

Keysight Technologies

# Understanding the Importance of Maximum Power Point Tracking Efficiency for Solar Inverters

Application Note



Solar energy is a growing field. Photovoltaic (PV) arrays harness solar energy and convert it to electrical energy. One of the most popular ways of taking that electrical energy and converting it to AC Power that can run electronic devices, or be fed back to the power grid is to use a solar inverter.

Maximum power point tracking (MPPT) is one of the most important tasks performed by a solar inverter. A solar inverter uses a maximum power point tracking algorithm that continuously runs to seek out the maximum power point of the photovoltaic (PV) array power characteristic that is powering its input. A PV array has an output characteristic known as an I-V curve. The output of the PV array is constantly changing due to factors such as cloud coverage and temperature. This means that the I-V curve that is being input into the solar inverter is also changing. The maximum power point changes as the PV array power characteristic changes, so the MPPT algorithm needs to adjust quickly to remain efficient.

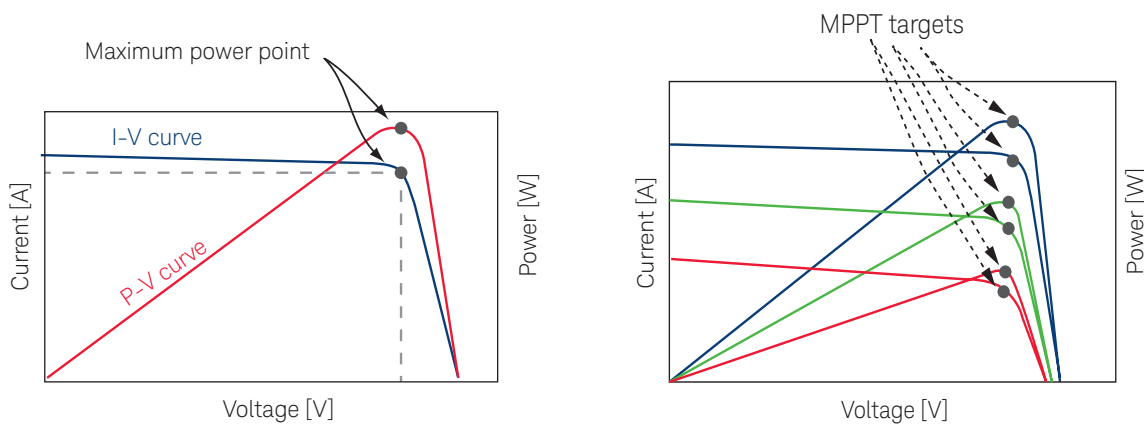


Figure 1. PV array output curves

Figure 2. Changing curves

In Figure 1, there are two curves shown. The curve titled I-V Curve is the output characteristic of a PV array. The P-V Curve is the power curve corresponding to the I-V curve. The maximum power point (MPP) on both curves is shown by the pointer. The MPP is where the solar inverter is providing the most amount of power for the I-V curve at its input. This is the most desirable and efficient place to operate. Figure 2 illustrates curves that are changing due to environmental factors such as solar irradiance and temperature. In this case, the MPP is going to change with the curves.

In simple terms, the MPPT algorithm continuously moves the point at which the solar inverter is operating in very small increments. It will move the operating point of the inverter along the I-V curve shown in Figure 1. If the PV Array delivers more power when it moves in a certain direction, the algorithm will continue in that direction until the power delivered starts to decrease. It will then operate as closely as possible to this point until there is another change in the input power to indicate that the MPP has changed. This process runs continuously at the rate of every few seconds to remain as efficient as possible.

To maximize solar energy usage from the PV array, the solar inverter needs to be operating at the maximum power point as often as possible. MPPT Efficiency is the metric that is used to determine this. In mathematical terms, MPPT Efficiency is the amount of power harvested by the solar inverter divided by the PV array's maximum potential power generation. Any potential power from the PV array that is not extracted by the solar inverter is wasted and cannot be recovered. A solar inverter with a low MPPT efficiency does not provide the best value to customers. It is important to note that MPPT Efficiency is different from conversion efficiency, which is the ratio of AC power out of the inverter to DC power into the inverter. Conversion efficiency is another important metric for a solar inverter.

