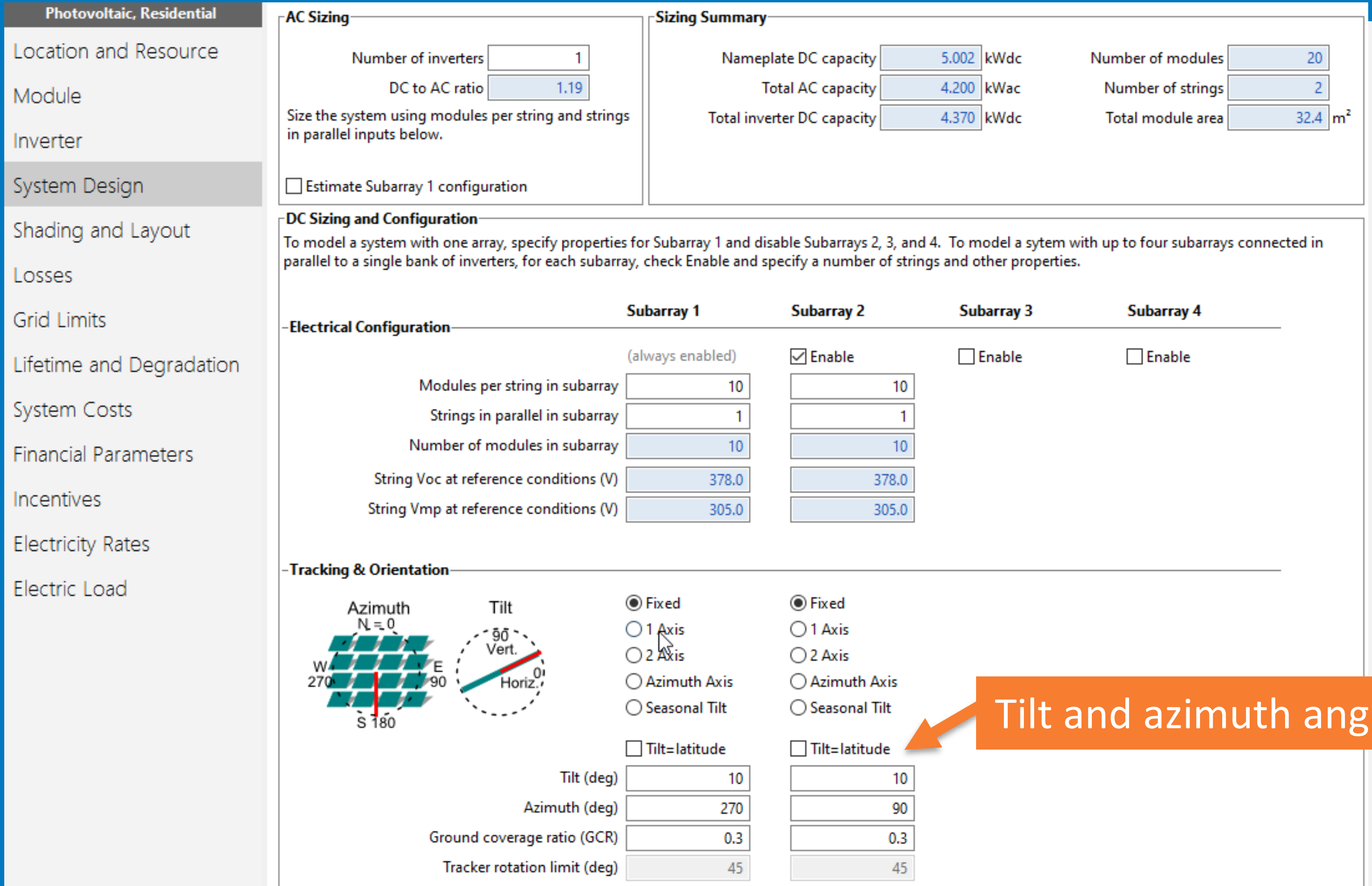
Module
- 250 DC W Trina Solar TSM-250

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




Tilt and azimuth angles

# 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.

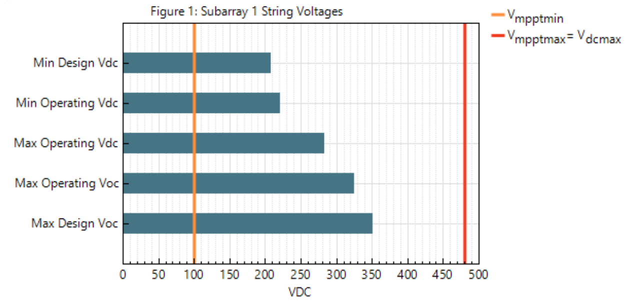
| Module | Array Power (kW) | Subarray 1 String Voc (VDC) | Subarray 2 String Voc (VDC) | Nameplate DC/AC Ratio |
|---|---|---|---|---|
| Trina Solar TSM-335DD06M.05(II) | 4.69 | 284.90 | 284.90 | 1.12 |
| Trina Solar TSM-335DD06M.15(II) | 4.69 | 284.90 | 284.90 | 1.12 |
| Trina Solar TSM-335DD06M.18(II) | 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 |

