Power acquisition effect for appropriate placement of MPPT units in a PV array

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Abstract. The PV generation system operates in maximum power point of PV array by MPPT control of power conditioning system (PCS). However, there is a problem that maximum power of the PV array configuration greatly decreases by partial shadow. For this problem, the authors previously proposed the method which connects MPPT unit to every PV panel between PCS and PV array. Moreover, the effect of this method was demonstrated by simulations and experiments. In the present day, this method is in practical use. However, the appropriate placement of MPPT units was still not clear. The authors previously investigated the appropriate placement of MPPT units from the viewpoint of acquisition of electric power and system stability, simulating P-V and I-V characteristics of some representative patterns connected MPPT unit to each PV panel in the PV array configuration. In this paper, power increase rate of the proposed PV array system is evaluated in experiment, compared to the conventional PV array system. It is clarified that maximum power of the proposed PV array system is 1.26 times, compared with maximum power of the conventional PV array system.

1. Introduction

The PV generation system operates in maximum power point of PV array by MPPT control of power conditioning system (PCS). However, there is a problem that maximum power of the PV array configuration greatly decreases by partial shadow.

For this problem, various MPPT methods have been investigated[1]-[3]. The authors previously proposed the method which connects MPPT unit to every PV panel between PCS and PV array. Moreover, the effect of this method was demonstrated by simulations and experiments[4]-[5]. In the present day, this method is in practical use. However, the appropriate placement of MPPT units was still not clear. The authors previously investigated the appropriate placement of MPPT units from the viewpoint of acquisition of electric power and system stability, simulating P-V and I-V characteristics of some representative patterns connected MPPT unit to each PV panel in the PV array configuration[6]. In this paper, power increase rate of the proposed PV array system is evaluated in experiment, compared to the conventional PV array system.

2. Circuit analysis of PV array with MPPT units

2.1. System configuration
Figure 1 shows the PV array configuration. The PV array is configured by some strings. The strings are composed of some PV panels and MPPT units connected to PV panel.
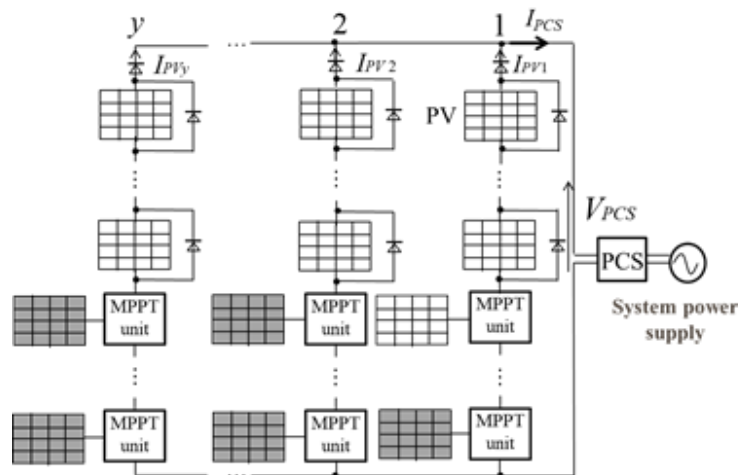
Figure 1. PV array configuration
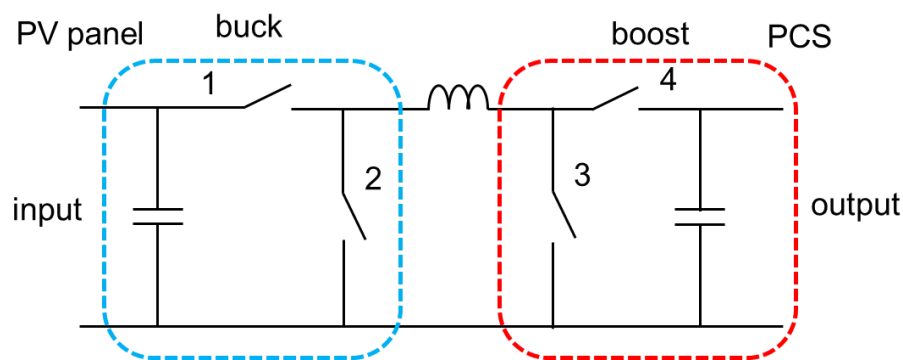
2.2. Control method of MPPT unit


Figure 2. Back-boost DC-DC converter

Figure 2 shows back-boost DC-DC converter in MPPT unit. In MPPT unit, the P&O (Perturb and Observe) method is used as MPPT control(Figure 3). Figure 3-(a) shows conceptual diagram of P&O method. It is executed by periodically perturbing (incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. The flowchart of this method is represented by Figure 3-(b).