Typically, when testing a solar inverter, using an actual PV array is unrealistic. PV arrays are large and their output is determined by factors such as sunlight exposure and temperature. The most practical way to test a solar inverter is to use a PV simulator which is a specialized power supply that mimics the output of a PV array. A PV simulator is fully programmable so different PV curves can be programmed by the user.

Keysight offers a 1,500 V/ 15 kW PV Simulator that also functions as an autoranging DC Power Supply. There are two models, N8937APV and N8957APV. The only difference between the two models is the input voltage; the N8937APV accepts 208 – 240 VAC while the N8957APV accepts 400 VAC. These PV simulators are specifically made to test devices that run on PV arrays at voltages up to 1,500 V. They can be easily paralleled to provide up to 150 kW of power.



Figure 3. N8900APV PV simulators

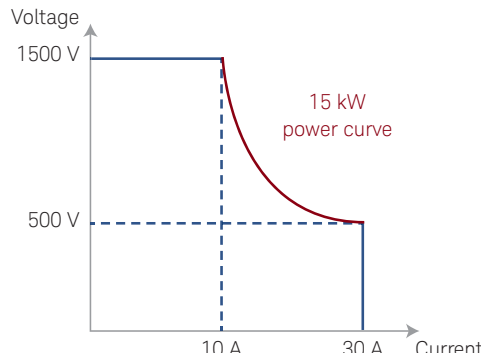


Figure 4. N8900APV autoranging output characteristic

Keysight offers SAS Control software that provides easy access to the features of the N8900APV. The software allows control of the power supply output, the ability to download custom I-V curves to the PV simulator, and an optional software upgrade to do automated MPPT Efficiency testing. One very useful feature of the software is that it graphically illustrates in real-time the operating point of the PV inverter with respect to the true MPP as shown in Figure 5.

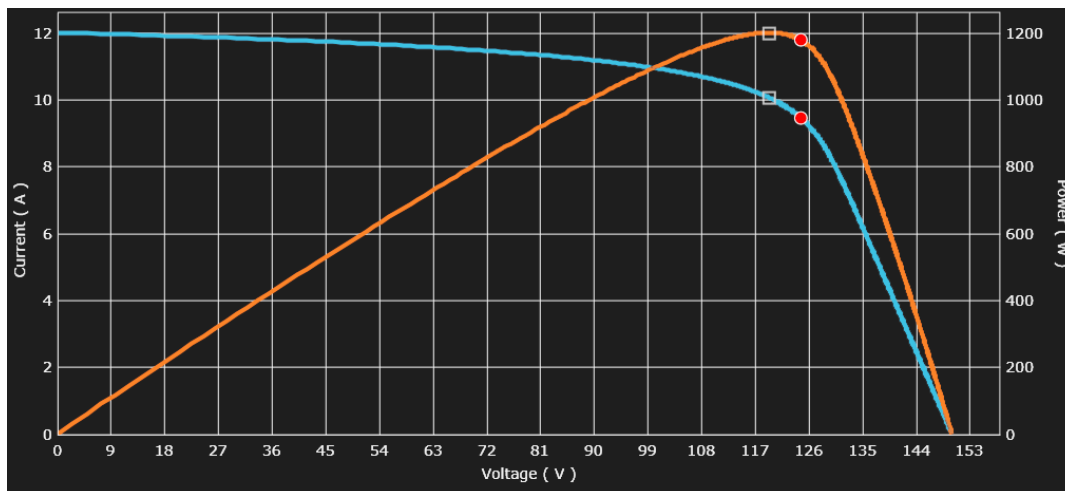


Figure 5. SAS Control Software Displaying MPPT

In Figure 5, the blue curve is the I-V curve that the PV simulator is simulating, the orange curve is the power curve (also known as the P-V curve), the two small boxes represent the MPP, and the red dots are the operating point of the solar inverter. In the graph above, the unit has not settled on the maximum power and is still seeking it out.

