OF THE IMPACT OF PARTIAL SHADING ON THE PERFORMANCE OF A GRID-TIED PHOTOVOLTAIC SYSTEM

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Overview

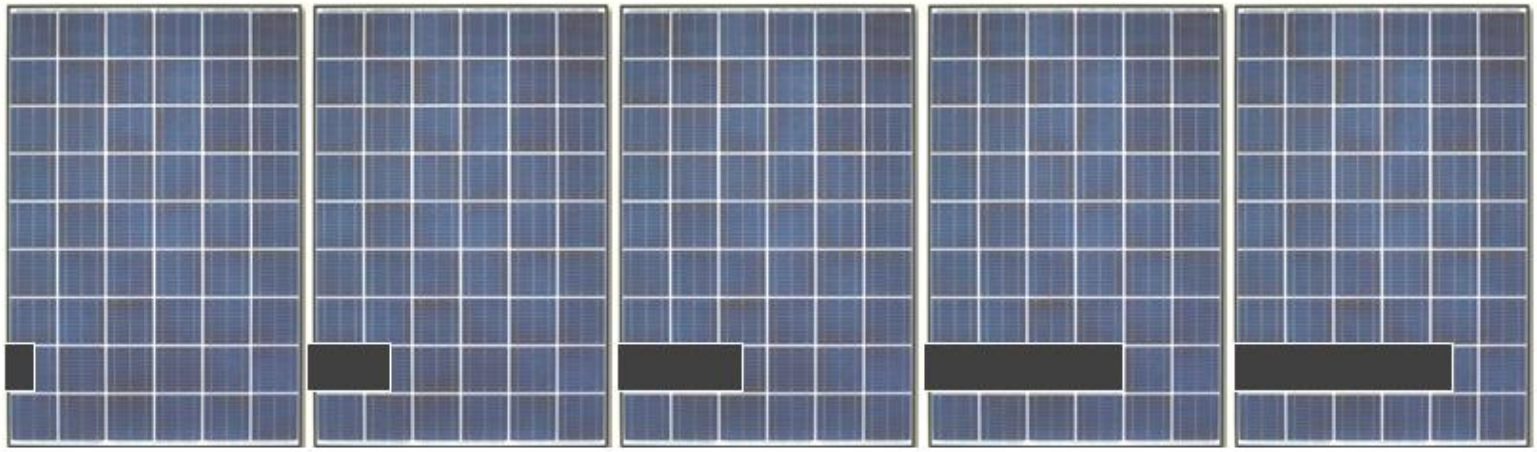
- Background/Introduction
- Importance of Bypass Diode Placement and Shade Geometry.
- PV System Description
- Calculation and Impact of Simple Shade
- Impact of Relatively Complicated Shade
- Conclusions

Introduction

- Partial shading of photovoltaic (PV) systems in urban areas is almost un-avoidable due to nearby structures or trees.
- The impact of shading on the PV system performance depends on a number of factors including shade intensity, location of the shade within the array surface, bypass diode placement, and the ability of the inverter to track maximum power.
- Hardware-based methods can help reduce shading losses in photovoltaic systems include micro-inverters and DC-DC converters, but these are often not economically justifiable.

Impact of Bypass Diodes

- **Rule of Thumb:**
  - the cell within a string that is receiving the least amount of sunlight dictates the current limit allowed by the string.
  - The module voltage will drop by an amount equal to the sum of cell voltages protected by the bypass diode plus the diode forward voltage.
- Example: PV module 3 strings (18 cells each).

