

Study on Reducing Output Noise in APV Array of Solar Power Generation Systems

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Abstract- Solar cells have the drawback that their power generation capacity drops significantly when shaded. To address this issue, the authors have developed an Active PV (APV) array system that constantly controls the characteristics of the PV array itself to maintain ideal conditions under various external conditions and have demonstrated its effectiveness. In this APV system, noise generated during the scanning operation, which is unique to APV systems, was propagating to the PCS, causing noise there. Therefore, this paper proposes shifting the scanning operation to suppress this noise. As a result, multiple DC-DC converters that do not control the scanning operation will exist within the string; these solar cells will operate according to the voltage law at a voltage that cancels out the voltage fluctuations of the solar cells performing the scanning operation. The proposed method significantly reduces this noise, thereby minimizing the impact of noise during scanning operations and alleviating the load on the PCS. In this paper, the effectiveness of the proposed method in reducing noise on the PCS side that occurs during the scanning operation of an APV system is examined. Experiments demonstrated that the proposed method could suppress voltage fluctuations on the PCS side.

Keywords: APV, Solar Power, MPPT.

I. Introduction

Solar power systems are increasingly being installed in large-scale power plants, such as mega-solar facilities, as well as in homes. They allow users to continue using electricity even during power outages caused by disasters, and any surplus electricity can be stored for self-consumption or sold back to the grid. However, solar panels have the drawback that their power generation capacity drops significantly when they are shaded. Partial shading of PV arrays—caused by factors such as bird droppings, dust, trees, neighboring buildings, and other obstacles—results in multiple maxima in the output characteristics of the PV array, complicating the system. Consequently, conventional Maximum Power Point Tracking (MPPT) control algorithms, such as the P&O method (the hill-climbing method)—a conventional maximum power point tracking (MPPT) control algorithm—may malfunction, leading to a significant drop in output, making it difficult to find the global maximum power point (GMPP) (A. Mäki and S. Valkealahti, 2012; A. Murtaza et al., 2014; M. Drif et al., 2008;). To address this issue, MPPT control methods for PV arrays under partial shading conditions, utilizing techniques such as approximate I-V curves and equalization algorithms, have been investigated (B. Raja et al., 2016; M. AL-Emam et al., 2018; M. A. Eltawil and Z. Zhao, 2013; M. A. Ghasemi, A. Ramyar, and H. Iman-Eini, 2018). The authors have previously developed (K. Itako, 2014; S. Yang et al., 2018;) and put into practical use a new scan-type MPPT control method that enables the detection of the GMPP under partial shading conditions. Furthermore, the authors have developed an Active PV (APV) array system that constantly controls the characteristics of the PV array itself to an ideal state under various external conditions and has demonstrated its effectiveness (C. Xu et al., 2021;).

In this APV system, noise generated during the scanning operation, which is specific to APV systems—propagated to the PCS, causing noise there as well. This paper proposed a method to shift the scan timing of each module based on the APV array system which authors previously developed and examined effectiveness. The proposed method significantly reduces this noise, thereby minimizing the impact of noise during scanning operations and alleviating the load on the PCS.

II. Configurations and Principles of Conventional Method and the APV System:

2.1 Conventional Solar Panel Array Systems

Conventional solar power generation systems consist of solar panels, power conditioners, loads, and other components. The power conditioner operates so that the solar panels can always output power at the maximum power point. A typical connection configuration is shown in Figure 1. In this configuration, the PV modules influence one another. The degree of shading on each PV module string varies; as a result, the maximum operating voltage of each PV module string also differs, as shown in the characteristics in Figure 2. Since maximum power point tracking (MPPT) is performed only on the PCS side, only the voltage on the PCS side

can be controlled. Consequently, it is not possible to operate all PV modules at their maximum power points, resulting in significant power loss. Furthermore, in conventional P&O MPPT methods, the operating point is only slightly varied to compare power levels, so the range within which power trends can be identified is limited. If the power fluctuates up and down several times, the system may end up operating at a local maximum power point rather than the global maximum power point.