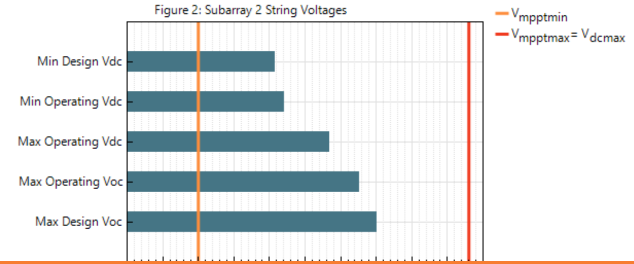
Table 5: Modules from different manufacturers that meet the inverter voltage requirements. Table displays up to 50 modules that result in the highest rated string Voc.

| 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

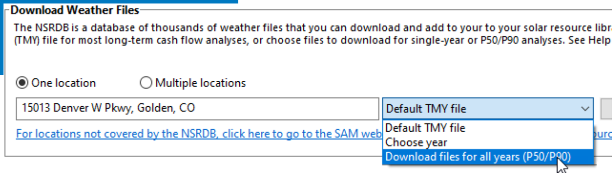
Snow model when data available in weather file

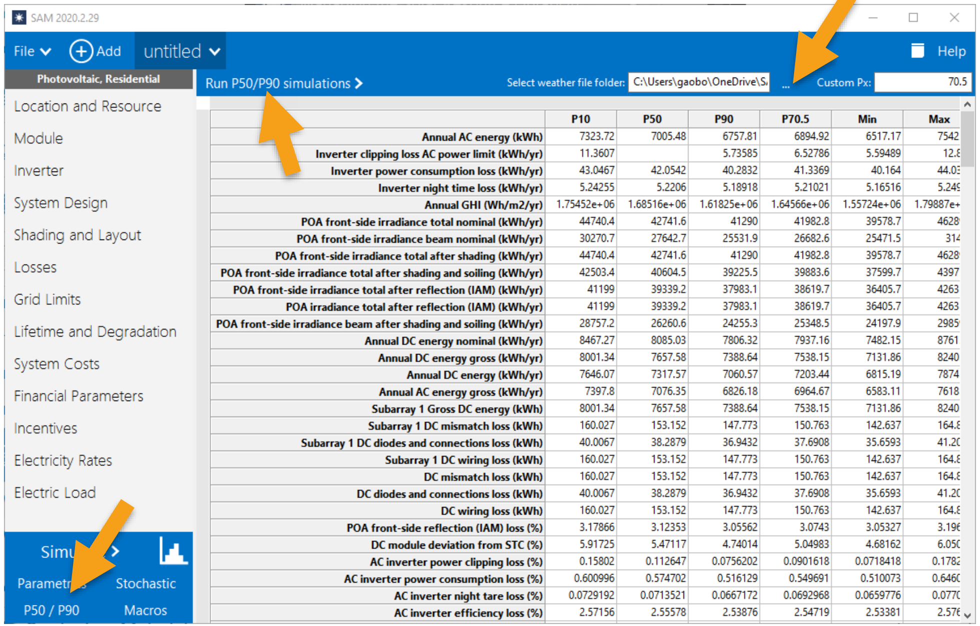
"Modeling Shading Losses for PV Systems"
https://sam.nrel.gov/photovoltaic/pv-videos

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.




