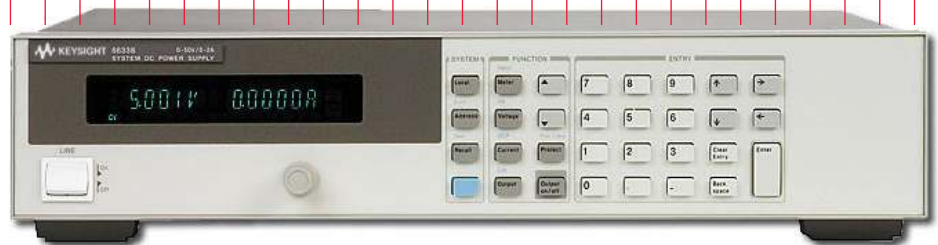


Keysight Technologies Solutions for Solar Cell and Module Testing

Application Note



Keysight 663XB Power Supplies Connected
in Anti-Series to Achieve Four-Quadrant
Operation for Solar Cell and Module Testing

Overview

To fully characterize the performance of a solar cell or module with a power supply, you need to apply voltage in forward and reverse polarities. When the solar device is illuminated, the power supply acts as a variable voltage load and you can measure the power I-V curve. When the solar device is dark, voltage is applied in both forward and reverse directions and you can measure the entire dark I-V curve. Complete characterization of a solar device generally requires a four-quadrant-capable power source.

Measuring the I-V performance of an illuminated solar device requires the power supply to sink current while sourcing positive voltage. Measuring the I-V performance of a dark cell requires the power supply to source positive and negative voltage and current to cover the full range of solar device operation. A bipolar power supply is generally the instrument of choice. When a bipolar source is not available, a pair of two-quadrant power supplies can be a viable alternative if you configure them appropriately.

Problem

Obtaining an uninterrupted test voltage that is adjustable over a range that encompasses positive and negative voltage and current values without a bipolar power supply can be a challenge. The use of a single- or two-quadrant power supply with a polarity reversing relay or switch matrix creates a discontinuity at or near zero volts that may not be acceptable.

Solution

Obtaining an uninterrupted voltage ranging from beyond a cell or module's open circuit voltage to full reverse polarity can be achieved with a pair of two-quadrant power supplies connected in anti-series. The negative terminals of the supplies are connected together and the positive terminals of both are connected to the solar device under test. Figure 1 depicts two Keysight Technologies, Inc. 6631B power supplies in an arrangement for testing the performance of a solar cell. The positive terminal of power supply 1 is connected to the positive terminal of the solar cell. The positive terminal of power supply 2 is connected to the negative terminal of the solar cell.

Each power supply must be capable of sourcing and sinking its full rated current. When you connect them in an anti-series configuration, the combination offers operation in four quadrants. When power supply 1 sources current, power supply 2 will sink current. Conversely, when power supply 2 sources current, power supply 1 will sink current. The current-sinking capability of each power supply must be equal to or greater than the sourcing capability of the other to obtain the full rated operating range.

With the solar cell illuminated, power supply 1 is programmed from zero volts to V_{oc} , and it will sink current generated by the solar cell. Power supply 2 is programmed to and held at zero volts. When the device is dark and the total voltage on the cell is greater than zero, power supply 1 will source current and power supply 2 will sink current. When the device is dark and the total voltage on the cell is less than zero, power supply 2 will source current and power supply 1 will sink current.

To ensure that the voltage applied to the solar cell is accurate, you must connect the sense leads appropriately. Connect the positive sense leads of each power supply to the solar cell where you plan to measure the voltage. Connect the negative sense leads to a common location, either on the lead that couples the negative outputs or on the negative terminal of one of the supplies. Figure 1 shows the negative sense leads attached to a point midway on the lead that connects the negative terminals of both supplies. Using remote sensing eliminates the voltage drops on the lead wires and greatly improves your accuracy.