Figure 4 shows equivalent circuit of the PV array configuration (Fig. 1). Where, M is the number of MPPT unit (MPPT unit group), N is the number of PV panel (PV panel group), y is the number of string, I_{PV} is string current, VPV is output voltage of each PV panel, V_{MPPTk} is output voltage of MPPT, V_{PCS} is input voltage of PCS and $X_k(0\sim1.0)$ is degree of a shadow on the PV panel.
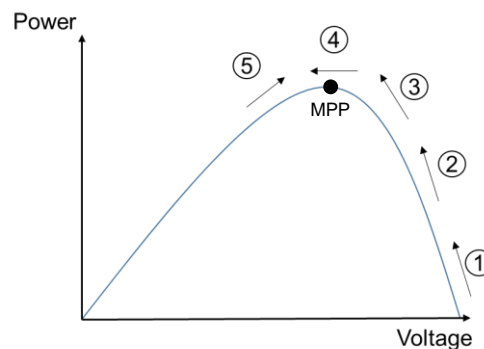
(a) Conceptual diagram
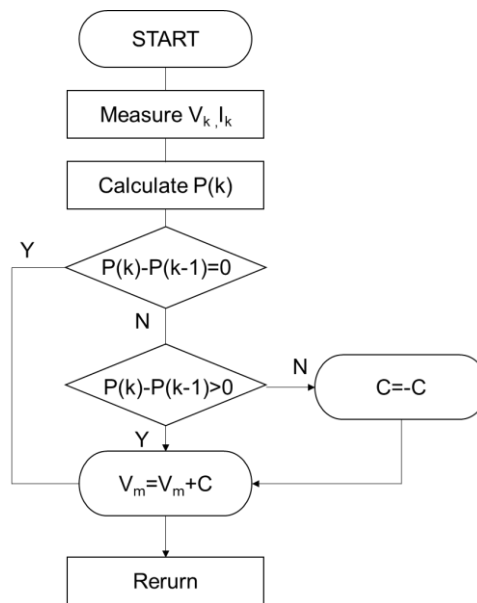
(b) Flowchart

Figure 3. P&O method
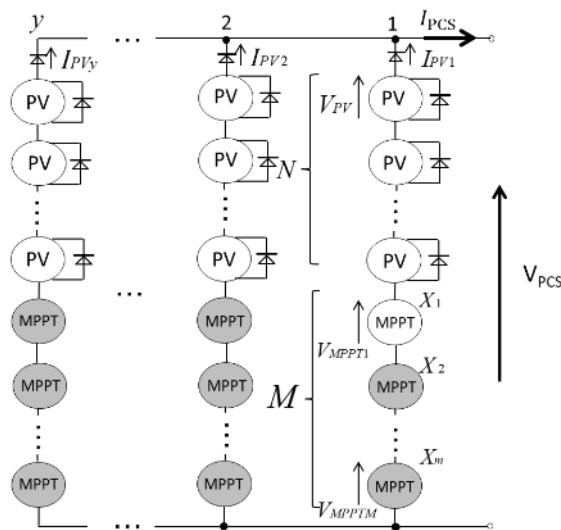
Figure 4. Equivalent circuit of PV array configuration

2.3. Operation of each mode

MPPT unit is able to extract the maximum power from the PV panel, so the MPPT unit is regarded as a constant power source. Each string has three circuit modes (Mode1~3), considering the bypass diode and the blocking diode.

In these strings, there are three circuit constitutions, as shown in the following.

(a)   string(a)

The string is composed of only PV panel with MPPT unit.

(b)   string(b)

The string is composed of only PV panel. In this string, a shadow does not exist for all PV panels.

(c)   string(c)

The string is composed of both the PV panel with MPPT unit and the PV panel.

(1) Mode1(Normal Mode)(ISC ≧ IPV>0)
This Mode exists in all string constitution (string(a)~(c)). In this Mode, bypass diode and blocking diode do not operate. Where, IPV is short current.

(2) Mode 2(Bypass Mode)(IPV>ISC)
This Mode exists in string(c). In this Mode, bypass diode operates. Therefore, output voltage of PV is zero. In string(b), because the shadow does not exist for PV panels, this mode dose not exists.