In terms of MPPT Efficiency testing, the Keysight SAS Control Software can perform pre-compliance tests to the EN50530 standard. The EN50530 standard contains a set of tests that determine how efficiently a solar inverter tracks the MPP of both static and dynamic I-V curves. EN50530 is a widely accepted standard in the solar inverter industry. Having an automated program to perform the MPPT Efficiency testing is necessary because these tests take a very long time to complete. A full Static MPPT Efficiency test can take up to six hours and a full Dynamic MPPT Efficiency Test takes just over seven hours. The software also allows custom MPPT Efficiency tests for test points that are not covered by the standard.

Vmp (V)	<input checked="" type="checkbox"/> 5 %	<input checked="" type="checkbox"/> 10 %	<input checked="" type="checkbox"/> 20 %	<input checked="" type="checkbox"/> 25 %	<input checked="" type="checkbox"/> 30 %	<input checked="" type="checkbox"/> 50 %	<input checked="" type="checkbox"/> 75 %	<input checked="" type="checkbox"/> 100 %
1000	--	--	--	--	--	--	--	--
850	--	--	--	--	--	--	--	--
700	--	--	--	--	--	--	--	--

Figure 6. SAS Control Software displaying static MPPT Efficiency test

From-To (W/m²)	# Cycles	Slope	Ramp Up (s)	Dwell High (s)	Ramp Down (s)	Dwell Low (s)	Duration (s)	MPPT Eff (%)	Prog
100-500	2	0.5	800	10	800	10	3540	--	
100-500	2	1	400	10	400	10	1940	--	
100-500	3	2	200	10	200	10	1560	--	
100-500	4	3	133.3	10	133.3	10	1447	--	
100-500	6	5	80	10	80	10	1380	--	
100-500	8	7	57.1	10	57.1	10	1374	--	
100-500	10	10	40	10	40	10	1300	--	
100-500	10	14	28.6	10	28.6	10	1071	--	
100-500	10	20	20	10	20	10	900	--	
100-500	10	30	13.3	10	13.3	10	767	--	
100-500	10	50	8	10	8	10	660	--	
300-1000	10	10	70	10	70	10	1900	--	
300-1000	10	14	50	10	50	10	1500	--	
300-1000	10	20	35	10	35	10	1200	--	
300-1000	10	30	23.3	10	23.3	10	967	--	
300-1000	10	50	14	10	14	10	780	--	
300-1000	10	100	7	10	7	10	640	--	
10-100	1	0.1	980	30	980	30	2320	--	

Figure 7. SAS Control Software displaying dynamic MPPT Efficiency test

The SAS Control software allows four types of I-V curves to be generated: a Keysight specific curve, a custom curve generated by the user, an EN50530 curve, and a Sandia curve. In order to execute an EN50530 test (either static or dynamic) the PV simulator will simulate an EN50530 PV curve. The PV Simulator firmware uses a mathematical formula to set its output to simulate I-V curves based on parameters entered by the user. When selecting a static MPPT custom test, any curve type can be used. When selecting a custom dynamic test, only the Sandia curve or the EN50530 curve can be selected. The software uses the built-in measurement system of the PV simulator to do the testing; no external equipment is required. When the test is set up, a measurement period is

specified. This is the rate at which the measurements for the test will be made. The lowest value that the measurement period can be set to is 15 ms. The instrument then measures the output. These readings can be set to be logged every measurement period. The readings that can be logged are:

- **VMP** – Maximum power voltage point
- **IMP** – Maximum power current point
- **PMP** – Maximum power point
- **Voltage** – Voltage as measured by the PV simulator
- **Current** – Current as measured by the PV simulator
- **Power** – Power calculated by the PV simulator
- **Meas Energy** – Calculated energy in Wh
- **MPP Energy** – Calculated MPP energy in Wh
- **MPPT Efficiency** – Calculated for each measurement period

Note that the instrument measures voltage and current simultaneously and then calculates the DC power by multiplying these measurements. This is how most power supplies *measure* power.

