

Solar Array Simulation Software

Solar panels convert electromagnetic energy into electric energy. The efficiency with which this is done is determined by various parameters. The parameters include surface area, material, technology, and the angle of incidence from the light source to the panel. Irradiance is the intensity of solar radiation or energy measured in the units of power over square meter (W/m^2). Typically, changes to irradiance will change the performance of the solar panel. This results in an increase or decrease in the maximum power it can harness.

Total irradiance (Figure 1) is the sum of direct irradiance, diffused irradiance, and reflected irradiance. Direct irradiance is the intensity of solar radiation created from uninterrupted line of sight to the sun. With direct irradiance, all light travel in a straight line, in the same direction. Diffused irradiance is caused when light is scattered through molecules in the atmosphere. Pollution or clouds are often the source of diffused irradiance. In this situation, the light rays are all traveling in random directions. Reflected radiation is created when light rays bounce off non-atmospheric objects such as the ground or a building.

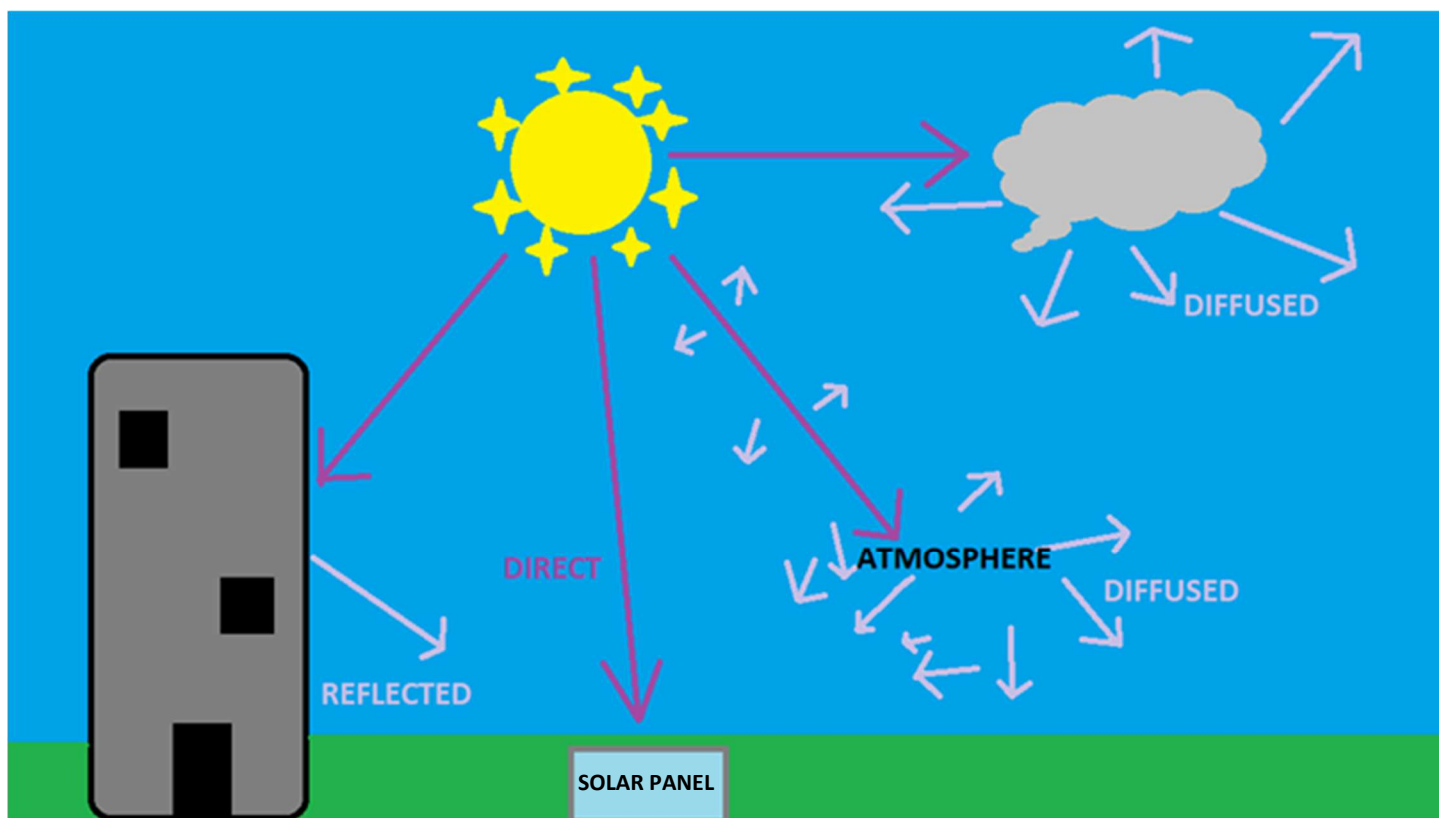


Figure 1 – Total Irradiance Diagram

The SAS software features an irradiance curve. This irradiance curve represents total irradiance. The SAS software also has a shadow simulation mode where the user can define shadows, range of time, direction, and array configuration in order to see how the output of the array is affected.

Each solar panel is characterized by certain parameters. The defining parameters are: V_{mp} , I_{mp} , P_{mp} , V_{oc} , I_{sc} , Beta (β).

- **V_{mp}** | Maximum Voltage Point - This is the predefined value provided by the manufacturer, which specifies the maximum value of voltage the panel can produce.
- **I_{mp}** | Maximum Current Point - This is the predefined value provided by the manufacturer, which specifies the maximum value of current the panel can produce.
- **P_{mp}** | Maximum Power Point - This is calculated by $V_{mp} \times I_{mp}$, and it changes as the value of V_{mp} and I_{mp} changes.
- **V_{oc}** | Open Circuit Voltage - This is the measured voltage of the solar panel when there is zero current passing through it.
- **I_{sc}** | Short Circuit Current - This is the measured current of the solar panel when there is a potential difference of 0 volts across.
- **Beta (β)** - Beta is the temperature co-efficient of the voltage for the solar panel. When the temperature increases, the power output from the panel decreases. Hence the temperature co- efficient plays a vital role in deciding the output power.

BASICS

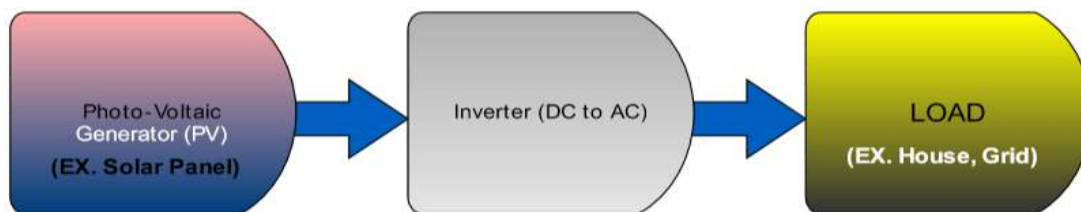


Figure 2 – PV Block Diagram

The block diagram (**Error! Reference source not found.**) is a high-level representation of a common solar panel set up. A photo-voltaic generator creates DC power from light. The B&K Precision PVS system is a DC power supply and, in conjunction with the SAS software, can behave like a solar panel. It is common to utilize multiple PV generators in series or in parallel. The SAS software can simulate panels in series and parallel setup.

The inverter turns DC power into AC power. Often an inverter has a built-in maximum power point tracker (MPPT). The MPPT is essentially a DC load. The MPPT will adjust its load (usually current) to extract the maximum power from the PV generator. DC loads and generators have 2 terminals, positive and negative. AC loads and generators have 3 to 5 terminals, this depends on whether it utilizes single or three phase power. Regardless, three of the terminals will be common, these are; L1 (Line)/Hot/Live, Neutral, and Earth Ground. If it utilizes three phase power it will also have L2 and L3. An inverter will not invert without a load to send the AC power to, such as a house or AC load.

SETUP WITH THE PVS

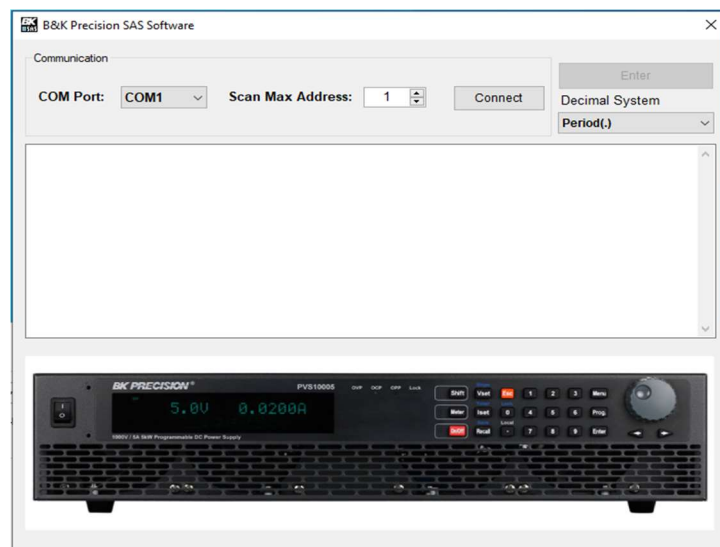
1. The PVS will be connected to the inverter. It connects with a positive and negative cable.
2. The inverter is connected to the load. Three wires go to the inverter; line, ground, and neutral.
3. Once the above connections are correct, the inverter can be switched on. Refer to the inverter's manual for proper use.
4. The SAS software can be used to communicate with PVS generator remotely.

SETUP THE SAS SOFTWARE

1. Download and install the SAS software from the [B&K Precision website](#).
2. The software includes a 30 day free trial with full functionality, after which a USB dongle with license must be purchased for continued usage.

- When the executable file is launched, the screen in Figure 2 will appear. Connect the PVS to the PC. Use Windows Device Manager to confirm which COM port the power supply has been assigned to. Select the COM port from the **COM Port** dropdown menu, then click **Connect**. Upon successful connection, the **Enter** button will be enabled. Click it to launch the software.

Figure 2 – SAS Connection Screen



Setting up a Basic Profile

- The SAS Dashboard (Figure 3) has curves and profiles for the SAS software's most basic functionality.
- Predefined profiles with different curves are listed in the **Profile Section**. The PVS can store up to 100 I-V profiles in its internal memory. The software makes it easier to load and save the profiles. Clicking on any of the Curve numbers from the list will select the I-V profile which can be loaded to the **P-V Curve Graph**. *NOTE: The P-V curve data are automatically generated based on the selected regulation standards EN50530, SANDIA, or NB/T32004.*
 - The X- axis of the P-V curve graph is voltage in volts. The Y- axis specifies the current in Amps and power in Watts. The red line in the curve is showing the P-V characteristics and the green line shows the I-V characteristics.
- To the right of the P-V Curve section is the **Irradiance Curve Graph**. This is a graphical representation of irradiance and temperature. The curve is determined by the selected profile in the **Irradiance Profile** section.
 - The X-axis of the irradiance graph is time in seconds. This reflects real time during operation and represents the change in irradiance throughout the day.
 - The Y-axis is Irradiance in W/m2 and temperature in C°. The yellow line in the curve is showing the irradiance characteristics and the pink line shows the temperature characteristics.
- The PVS can be controlled in the **Control Section**. The output can be turned on and the **Green Arrow** button will enable the MPPT. From left to right the buttons are as follows:
 - Run** – This button is used to start the simulation.
 - Pause** – This button is used to pause the simulation.
 - Stop** – This button is used to stop the simulation.
 - Repeat** – This button is used to repeat the simulation back to back.