(3) Mode 3(Blocking Mode)(NVOC<VPCS, IPV=0)
This Mode exists in string(b). Where, NVOC is total open voltage of PV panel. VOC is the open voltage of PV panel.

3. Conception of appropriate placement

The following shows a conceptual diagram of P-V characteristics in the conventional PV array system and of P-V characteristics in the appropriate placement of MPPT units in the PV array system using MPPT unit. Where, the PV array is configured by 6 strings, assuming the household PV array system. Where, one string has 6 series PV panels. The string has the constitution of string(a), (b) and (c). Grey part in Fig.5 shows the shadow.

3.1. Conventional PV array system

Figure 5-(a) shows the conventional PV array system. Figure 5-(b) shows the P-V characteristics of conventional PV array system. In this figure, the sum P_0 of maximum power of each PV panel is shown in dotted red line. P_0 is the potential power of the PV array in Figure 5-(a). P_{max} is maximum power of conventional PV array system. In this case, this PV array system is not able to extract the power of PV panel with shadow. It is difficult to track maximum power point, because multi-peeks in the P-V characteristics exist for V_{PCS}. As a result, this PV array system is not able to operate at the maximum power. In this PV array system, output power is decreased by mismatch of the string maximum power points. When a shadow exists in PV panel, PCS is not able to extract the potential power P_0 from this PV array system.
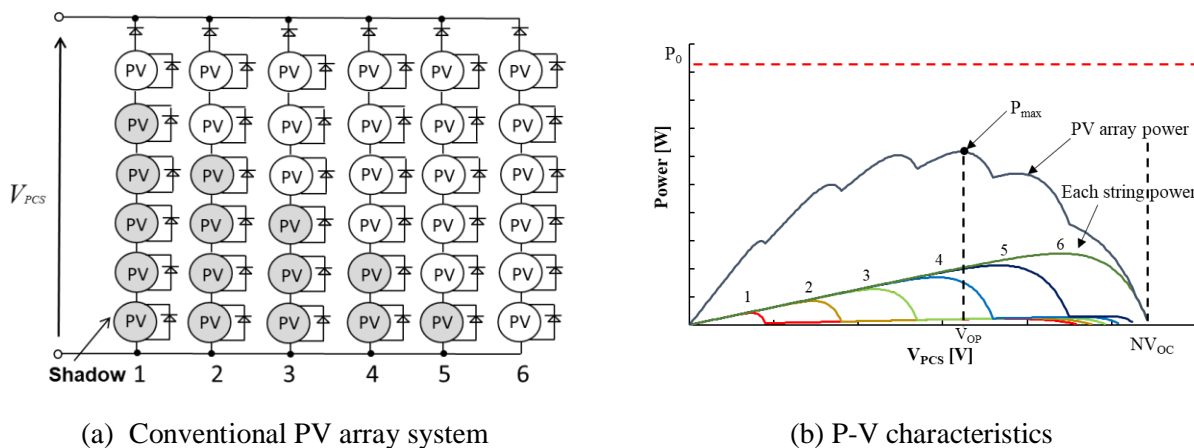

(a) Conventional PV array system	(b) P-V characteristics

Figure 5. Conventional PV array system

3.2. Best placement of MPPT units

Figure 6-(a) shows the best placement of MPPT units found by simulation of some representative patterns to solve the above mentioned problem. This figure shows the PV array configured in one string(b) and the other strings(a). Figure 6-(b) shows P-V characteristics. MPPT control of PCS is able to definitely find one power peak point of string(b), because the power of string(a) is constant for V_{PCS}.

Therefore, the system is stable and PCS is able to operate in maximum power point. P_{max} is the same as P_0. PV array system is able to extract the potential power P_0 in principle.