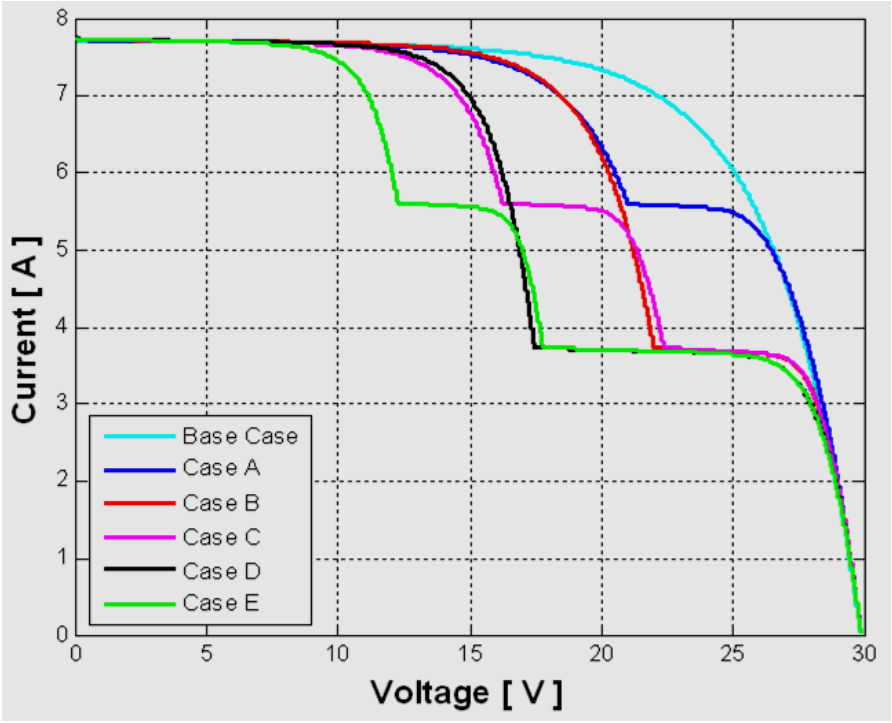


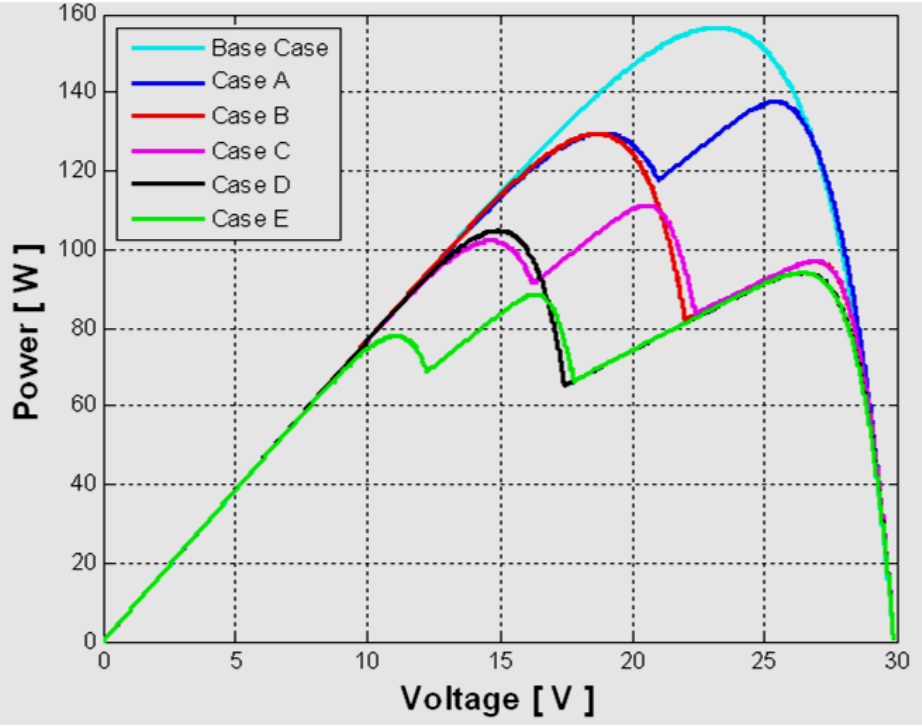
Case A Case B Case C Case D Case E

Illustration of Simple Progressive Shade on PV Module.

Impact of Bypass Diodes

- **Assumption:** Sunlight received under shade (due to diffused and reflected sunlight) = 50%.
- **Major Concern:** the power curve may have multiple peaks which can “fool” Maximum Power Trackers.