- **Rewind** – This button is used to rewind the simulation by the number of seconds specified in the Seconds box.
- **Forward** – This button is used to forward the simulation by the number of seconds specified in the Seconds box.
- **Seconds** – This box enables the user to input the number for seconds to be used when rewinding or forwarding the simulation.
- Current, voltage, power and irradiance data are logged and graphed in the **MPPT Status** section. Selecting the checkbox **Enable Datalogging** will log the same data into a .CSV file.
 - V_{mp} and I_{mp} are defined in page 2.
 - **MPP** – Maximum power point is the highest possible power at a voltage point.
 - **MPPT Efficiency** – This is how close MPPT is to the actual MPP. $(MPPT\ Power / MPP) * 100\%$
 - **Average Efficiency** – This is the average MPPT efficiency.
 - **Power vs Time, Voltage vs Time, Current vs Time** graphs are a recording of the parameters with respect to time.
- Predefined profiles are editable and can be used as a base for entirely new profiles. Custom irradiance and temperature (IRTP) curves are also creatable.

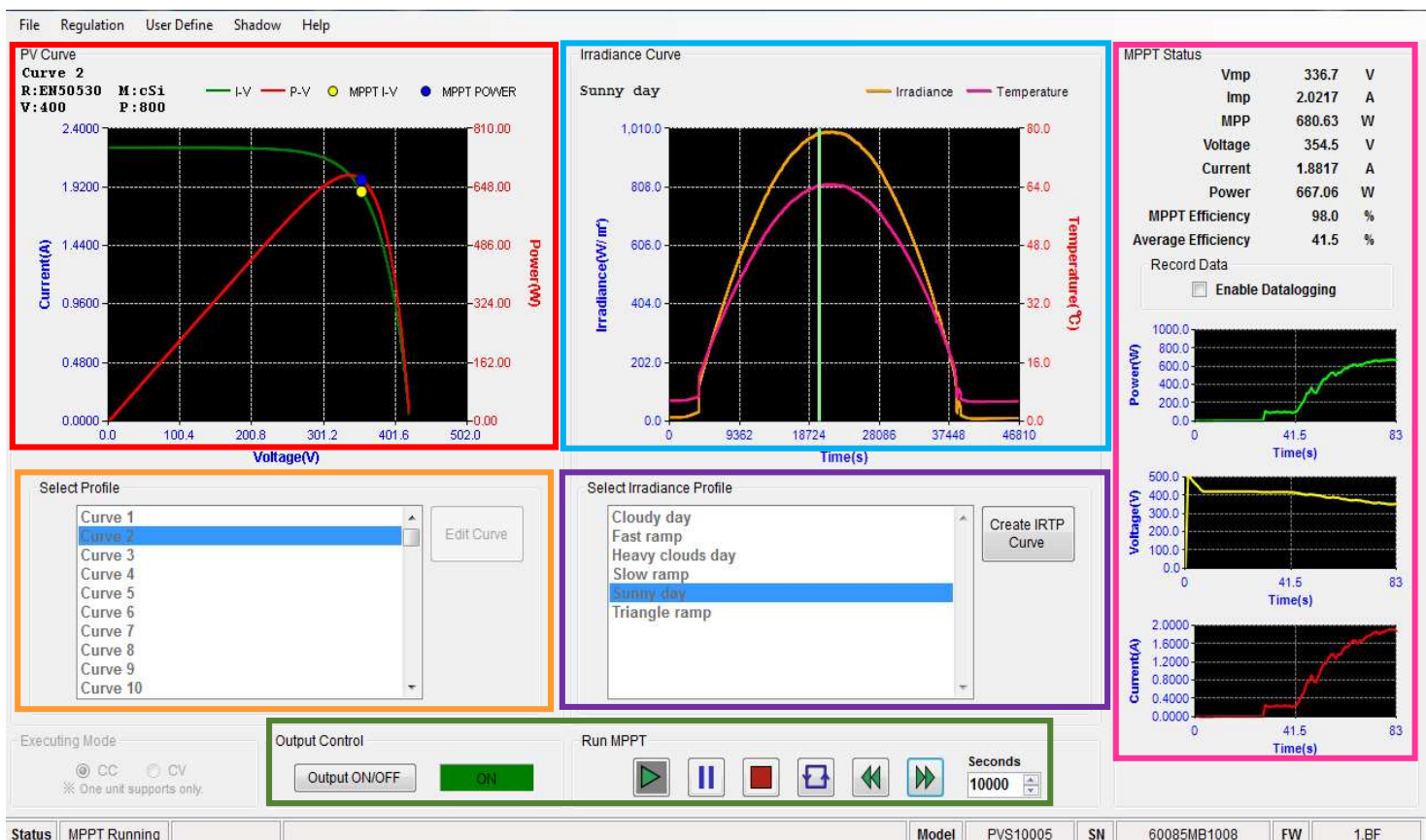


Figure 3 – PVS Dashboard

EXAMPLE

1. **Curve 2** and the **Sunny Day** irradiance profiles are selected. Irradiance and the output voltage of a panel are directly related. The curve profile determines the current associated with different voltage levels of a panel.
2. The irradiance profile defines total irradiance over a period of time. The “Sunny day” irradiance profile simulates a clear day with no shadows from sunrise to sunset.
3. The Output can be turned ON by clicking the **Output ON/OFF** and the **Green Arrow** button is used to start running the MPPT.
4. As time passes, the green line on the irradiance/time graph will move towards the right through the time axis.
5. Observe that as time passes, the power increases with the irradiance, the voltage decreases and the current increases.
6. In the PV curve graph, the green line represents the current output at a given voltage for the simulated panel. The red line represents the power output at a given voltage.
7. The blue and yellow dots represent the maximum power (MPP) output at the momentary voltage of the panel.
8. In the above example, at the current level of irradiance, the yellow dot on the IV curve is around 354V and 1.88A. The blue dot on the PV curve is at around 354V and 680W.

Creating Curves and Profiles

CREATING AN IV CURVE

1. The user can generate a customized IV curve according to specific standards: EN50530, SANDIA, NB/T32004. In the Profile Section, the **Edit Curve** button opens the Curve Config Popup window.

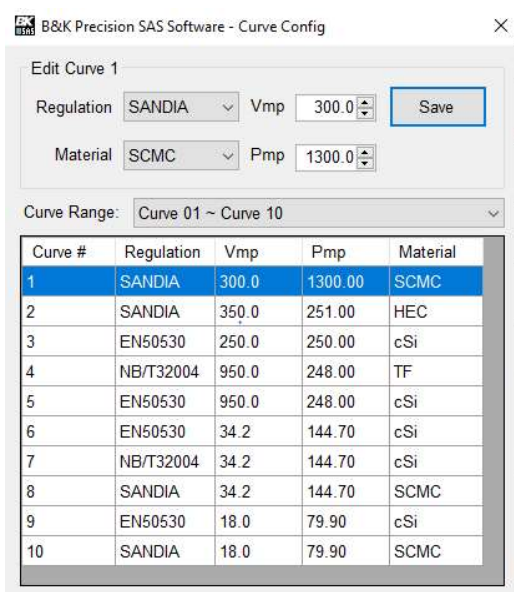


Figure 5 – Curve Config Popup Window

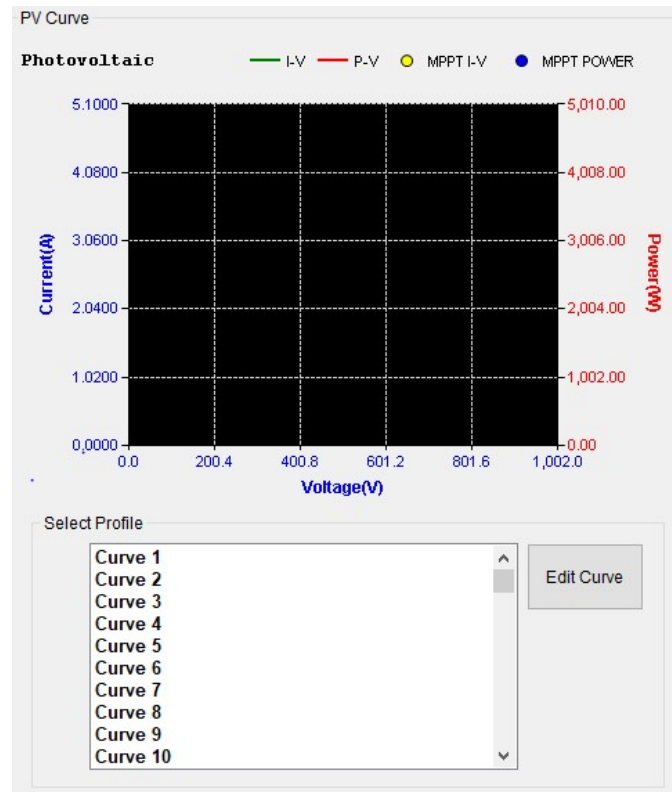


Figure 4 – Edit Curve Section

2. In Curve Config window, the selected curve is the one which will be edited. The range of curves shown can be changed via the **Curve Range** dropdown menu.
3. Editing the curve allows the following parameters to be changed:
 - **V_{mp}** | Maximum Voltage Point – This determines the voltage point (x-axis) at which the MPP will be located.
 - **P_{mp}** | Maximum Power Point – This determines the power point (y-axis) where the MPP will be located and determines the I_{mp} (y-axis).
 - **Material** – The material of the simulated panel changes the curve, different panel materials have different characteristics.
 - **Regulation** – The regulation determines the base IV curve, which is then modified by the material.
4. The **Save** button will save the curve to the PVS.

EXAMPLE

Below are some example curves created according to the specification of real solar panels.