From the viewpoint of acquisition of electric power and system stability, the best placement of MPPT units is able to be simply described as shown in Figure 7. This equivalent circuit is composed of one string(b) to determine the MPPT operation point of PCS and the string(a) group to eliminate the mismatch of the string maximum power points. In this PV array system, PCS is able to extract the potential power P_0.
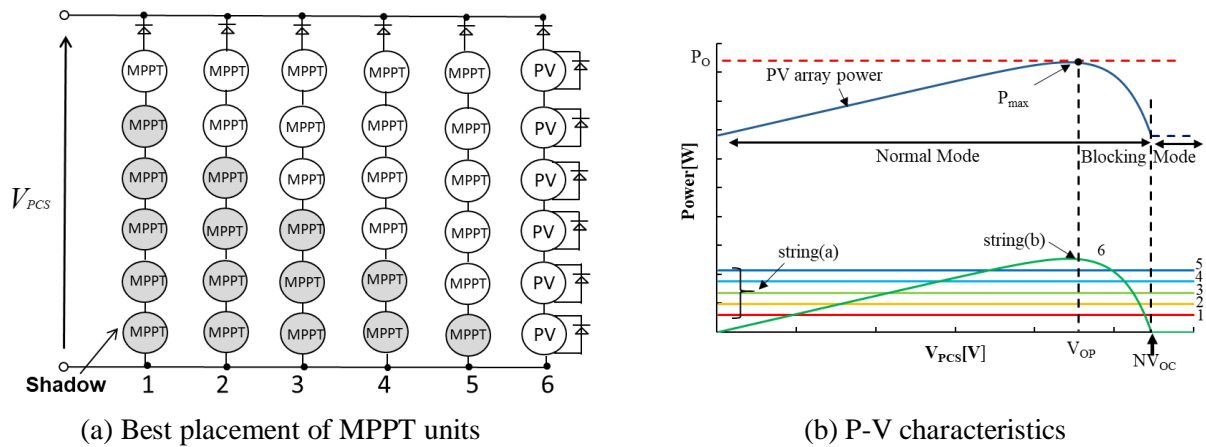

(a) Best placement of MPPT units   (b) P-V characteristics

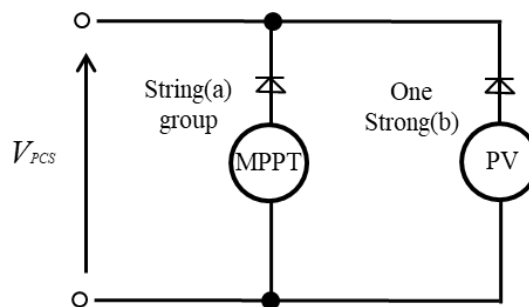**Figure 6.** Best placement of MPPT units

Figure 7. Equivalent circuit of best array configuration

4. Experiment

In order to confirm the validity of equivalent circuit(Figure 7.), the following experiment is carried out. The PV array is configured by 2 strings, assuming the fundamental PV array system(Figures 8 and 9). Where, one string has 2 series PV panels. The string has the constitution of string(a) and (b). Gray part in PV2 of Figures 8 and 9 shows the shadow, and efficiency of the MPPT unit is 86.4[%]. In this experiment, PV simulator is used instead of the PV panel. Each parameter of the PV simulator is shown in Table 1. In PV simulator of PV2, Short-circuit current is set low in order to emulate a shadow condition.

Table 1. Each parameters of the PV simulator

|	Maximum output operating voltage [V]	Maximum output operating current [A]	Maximum output power [W]	Open-circuit voltage [V]	Short-circuit current [A]
PV1	14.8	3.72	55.1	21.8	4.0
PV2	14.1	0.79	11.1	18.1	1.08
PV3	16.0	3.11	49.8	20.4	3.46
PV4	16.0	3.11	49.8	20.4	3.46

4.1. Conventional PV array system

Figure 8-(a) shows the conventional PV array system. Figure 8-(b) shows the P-V characteristics of conventional PV array system. In this figure, the potential power P_0 is 165.8[W]. Maximum power P_{max} of conventional PV array system is 124.0[W]. In this case, this PV array system is not able to extract the power of PV panel with shadow. It is difficult to track maximum power point, because multi-peeks in the P-V characteristics exist for V_{PCS}. As a result, this PV array system is not able to operate at the maximum power. Where, useful utilization factor U is defined as the following equation (1).

$$U = \frac{P_{max}}{P_0} \times 100[\%]$$
(1)

