Daily Performance Comparison of PV Modules Operating in Maui

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Introduction

The performance ratio (PR) has been used to compare PV daily performance, but it does not provide enough information to understand the variability between modules and locations. Complex modelling tools predicting the instantaneous production of the PV module provide additional insights on energy rating if the module reference data set is available [1]. A PV test platform, commissioned on the island of Maui in February 2016, has been used to conduct a side-by-side comparison of 10 different PV modules. A new energy rating analysis is proposed to elucidate the performance differences between PV modules without complex modelling.

Objectives

Develop an improved energy rating analysis
- to better understand performance differences between PV technologies and locations
- to identify the impact of the environmental and operating conditions

without complex modelling

Acknowledgements

United States Department of Energy (DE-EE0003507),
Office Naval Research (N00014-10-10310),
Maui Economic and Development Board,
First Solar, HNU Energy, and Grandalytic.

Methods [2]

Performance Criteria:
- Performance ratio (1) dissociated into current (2) and voltage (3) performance: $PR \approx IP \times VN$
- Optical performance IP_{SC} (4) calculated from short-circuit current (I_{SC})
- Daily performance calculated using dataset with angle-of-incidence below 70° (for high accuracy of solar sensors)
- Irradiance (G) measured with a secondary standard pyranometer

Empirical Models:
(5) $\mathrm{Perf} = \mathrm{O_{IRR}} + \mathrm{C_{IRR}} \times \mathrm{IRR}$ calculated
(5-1) on overcast days (irradiation < 3 kWhm^{-2})
(5-2) on sunny days (irradiation ≥ 3 kWhm^{-2})
$Perf$ is one of the PV performances defined in (1-4); O_{IRR} and C_{IRR} are the offset and coefficient of the linear fit of $Perf$ versus irradiation

1) Performance Ratio

$$\mathrm{PR} = \frac{\int_{\Delta t} P_{PV} \cdot dt}{P_{MP,STC}} \times \frac{G_{STC}}{\int_{\Delta t} G \cdot dt}$$

2) Voltage Performance

$$\mathrm{VN} = \frac{\overline{V_{PV}}}{V_{MP,STC}}$$

3) Current Performance

$$\mathrm{IP} = \frac{\int_{\Delta t} I_{PV} \cdot dt}{I_{MP,STC}} \times \frac{G_{STC}}{\int_{\Delta t} G \cdot dt}$$

4) Optical Performance

$$\mathrm{IP_{SC}} = \frac{\int_{\Delta t} I_{SC} \cdot dt}{I_{SC,STC}} \times \frac{G_{STC}}{\int_{\Delta t} G \cdot dt}$$

P_{PV}, V_{PV}, I_{PV} operating power, voltage, and current of the module
$P_{MP,STC}$, $V_{MP,STC}$, $I_{MP,STC}$, $I_{SC,STC}$ datasheet specifications at standard test conditions (STC)

Test Protocols:
- 10 PV technologies (Table 1) evaluated by an IV tracer in outdoor conditions
- PV test platform (Fig. 1) includes 15 PV systems with 3 system architectures (string inverter, microinverter, optimizer)

Fig. 1: PV test platform commissioned in February 2016 in Kihei, Maui

Table 1: Description of the PV modules in operation at MEDB, Maui

PV acronym	PV technology	Rated power (P_{MP}) [W]	η [%]
S1	Standard p-type polycrystalline	250	15.4
S2	Standard p-type polycrystalline	250	15.2
S3	Standard p-type polycrystalline	260	15.5
S4	Standard p-type monocrystalline	265	16.5
H1	High efficiency n-type monocrystalline with heterojunction intrinsic thin layer	240	19.0
H2	High efficiency n-type monocrystalline with rear contact	245	19.7
H3	High efficiency n-type monocrystalline, Bifacial Hybrid Cell Technology	300	18.2
C1	Copper indium gallium selenide (CIGS)	145	13.3
C2	CIGS	170	13.8
D1	Cadmium telluride (CdTe)	77.5	10.8