JKM215M-72 by Jinko Solar (Figure 6)

VMP = 34.2

PMP = 144.7

Material = CSi

Curve 6 = En50530

Curve 7 = NB/T32004

Curve 8 = Sandia (SCMC)

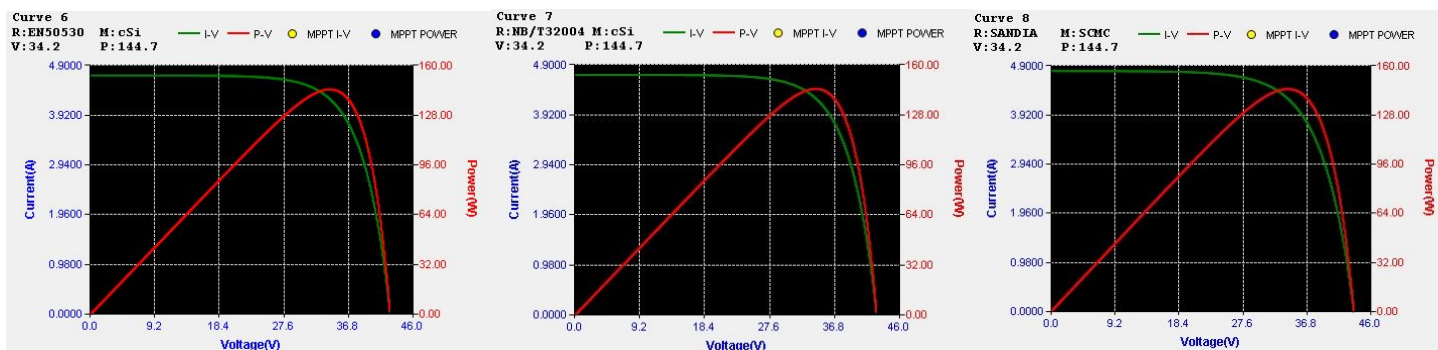


Figure 6 – Curves 6, 7, and 8. (Left to Right)

Generic Panel (80W) (Figure 7)

VMP = 18

PMP = 79.9

Material = CSi

Curve 9 = En50530

Curve 10 = Sandia (SCMC)

Curve 11 = NB/T32004

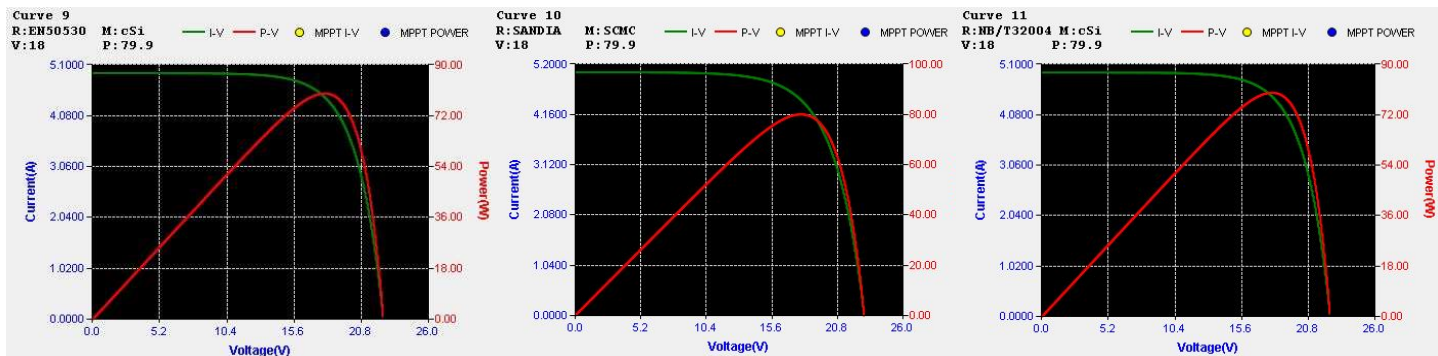


Figure 7 – Curves 9, 10, and 11. (Left to Right)

PowerFlex+ by Global Solar (Figure 8)

VMP = 93.2

PMP = 307.6

Material = TF

Curve 12 = En50530

Curve 13 = Sandia (SCMC)

Curve 14 = NB/T32004

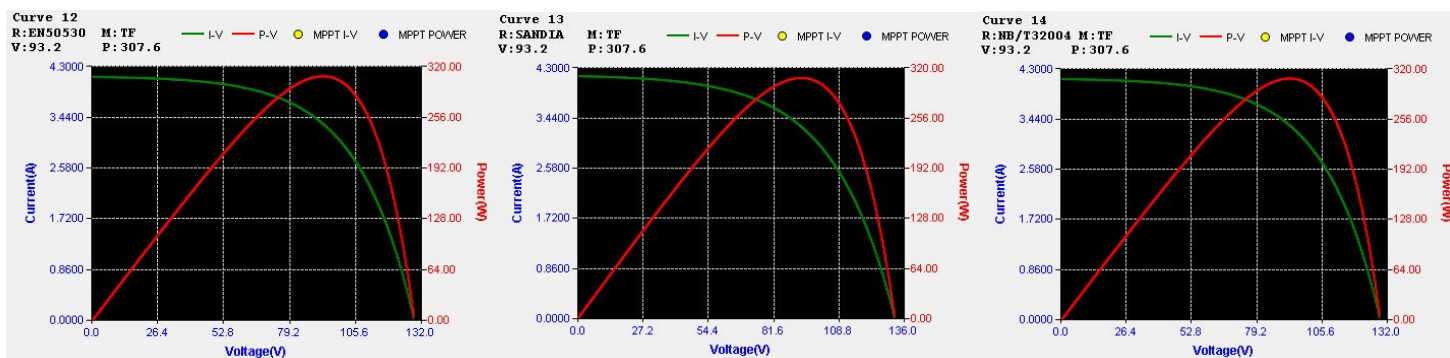


Figure 8 – Curves 12, 13, and 14. (Left to Right)

CREATING AN IRTP CURVE

There are two methods to create an IRTP Curve. One way is to create an IRTP file and save it in the install directory of the SAS software and the other way is to use the included IRTP creation tool.

1. IRTP Creation Tool

An IRTP curve can be created by navigating to the Irradiance Profile section (Figure 9) and selecting the **Create IRTP Curve** button. Random Day and Random Day 2 are some examples of a user defined IRTP Curve.

In the Create Irradiance and Temperature Curve popup window (Figure 11), it is possible to specify the following for each individual step:

- Irradiance – The amplitude of irradiance of the step, up to 1000 W/m².
- Temperature – The ambient temperature of the step
- Execution Time – The amount of time the step takes. *NOTE: Total execution time must be a minimum of 60 seconds.*
- Irradiance Slope – This is the rate of change of the irradiance amplitude per second of executing time.
- Temperature Slope – The rate of change of temperature per second of executing time.

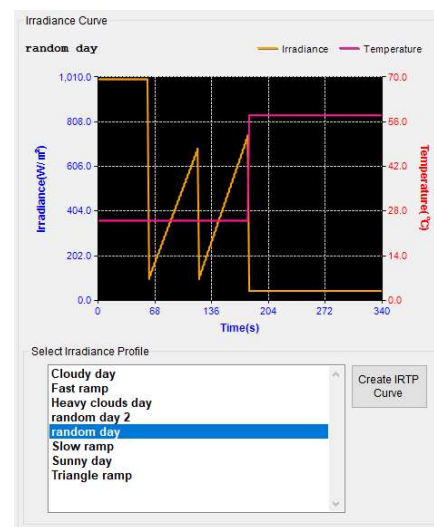


Figure 9 – Irradiance Profile

B&K Precision SAS Software - Create Irradiance and Temperature Curve

File Name:

Setting

Irradiance (W/m²) Irradiance Slope (W/m²/sec)

Temperature (°C) Temperature Slope (°C/sec)

Executing Time (Sec)

Irra. Slope	Irra.	Temp. Slope	Temp.	Sec

Figure 11 - Create Irradiance and Temperature Curve PopUp Window

File Name:

Setting

Irradiance (W/m²) Irradiance Slope (W/m²/Sec)

Temperature (°C) Temperature Slope (°C/Sec)

Executing Time (Sec)

	Irra. Slope	Irra.	Temp. Slope	Temp.	Sec
X	50	500	2	25	6
X	-20	800	1	37	10
X	-5	600	-0.5	47	30
X	-2	450	-0.5	32	30

Figure 10 – Example Curve

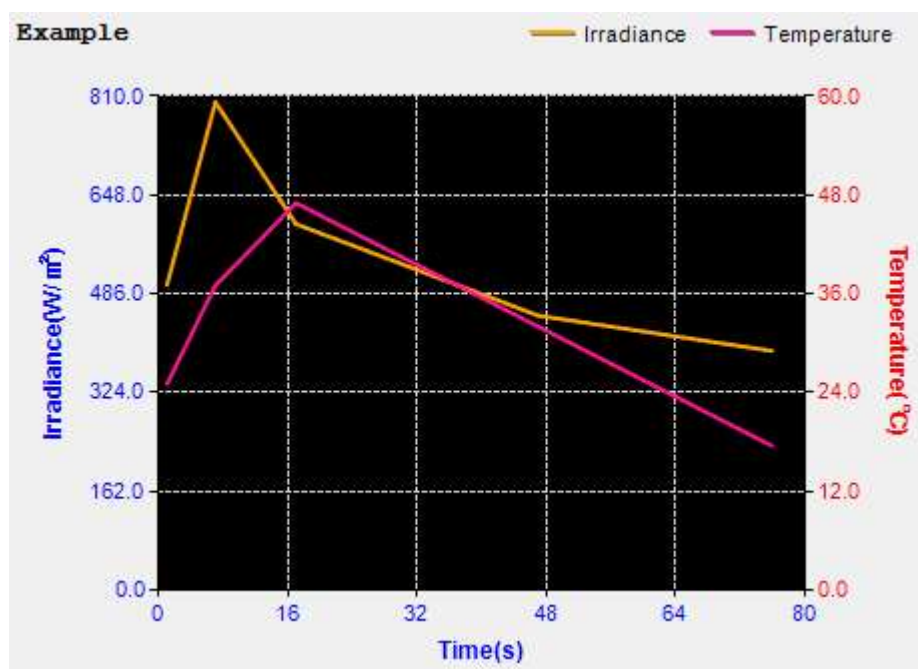


Figure 12 - Example Curve Graph

2. User Created File

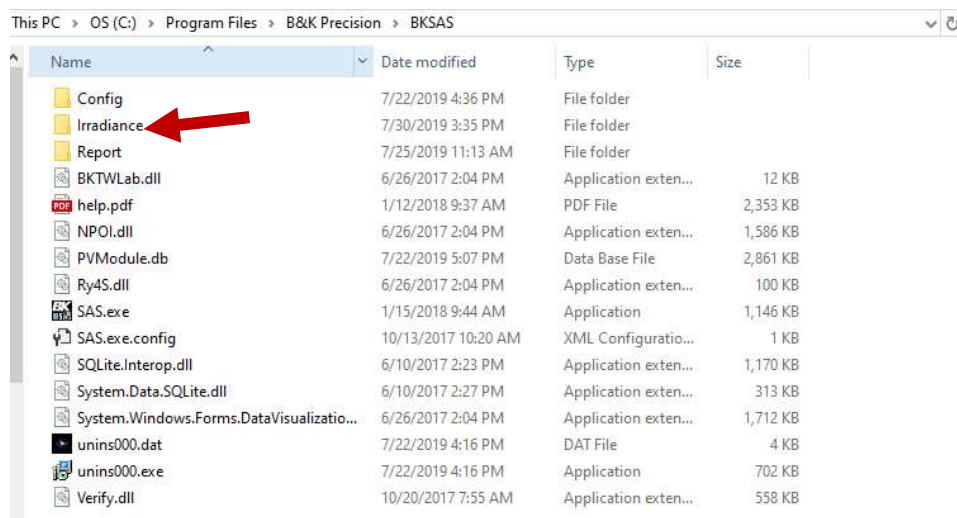


Figure 14 - Navigating to the Irradiance Folder

1000	25
1000	25
1000	25
1000	25
97	25
107	25
117	25
127	25
137	25
147	25
157	25
167	25
177	25
187	25
197	25
207	25
217	25
227	25
237	25

Figure 13 – Example File

1. The user-created IRTP file can be created from a text document by navigating to the SAS software installation directory, and then to the Irradiance folder as shown in Figure 14.
2. A text document has to be created which must follow the required format: There are two columns, irradiance and temperature. These values should be separated by tabs. Each row represents a second in the irradiance curve. Figure 13 is an example of a file created following the format.
3. The irradiance curve must be a minimum of 60 rows (60 seconds). A finished file should be saved with an .IRTP extension. A saved curve appears in the irradiance curve list automatically, failing which the software can be restarted.
4. The folder consists of other IRTP curves that can be viewed and edited. This functionality does not currently exist in the software itself.

