Characterization of photovoltaic systems

34553 Applied Photovoltaics

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Abstract: In this exercise, we will investigate how partial shading impacts the I-V curve of full-sized c-Si solar panels.

References and links

- Lecture from course 34553 (Block 2)
- Slides from course 34552, lecture session 7 | Maximum Power point tracking, shading and PV electronics.
- https://www.pveducation.org/pvcdrom/7-modules-and-arrays/bypass-diodes

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1. Introduction

In this exercise you will explore the impact of shading on the I-V curve and power-voltage (P-V) curve of a PV panel. The PV device under test (DUT) is a 60 cell mono-Si solar panel with 3 bypass diodes manufactured by Gaia Solar. The cell stringing architecture of this DUT is representative of typical c-Si panels. As illustrated in Figure 1, each bypass diode is in parallel and reverse polarity of a substring with 20 cells in series. The cell configuration shown in the right hand schematic of Figure 1 can be looked at in the following way: Cell columns A and B create one substring, cell columns C and D create a second substring, and cell columns E and F are the third substring. Each bypass diode provides an alternate current path that protects the cells within the respective 20 cell substring from excessive reverse voltages and from hotspot heating that can occur during partial shading events.

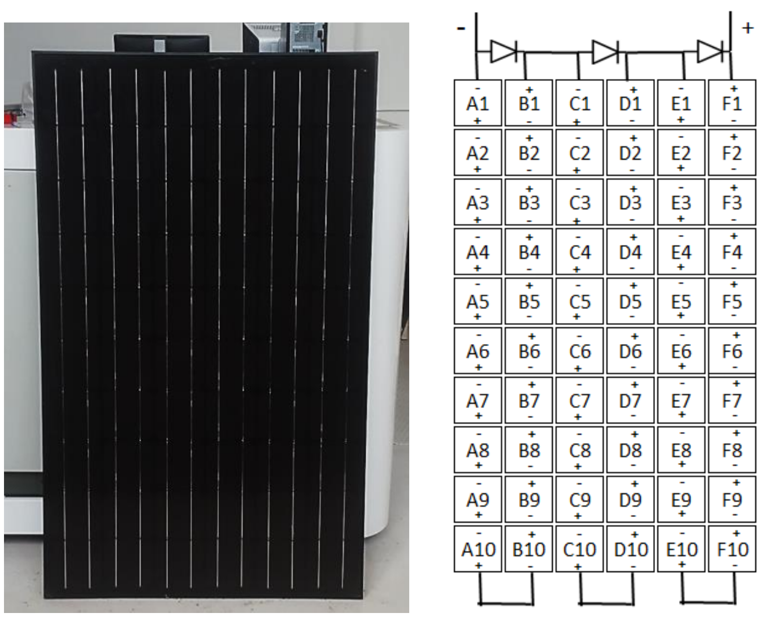

Figure 1: 60 cell Gaia Solar DUT (left) and cell stringing/cell map for the DUT (right).

2. Theory

The theory behind this exercise is described in detail in the lecture slides on maximum power point tracking (MPPT) and shading, and in your text book in section 5.4. A simple theoretical explanation is provided here.

The total output current of a string of serially connected solar cells is determined by the current of the weakest performing cell and PV panels typically consist of serially connected cells with three bypass diodes as shown in Figure 1. The bypass diodes have two purposes: 1) improve the module's power performance under shaded conditions and 2) to protect any shaded PV cell from excessive reverse voltages and from hotspot effects. When a PV panel is unshaded, the bypass diodes are in *reverse* bias and thus do not conduct current. However, when a cell within the panel is either partially or fully shaded, the current mismatch between substrings causes the respective bypass diode to operate in *forward* bias and it conducts current. Bypass diodes thus provide an alternate path for current within the module.

When the bypass diodes are activated during cell shading, an unwanted consequence is that the P-V curve can contain local maxima. Such local maxima place additional requirements on the electronics as well as the MPPT algorithm to determine the I-V curve's true MPP. Examples of local maxima in the P-V curve are shown in the right hand graph of Figure 2.