Therefore, U is calculated as 74.8[%]. In this PV array system, output power is decreased by mismatch of the string maximum power points. When a shadow exists in PV array, PCS is not able to extract the potential power P_0 from this PV array system.
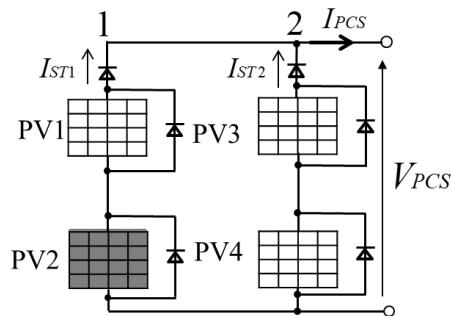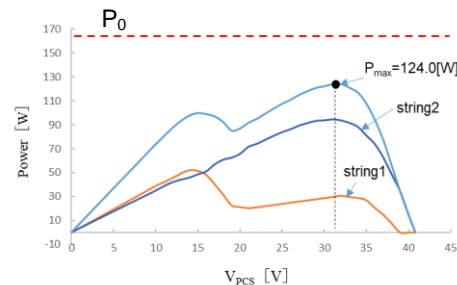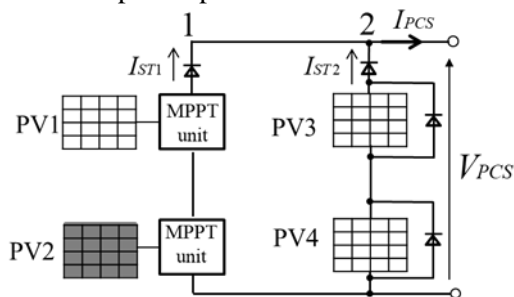

(a) Conventional PV array system   (b) P-V characteristics
**Figure 8.** Conventional PV array system

4.2. Proposed PV array system

Figure 9-(a) shows proposed PV array system (best placement of MPPT units). This figure shows the PV array configured in one string(b) and the other string(a). Figure 9-(b) shows P-V characteristics of proposed PV array system. MPPT control of PCS is able to definitely find one power peak point of string(b), because the power of string(a) is constant for V_{PCS}. Therefore, the system is stable and PCS is able to operate in maximum power point. In this experiment condition, P_{max} is 156.8[W]. U is calculated as 94.6[%]. When a shadow exists in PV array, PCS is able to extract the potential power P_0 from this PV array system.

In this experiment condition, P_{max} of the proposed PV array system is 1.26 times, compared with P_{max} of conventional PV array system. In proposed PV array system, MPPT control of PCS is able to definitely find one power peak point. Therefore, the system is stable and PCS is able to operate in maximum power point.
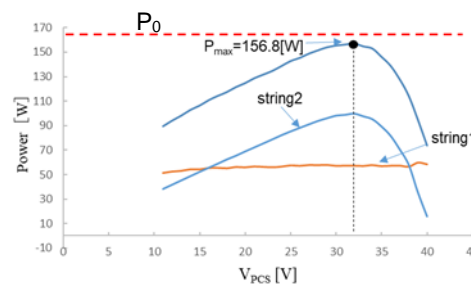
(a) Proposed PV array system   (b) P-V characteristics
Figure 9. Proposed PV array system

5. Conclusion

The authors previously proposed the appropriate placement of MPPT was proposed from the viewpoint of acquisition of electric power and system stability, simulating P-V and I-V characteristics of some representative patterns connected MPPT unit to each PV panel in the PV array configuration. power increase rate of the proposed PV array system was evaluated in experiment, compared to the conventional PV array system. In this experiment condition, it is clarified that maximum power of the proposed PV array system is 1.26 times, compared with maximum power of the conventional PV array system.

6. References

[1]   G. Petrone, G. Spagnuolo, and M. Vitelli, "An Analog Technique for Distributed MPPT PV Applications", *IEEE Trans. Ind. Electron.* Vol. 59, no. 12, pp. 4713 – 4722. Dec. 2012

[2]   M. A. Ghasemi, A. Ramyar, and H. I.-Eini, "MPPT Method for PV Systems Under Partially Shaded Conditions by Approximating I–V Curve," *IEEE Trans. Ind. Electron.* Vol. 65, no.5, pp.3966 – 3975, May. 2018

[3]   Mo. Lasheen, A. K. A. Rahman, M. A.-Salam, S. Ookawara, "Adaptive reference voltage-based MPPT technique for PV applications," *IET Renewable Power Generation.* Vol.11, no.5, pp. 715 – 722, Apr. 201

[4]   C.Huang, K.Itako, T.Mori and Q.Ge, "MPPT Control System for PV Generation System with Mismatch Modules", *Journal of Energy and Power Engineering(USA),*9, 2015, pp.83-90.

[5]   C.Huang, K.Itako and T.Mori, Q.Ge,"MPPT Control Method Using Buck Type DC-DC Converter for PV Generation System with Mismatched Modules" *Proceedings of ICEE 2014*

[6]   Y.Takeda, K.Yoshihara and K.Itako. " Best Solution for Placement of MPPT Units in a PV Array" *Proceedings of Grand Renewable Energy 2018*