"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**

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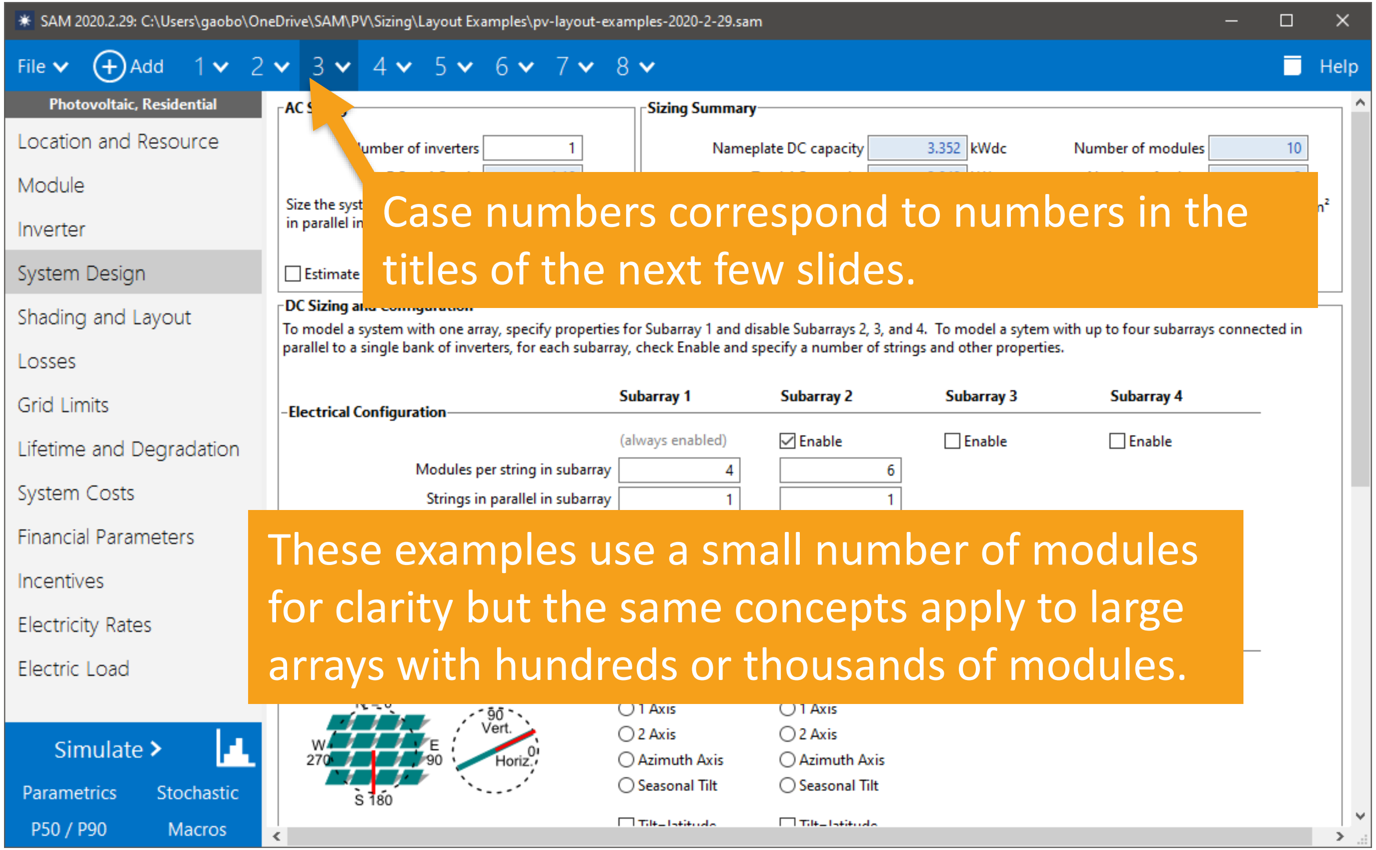
# Array Layout Examples

Supporting Slides

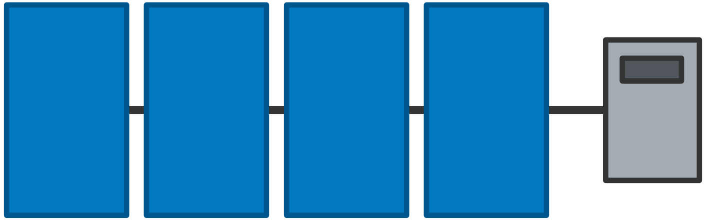
# Layout examples are in *pv-layout-examples-2020.2.29.sam* file

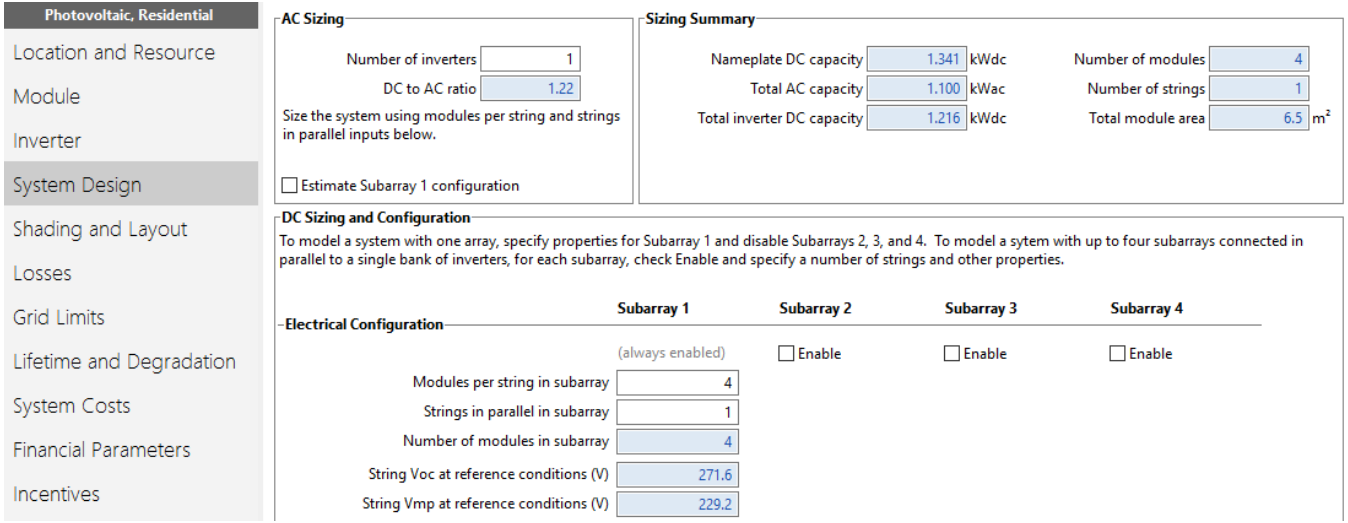



Case numbers correspond to numbers in the titles of the next few slides.