PV System Description

- Array Specifications (under STC):
  - One string of 10 PV modules(KD205GX-LPU) - each with 3 bypass diodes.
  - maximum power: 2.05 kW (peak),
  - open circuit voltage and short circuit current: 332 V and 8.36 A,
  - voltage and current at maximum power: 266 V and 7.71 A.

Impact of Simple Shade: Vertical Post

- One can calculate the shadow on the array with relative ease.
  - Given a geographic location with latitude angle, *the sun* position can be located by its altitude and azimuth angles at any given times of any given day of the year.

Impact of Simple Shade: Vertical Post

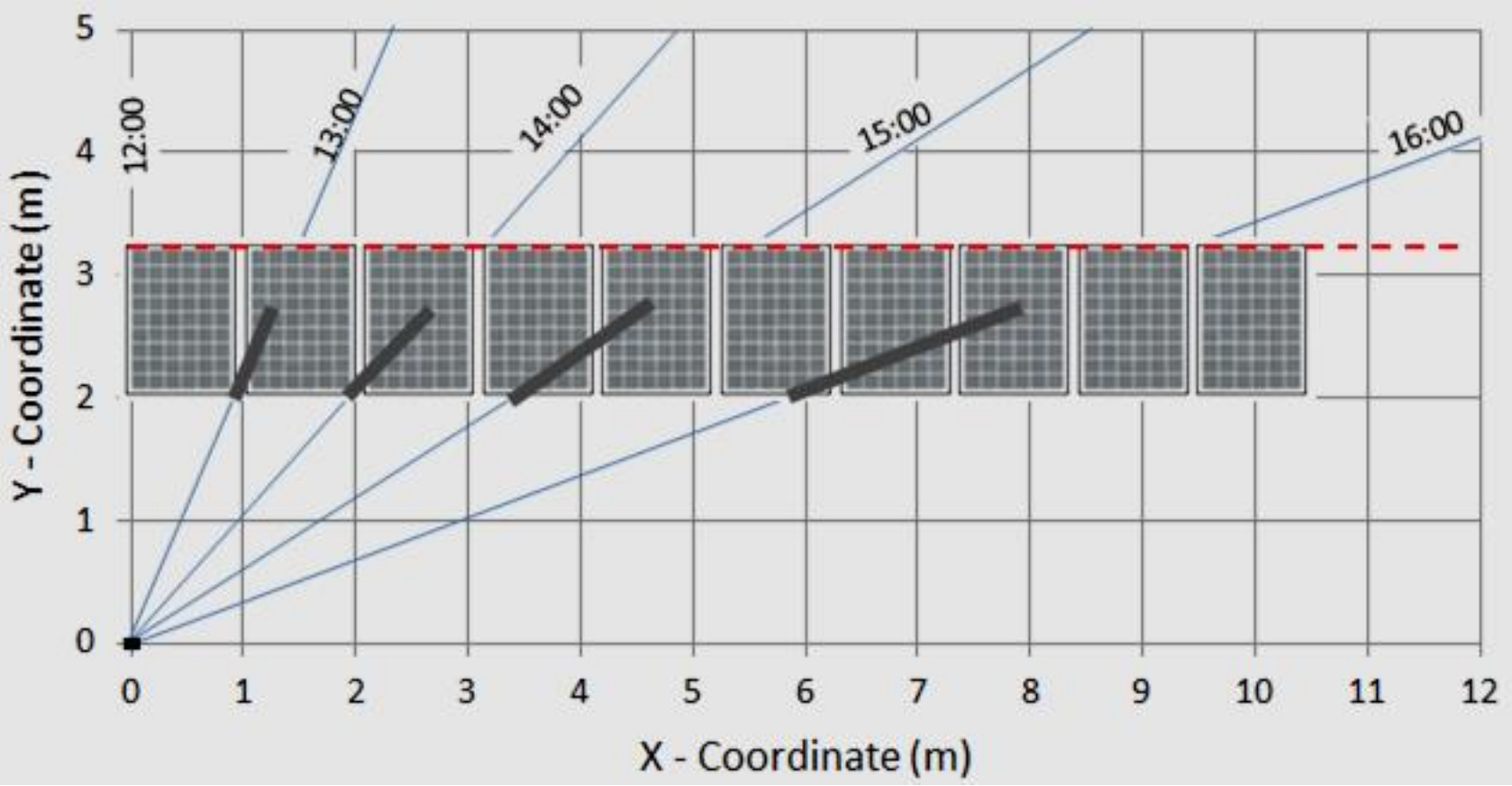
- The shadow of the vertical post having a height *h,* will have the following x-y Cartesian coordinates on the horizontal plane:

$$x = h\frac{\sin\psi}{\tan\alpha}, \qquad y = h\frac{\cos\psi}{\tan\alpha}$$

- The projection of this shadow on the PV array depends on its
  - location relative to the post,
  - elevation relative to the base of the post,
  - and its orientation.
- Once such parameters are known, one can determine that shadow geometry on the array with relative ease.

Sample of Actual Shadow Movement (Date: 3/20/15)

Sample of Calculated Shadow Movement (Date: 3/20/15)

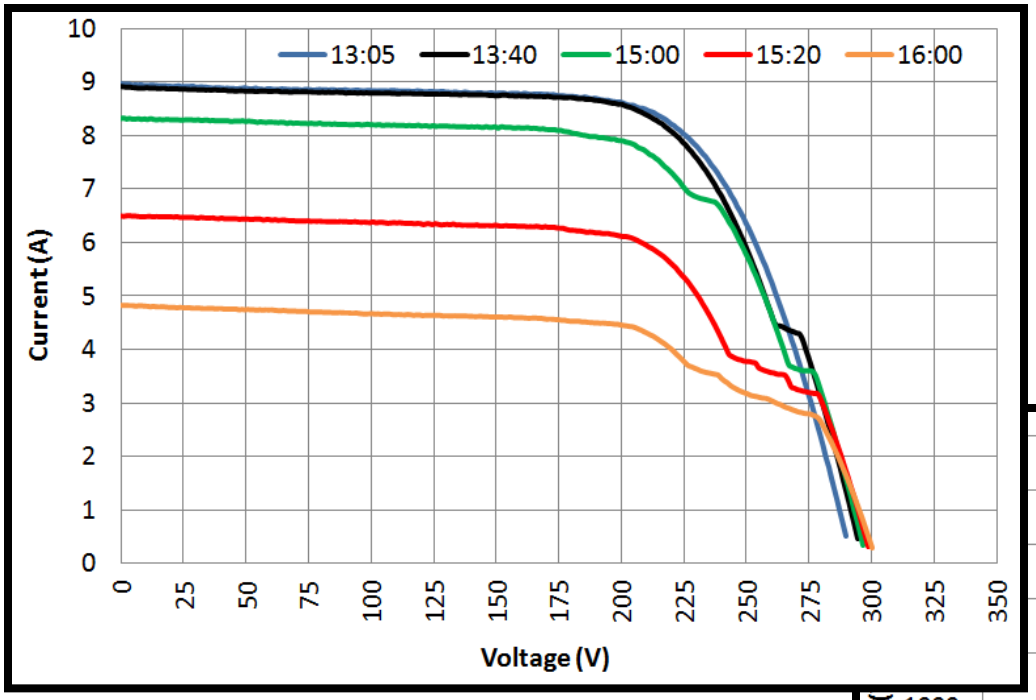


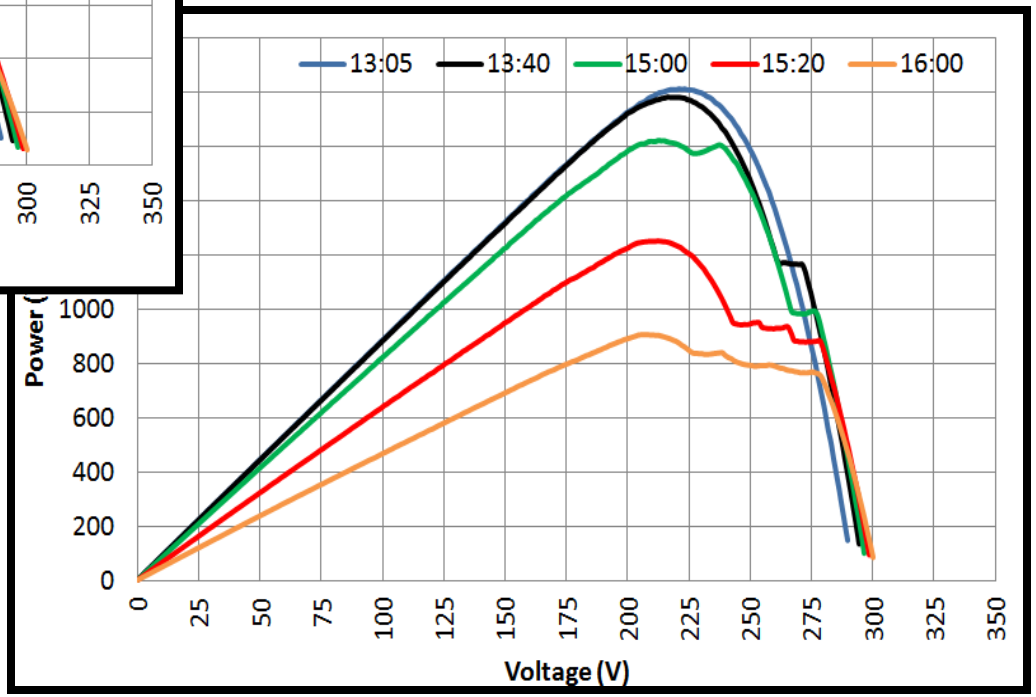
* Time Shown is in Solar Time

Sample of Shadow Movement (Date: 3/20/15)

Date and Time* (03-20-2015) (* clock time)	No. of Partially Shaded Sub-strings (cal. and recorded)	Sunlight Received by most Shaded Cell (%) (recorded)
13:05	0	0
13:40	1	50,
15:00	2	45, 80
15:20	3	50, 55, 60
16:00	5	50, 50, 60, 60, 75

Sample of Measure IV and PV Curves (Date: 3/20/15)





Note: multiple power peaks occur at 15:00. The inverter operated at the global peak.

