Analysis of Distributed Maximum Power Point Tracking of PV System under Partial Shading Condition

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Abstract - In case of series-parallel connected PV array under partial shaded condition, lowest current carrying PV module limits the current of whole array and leads to power loss in overall system. The power-voltage characteristics exhibits multiple maximum power points (MPP), making it difficult to find global MPP by using conventional maximum power point tracking (MPPT). Distributed maximum power point (DMPPT) is the prominent solution to overcome the power loss in which each module is having individual MPPT. This paper discuss the analysis of DMPPT under partial shading conditions

Keywords - DMPPT, Partial Shading condition, Photovoltaic (PV),

I. INTRODUCTION

As the world's demand for electrical energy is rapidly increasing, the prices for conventionally produced electrical energy are rising as well. This, along with environmental concerns, It is also worth to note that very high amount of carbon dioxide (CO₂) from thermal power plants contribute to global warming leading to climate change. These conventional energy sources are limited in nature and will last long for few decades. The growth in demand and the proportionally increase in fuel price have promoted the development of alternative energy technologies. Distributed power generation based on renewable energy is one of such alternative methods. Among these renewable energy sources, solar photovoltaic (PV) has seen a fast development in recent years, which helped to increase its practical use for producing alternative energy.

The Current-Voltage and Power-Voltage characteristic of a solar cell is non-linear, there is single maximum power point (MPP) on power-voltage characteristics of PV cell, where it need to operate. But this non-linearity makes it difficult to determine the maximum power point. It is straightforward to determine the maximum power point on a linear curve as maximum power is transferred at the midpoint of the current-voltage characteristic. For a solar cell, the non-linear relationship means the maximum power point has to be determined by calculating the product of the voltage and output current. In order to extract maximum power from the solar cell, the solar cell must always be operated at or very close to where the product of the voltage and output current is the highest.

In photovoltaic (PV) energy systems, PV modules are often connected in series for increased string voltage; and in parallel to increase the current, however, I-V characteristics mismatches often exist between series or shunt connected PV modules. The factors which are causes mismatch to the single or module may classify; the internal factors which includes, small manufacturing tolerances, occasional minor damage due to cracking, small temperature differences, depending on where cells are located in the module and degradation of cell blooming layer due to aging. Degradation rate of each module is different, some modules degrades more rapidly than others [7]. Likewise external factors includes; the dirt on the anterior part of the cells, the degradation of the materials used for the cells encapsulating and the major factor is partial shading or the unequally radiation of the cells. All these factors are responsible to reduce the overall performance of the module which means; the generated power of module is less than the sum of the generated power of the single cell.

In partial shading (PS) the current generated by shaded module make to force to perform unshaded module at lower current resulted into decrease into output power. This prevent unshaded module to generate the power at their full capacity [2]. However, overall output power can be decreased by underperforming modules resulted ultimately in loss [1]. This happen due to shaded module may get reverse biased fig. 1(a) and module may act as load and the current which generated by shaded module make to force unshaded module at lower current [3]. This situation can lead to hot spot formation and module gets damaged.

To avoid thermal overload and the formation of hot spots, sub-strings of cells inside the interconnection circuit of modules are bridged by bypass diodes as shown in fig. 2(a). This measure limits the bias voltage at the shaded cell and thus the dissipated power [2]. This diode completely bypassed the shaded module and power from unshaded module available continuously. This strategy helps to increase the overall available power but leads to some other disadvantages are; power generated by shaded module completely missed and appearance of various MPP as shown in fig. 2(b).

Under PS conditions the conventional MPPT controller mostly finds local MPP instead of finding the global MPP [4]. The power loss due to missing of global
MPP may lead up to 70% [5]. Hence, the generated PV power, as well as the overall system efficiency, is low. Some researchers addressed this problem that helps in determining the global MPP in PV characteristics. The dedicated DC-DC converter is used to perform MPPT on module level [6-8]. This dedicated DC-DC converter makes sure the delivery of maximum power which is available. This MPPT is distributed on the module level rather than finding the global MPP termed as Distributed Maximum Point Tracking (DMPPT).

![Diagram](https://via.placeholder.com/150)

**Fig. 1 (a) Series-connected PV modules having partial shading showing current incompatibility. (b) I–V characteristics of the shaded and unshaded PV modules showing current incompatibility, (c) using bypass diodes, (d) appearance of multiple MPP [2].**

### II. MATHEMATICAL MODEL OF PV MODULE

A photovoltaic cell consists of a p-n junction that is exposed to light, which results in the generation of charge carriers that can cause a current flow when the cell is connected to a load. The available current flow is proportional to the incident light and depends on the semiconductor characteristics. Such an equivalent circuit-based model is mainly used for the MPPT technologies. The equivalent circuit of the general model which consists of a photo current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, is shown in Fig. 2.

![Diagram](https://via.placeholder.com/150)

**Fig. 2 The equivalent circuit of solar cell [9]**

The voltage-current characteristic equation of a solar cell is given as in [8],

\[
l = I_{ph} - I_n - I_{sat} = I_{ph} - I_s \left( \frac{V + IR_sh}{nV_T} - 1 \right) - \frac{V + IR_sh}{R_sh}
\]

(1)

Where:
- \( I_{ph} \) is light generated or photo current [A]
- \( I_s \) is the saturation diode current [A]
- \( V_T \) Terminal voltage
- \( A \) is an ideal factor,
- \( R_{sh} \) is a shunt resistance, and \( R_s \) is a series resistance.