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

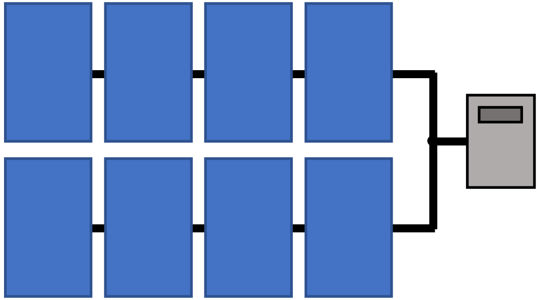
# 1: One string, one inverter, one MPPT

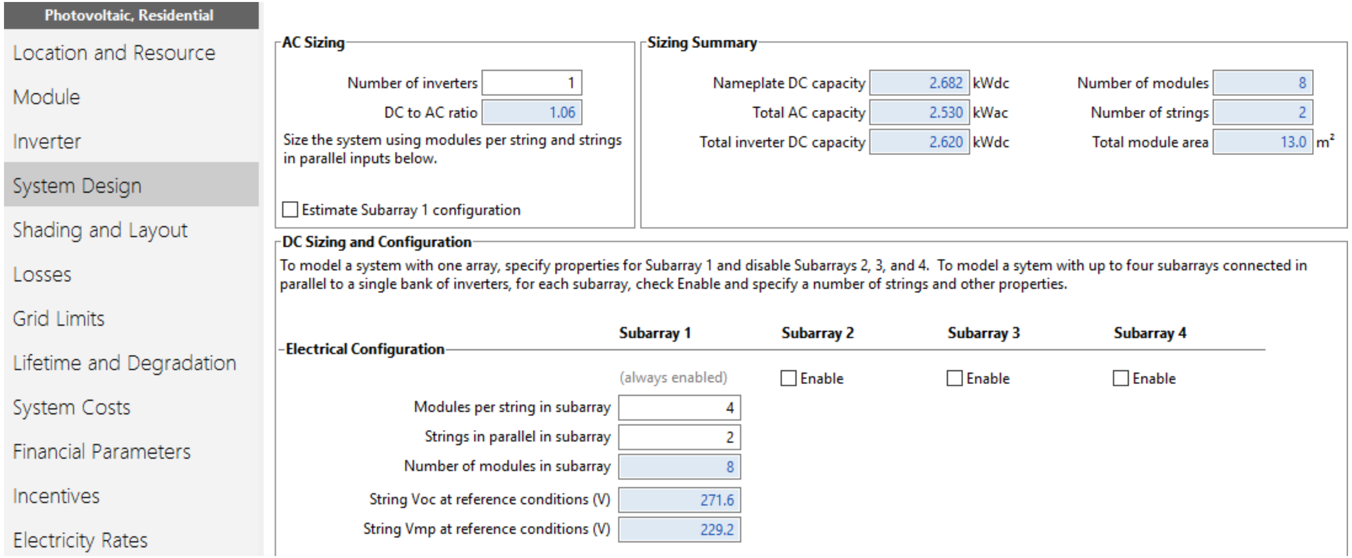




# 2: Two identical strings, one inverter, one MPPT

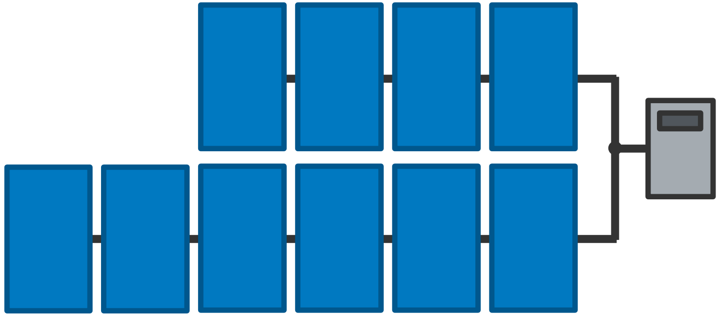
"Identical strings" means both strings have same number of modules, orientation, tracking and shading, so both subarrays operate at same voltage.

