Development of Active PV Array Using Real-Time Scanning Method

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Abstract. This paper presents a novel control strategy for active photovoltaic (APV) array using real-time scanning method. This proposed technology reduces extreme power drops due to the partial shading conditions (PSCs). In this paper, PSIM software is used to simulate the conventional photovoltaic (PV) array and the newly proposed APV array. The comparative analysis results show that this newly proposed technology can effectively reduce the power loss caused by the PSCs to the PV generation system. Assuming a practical system, we will verify the practicality of the proposed system by conducting a demonstration experiment with a large array scale. We also built a monitor system to monitor the generated power of each unit.

1. Introduction
For the PV power generation system, the output power of the PV array will deviate from the maximum power point (MPP) as the external environment changes [1][2]. In view of the problems of the conventional maximum power point tracking (MPPT) methods are unable to track the global power peaks, etc., various MPPT methods have been proposed, compared and analysed [3]. However, in the conventional PV array consisting of only PV panel as power generation modules, shown in figure 1 (a), even the accurate and efficient global maximum power point tracking (GMPPT) method cannot determine that each PV power generation module is operating in its optimal power generation state, and the algorithm is becoming more and more complicated [4].

To solve this problem, a novel PV-unit module is proposed as an independent basic power generation unit in order to improve the output power of PV array under PSCs, shown in figure 1 (b).

In this paper, the simulation comparison results of the above two schemes with PSIM software are included, which proves that the proposed method is feasible and efficient.

Figure 1. (a) Conventional PV module. (b) Proposed PV-unit module.
2. PV generation module
The specifications of the PV module employed in this simulation are summarized in Table 1.

| Parameter | Description           | Value |
|-----------|-----------------------|-------|
| $P_{\text{max}}$ | maximum power        | 60W   |
| $V_{\text{oc}}$ | open-circuit voltage | 21V   |
| $I_{\text{sc}}$ | short-circuit current | 3.8A  |
| $V_{\text{op}}$ | optimal operating voltage | 17V |
| $I_{\text{op}}$ | optimal operating current | 3.5A |

3. Conventional PV array
The structure of the conventional PV generation system is shown in figure 2 (a). In this structure where the power generation modules are connected in series and parallel and then directly connected to the power conditioning system (PCS), when the system is under PSCs, the system will not be able to run on its optimal state. In addition, when such a system faces the hot spot failure, the power loss due to hot spot suppression will increase as the number of power generation components increases [5].

![Figure 2](image)

(a) Conventional PV array. (b) APV system.

4. Proposed APV system
In response to these concerns, figure 2 (b) presents the configuration of an actual-scale APV system assumed to be a household PV system. Compared with the conventional control structure complex hybrid control method, this paper proposes a separate control mode, and conducts PSIM simulation analysis. A unit module performs scanning analysis and determines the optimal state of each of the PV panel. MPPT is performed by PCS module. In order to reduce the complexity of the system, this MPPT module adopts perturb and observe (P&O) method which is the most common used algorithm due to the ease of implementation and the simple control mechanisms [6]. The unit is connected to each PV panel, and the output side is connected in series. In order to verify the effectiveness of the APV system, the simulation number of strings is 2, and each string is configured with 3 panels. Here, we focus on String 1 and show a method for setting buck-boost ratio.

4.1. DC-DC ratio
With reference to the research of other scholars [7], this paper chooses a double-switch buck-boost converter as the DC-DC converter used by the unit, shown in figure 3. The buck-boost converter adjusted by pulse width modulation (PWM) can ensure the independence between input and output. Each unit calculates the buck-boost ratio $\gamma_{(j)}$ in real time through periodic scanning to perform the controlling function.
The converter ratio $\gamma(j)$ is mainly used to select the working mode of the converter. Shown as:

$$
\gamma(j) = \frac{V_{\text{out}(j)}}{V_{\text{in}(j)}}
$$

(1)

For example, when the ratio is greater than 1, it means that the output of the converter is greater than the input, and the converter should be set to Boost mode. It can be expressed as:

$$
\gamma_0(j) = \frac{V_{\text{out}(j)}}{V_{\text{op}(j)}}
$$

(2)

Here, $\gamma_0(j)$ represents the ideal control ratio of each converter in the unit, $V_{\text{out}(j)}$ represents the ideal output voltage of each unit; $V_{\text{op}(j)}$ represents the optimal operating voltage of the corresponding PV panel. Each PV power generation module in the string is connected in series, thus they share the same current. Hence the ideal output voltage of each unit will be determined according to the ratio of the power generated by its corresponding module to the total power of the string, can written as:

$$
V_{\text{out}(j)} = \frac{\sum_{j=1}^{N} P_{\text{max}(j)} \times V_{\text{pcs}}}{\sum_{j=1}^{N} P_{\text{max}(j)}}
$$

(3)

Where $P_{\text{max}(j)}$ is the maximum power generation value of each PV panels obtained by the real-time scanning method performed by the unit, $V_{\text{pcs}}$ is the optimal operating voltage set in the PCS module, which can be set according to photovoltaic panel parameters before system operation. Therefore, the DC-DC converter ratio can be defined as follows:

$$
\gamma(j) = \frac{V_{\text{out}(j)}}{V_{\text{in}(j)}} = \frac{\sum_{j=1}^{N} P_{\text{max}(j)} \times V_{\text{pcs}}}{\sum_{j=1}^{N} P_{\text{max}(j)}}
$$

(4)

This indicates that to determine the operating mode of the converter, real-time scanning method is needed to obtain the optimal operating voltage and corresponding maximum power point of each PV module in the string.