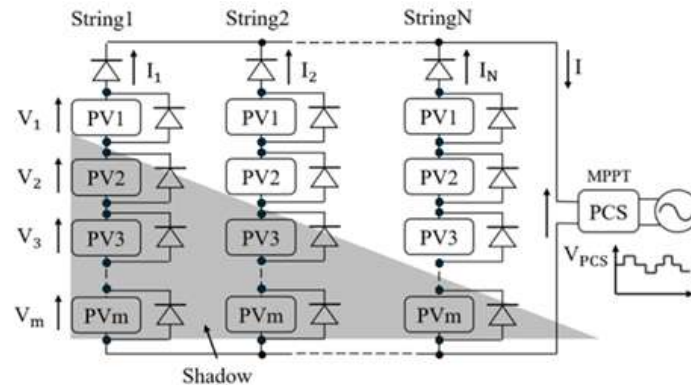


Figure 1. Conventional solar power array system

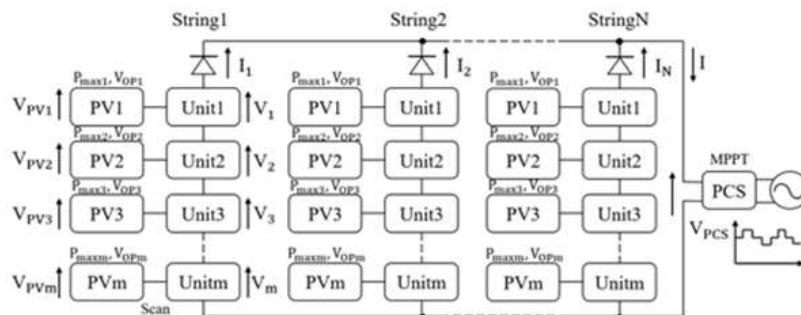


Figure 2. P-V characteristics of a conventional solar power array system

2.2 APV Array System

Conventional solar power generation systems consist of solar panels, power conditioners, power grid, and other components. The APV system shown in Figure 3 was proposed in previous research. As shown in Figure 4, each unit connects a step-up/step-down DC-DC converter to each solar cell. During step-up (boost) operation, S1 is turned on, and S2 is controlled by a PWM signal. During buck operation, S2 turns off, and S1 is controlled by a PWM signal. By periodically scanning the maximum power point of each PV module, individual duty cycle settings are configured for each module so that each module achieves maximum power when the string voltage is V_{PCS0} . This extracts maximum power from each PV module and effectively prevents mismatches between PV module strings. As a result, the output characteristics during shading shown in Figure 2 become as shown in Figure 5.

