I-V Curves and PV Performance

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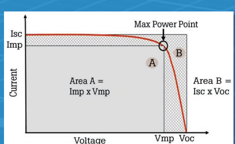
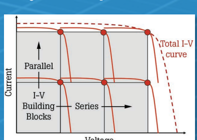
Basics

The I-V (current vs. voltage) curve represents all of the possible current and voltage 'points' at which PV module(s) could be operated or loaded, making it the most complete and detailed performance characterization available for PV modules and arrays. I-V curve tracing is the best choice for commissioning, auditing, troubleshooting, and providing evidence for module warranty claims.

I-V curve tracers measure the Short Circuit Current (Isc), Open Circuit Voltage (Voc), and all other points in between. They measure the true Maximum Power Point (Imp, Vmp) and Maximum Power value (Pmax), independent of the performance of the inverter and other strings in the array. Testing time and costs are minimized because the performance measurement requires only a single test, and the test can be performed without waiting for the inverter to be installed.



Definitions:
Isc = Short Circuit Current
Voc = Open Circuit Voltage
Imp = Current at Max Power
Vmp = Voltage at Max Power
Pmax = Maximum Power
Fill Factor = Area A/Area B
Performance Factor (%) = Measured Pmax / Predicted Pmax
Current Ratio = Imp/Isc
Voltage Ratio = Vmp/Voc



You can think of the I-V curve for an array as being made up of building blocks, where each building block is defined by the Max Power Points of the individual modules.

The cell groups within the module, each with a bypass diode, are also building blocks. Restrictions of current from external or internal causes impact the cell group's contribution to the overall I-V curve.

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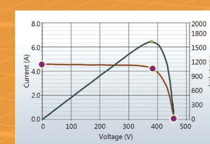
Measure

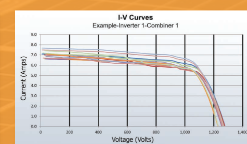
The Fluke I-V Curve Tracers are a complete electrical test solution for verifying PV array performance. The I-V Measurement Unit measures the I-V and P-V (power vs. voltage) curves of modules and strings, and the SolSensor measures the irradiance and module temperature at the same instant. The measured results are compared to the performance predictions of a sophisticated built-in PV model. The database of more than 70,000 modules is updated automatically when web connected. Wireless interconnections between the PC/tablet software, I-V Measurement Unit, and SolSensor save time and improve workplace safety. Data analysis and reporting are automated.

Commission

I-V curves are the preferred method for verifying array performance during the commissioning phase of a project. The measured I-V curve is compared with the performance predicted by a built-in PV model, which takes into account the irradiance and module temperature at the instant of the I-V measurement. The predicted I-V curve shape is shown by three red dots indicating the expected Isc, max power point, and Voc (see graph at right). The Performance Factor is calculated as the ratio of the measured Pmax to the predicted Pmax and provides a quick metric for PV string performance. I-V curves measured at commission time for each string are typically archived as a baseline that can be used for reference in future performance testing of the system.



Three dots represent the prediction of the built-in PV model. The power curve is shown in turquoise.



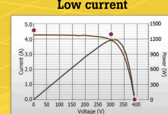
Populations of I-V curves are analyzed to identify outliers.

Troubleshoot

Deviations of a measured I-V curve from the ideal smooth curve or from the predicted Isc, Imp, Vmp, and Voc (three dots) give insight into the possible causes of performance problems. The examples to the right represent six classes of I-V curve deviation for a PV module or string. Deviations resulting from measurement setup such as sensor placement or model parameters in the software are marked wtih. (*)

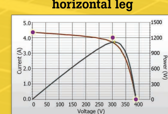
Isc
Pmax
P-V
I-V
Current
Voltage
Voc
Power

Low current



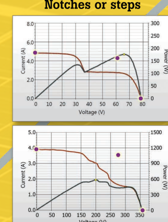
- Uniform soiling
- Band of shade or dirt extending across all cell groups
- Difference in irradiance between SolSensor and the PV string under test
- Irradiance sensor not facing same direction as modules*
- Discoloration of encapsulant
- Degraded cell efficiency
- Incorrect inputs to predictive model*

Steeper slope in horizontal leg



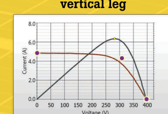
- Tapered sliver of shade or dirt extending across all cell groups
- Range of Isc across modules
- Decreased shunt resistance in cells
- Potential Induced Degradation (PID)

Notches or steps



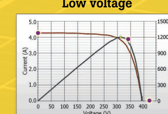
- Non-uniform shading or soiling
- Non-uniform irradiance (backside in bifacials, or inconsistent module orientation)
- Damaged or failing cells

Less steep slope in vertical leg



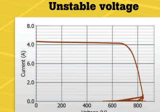
- Incorrect PV wire gauge, length, or metal inputs to the predictive model*
- Excess resistance in wiring/connections
- Broken or degraded solder bonds
- Corroded cell or ribbon metal
- Degraded connections in module J-box
- Potential Induced Degradation (PID)

Low voltage



- Thermocouple poor contact with module backside*
- Thermocouple at cooler than average location*
- Momentary gust of wind
- String missing a module
- Shorted bypass diode (single string)
- Degraded cell Voc
- Potential Induced Degradation (PID)
- Incorrect temperature coefficient in predictive model*

Unstable voltage



- Intermittent electrical connection
- Arcing during I-V Sweep
- Rare module-internal effects

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