When the software does a static MPPT Efficiency test, the user inputs the details of their solar inverter and PV array so that the PV Simulator can correctly calculate the curve. The user also inputs:

- **PMP** – The maximum power of the PV array being simulated
- **Vmp (max)** – The maximum voltage that the PV array is rated for
- **Vmp (nom)** – The nominal voltage that the PV array is rated for
- **Vmp (min)** – The minimum voltage that the PV array is rated for
- **Tech** – The technology of the PV array (can be crystalline silicon (C-Si) or thin-film)
- **Setup time** – Time to wait for the solar inverter to stabilize before beginning any testing

The default setup time is 300 s (which is the maximum wait time specified in the standard) but this can be changed by the user based on the requirements of their solar inverter. The solar inverter is tested at the maximum, minimum, and nominal Vmp values to cover the entire operating range. Different percentages of the Vmp are tested (from 5% to 100%) to cover a wide array of operating points. In total, there will be 24 different MPPT efficiencies calculated (see Figure 6 for the table). A simplified algorithm for the test is:

1. Wait for the solar inverter to stabilize per the specified setup time
2. Set to the first test point (5% of the maximum VMP)
3. Operate at that test point for the time specified by the standard while taking measurements every measurement period
4. Once the test time elapses, move to the next curve without disabling the output
5. Wait for the solar inverter to stabilize per the setup time
6. Repeat until all the test points are completed

Once all the data is collected, the static MPPT Efficiency is calculated per the standard for all 24 test points and written to the measurement report.

For the dynamic MPPT test, the user needs to input the PMP, VMP, Tech, setup time, and meas period for their hardware. The test follows the table in the standard, shown in Figure 7. There are 18 different steps that correspond to changing solar irradiance on the PV array (in  $\text{w}/\text{m}^2$ ) over different time intervals. Almost all are done for multiple cycles so there is a total of 136 tests performed. Reliably automating this test is key to saving time. When testing, the software:

1. Operates the unit at the initial curve
2. Waits for the solar inverter to stabilize per the setup time
3. Ramps up to the final curve
4. Waits the specified dwell time
5. Ramps down to the initial curve
6. Waits for the solar inverter to stabilize per the setup time
7. Repeats this until the number of cycles for the step are completed
8. Repeats the entire process for every step in the table

The unit collects the data in the same fashion as it does for the static test. The MPPT efficiency is calculated for each step. A final dynamic MPPT efficiency is calculated using each step at the end of the test.

The dynamic MPPT Efficiency test is more complicated than the static MPPT Efficiency test since it needs to actively change the PV curves. The software does this using the built-in scaling feature. Scaling allows the curve to be set to a percentage of the maximum voltage and current. The software will then output the scaled curve without disabling the output. For Dynamic MPPT efficiency, the I-V curves are required to change from an initial curve to a final curve over a specified time. Intermediate curves are calculated using scaling to meet the slope required. These curves are then output in sequence incrementally to change the curves to meet the timing requirement in a controlled way. The number of intermediate curves is dependent on the slope and the amount of time the curve needs to ramp.

When all the testing is completed, the software generates two files. The first file is the test report. The test report contains relevant information about the software, the instrument, and the test setup. The static MPPT Efficiency test report provides all the calculated MPPT efficiencies as well as the average efficiency for the entire test. The dynamic MPPT efficiency report gives the efficiency of each step, the average efficiency for the entire test per the standard, and the weighted California (CEC) and European (EU) average efficiency. The second file is a collection of all the data logged used to calculate the efficiencies. All this data is collected as the test runs and is available upon the conclusion of the test.

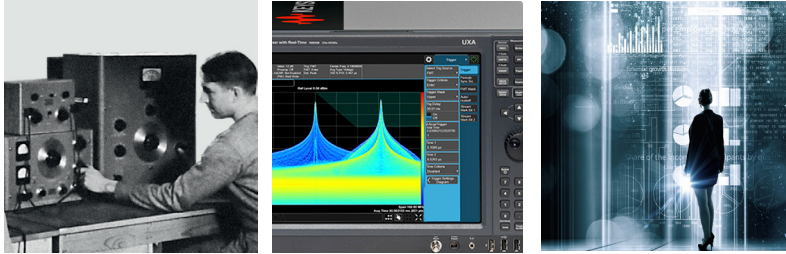
MPPT efficiency testing is a very important part of solar inverter testing. Keysight's solution for automating the testing will save time and effort. The user only needs to set the initial parameters and to set the test to run. The software will log all the measurements (per the standard) and generate the necessary measurement reports. Please contact Keysight about this solar inverter test solution or any other testing needs.



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