Setting Up a User-Defined Profile

A .CSV file can be created with two columns and at least 128 rows. The first column represents voltage and the second column represents current of the customized curve. Each row is a point on the curve. As mentioned before, the minimum points required to have a customized curve is 128 points and the maximum number of points is 4096 points.

- To create a user-defined profile, the **User Define** option must be selected from the top left of the SAS software dashboard.
- A new window called User Define Test appears.
- The **P-V graph**, **Output Controls**, **MPPT Status** and **Run MPPT** in this window are similar to the ones found in the SAS dashboard (found in Figure 3). **Data load** option is used to upload the user defined data points in a CSV file.
- The **Curve Data** section holds the value from the loaded data set. V_{oc} , I_{sc} , V_{mp} , I_{mp} and P_{mp} are calculated based on the values provided by the user. The definitions of the above parameters can be found in page 2.
- To load a User-Defined profile, a data set in a CSV file (comma separated) must be created. This can also be done in a spreadsheet (as shown in Figure 15) and exported as a CSV. *NOTE: It should be verified that the value of the voltage and current are within the range, so that the inverter could operate correctly.*

	A	B
1	0	4
2	3	3.942
3	6	3.884
4	9	3.826
5	12	3.768
6	15	3.71
7	18	3.652
8	21	3.594
9	24	3.536
10	27	3.478
11	30	3.42
12	33	3.362
13	36	3.304
14	39	3.246
15	42	3.188
16	45	3.13

0,4
3,3.942
6,3.884
9,3.826
12,3.768
15,3.71
18,3.652
21,3.594
24,3.536
27,3.478
30,3.42
33,3.362
36,3.304
39,3.246
42,3.188
45,3.13

Figure 15- data set in a spreadsheet

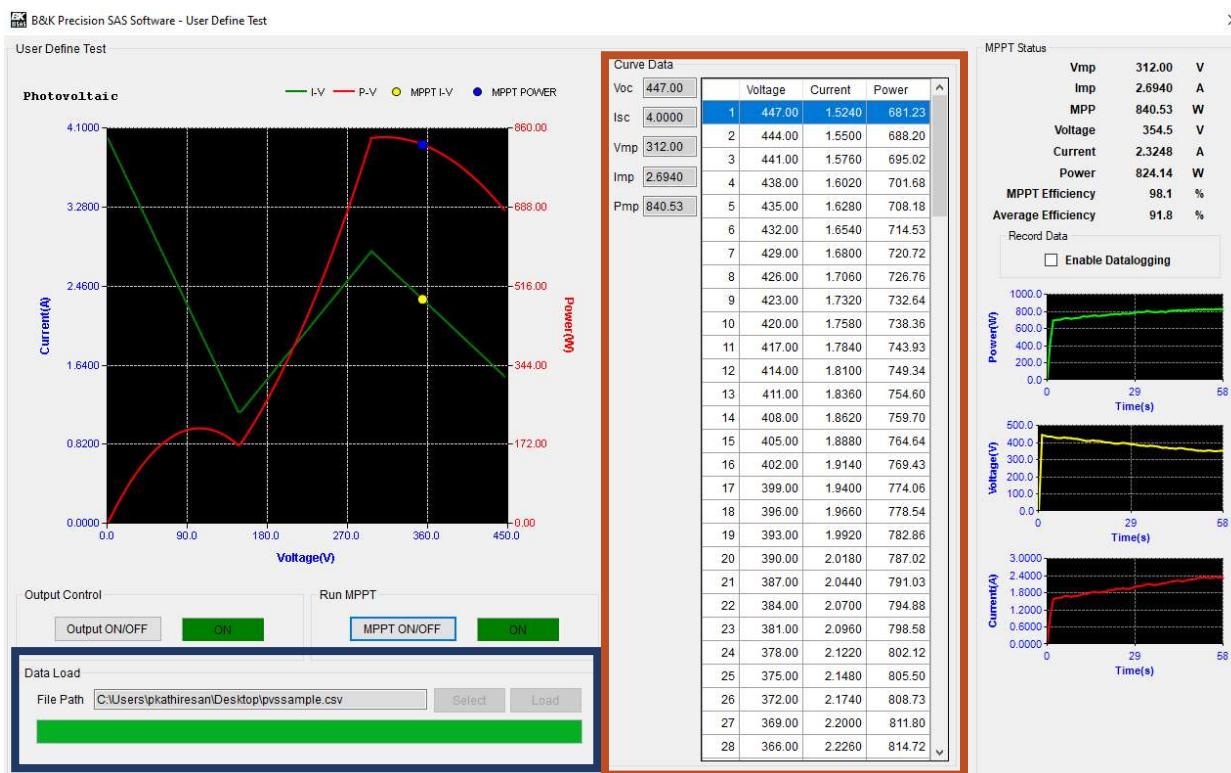


Figure 16- User Define Test

EXAMPLE

1. To load the data file, the **select** button must be clicked, the .CSV file stored with the specified syntax should be navigated to and uploaded.
2. The Output can be turned On by clicking the **Output ON/OFF** and the **MPPT ON/OFF** button is used to start running the MPPT.
3. In the PV curve graph, the green line represents the current output at a given voltage for the simulated panel. The red line represents the power output at a given voltage.
4. The blue and yellow dots represent the maximum power (MPP) output at the momentary voltage of the panel.
5. The MPP for both the curves are maintained at the highest power value within the voltage limits of the inverter.
6. In the example, the point of peak power is at around 300V. However the operating voltage of the inverter used in this example is 350V to 600V. As such, the MPPT will find the point of highest power within that range. Because the curve only slopes down from 300V, the point of highest power is therefore 350V.

Regulations

There are three types of regulation standards that can be used to generate I-V curves: EN50530, SANDIA, NB/T32004. The regulations are relatively similar and are common standard testing procedures for MPPT efficiency.

STEPS TO CONNECT: (FOR EN50530, SANDIA and NB/T32004)

- The **regulation** option from the drop down toolbar menu in the SAS software dashboard should be chosen. This is shown in Figure 17.
- The dropdown menu consists of three different regulation and one of them can be selected. A new box opens up for the options chosen respectively.
- A few parameters have to be adjusted for each regulation. **Maximum power (P_{max})**, **Material**, and the **waiting time before execution** is common for all the standards and it must be specified.
 - **Maximum Power (P_{max})** – P_{max} is the maximum power the PVS generator can output. *NOTE: P_{max} shouldn't go over the range the inverter could handle.*
 - **Material** – The material of the cells in the solar panel.
 - **Waiting time before execution** – The time the software takes before starting the simulation.
- The configuration can be saved by choosing the **save Config** button. The output can be enabled by pressing **Output ON** button and the **executing time** section will show the runtime of the simulation.
- The P-V graph and the MPPT Status in this window are similar to the ones found in the SAS dashboard (found in Figure 3).
- Two types of simulation (**static, dynamic**) can be chosen. Each simulation requires a different set of parameters to be filled.

STATIC: (FOR EN50530, SANDIA and NB/T32004)

The static option lets the user change their desired power level percentage and the V_{mp} values any time during simulation (Figure 17). Changing the parameters allows the user to see the changes graphically as the MPP point fluctuates. The measured values are displayed in the MPPT status box, showing current, voltage, and power over time in a plotted graph.

- In the V_{mp} levels section, **V_{max} maximum value**, **V_{min} minimum value** and the **V_{nom} nominal value** of the voltages are taken as inputs from the user. This is used to set a range for the operating voltage of the PVS.
- The columns are separated by the different power level percentages and the rows are separated by the V_{mp} voltage settings on the left.
- The **power percentage** values should be chosen and aligned with the **V_{mp} Level values** desired. By default, an array of percentages are set: 5%, 10%, 20%, 25%, 30%, 50%, 75%, and 100%. These are the percentages of the maximum power. They can be changed by using the control arrow keys next to each entry box.
- **The Test time** can also be chosen from the menu, it shows the amount of time the simulation should run.