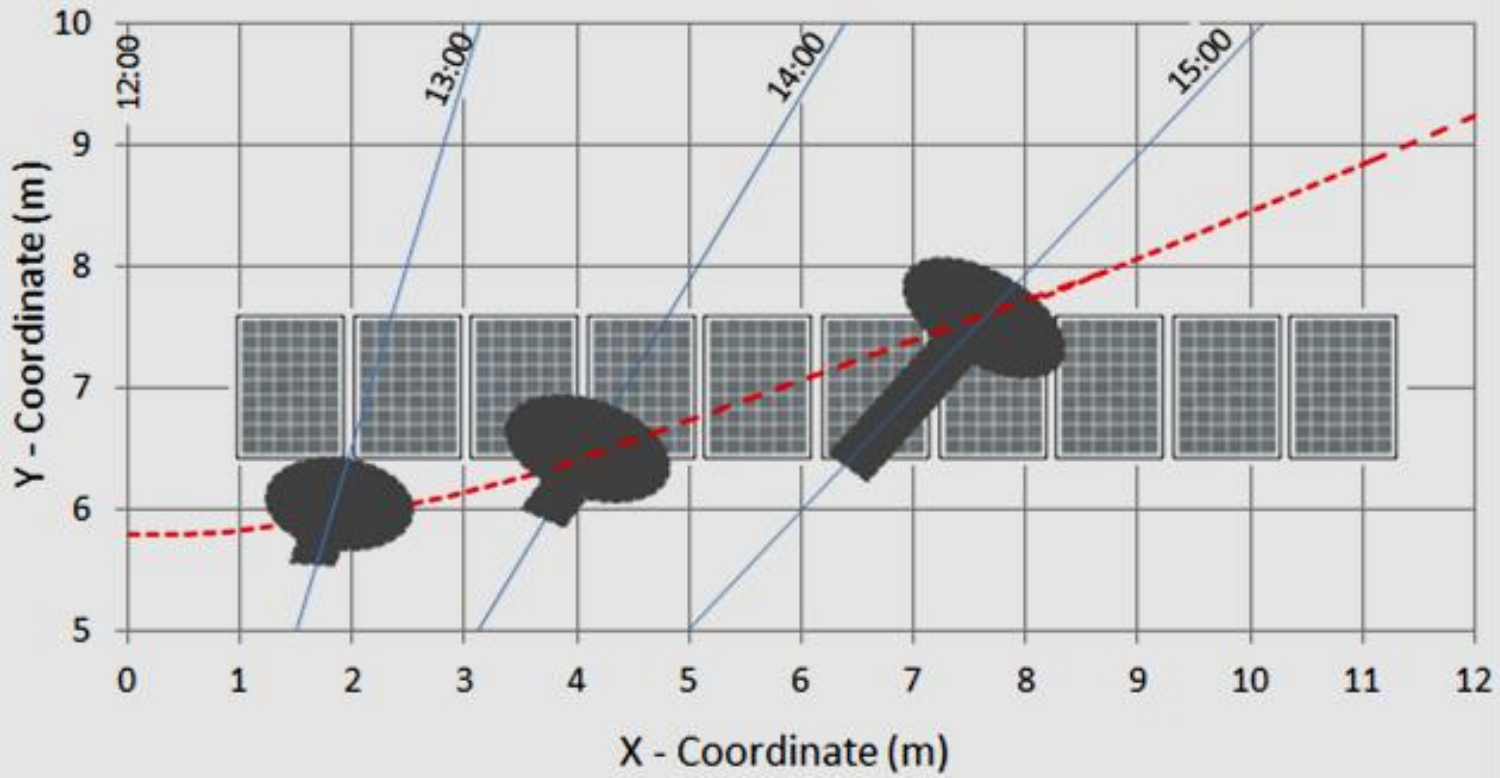
Impact of Relatively Complex Shade: Permanently-Installed Solar Dish Collector

- Herein, the shadow geometry is too complicated to calculate due to the uneven shape of the structure.