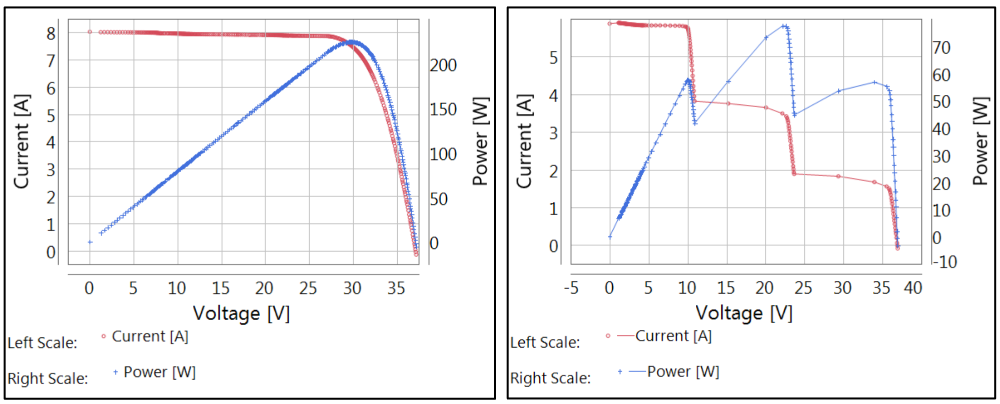

Figure 2: I-V and P-V curves of an unshaded 60 cell PV panel (left) at STC, and the performance curves of the same panel when it has cell A2 shaded by 80%, cell C2 shaded by 60%, and cell F2 shaded by 30%.

3. Experimental setup

The system you will be working with is used by DTU Fotonik's Applied Photovoltaics (APV) team for measuring I-V curves on PV panels up to 1.2 m x 2.0 m in size. The light source consists of many LEDs that are controlled by eight addressable channels. The spectral distribution and intensity of the light can be customized via the computer interface, but for this exercise the spectral distribution is set to be similar to AM 1.5G with a broadband intensity near 1000 W/m^2 (i.e. STC conditions). When the DUT is illuminated, an I-V curve will be made using a single quadrant load and a 4-wire measurement. A trained staff member from DTU Fotonik's APV team will assist you with the measurements.

Table 1: Partial Shading Scenarios to Test

I-V Test No.	PV Module Shading Condition
1	Unshaded
2	Cell A2 shaded by ≈ 30%
3	Cell A2 shaded by ≈ 60%
4	Cell A2 and B2 shaded by ≈ 60%
5	Cell A2 shaded by ≈ 60% and C2 shaded by ≈ 30%
6	Entire row 10 shaded by ≈ 30%

4. Experimental Methods

The DTU Fotonik APV team will assist in placing cardboard cutouts over the approximate areas shown in Table 1. These scenarios are chosen to help you understand two important concepts: 1) how the cells and bypass diodes in typical c-Si modules are connected and 2) how the I-V curve of a typical c-Si panel is affected when specific cells are shaded. This knowledge is important for PV designers who need specify the layout and panel mounting strategy (i.e. portrait or landscape mounting) for fielded PV systems. Note that these cardboard cut outs result in a light intensity of ≈ 0 W/m^2 under the shaded cell area, which isn't going to be the case for shadows cast by distant objects found in the field.

5. Presentation

The measured I-V curves will be uploaded to Learn platform as a .csv file. Prepare a short presentation showing plots of the measured I-V and P-V curves, and responses to the following questions.

The presentation should fit in around 6 slides and should include:

- Background and purpose/motivation of the method/exercise (1 slide)
- Description of the experimental setup and procedure (1 slide)
- Results and conclusions (4 slides)

Questions and tasks for presentation:

1. Prepare a table with the MPP, voltage at MPP (Vmp), and current at MPP (Imp) of each I-V curve.
2. Why is there essentially no difference between I-V curve number 3 and 4?
3. Look at the difference between I-V curve number 1 and 6. What do you expect the I-V curve would look like if instead of shading entire row 10 by 30%, entire column A were shaded by 30%?
    a. Draw an approximate I-V curve where entire column A is shaded by 30% at STC.
    b. How much power can we expect to gain or lose by shading column A by 30% instead of shading row 10 by 30%?
    c. Explain how the mounting orientation of the PV panel (i.e. portrait vs. landscape) can affect performance of the PV system.
4. Imagine an unshaded PV panel in the field is suddenly exposed to the shading conditions you tested in I-V test number 5. What feature in the inverter would be needed to insure that the panel still operates at its proper MPP and not at a local MPP?
5. Based on the six I-V curves measured in this exercise, draw an approximation of what the I-V curve would like if at STC:
    a. Cell A2 is shaded by ≈ 60%, C2 is shaded by ≈ 30%, and F5 is shaded by ≈ 90%.
    b. Cell A2 is shaded by ≈ 60%, C2 is shaded by ≈ 30%, and D2 is shaded by ≈ 30%.