Detect The Variation of Maximum Power Point of the PV Module Under Different Factor of Shading

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Abstract. A simulation-based study under partial shading condition is presented for a photovoltaic (PV) module in this paper. In a solar photovoltaic module, some of its cells may fall into the shadow. With multiple peaks, the PV characteristic gets more complex under partial shading conditions. The purpose of this paper is to demonstrate the effects which can cause partial shading in a PV module. Where is done through Simulation by MATLAB / Simscape. Under partial shading and uniform irradiation, the characteristics of the PV module are compared. All results are displayed in graphical forms to demonstrate the outcomes.

Keywords. Photovoltaic module; Partial shading; Maximum Power Point Tracking; Simulation.

1. Introduction
Energy and its related services are increasingly needed to cope with social and economic human growth, education, and health. Returning to sustainability to help tackle climate change is an excellent solution that must efficiently fulfil the need for future generations’ energy [1]. PV solar power has many advantages, making it one of the most exciting renewable energy sources in the world. It is non-polluting, has no moving components that could break down, needs limited maintenance, and little monitoring and has a life of 20-30 years with low operating costs [2]. Photovoltaic (PV) solar-oriented cells can transform solar energy into electrical power and combine to gain more power through various cell interconnections. By arranging PV cells sequentially, the sun-based PV module is created. In contrast, the PV module is framed by a series and parallel combination of PV modules [3]. Because of partial shading induced by the shadows of moving clouds, trees, or surrounding structures, solar irradiation on a specific module might not be uniform [4]. It usually affects the I-V characteristics curve and the P-V characteristics curve [5-6]. The researchers note that not only will the output voltage and power decrease when partial shading occurs, but multiple peaks will be obtained instead of providing one maximum power peak [6]. And several algorithms and artificial intelligence are tested, diagnosed, and repaired [7-8]. This research aims to demonstrate the effect of partial shading on the curve of current and voltage and the power characteristics curve. The remainder is organized as follows: PV modelling is section 1; the proposed PV module in section 2; the simulation results are described in section 3; the conclusion is finally given in section 4.

2. PV module modelling
The aspect that often affects the precision of simulating PV module is the PV cell model. To simulate the actual behaviour of a PV cell under different environmental conditions, modelling a PV cell requires an I-V property estimate [9]. The single diode model is one of the simplest models that many researchers have suggested. This consists of a parallel source of current to the diode [6,9-12], as Figure 1 shows.
The current $I_{ph}$ is the photocurrent of the cell. $I_o$ reflects the current of PV saturation and thus $R_{sh}$ and $R_s$ are both intrinsic shut-off and cell series resistances. PV cells are wired together to form a module that is usually glass-covered and combined to provide a high voltage and current value. PV module mathematical model [9-12] is shown in Equations (1)-(4) below.

For PV photocurrent, $I_{ph}$

$$I_{ph} = [I_{shc} + K_t c (T_{mot} - T_{rt})] * \frac{Y}{1000}$$

(1)

$I_{shc}$ is the PV module short circuit current at STC (A), $K_t c$ is the short circuit current temperature coefficient at $I_{shc}$ (A/$^\circ$C), $T_{mot}$ is the module operating temperature (K), $T_{rt}$ is the reference temperature (K), $Y$ is the PV module illumination (W/m$^2$).

For PV reverse saturation, $I_{rst}$

$$I_{rst} = I_{shc} / (e^{\frac{qV_{oc}}{N_{ser}AK_c(T_{mot}/T_{rt}) - 1}})$$

(2)

$q_e$ is Electron charge (C), $N_{ser}$ is the number of cells connected in series, $A$ is ideality factor.

For PV saturation current, $I_{st}$

$$I_{st} = I_{rst} \left[ \frac{T_{mot}}{T_{rt}} \right]^3 \frac{q_e E_{bg}}{N_{ser}AK_c(T_{mot}/T_{rt}) - 1}$$

(3)

$E_{bg}$ is the bandgap for silicon (V), $K_c$ is Boltzmann constant (J/K).

For PV output current, $I_o$

$$I_o = I_{ph} - I_{ph} \left( e^{\frac{qV_{oc}}{N_{ser}AK_cT_{mot}} - 1} \right)$$

(4)

Where $V_{oc} = 21.24$ V, $N_{par} = 1$ and $N_{ser} = 36$.

3. Proposed PV module

As a reference module, the Solkar 36w PV module will be used, and the name-plate information is shown in Table 1.

| Table 1: Solkar 36w PV Electrical Properties Data Module |
|-----------------------------------------|----------------|
| Maximum power                           | 37.08 W        |
| Maximum power voltage ($V_{mp}$)        | 16.56 V        |
| Maximum power current ($I_{mp}$)        | 2.25 A         |
| Open-circuit voltage ($V_{oc}$)         | 21.24 V        |
| Short-circuit current ($I_{shc}$)       | 2.55 A         |
| Total number of series cells ($N_s$)    | 36             |
| Total number of parallel cells ($N_p$)  | 1              |
| All above under STC condition           |                |

Depending on sunlight temperature and radiation, PV-cells directly transform energy into electricity, which gives performance characteristics of both I-V and P-V. Steps 1 to 7 below shows the Simulation of the measures involved in Simulink.