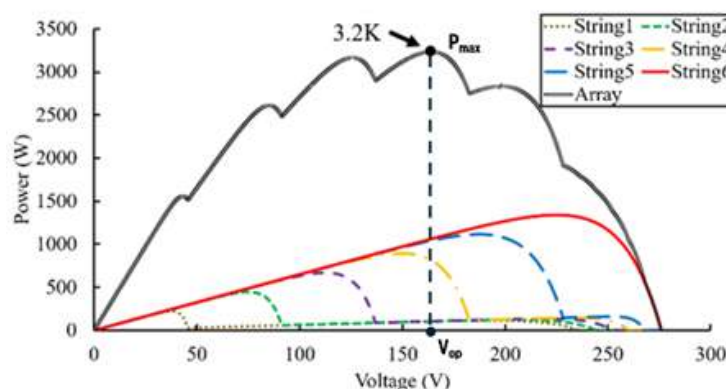


Figure 3. Configuration of the APV Array System

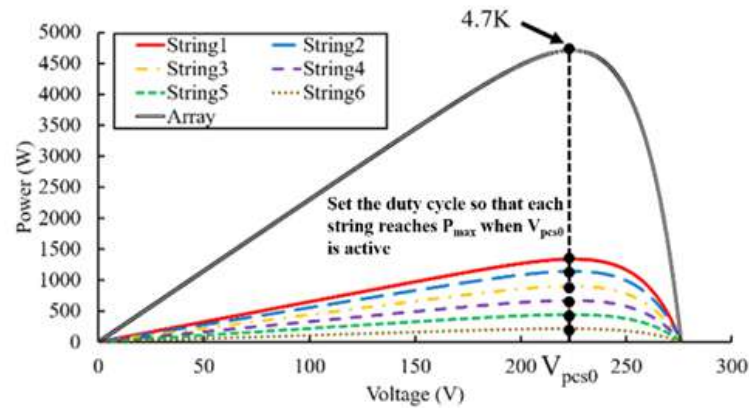


Figure 4. PV module connected to a DC-DC converter

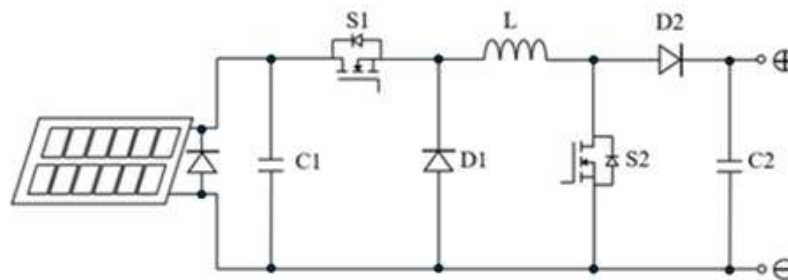


Figure 5. P-V characteristics of the APV array system

III. Causes and Suppression of Scan Noise

During operation of the APV array system, the status of all solar cells is scanned simultaneously at regular intervals. During this scanning operation, the input voltages of the solar cells $V_{PV1}, V_{PV2}, V_{PV3}, \dots, V_{PVm}$, change abruptly. As a result, the PCS input voltage V_{pcs} also fluctuates significantly. Consequently, the PCS operates to suppress these fluctuations, causing momentary noise.

Therefore, this paper proposes shifting the scanning operation to suppress noise. As a result, there will be multiple DC-DC converters within the string that do not control the scanning operation, and the converter output voltages $V_1, V_2, V_3, \dots, V_m$, will operate in accordance with the voltage law at voltages that counteract the voltage fluctuations of the solar cells undergoing the scanning operation. Consequently, the voltage fluctuation noise transmitted to the PCS is canceled out. Furthermore, the greater the number of modules in the string that are not undergoing scanning, the lower the ratio of voltage fluctuations experienced by each individual module during scanning, resulting in reduced noise on both the solar cell side and the PCS side.

IV. Experimental Results

To evaluate the effectiveness of the proposed control system, experimental verification was conducted. Figure 6 shows the experimental setup. In the experiment, two panels were configured to form a single string, and the input voltage of the PCS was compared while the output voltages of each solar cell were measured. During the experiment, the irradiance was approximately $600 \text{ [W/m}^2\text{]}$, the panel temperature was approximately $40 \text{ [}^\circ\text{C]}$, and the solar cells used had a short-circuit current of 3.47 [A] , an open-circuit voltage of 21.1 [V] , and a maximum power of 56 [W] . Both methods were operated with a scan interval set to approximately 10 seconds.