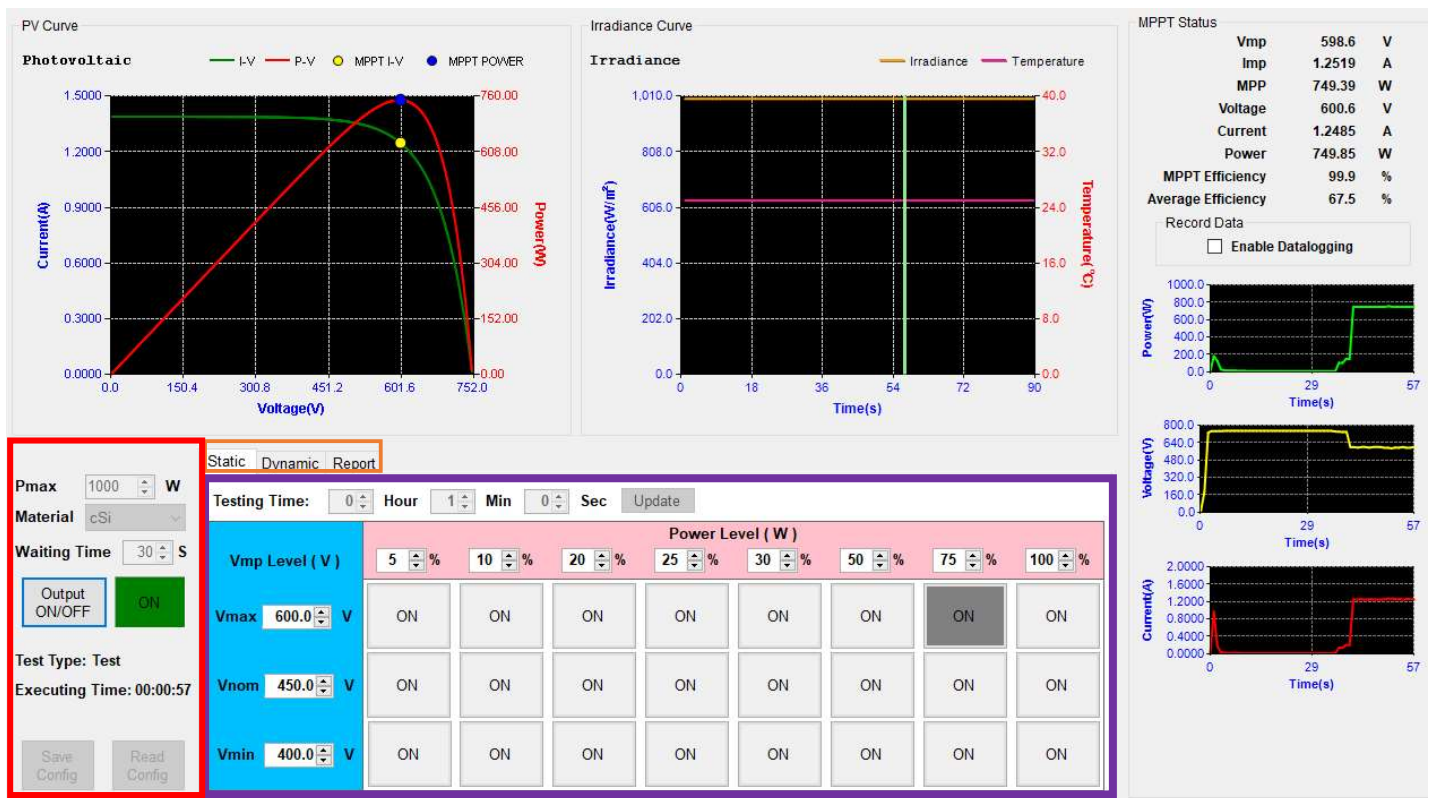


Figure 17- Static simulation

EXAMPLE

1. To create a static simulation, the inputs are provided by the user as shown in Figure 17.
2. The testing time is selected as per the requirement and **Update** button is pressed to save the changes made.
3. V_{max} , V_{nom} and V_{min} are specified to be 600V, 450V and 400V respectively, which means that the operating voltage of the PVS in this case is from 400V – 600V.
4. The power level percentage is selected as 75% which means that 75% of 1000W (P_{max}) is selected for this simulation.
5. The power level percentage (75%) is aligned with V_{max} , which shows that the power percentage is considered at that particular voltage, which is 600V in this case.
6. The **Save Config** button is clicked to save the present input parameters in a text file and the Output is ON which was done by clicking the **Output ON/OFF**.
7. In the PV curve graph, the green line represents the current output at a given voltage for the simulated panel. The red line represents the power output at a given voltage.
8. The blue and yellow dots represent the maximum power (MPP) output at the momentary voltage of the panel.
9. In the above example the MPP is at 750W which is 75% of 1000W and voltage value is at 600V as expected. The current value is 1.24A which is determined by the percentage ($P = V \cdot I$).

DYNAMIC: (FOR EN50530, SANDIA and NB/T32004)

The Dynamic mode lets the user choose a specific option with predefined values in them (Figure 18). The voltage value increases or decreases according to the irradiance curve. The percentage ranges limits the power to this specified range. The irradiance curve determines the voltage, the current value depends on the power value and voltage. Changing the range helps the user observe the changes graphically as the MPP changes in time. The measured values are displayed in the MPPT status box, showing current, voltage, and power over time in a plotted graph. The user should be able to extract the data as a plot or csv file and this feature is essentially a basic data logger.

- Dynamic testing allows the user to run tests through various sequences. The V_{mp} levels should be specified, but unlike Static mode, Dynamic mode lets the user choose only one base value for V_{max} .
- The user can choose three sub options from the menu. Each option specifies the percentage of power and has different graphs with Repetitions, slope, Ramp Up Time, Ramp Down Time, Dwell Time and Duration respectively.
 - **Repetitions** - The amount of times the simulation is repeated.
 - **Ramp Up Time** - This is the amount of time it takes for the particular curve to reach its peak.
 - **Ramp Down Time** - This is the amount of time it takes for the particular curve to reach its bottom or zero.
 - **Dwell Time** - The time intervals between the conclusion of one curve to the beginning of another curve.
 - **Duration** - The total time taken for a curve to be finished.
- ENT50530 and NB/T32004 have three types of dynamic testing: 10% - 50% tab will test at that percentage range of the maximum power. Similarly, 30% - 100% tab will test at that range and 2-100 W/m² will run a Start-up and Shutdown test.
- SANDIA has three different types of dynamic testing: Slow Ramp (0-100%) tab will test at that percentage range of the maximum power with least repetition, Fast Ramp (10 - 80%), and Triangle Ramp (10-80%) are different tabs which tests at that percentage range of the maximum power.

EXAMPLE for ENT50530 or NB/T32004

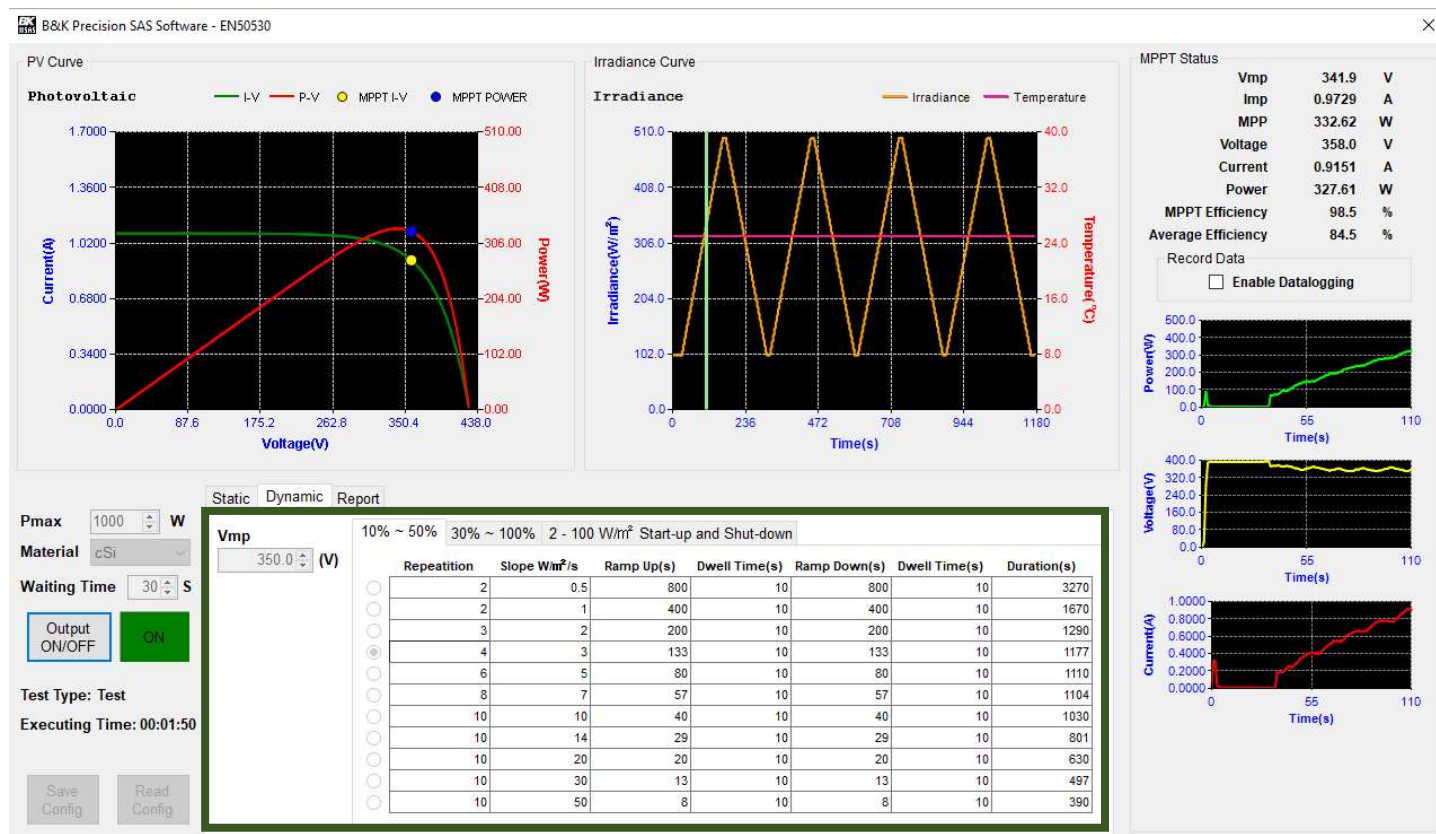


Figure 18- Dynamic simulation for ENT50530 OR NB/T32004

1. To create a dynamic simulation, the inputs are provided by the user as shown in Figure 18.
2. V_{mp} value is chosen as 350V, in this scenario V_{mp} is the maximum value the PVS can output.
3. 10% - 50% of maximum power is chosen as the range. Choosing this option maintains the P_{max} range from 100W to 500W.
4. The values of Repetition (4), Slope (3), Ramp up (133), Dwell time (10), Ramp down (133), Dwell time (10) and Duration (1177) are specified.
5. The **Save Config** button is clicked to save the present input parameters in a text file and the Output is ON which was done by clicking the **Output ON/OFF**.
6. In the PV curve graph, the green line represents the current output at a given voltage for the simulated panel. The red line represents the power output at a given voltage.
7. The blue and yellow dots represent the maximum power (MPP) output at the momentary voltage of the panel.
8. In the above example the MPP is at 332W which is 33% of 1000W and voltage value is at 358V as expected. As the green vertical line passes through the irradiance curve, the percentage of P_{max} is changed as per the curve and the corresponding results can be observed in the MPPT status section.