Step 1:
Figure 2. (a) Subsystem no.1 (b) Conversion of operating temperature from Celsius to Kelvin (K).

Is shown in Figure 3. (b) the circuit inside the subsystem no.1.

Step 2:
Figure 3. (a) depicts Subsystem No.2. As follows, this model takes inputs.
Irradiation [Insolation] – \([G = 1 \text{ k W/m}^2] = 1\)
\(T_{\text{mot}} = 30 \text{ to } 70 \degree C\)
\(T_{\text{rt}} = 25 \degree C\)
\(I_{\text{shc}} = 2.55\text{A}\)

Figure 3. (b) shows the circuit within the subsystem no.2.

Step 3
Figure 4. (a) depicts subsystem no.3. As data, this model takes \(I_{\text{shc}} = 2.55\text{A}\) and \(T_{\text{rt}} = 25 \degree C\).

Figure 4. (a) Subsystem no.3. (b) Based on equation (2), this model calculates PV reverse saturation current, \(I_{\text{rst}}\)
The circuit of subsystem no.3 is constructed in Figure 4. (b).

Step 4:
See Figure 5. (a) for subsystem no.4, this system is built in Figure 5. (b).

![Figure 5. (a) Subsystem no.4. (b) Based on equation (3), this model calculates PV saturation current, I_{st}.](image)

Step 5:
See Figure 6. (a) for subsystem no.5, the circuit under subsystem no.5 is given in Figure 6. (b).

![Figure 6. (a) Subsystem no.5. (b) Based on equation (4), this model calculates PV (N_{ser} * A * K_c * T_{mot}).](image)

Step 6:
See Figure 7. (a) for subsystem no.6 and Figure 7. (b) for the circuit under subsystem no.6.
Figure 7. (a) Subsystem no.6. (b) Based on equation (5), this model calculates PV output current, $I_o$.

This model uses the following equation of functions.

$$I_o = u(3)-u(4)*[\exp((u(2)*(u(1)+u(6)))/(u(5)))-1]$$

Step 7:

The six models above are interconnected, as shown in Figure 8.

Figure 8. This model integrates and connects all six subsystem models above.

Figure 9. displays the Final Model.
The final model takes input irradiation, Celsius operating temperature and module voltage, and gives output current $I_o$ and output voltage $V_{pv}$.

4. Simulation results
The results have been performed on PC with 3 GB RAM, Core i3 Processor with Windows 7 and MATLAB Simulink R2017b. The PV module is modelled. The values of currents and voltages with shading are shown in Table 2, on the equations, and technical data of the PV module referred to above. By following the sequences, the model is constructed before the final model is shown. During the shading of the modules, it is noticed that the irradiance will decrease from 1000 W/m$^2$ to 100 W/m$^2$.

When partial shading is 10% on PV module the maximum power point is (33.34 w), and also when partial shading is 20% the maximum power point will be (29.57 w), and so on when it is (30% - 40% - 50% - 60% - 70% - 80% - 90%) the maximum power point will be (25.78 - 21.97 - 18.14 - 14.35 - 10.55 - 6.825 - 3.212) w sequentially. At the same time, the temperature is constant (25 ° C), and the decrease of the highest peak of the I-V characteristic and the P-V characteristic is clearly seen as shown in Figs (10-14)

| Partial Factor | Imax (A) | Vmax (V) | MPPT (W) |
|----------------|----------|----------|----------|
| 10%            | 2.066    | 16.13    | 33.34    |
| 20%            | 1.833    | 16.13    | 29.57    |
| 30%            | 1.598    | 16.13    | 25.78    |
| 40%            | 1.362    | 16.13    | 21.97    |
| 50%            | 1.125    | 16.13    | 18.14    |
| 60%            | 0.886    | 16.13    | 14.35    |
| 70%            | 0.646    | 16.13    | 10.55    |
| 80%            | 0.406    | 16.13    | 6.825    |
| 90%            | 0.165    | 16.13    | 3.212    |

5. Conclusion
The Simulation-based analysis for partial shading conditions on PV module is done in this paper. All PV cell simulation models are modelled in MATLAB / Simulink environment with the use of Simscape. When simulating the above models and making comparisons, it is observed that not only the voltage and power output are reduced under partial shading, but also multiple peaks are obtained instead of a single maximum power peak. Simulation comes under partial validation of device output.

(a) (b)

Figure 10. Partial shading factor (10% and 20%) : (a) Curves of I-V, (b) Curves of P-V
Figure 11. Partial shading factor (30% and 40%) : (a) Curves of I-V, (b) Curves of P-V

Figure 12. Partial shading factor (50% and 60%) : (a) Curves of I-V, (b) Curves of P-V

Figure 13. Partial shading factor (70% and 80%) : (a) Curves of I-V, (b) Curves of P-V

Figure 14. Partial shading factor 90% : (a) Curves of I-V, (b) Curves of P-V
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