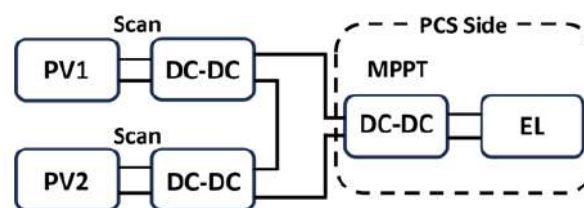


Figure 6. Experimental circuit configuration

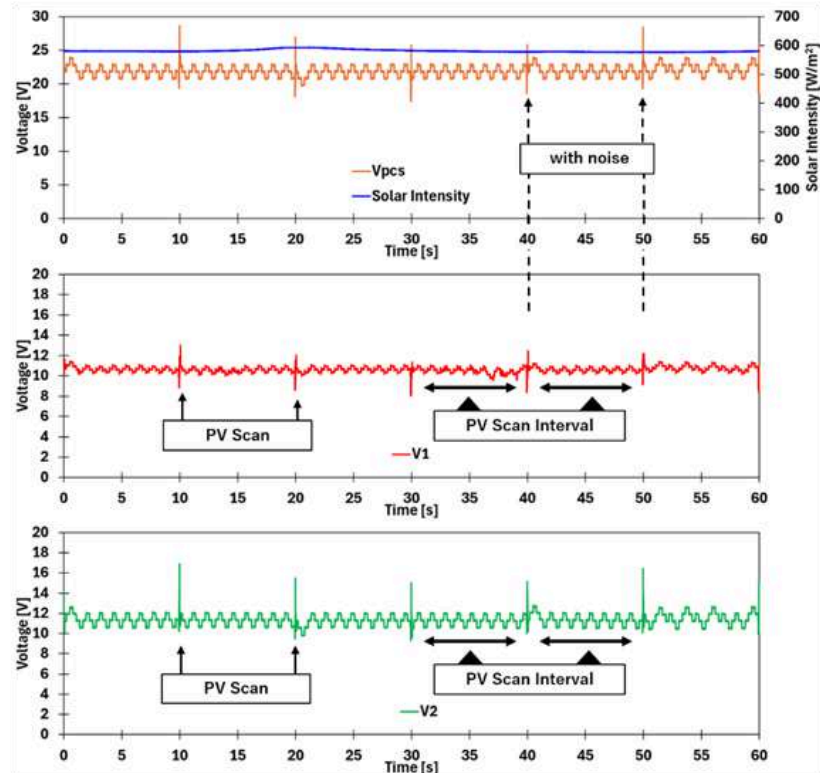


Figure 7. Experimental waveforms for the conventional method (Conventional method)

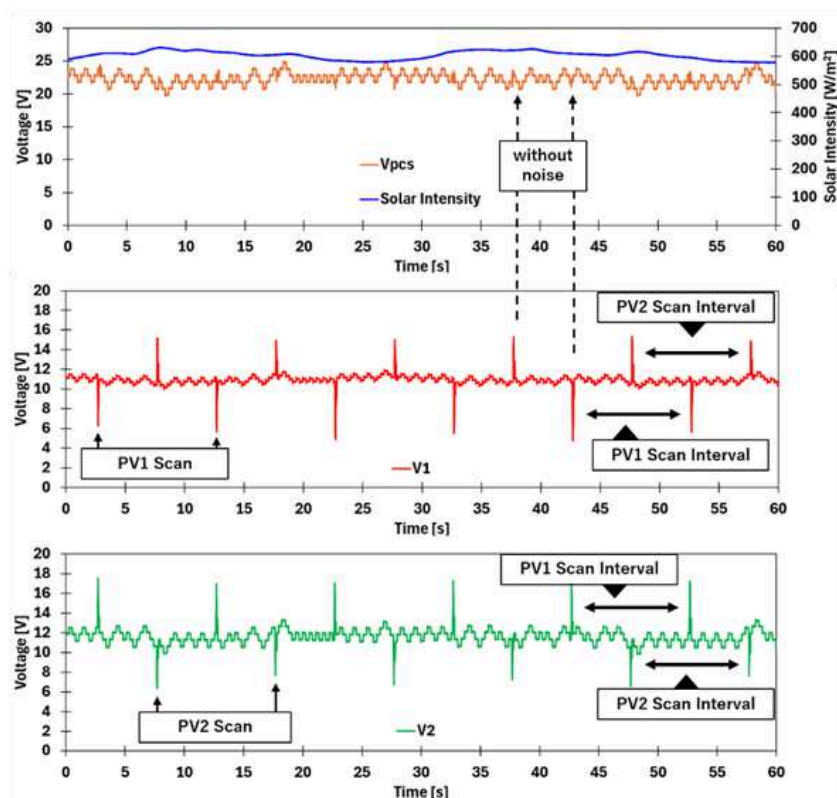


Figure 8. Experimental waveforms for the proposed method (Proposed method)

Figure 7 shows the experimental results for the conventional system. In the conventional system, noise of approximately 20 V occurs in the PCS-side voltage during scanning. Figure 8 shows the experimental results for the proposed system. In the proposed system, scanning of PV1 and PV2 alternates every 10 seconds. As a result,

MPPT control operates without voltage fluctuations during PV scanning affecting the PCS-side voltage, making it less likely for noise to occur during scanning.

V. Conclusion

This paper examines the effectiveness of the proposed method in reducing noise on the PCS side that occurs during the scanning operation of an APV system. Experiments demonstrated that the proposed method could suppress voltage fluctuations on the PCS side. This method does not require the addition of filter circuits or other components to reduce noise; it can be implemented simply by modifying the scanning time in the operating program.

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