EXAMPLE for SANDIA

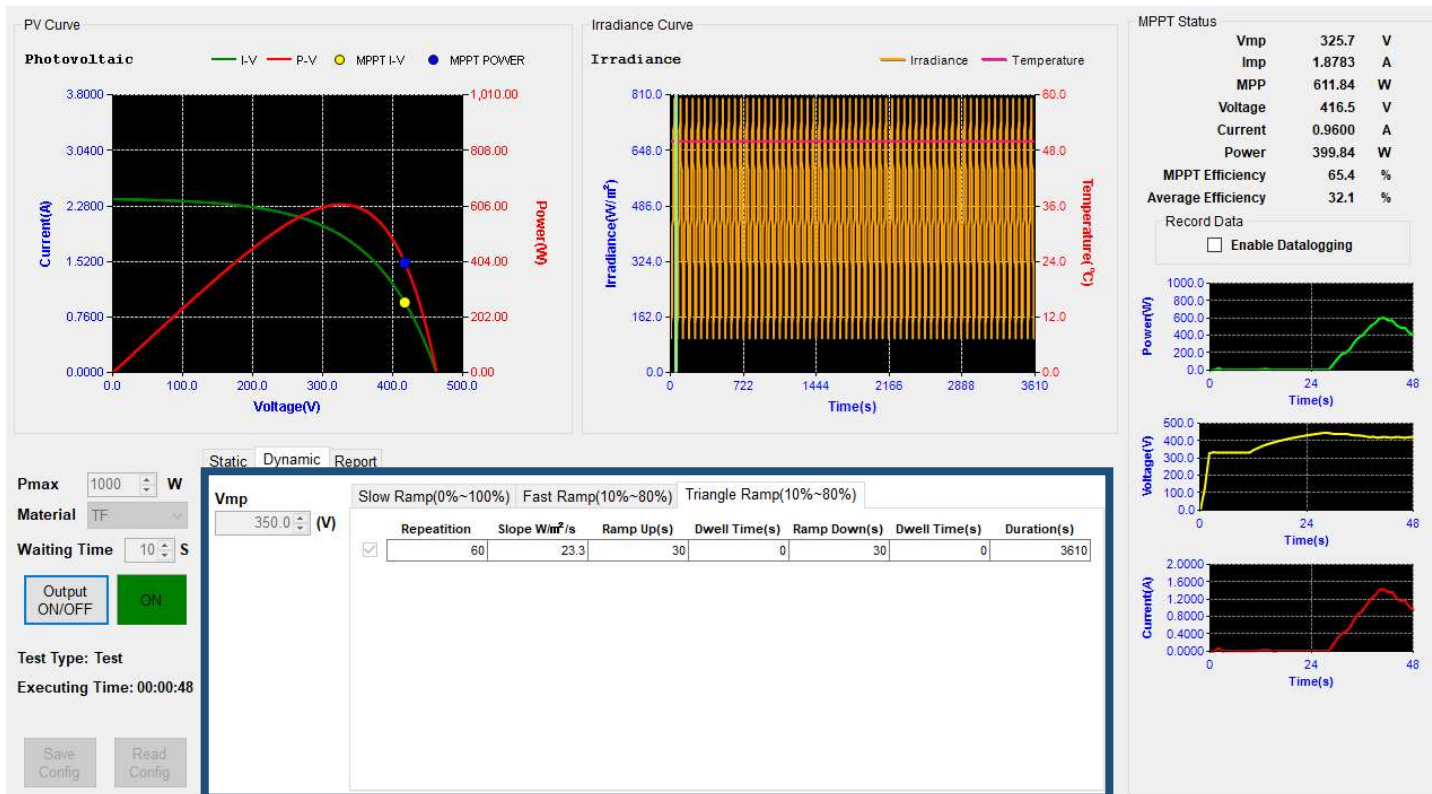


Figure 19- Dynamic simulation for Sandia

1. To create a dynamic simulation, the inputs are provided by the user as shown in Figure 19.
2. V_{mp} value is chosen as 350V, in this scenario V_{mp} is the maximum value the PVS can output.
3. Triangle Ramp 10% - 80% of maximum power is chosen as the range. Choosing this option maintains the P_{max} range from 100W to 800W.
4. The values of Repetition (60), Slope (23.3), Ramp up (30), Dwell time (0), Ramp down (30), Dwell time (0) and Duration (3610) are specified.
5. The **Save Config** button is clicked to save the present input parameters in a text file and the Output is ON which was done by clicking the **Output ON/OFF**
6. In the PV curve graph, the green line represents the current output at a given voltage for the simulated panel. The red line represents the power output at a given voltage.
7. The blue and yellow dots represent the maximum power (MPP) output at the momentary voltage of the panel.
8. In the above example the MPP is at 611.84W which is 61% of 1000W and voltage value is at 416.5V as expected. Since the repetition value is longer and ramp up and ramp down time are short the MPP values change faster.

REPORT: (FOR EN50530, SANDIA and NB/T32004)

Once the simulation is finished, the data from the simulation can be saved for future reference by choosing the **Report** tab. The Report tab is organized so that the desired kind of report can be generated. The Report is differentiated by material, percentage level and type of simulation as shown in Figure 20. Pressing the **Generate** option will start the report generation and **Stop** button stops the report generation.

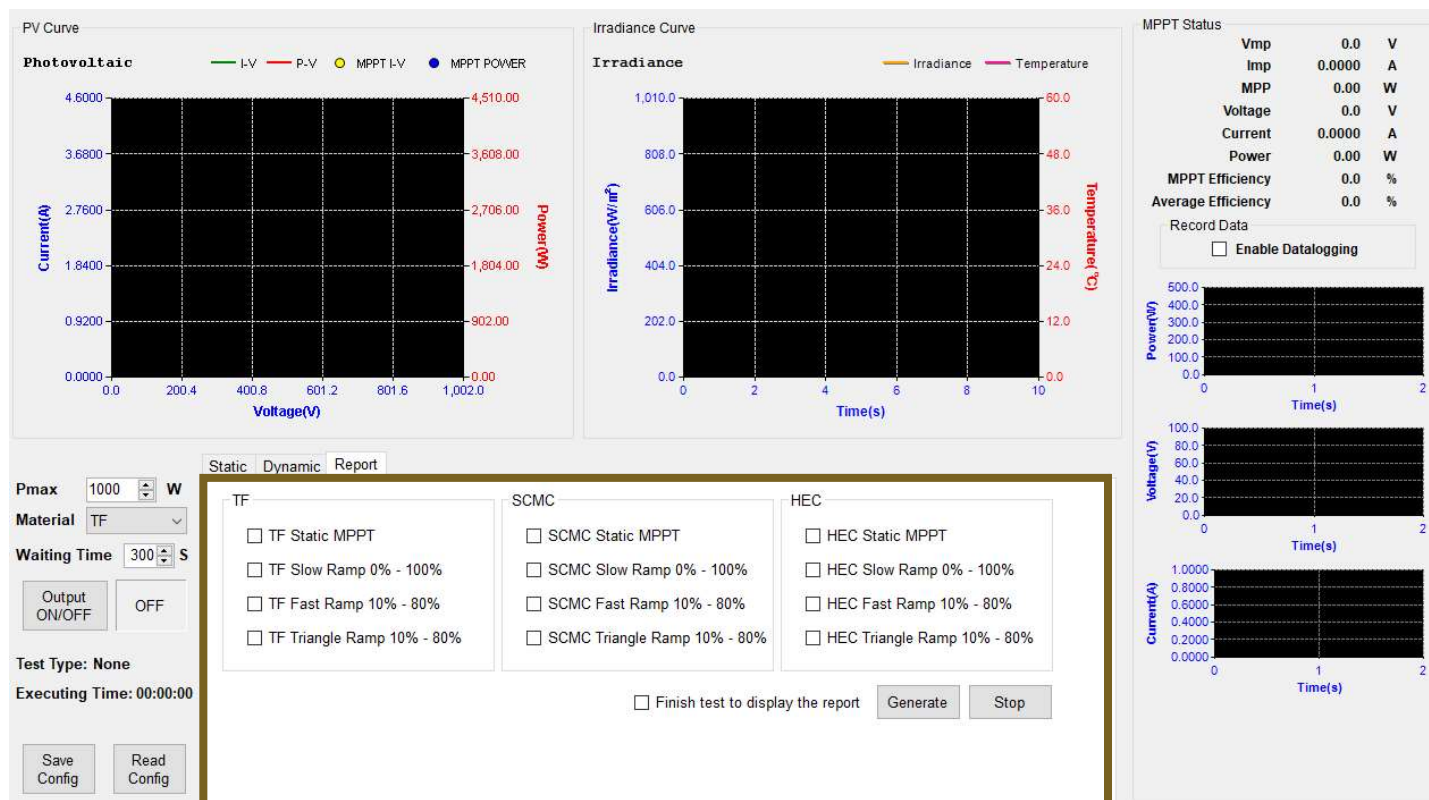


Figure 20- Report Generation

Shadow Simulation Setup

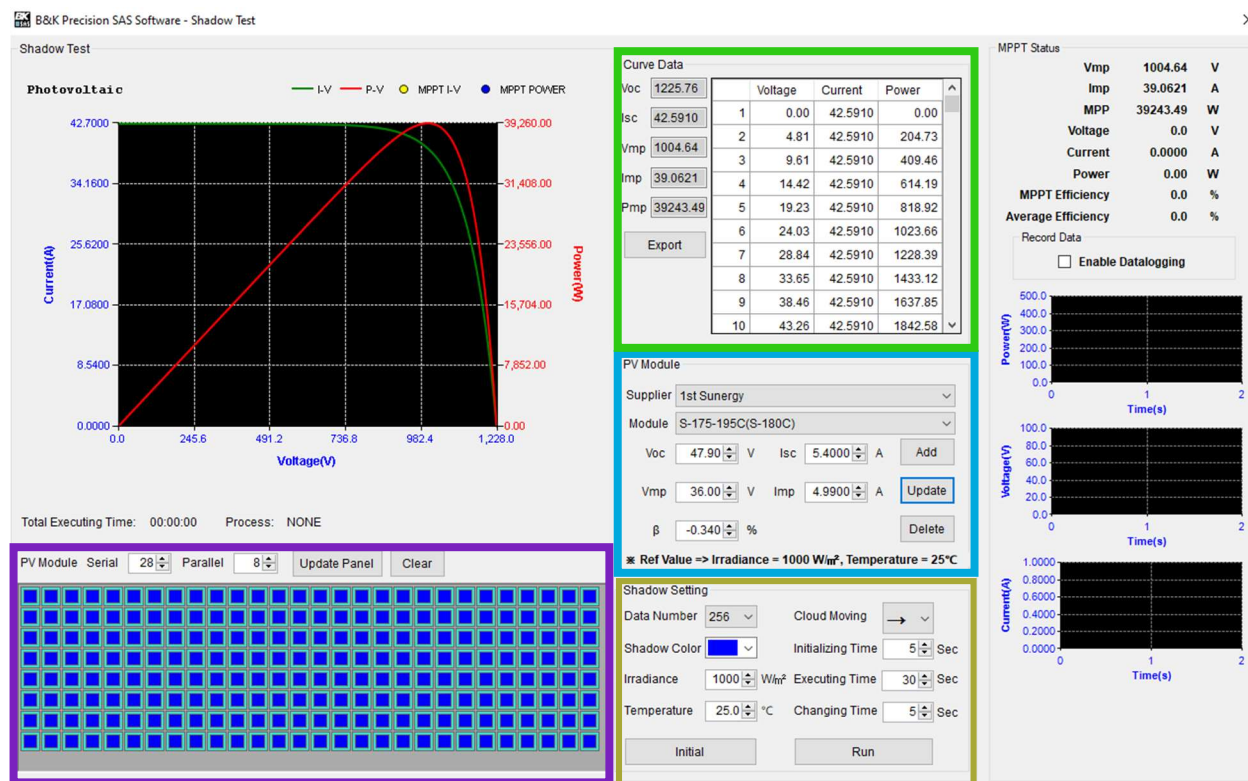


Figure 21- Shadow Simulation Menu

The shadow simulation function can be accessed by selecting Shadow option from the dropdown menu on the SAS software dashboard. A window similar to Figure 21 will appear.