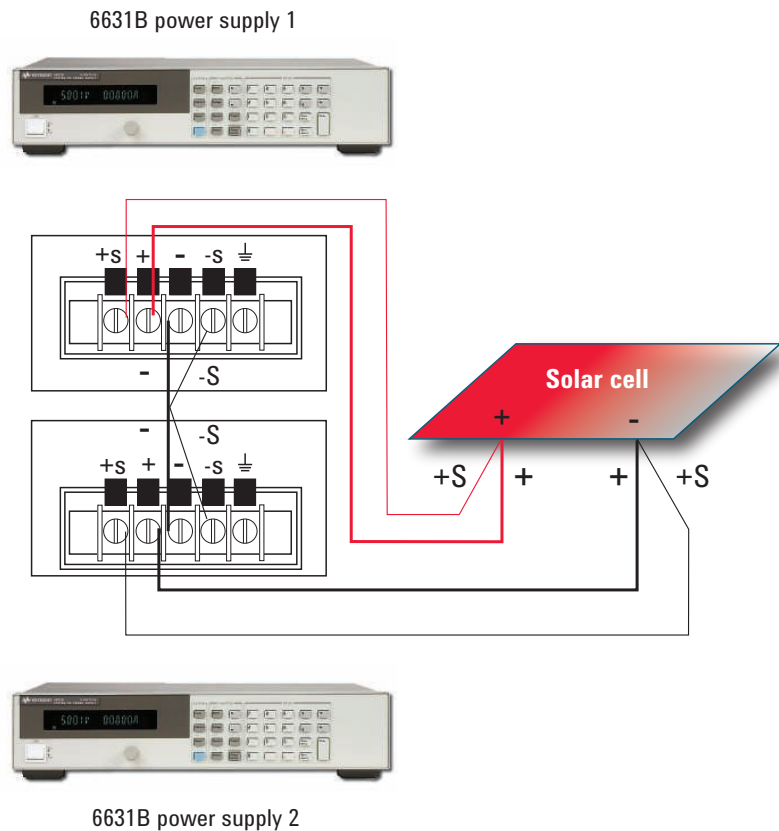


Figure 1: Two 6631B two-quadrant power supplies connected in anti-series

Process

An example test sequence is outlined below.

Test steps are executed in one continuous sequence to obtain:

1. Illuminated I-V curve
2. Dark I-V curve (forward bias region)
3. Dark I-V curve (reverse bias region)

Program power supply 1 and 2 voltages to obtain the required solar cell voltages in forward and reverse polarities. To measure the I-V curve of a solar cell when it is illuminated, incrementally increase the voltage of power supply 1 to V_{oc} . To measure the dark I-V curve, use power supply 1 at V_{oc} and incrementally increase the voltage of power supply 2 to offset the voltage of power supply 1 until you reach the required reverse bias level.

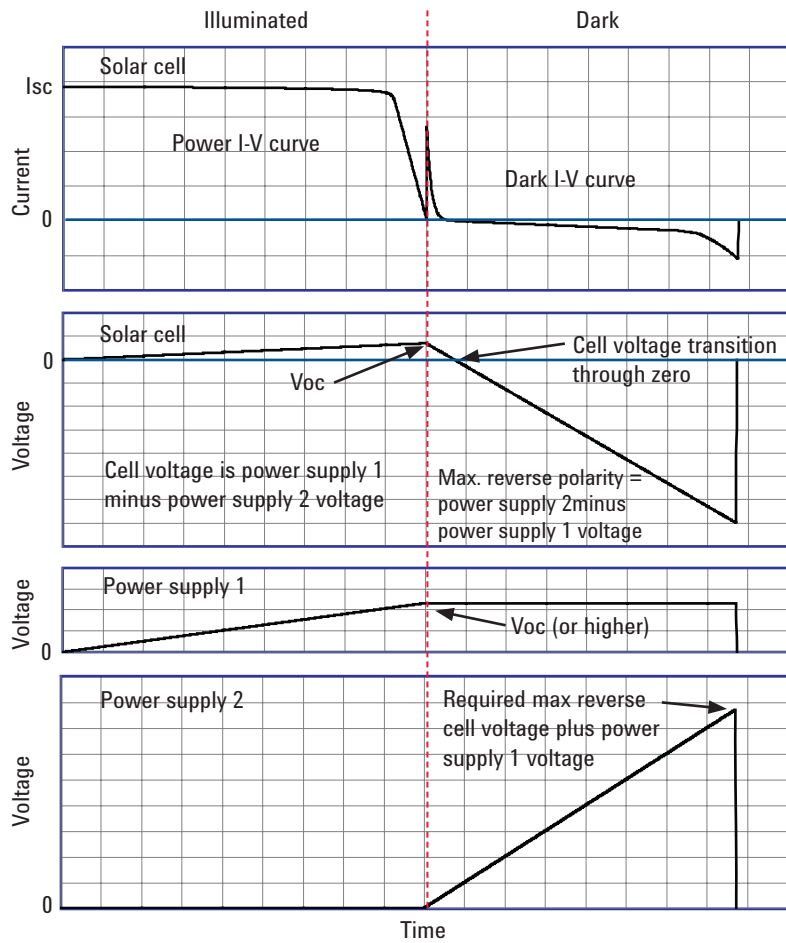


Figure 2. Solar cell voltage and current and the voltages of power supplies 1 and 2 plotted against time