The shunt resistance \( R_{sh} \) is inversely related with shunt leakage current to the ground. In general, the PV efficiency is insensitive to variation in \( R_{sh} \) and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. On the other hand, a small variation in \( R_s \) will significantly affect the PV output power. For an ideal PV cell, there is no series loss and no leakage to ground, i.e., \( R_s = 0 \) and \( R_{sh} = \infty \).

Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series-parallel configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage.

The most important parameters widely used for describing the cell electrical performance are the open-circuit voltage \( V_{oc} \) and the short circuit current \( I_{sc} \). The aforementioned equations are implicit and nonlinear; therefore, it is difficult to arrive at an analytical solution for a set of model parameters at a specific temperature and irradiance. Normally \( I_{ph} >> I_{sc} \) and ignoring the small diode and ground-leakage currents under zero-terminal voltage, the short-circuit
current $I_{SC}$ is approximately equal to the photocurrent $I_{PH}$, i.e.,

$$I_{PH} = I_{SC}$$  \hspace{1cm} (2)

On the other hand, the $V_{OC}$ parameter is obtained by assuming the output current is zero. Given the PV open-circuit voltage $V_{OC}$ at reference temperature and ignoring the shunt-leakage current, In addition, the maximum power can be expressed as

$$P_{MAX} = V_{MAX} \cdot I_{MAX} = \gamma V_{OC} I_{SC}$$  \hspace{1cm} (3)

Where, $V_{MAX}$ and $I_{MAX}$ are terminal voltage and output current of PV module at maximum power point (MPP), and $\gamma$ is the cell fill factor.

### III. MAXIMUM POWER EXTRACTION FROM PV MODULE

Maximum power point tracking (MPPT) function is usually incorporated in the solar power management system to ensure that maximum available power is received from the solar photovoltaic panel.

#### A. Centralized MPPT

The centralized topology, in which all PV modules are connected in series to a single inverter with a centralized MPPT; all PV modules connected in series are forced to drive the same current as shown in fig.1. If they cannot drive this current, then their associated bypass diodes conduct. Although diodes protect PV modules from “hot-spot” effects, they introduce multiple maxima on the array power–voltage $P$–$V$ curve resulting in problems with MPPT. Even if the MPPT reaches the greatest power maxima the shaded PV modules would be acting as passive loads, significantly reducing the efficiency of the whole PV system.

#### B. Distributed MPPT

A DC-DC converter dedicated to each module is inserted, and each converter performs its own MPPT operation as shown in fig.3. This process is called Distributed MPPT (DMPPT). There is interconnection between the associated dc–dc converters instead of PV modules. Therefore, each PV module can operate at its own optimal power and current, and all the available energy in the PV array can be delivered. Losses from shading of a single PV module are limited to that module; any unshaded modules nearby are unaffected.

DC-DC power converters are one of the standard components of switch mode power supplies (SMPS). Among the varieties of DC-DC converters, the Boost regulator is used in applications where the output voltage should be higher than the input. The boost converter of fig. 4 with a switching period of $T$ and a duty cycle of $D$ is given. Again, assuming continuous conduction mode of operation, the state space equations when the main switch is ON is:

$$\begin{align*}
\frac{dI_L}{dt} &= \frac{1}{L} (V_{in}) \\
\frac{dv_c}{dt} &= \frac{1}{C} \left( -\frac{v_c}{R} \right)
\end{align*}$$  \hspace{1cm} (4)

And when the switch is OFF

$$\begin{align*}
\frac{dI_L}{dt} &= \frac{1}{L} (V_{in} - v_c) \\
\frac{dv_c}{dt} &= \frac{1}{C} \left( i_L - \frac{v_c}{R} \right)
\end{align*}$$  \hspace{1cm} (5)

DC-DC boost converter mainly used for the extraction of maximum power from the solar module by varying the duty cycle $D$.

### IV. SIMULATION RESULT

The proposed system is implemented in Matlab/Simulink with boost converter. Under the condition of unequal radiances; the power obtained
from the plant is strongly influenced by its configuration. P&O hill climbing technique is used to control the duty cycle of the DC-DC boost converter.

The simulation carried out considering different irradiation for each PV module as mentioned in Table I.

Table I simulation result with one module shaded condition

<table>
<thead>
<tr>
<th>PV Module</th>
<th>PV1</th>
<th>PV2</th>
<th>PV3</th>
<th>PV4</th>
<th>Whole Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiation</td>
<td>300</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Power (Watt)</td>
<td>DMPPT</td>
<td>23.15</td>
<td>65.34</td>
<td>66.79</td>
<td>66.79</td>
</tr>
<tr>
<td></td>
<td>Centralised MPPT</td>
<td>21.75</td>
<td>31.39</td>
<td>66.76</td>
<td>186.1</td>
</tr>
</tbody>
</table>

It is observed form the result table and graphs plotted from the Matlab/Simulink; When the partial shading comes into picture the DMPPT technique represented the better result as shown in fig. 4 and Fig. 5. DMPPT technique helps to transfer more power than conventional MPPT

![Fig. 4 PV Array output power with (a) centralized MPPT (b) distributed MPPT.](image)

![Fig. 5 PV2 module output power with (a) centralized MPPT, (b) distributed MPPT](image)

![Fig. 6 PV1 module output power with (a) centralized MPPT, (b) distributed MPPT](image)

V. CONCLUSION

It is observed from the simulation result the shaded module lower the power generation of the module in the same string while using conventional MPPT. However, using DMPPT made sure to each module transfer its
maximum available power means whatever the power loss due to conventional MPPT can be minimized by using DMPPT. From simulation result it may conclude that system efficiency is increased up to 19% in case of DMPPT.

It is important to note that, additional cost of converter and control circuitry may be result in overall rise in system cost. But it plays vital role to improve the system efficiency in partial shading condition.

VI. REFERENCES