- A PV Module should be selected before running the simulation. The PV Module settings can be changed by navigating to **PV Module section** and the parameters can be edited to load its IV profile. The PV module design can be chosen from the predefined modules. A new module can be created by pressing the **Add** button.
 - **Supplier**– The software already has a database of most major suppliers of PV modules with their PV specifications. Appropriate supplier of the PV- Module can be chosen by choosing the drop down menu.
 - **Module**– This is the model/product from the selected Supplier.
- The SAS software also allows the editing of predefined modules by changing the parameters, but the changes can't be saved.
- A custom PVS module can be created by specifying its parameters; Voc, Isc, Imp, Vmp and Beta (β). The definitions of the above parameters can be found in page 2.
- The **Update** button is used to update custom panel parameters.
- The **Delete** button is used to delete custom panels. *NOTE: The default PVS modules cannot be updated as they are predefined by the company and the software.*

- The PV module array is located in the **PV Array** section. The number of panels in series and parallel can be set. Shadows are also created in this location. The **Update Panel** button will update the graph with the currently selected PV module and the array.
- Clicking on one of the panels in the array will enable Drawing Mode. Moving the cursor around will draw shadows. The **Clear** button clears all drawn shadows.
- Settings effecting the simulation process are in the **Shadow Settings** section. In Shadow Settings, adjustable parameters are provided:
 - Data Number – The number of data points used to plot the graph. This affects the “Curve Data” and the graph.
 - Cloud Moving – This determines the direction the clouds are moving in the simulation.
 - Shadow Color – This option sets the color for the squares used to represent shadows. *NOTE: Default color is blue, the same color as having no shadow.*
 - Initializing Time – The amount of time between the PVS output being on and the simulation beginning to update. This is used in order to allow the inverter to start up before the simulation begins.
 - Irradiance – Base irradiance value, the actual irradiance value will be adjusted up and down according to all user defined parameters.
 - Executing Time – The amount of time between when the simulation begins and ends.
 - Temperature – Ambient temperature value, this determines simulated PV module efficiency according to its temperature coefficient.
 - Changing Time – The amount of time between simulation updates. Each update of the simulation will move the shadow in the user-defined direction by one square.
- Once shadows are drawn, the PV graph is updated via **Initial** button. The simulation is begun by selecting **Run**. *NOTE: Pressing the **Update Panel** button will reset all drawn shadows.*
- The **Curve Data** section holds the power, voltage, and current values for each data point. The number of data points is determined in the **Shadow Settings**. These values are calculated based on all user defined settings.
- The P-V graph and the MPPT Status in this window are similar to the ones found in the SAS dashboard (found in Figure 3).

EXAMPLE

The shadow simulation mode enables a specific situation to be defined, it will generate a PV and IV curve, and simulate it. Essentially, each parameter adjusted results in a new curve, whether slightly different or very different. This example begins at the shadow simulation screen.

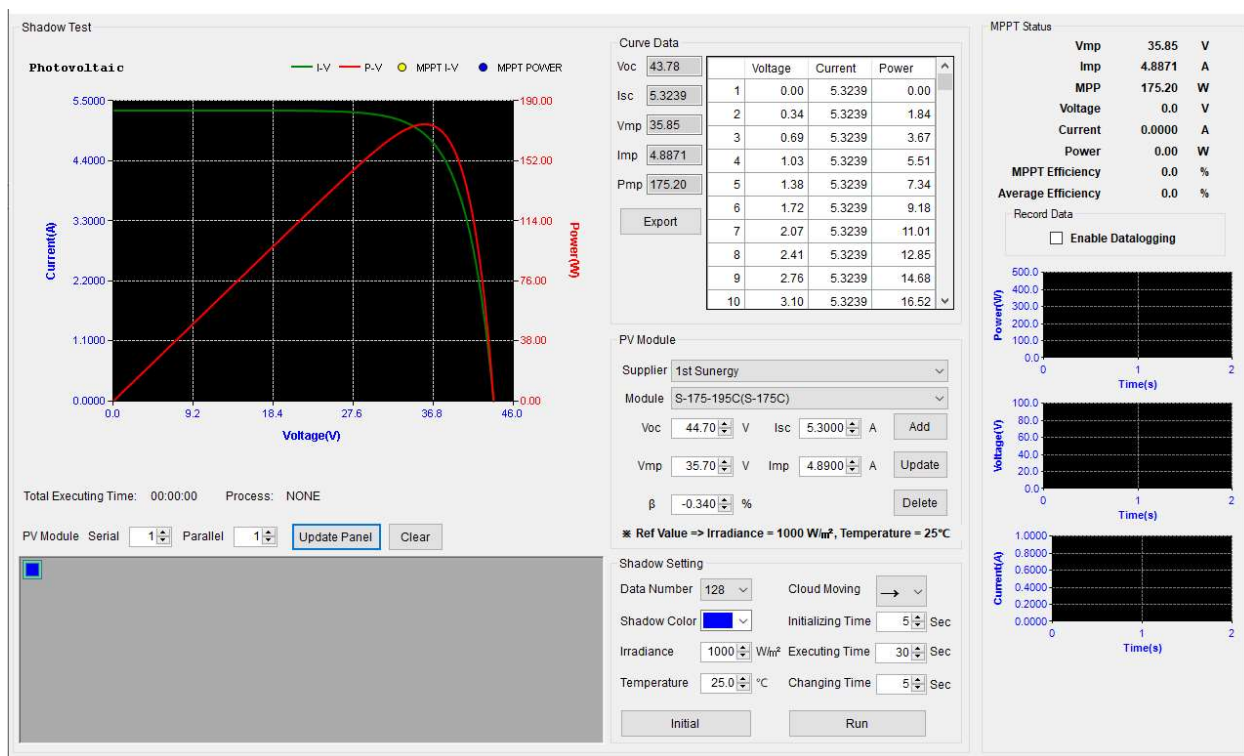


Figure 22 - Shadow Test Example

In order to model the array correctly, the following must be taken into account:

- The PVS10005 used in this simulation can output a maximum of 1000V, 5A, and 5kW.
- The inverter used in this example has a maximum operating voltage of 600V and a minimum operating voltage of 350V.
- The shadow simulation mode models an array which has panels in series and/or in parallel. When solar panels are in series, their voltages add up. When solar panels are in parallel their currents add up.
- The simulated array must be defined such that the maximum voltage, current, and power stay within the capabilities of the PVS and inverter.

Figure 23 – PV Module

1. The first step is to select a solar panel, in the PV Module Screen (Figure 23). Many solar panels have an I_{sc} and I_{mp} of 5A or more. Selecting such a panel would limit the array in this example to series-panels only. A panel with very low current parameters is ideal. The software can simulate up to 28 panels in series. A panel must be selected with a high enough voltage that at least 28 in series reaches the minimum operating voltage of the inverter. As such Aditi Solar Model: Aditi Mono (12V-10WP) is selected for the example. This panel has very low current parameters and good enough voltage parameters. The largest array that can be created with this panel is 7 strings in parallel ($0.61A * 7 = 4.27 A$) and 28 panels in series ($28 * 21.4V = 599.2$).

Figure 25 - Aditi Solar Panel

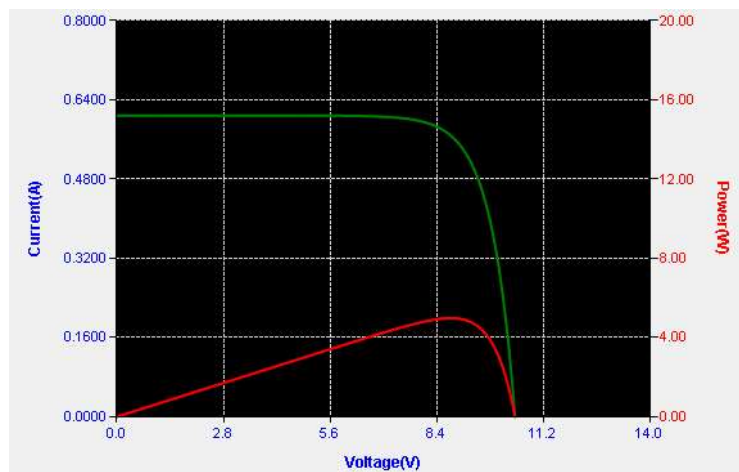


Figure 24 - Aditi Solar Graph 1

2. Selecting the **Update Panel** button under the graph automatically generates a graph (Figure 24).
3. The array must be created. For demo purposes, the largest array possible is created. This is twenty-eight in series and seven in parallel.
4. The panel is updated again to reveal a new graph.
5. The data points must be verified to be within range. This is done in the curve data section (Figure 28).

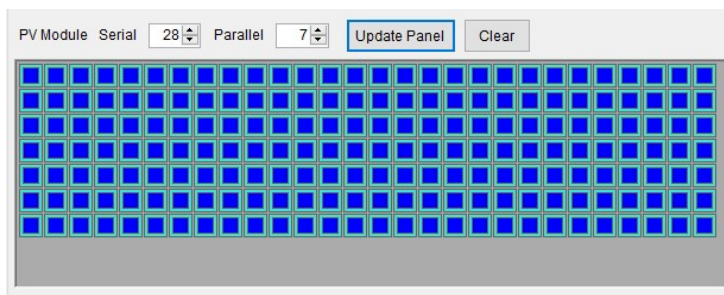


Figure 27 - Solar Array

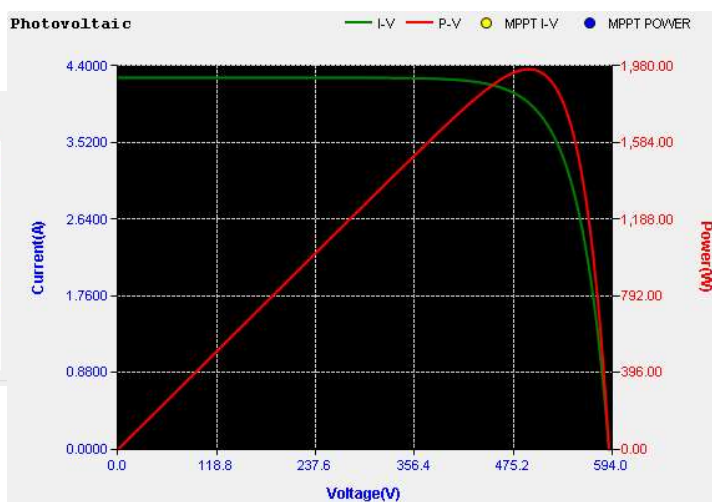


Figure 26 - Aditi Solar Graph 2

6. V_{oc} is a maximal voltage, when the current is at or near 0. I_{sc} is a maximal current, when the voltage is at or near 0. P_{mp} is a maximal power, when $V_{mp} * I_{mp}$ is maximum. We verify that V_{oc} and I_{sc} are within the range of the PVS and inverter.
7. A few parameters are adjusted in the shadow settings (Figure 30) before creating shadows. Namely cloud direction and timing parameters.
8. Shadows are made using the drawing tool (Figure 29).