### 4.2. Reference voltage

The output voltage $V_j$ of each converter in real-time is shown in the following equation.

$$
V(j) \approx \frac{P_{\text{max}(j)} \times V_{\text{pcs}}}{\sum_{j=1}^{N} P_{\text{max}(j)}}
$$

(5)

Where, $V_{\text{pcs}}$ is the real-time operating voltage at PCS side. Due to the series structure, the output voltage of each unit is approximately determined by the magnitude of solar power generated by its own. According to the above equations, the PV reference voltage $V_{\text{ref}(j)}$ for each panel can be simplified as follows:

$$
V_{\text{ref}(j)} = \frac{V(j)}{\gamma_0(j)} = \frac{V_{\text{op}(j)} \times V_{\text{out}(j)}}{V_{\text{in}(j)}} = \frac{V_{\text{op}(j)} \times \sum_{j=1}^{N} P_{\text{max}(j)} \times V_{\text{pcs}}}{\sum_{j=1}^{N} P_{\text{max}(j)} \times V_{\text{pcs}}} = \frac{V_{\text{pcs}} \times V_{\text{op}(j)}}{V_{\text{pcs}}} = m V_{\text{op}(j)}
$$

(6)

Here, $V_{\text{op}(j)}$ is MPP (optimal) voltage of each panel acquired from scan. Moreover, due to MPPT at the PCS side, $V_{\text{pcs}}$ is always approaching the set constant $V_{\text{pcs}}$ (matching factor $m=1$), allowing the reference voltage of each panel to approach its MPP voltage refreshed after scan. That is, the optimal voltage can be regulated appropriately from the PCS side to each panel. This transfer control ensures that each panel operates at their own MPP.
5. Simulation results

5.1. Shadow module
In order to simulate the PSCs of the PV system caused by factors such as falling leaves or clouds in the natural environment. A PV panel is divided into two parts, with the shaded part set to 10% of the standard light intensity (1000 [W/m²]), shown in figure 4 (a).

![Simulation result of shadow module](image)

According to the parameters shown in Table 1 and the above simulation results, shown in figure 4 (b) &(c), it can be concluded that in the PSCs, the maximum output power of the PV panel is 30.3[W], the corresponding voltage value is 8.5[V], and the current value is 3.6[A].

5.2. APV system
According to the equation (6), we present a control diagram shown in Figure 5 (a). By controlling each unit with Figure 5 (a), the output of each PV panel is maximized, and a single output peak point arises for the string at V_{pcs0} to achieve the ideal P-V characteristics. Similarly, other strings are also set according to the same V_{pcs0}. Thus, the optimal operating voltage of all strings becomes V_{pcs0}, mismatches between strings are avoided.

In order to verify the feasibility and high efficiency of APV system constructed by PV-unit modules, two simulation systems are built in PSIM, as shown in Figure 2 (a) and Figure 2 (b). Normal panels are under standard test condition (1000 [W/m²], 25°C), the simulation results show in Figure 5 (b) &(c).
It can be concluded from Figure 5 (b) that when shadows are added, the balance will collapse and the overall output will drop dramatically, however the output power is quickly restored by scanning, and each panel will output at their MPP. From the overall system perspective, as shown in Figure 5 (c), on this simulation condition, the APV system can enhance the output power of the system by 1.65 times under PSCs.

6. **Construction of actual APV system**

Assuming a practical system, we will verify the practicality of the proposed system by conducting a demonstration experiment with a large array scale. We also built a monitor system to monitor the generated power of each unit.

As shown in Figure 6, a string is composed of multiple panel units, and these are connected in parallel to form an array. We will manufacture multiple units and develop a new control program to control these units. We use the 3G wireless communication system for the purpose of the utilization in the mega solar system. The repeater transmits array data to the cloud server via wireless communication, and is configured to be able to monitor parameter adjustments, power of each panel, I-V data, etc. on a monitor via LAN.
Figure 7 (a) shows the panel installed on the roof of our laboratory, moreover, the Figure 7 (b) shows the smart PV array units (DC-DC converters) and repeater. Figure 8 (a) shows a 3G communication device and Figure 8 (b) shows the monitor screen. In the future, we plan to use this system to verify the practicality of this method under various conditions.

Figure 6. Active PV system.

Figure 7. (a) PV array. (b) Active PV array units (DC-DC converters) and repeater.

Figure 8. (a) 3G communication device. (b) Monitor screen.
7. Conclusion
Consequently, the array operates at the MPP state through MPPT control of the PCS, and all panels operate at the maximum power. That is, this unit does not have the MPPT function, however, has the function of appropriately transmitting the change of the input voltage $V_{pcs}$ based on the MPPT control of the PCS to the PV panel.

According to the theoretical analysis and simulation results, the advantage of the APV system is verified. The maximum output power of APV system under PSCs is increased greatly than the conventional PV array structure.

In addition, the actual system of APV system was built. In the future, we plan to use this system to examine its effectiveness under various conditions.

8. References
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