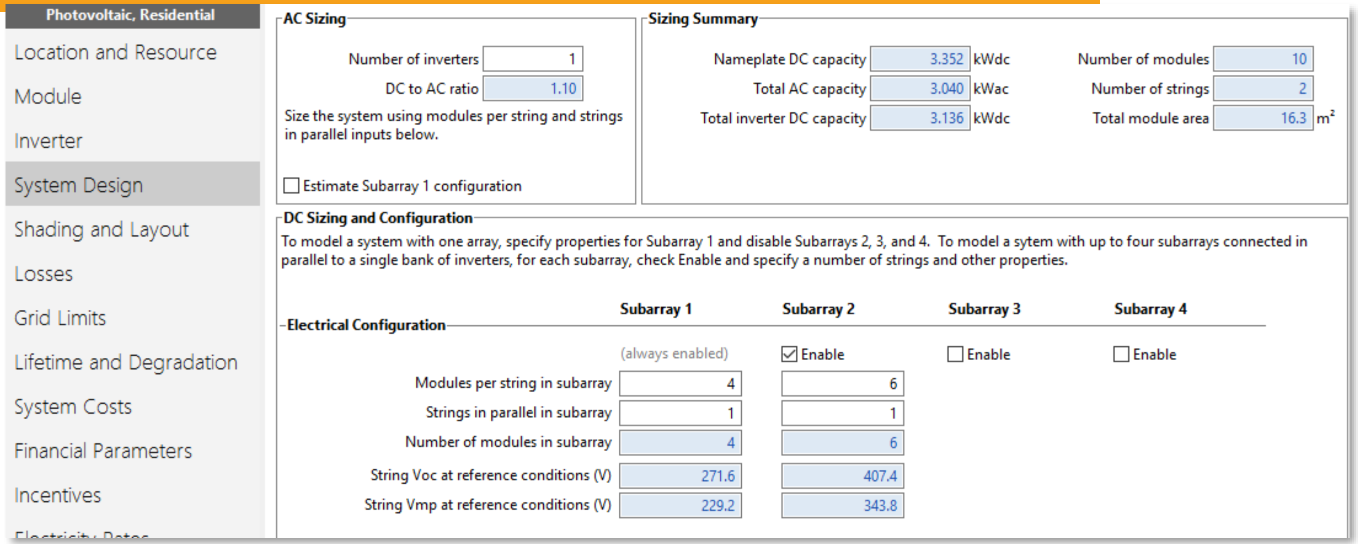




# 3: Two different strings, one inverter, one MPPT

"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.





# 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 (Vmp). The voltage mismatch causes electrical losses and an inverter input voltage less than Vmp. By default, SAM estimates the inverter input voltage by averaging the subarray Vmp 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**

- Location and Resource
- Module
- Inverter
- System Design
- Shading and Layout
- Losses
- Grid Limits

**Inverter CEC Database**

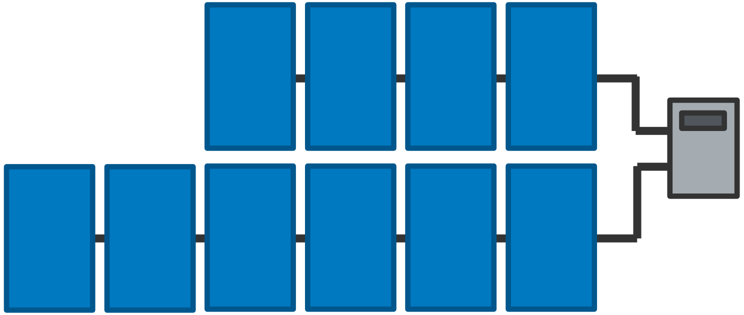
Filter: [ ] Name

| Name | Paco | Pdco | Pso | Pnt | Vac | Vdcmax | 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 | 36 | 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: 2



**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: 1

DC to AC ratio: 1.10

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

☐ Estimate Subarray 1 configurat

**Sizing Summary**

| | | | | | |
|---|---|---|---|---|---|
| Nameplate DC capacity | 3.352 | kWdc | Number of modules | 10 | |
| Total AC capacity | 3.036 | kWac | Number of strings | 2 | |
| Total inverter DC capacity | 3.132 | kWdc | Total module area | 16.3 | $m^2$ |

**Each string operates at a different voltage.**

**DC Sizing and Configuration**

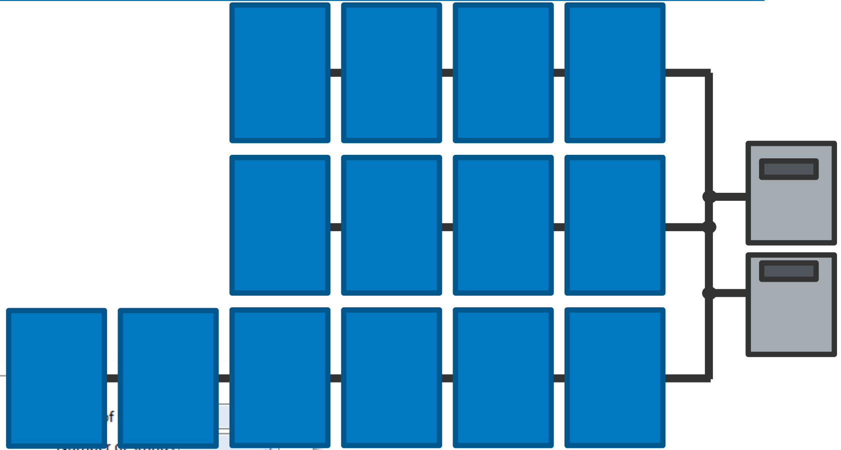
To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a sytem with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.