Sample of Actual Shadow Movement (Date: 11/17/14)

Sample of Calculated Shadow Movement (Date: 11/17/14)

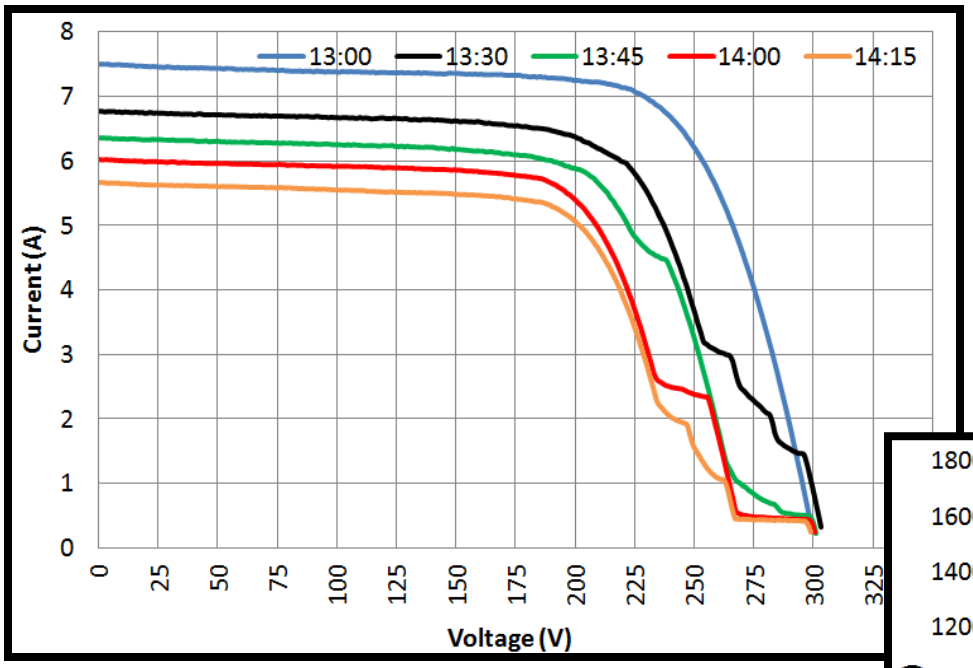
- Attempts have been made to compute the shadow geometry.
- Errors were noted when compared to the photographs.