Results

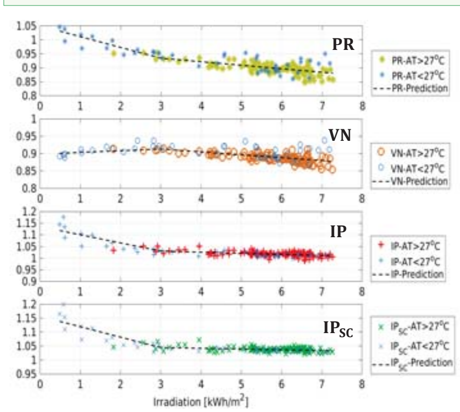

Fig. 2: PV Performances versus Irradiation – Data and model (Module S4)

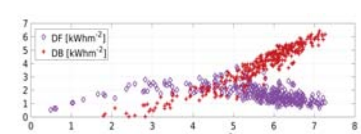

Fig. 3: Energy from the direct and diffuse components versus global irradiation

- PV performance correlated to irradiation (Fig. 2)
- VN and PR affected by AT (Fig. 2)
- IP and IP_{SC} impacted by operating conditions (soiling, shading) [2]
- PV performance versus irradiation (Fig. 4)
  - related to direct beam / diffuse (Fig. 3)
  - dependent on the PV technologies and module designs
  - points out poor efficiency in low light conditions
  - identifies best technologies at specific irradiation
- Yearly average performance (Fig. 5)
  - determines strengths and weaknesses in terms of optical and thermal performances

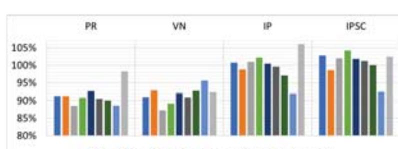

Fig. 5: First-Year Average Performances

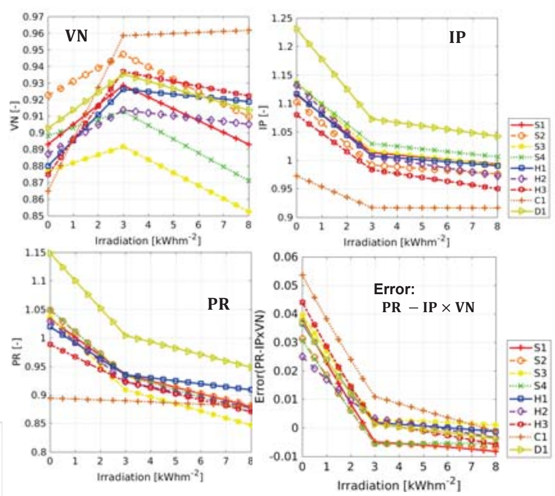

Fig. 4: PV Performances versus Irradiation – Module Comparison

$\mathrm{PR} \approx \mathrm{IP} \times \mathrm{VN}$ true in sunny conditions (Error ±1%)
PR in overcast conditions mostly affected by IP

Conclusions

New energy rating analysis approach:
- determines PV module capabilities in terms of PR, optical (IP, IP_{SC}) and thermal (VN) performances, and efficiency in low light conditions
- helps differentiate the effects of the environmental and operating conditions
- identifies main environmental parameters (irradiation, ambient temperature)
- dissociates the impacts of PV performance parameters
  - IP vs Irradiation: function of location (spectral), orientation (angle-of-incidence), operating conditions
  - VN vs Irradiation: function of ambient temperature, wind conditions, mounting

⇒ Method expected to help compare PV modules in different test locations

References

[1] D. Dirnberger at al., PV module energy rating: opportunities and limitations, Progress in Photovoltaics: Research and Applications (23), pp. 1754-1770, 2015.
[2] Busquet S., Kobayashi J., Rocheleau R. E., Operation and performance assessment of grid-connected PV systems in operation in Maui, Hawaii, 44th IEEE Photovoltaic Specialists Conference, 2017.