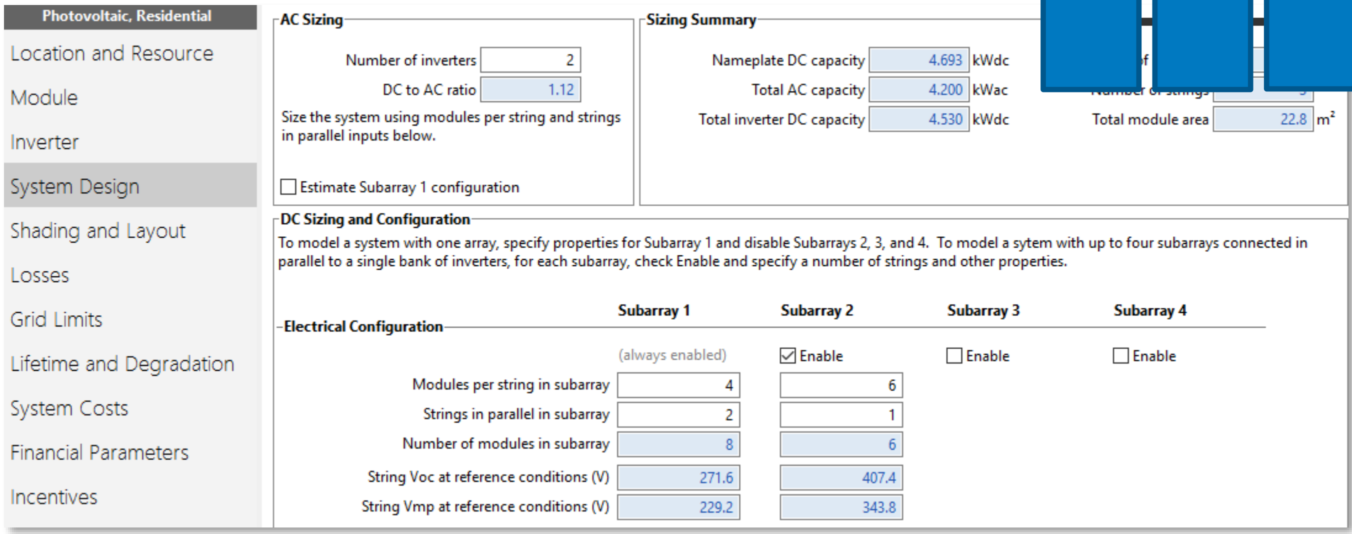
**Electrical Configuration**

| Set subarrays for multiple MPPT | Subarray 1 | Subarray 2 | Subarray 3 | Subarray 4 |
|---|---|---|---|---|
| | (always enabled) | ☑ Enable | ☐ Enable | ☐ Enable |
| Modules per string in subarray | 4 | 6 | | |
| Strings in parallel in subarray | 1 | 1 | | |
| Number of modules in subarray | 4 | 6 | | |
| String Voc at reference conditions (V) | 271.6 | 407.4 | | |
| String Vmp at reference conditions (V) | 229.2 | 343.8 | | |
| Inverter MPPT input for subarray | 1 | 2 | | |

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

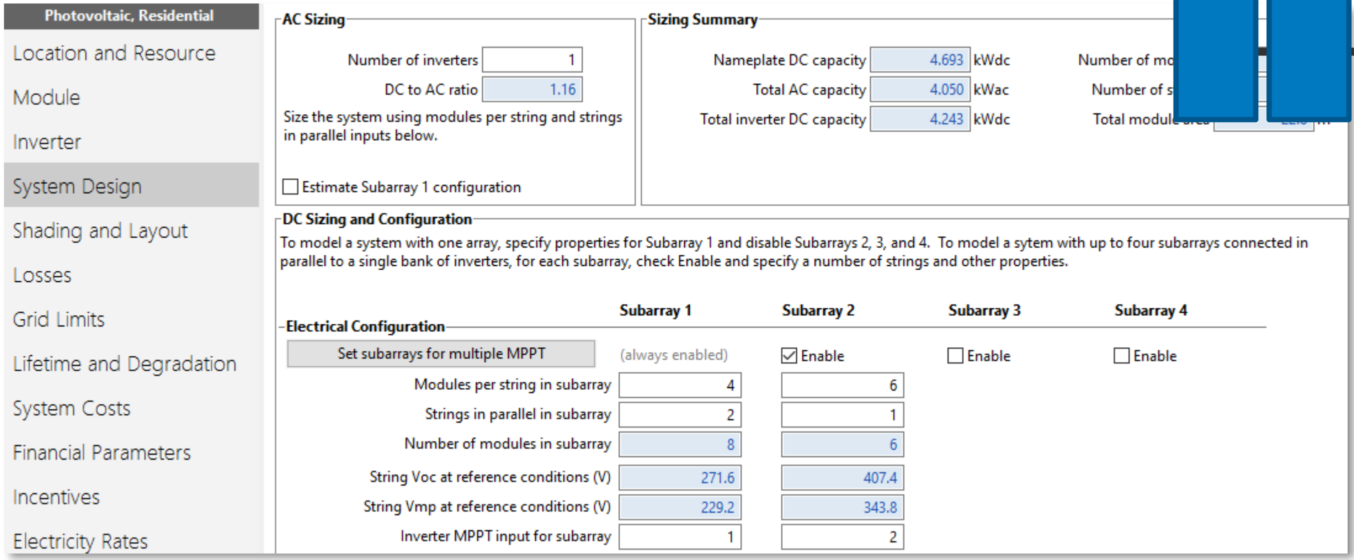
Inverter DC voltage is either average of subarray voltages, or if you enable it, calculated using voltage mismatch option.