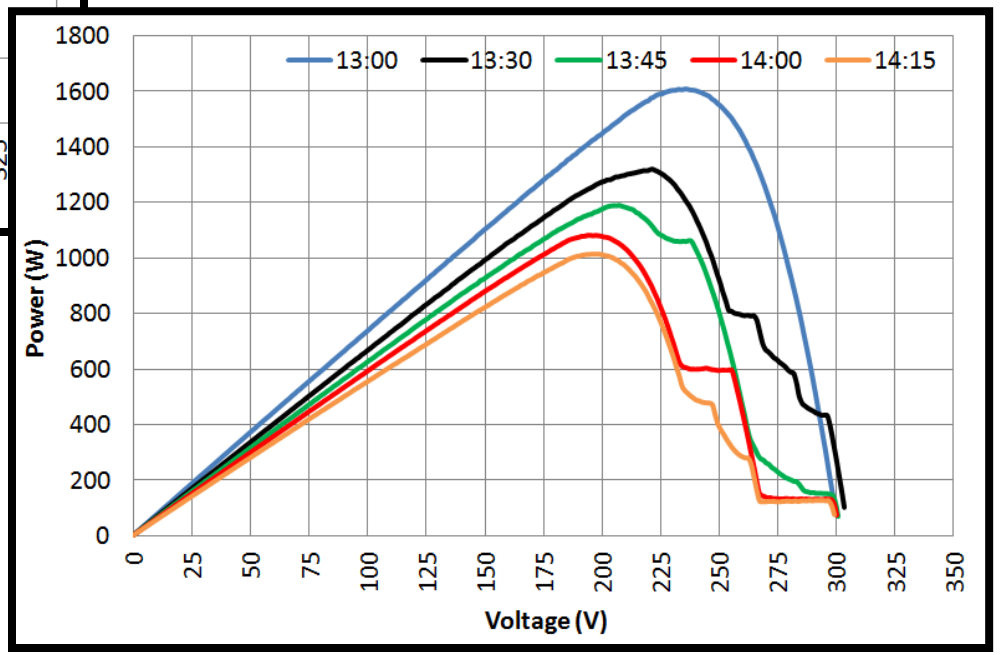


Sample of Measure IV and PV Curves (Date: 11/17/14)

Date and Time (11-17-2014)	No. of Partially Shaded Sub-strings	Sunlight Received by most Shaded Cell (%)
13:00	0	0
13:30	3	20, 30, 45
13:45	4	10, 10, 10, 70
14:00	5	10, 10, 10, 40, 40
14:15	5	10, 10, 10, 20, 35

Sample of Measure IV and PV Curves (Date: 11/17/14)





Conclusions

- The bypass diode placement is shown to play the most critical role in PV system performance as this regulates the impact of shading on array performance.
- Even with simple shadow geometries, the I-V and P-V curves can only be predicted with accuracy if the relative amount of sunlight that strikes the most shaded cell in each sub-string is known.
- Analytical tools are found to have limited practical applications due to lack of knowledge about such irradiance values, and it is recommended that one resorts to actual measurements for accurate analysis.

Acknowledgement

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Questions and/or Comments?