Technical Specifications

Test step 1: Illuminated cell I-V curve measurement (power quadrant)

Solar device and power supply status

- Solar device sources current
- Power supply 1 sinks current
- Power supply 2 sources current (output maintained at zero volts)

Setup:

- Program power supply 1 to 0 V and program current limit to beyond I_{sc}
- Program power supply 2 to zero volts and program its current limit to beyond I_{sc}

Procedure:

1. Illuminate the solar device
2. Program power supply 1 to increase its voltage from zero to V_{oc} in small increments and remain at V_{oc} after illumination is extinguished.
3. Keep power supply 2 programmed to 0 V

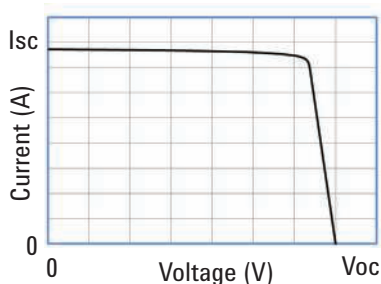


Figure 3: Illuminated cell I-V curve measurement (power quadrant)

Test step 2: Dark I-V curve measurement (forward bias region)

Solar device and power supply status

- Current flows into the positive terminal of the solar cell
- Power supply 1 sources current
- Power supply 2 sinks current

Setup:

- Power supply 1 voltage level begins at V_{oc}

Procedure:

- 1) Program power supply 2 to increase its voltage in small increments to offset the voltage of Power Supply 1 until the net voltage across the solar cell is zero.

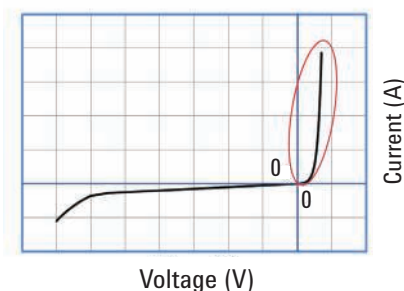


Figure 4: Dark I-V curve measurement (forward bias region)

Test step 3: Dark I-V curve measurement (reverse bias region)

Solar device and power supply status

- Current flows into the negative terminal of the solar cell
- Power supply 1 sinks current
- Power supply 2 sources current

Procedure: (continuation from test step 2)

- 2) The test continues with the increase of the voltage of power supply 2 in small increments to obtain the desired net negative voltage that reverse biases the solar cell.
- 3) When the reverse bias test is completed, both power supplies are programmed to zero volts.

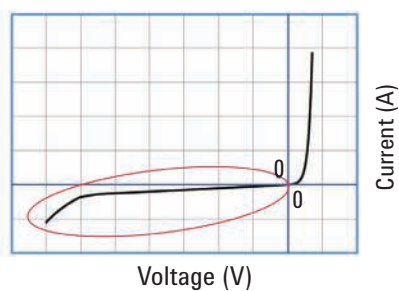


Figure 5: Dark I-V curve measurement (reverse bias region)

Alternative Test Sequences

Other test voltage sequences are possible. For example, if you want to perform both illuminated and dark cell tests, an alternative approach for test step 2 is to program the voltage of power supply 1 to decrease gradually to zero after you have completed test step 1. With the cell in darkness, you can obtain the I-V characteristic in the forward region, as depicted in test step 2. When power supply 1 voltage reaches zero, you can increase power supply 2 voltage to reverse bias the cell to obtain the I-V characteristic depicted in test step 3.

Using either approach to solar cell testing will result in a transition from forward to reverse bias through zero volts without the delay and associated circuit interruption associated with polarity reversal relays and switches. If it is absolutely necessary to avoid all discontinuities as the cell is reverse biased, it is important to note that the second approach may introduce a small discontinuity near zero volts due to programming offsets.

Conclusion

Successfully configuring power supplies in anti-series for testing illuminated and dark solar cells requires that each supply is capable of sinking the current that will be sourced by the other. Power supply 1 in the configuration must be capable of sinking, and power supply 2 must be capable of sourcing, the current produced by the solar cell under illumination.

Related Keysight Literature	Publication Type	Pub number
<i>6631B, 32B, 33B & 34B Power Supplies</i>	Catalog pages	5989-8959EN
<i>Solar Cell and Module Testing</i>	Application Note	5990-3263EN

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