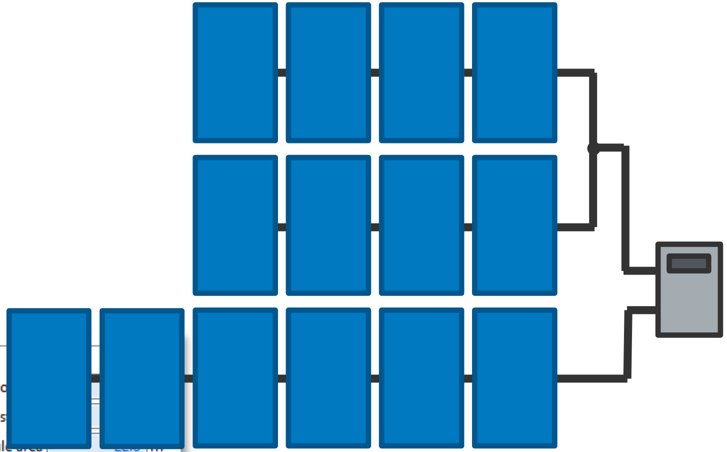




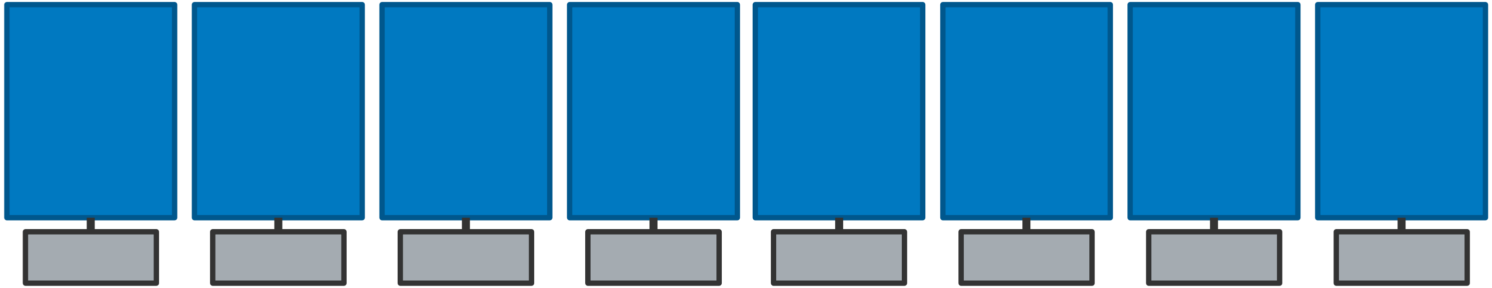
# 6: Three strings (two identical), one inverter, two MPPTs

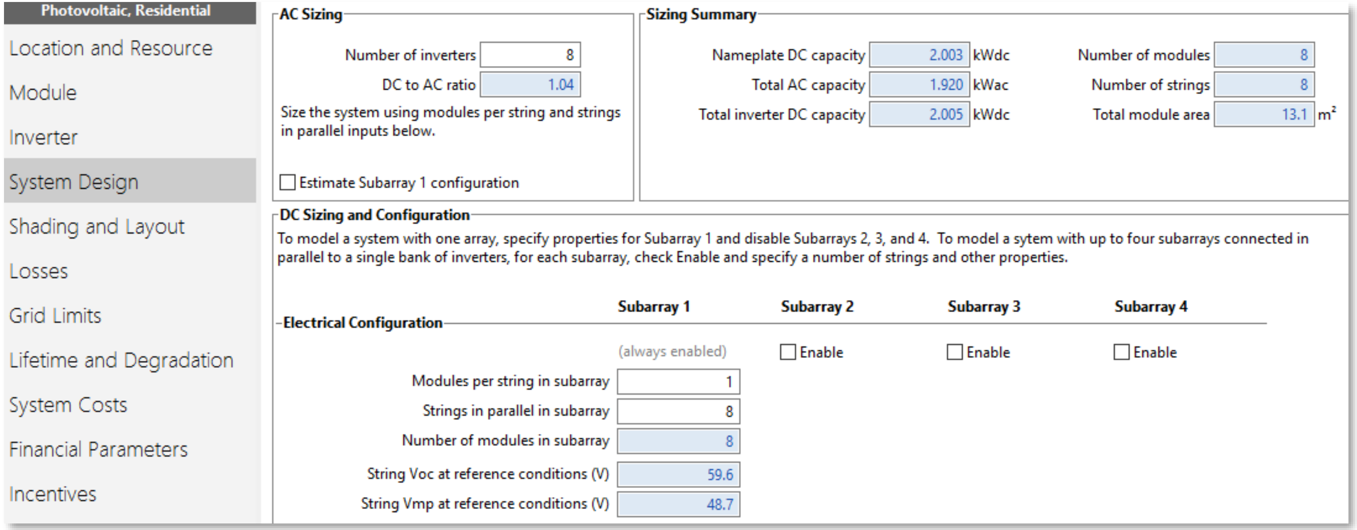
Both strings of Subarray 1 operate at same voltage, string of Subarray 2 operates at its own voltage.