Curve Data

	Voltage	Current	Power
Voc	590.05		
Isc	4.2658		
Vmp	492.48		
Imp	3.9857		
Pmp	1962.90		
1	0.00	4.2658	0.00
2	4.65	4.2658	19.82
3	9.29	4.2658	39.64
4	13.94	4.2658	59.46
5	18.58	4.2658	79.28
6	23.23	4.2658	99.10
7	27.88	4.2658	118.92
8	32.52	4.2658	138.74
9	37.17	4.2658	158.55
10	41.81	4.2658	178.37

Export

Figure 28 - Example Curve Data

Shadow Setting

Data Number: 128 Cloud Moving: [Arrow Icon]

Shadow Color: [Grey Box] Initializing Time: 10 Sec

Irradiance: 499 W/m^2 Executing Time: 3000 Sec

Temperature: 25.0 $^{\circ}C$ Changing Time: 20 Sec

Initial Run

Figure 30 - Example Shadow Settings

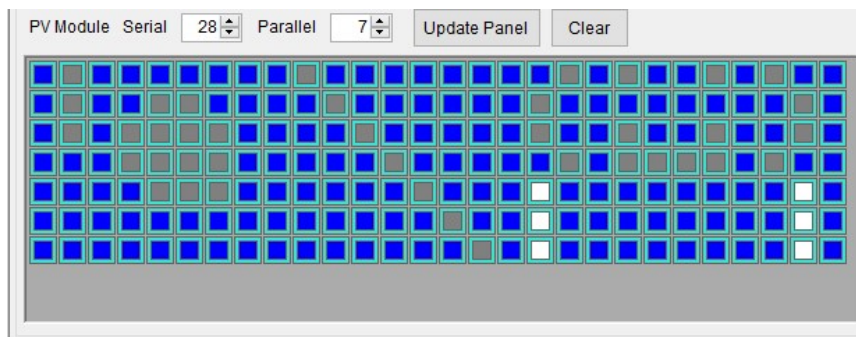


Figure 29 - Example Shadows

9. In order to see how the curves are affected by the shadows, the initial button is pressed. This results in the following, final curve (Figure 31).

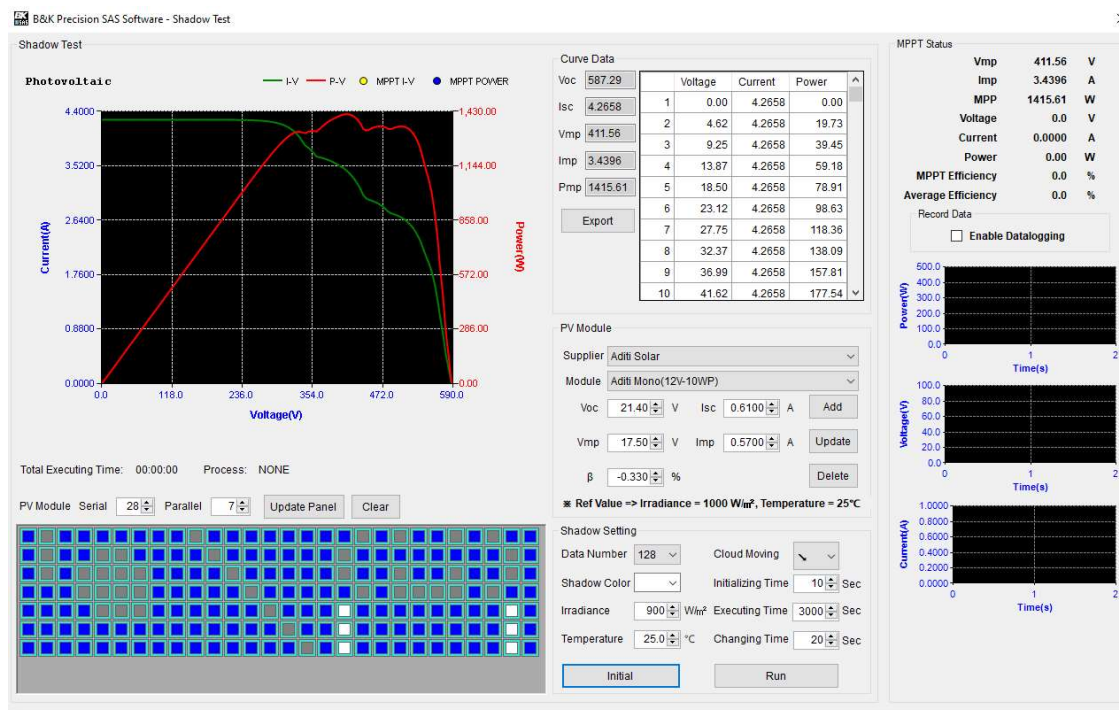


Figure 31 - Final Curve

10. The simulation is begun using the **Run** button ().

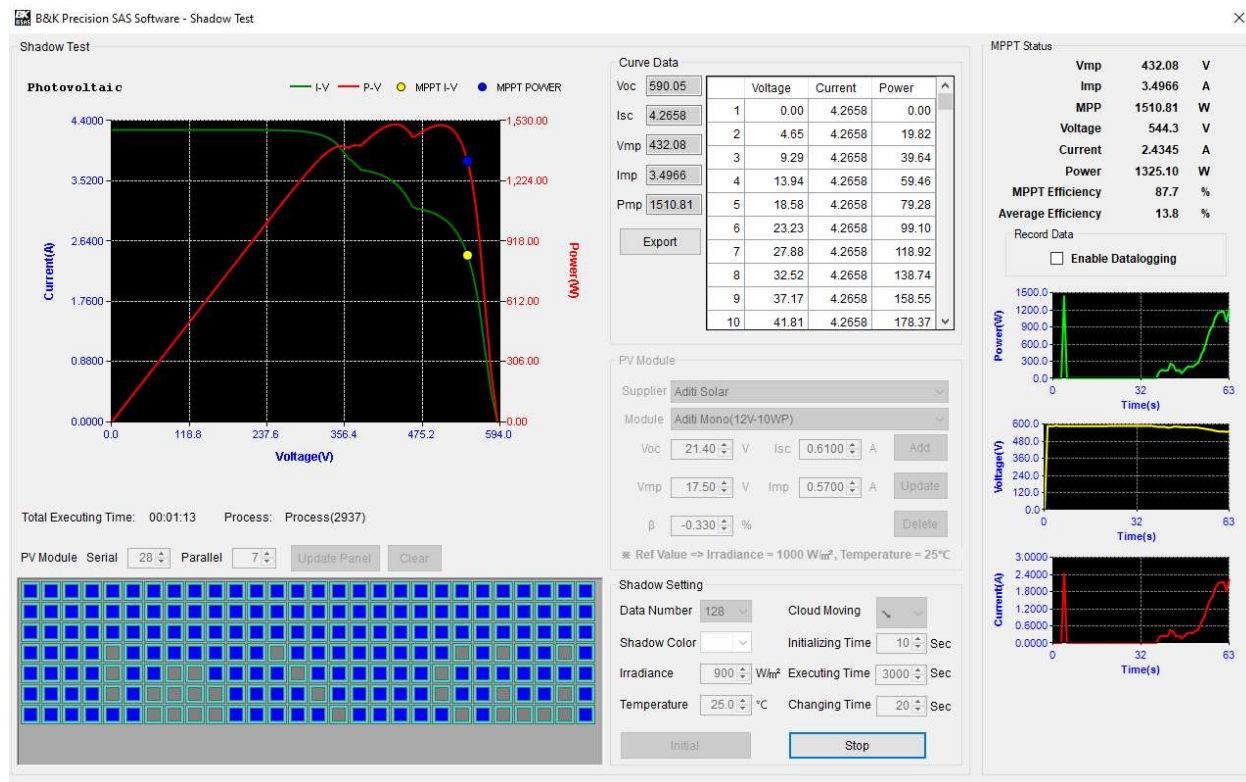


Figure 32 - Shadow Simulation Begins

As time passes the shadows will move, the MPP will change dynamically, and the MMPT will adjust the load accordingly.

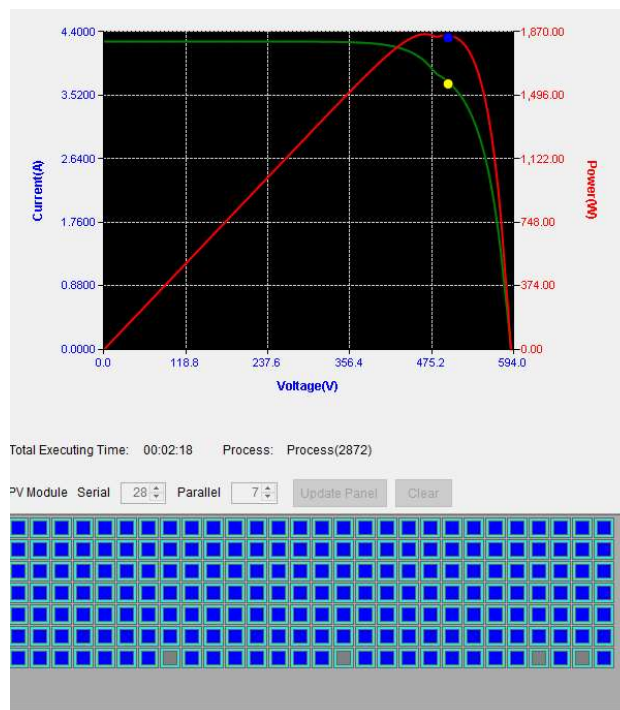


Figure 33 - Shadow Simulation at 2 Minutes

With the shadows leaving the graph approaches an ideal graph, in Figure 33, the shadows are mostly gone. However with those that are still there, the MPP is still not where it would be in the ideal graph.

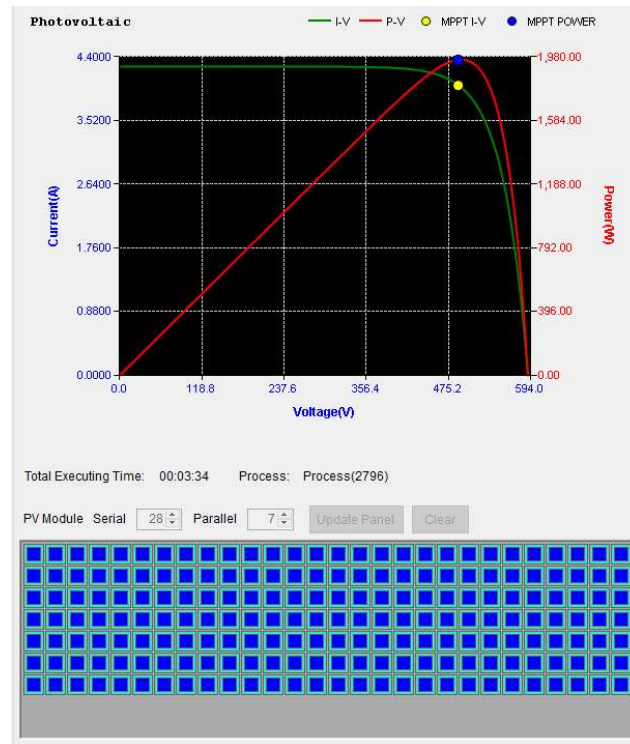


Figure 34 - Shadow Simulation Finished

With the last of the shadows, the graph in Figure 34 reaches an ideal. The MPP is ideal, and the MPPT goes to that point.