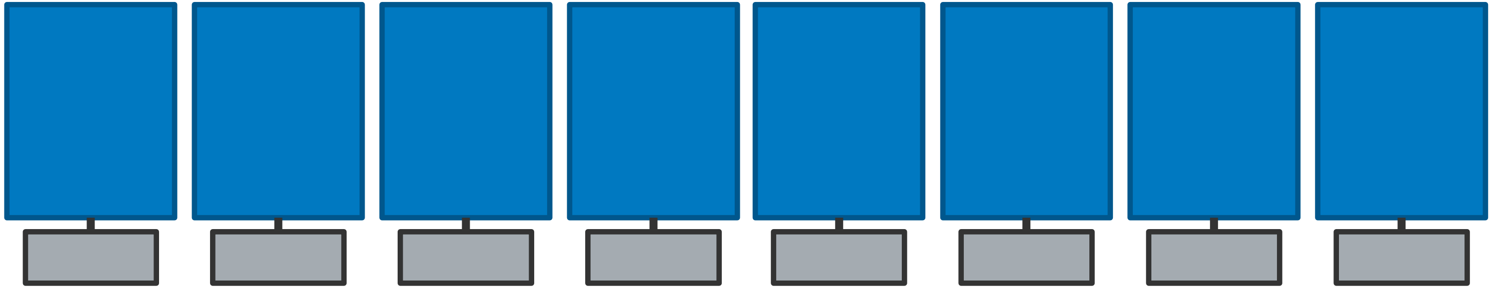



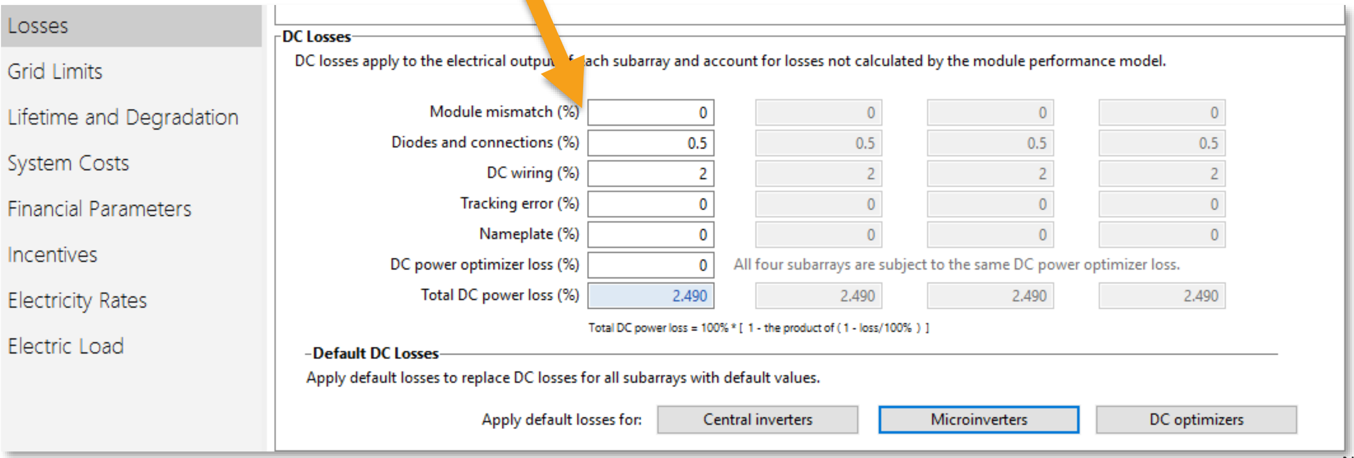
# 8: Microinverters





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





# 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

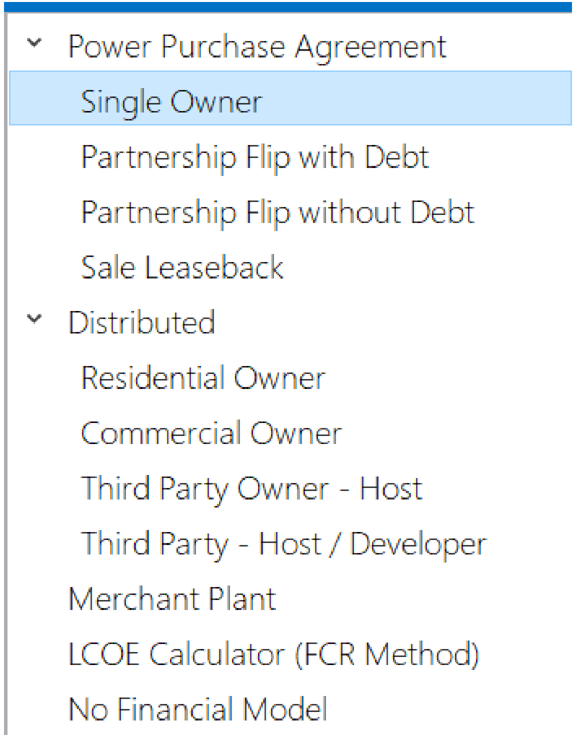
Reduce customer’s electricity bill

**Merchant Plant**

Sell power at market prices

**LCOE Calculator**

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




See https://sam.nrel.gov/financial-models

# 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?