A Novel PV Array Connection Strategy with PV-buck Module to Improve System Efficiency

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***Abstract*-The traditional directly connected PV array has low output power and efficiency under partially shaded condition. This paper proposes a new PV array connection method by installing a buck converter for each PV panel before being connected as novel PV array. More power can be extracted from novel PV array than the traditional PV array by using perturb and observer (P&O) MPPT (Maximum Power Point Tracking) algorithm under any uneven irradiance condition. The simulation results show that the proposed method is feasible and efficient, meanwhile the complex GMPPT (Global MPPT) algorithm is not required.**

Keywords-PV; MPPT; partially shaded condition; distributed converter PV array

I. INTRODUCTION

The PV power system becomes popular in this new era because the solar energy is renewable and environmental friendly. Although the research and development on solar cell design and fabrication is carried out continuously to reduce the high capital cost, the improvement of overall PV system performance is equally important. One of the interesting areas is by implementing MPPT technique to control the operating condition of the PV system. This approach is to track the maximum available output power of the PV system and hence to ensure that the maximum power can be extracted regardless the changes of environmental conditions such as solar irradiance level and ambient temperature.

In order to increase the extracted power from PV system, a bunch of individual PV panels (it can be defined as PV-diode Module shown in Fig. 1 (a)) are connected in series and parallel to construct a PV array and enhance the output capacity. However, this kind of connection has a serious drawback under partially shaded condition. The maximum power cannot be acquired when the irradiance or temperature on each PV panel are not the same in the PV array system. Bruendlinger and et al. have tested various commercially available inverters in partially shaded conditions and have found that the power loss due to shading can be as high as 70% [2]. Even using accurate and efficient GMPPT algorithm, it cannot ensure that each PV-diode module can produce maximum power under partially shaded condition because of the existence of bypass diode.

To improve the output power of PV array under partially shaded condition, this paper proposes a novel method that let every PV module output maximum power, meanwhile to avoid using the complex GMPPT algorithm.

II. NOVEL STRUCTURE OF PV ARRAY

In a traditional PV-diode array, if there are two PV-diode modules of column *j*th under different irradiance (PV1:1000 W/m^2 ; PV2:800 W/m^2), then their I-V characteristic curve would be shown in Fig. 1(b) and their MPPs are point a and point b. GMPPT will be used in this PV-diode array system. The operating current I may be equal to I_1 or I_3, and I_2 is the shaded PV-diode module's short - circuit current. If $I = I_1$, PV1 would work at MPP, PV2's would not output power, because $I > I_2$ and its bypass diode would turn on. If $I = I_3$, PV2 would work at MPP and PV1 work at point d. It is obvious that the power at point d is smaller than MPP(point a). Thus, wherever the column operating current is, the system would not make sure each PV-diode module produce maximum power under partially shaded condition.

In order to increase the extracted power for the PV array, a buck converter is proposed to parallel with each PV panels before being connected in series, as shown in Fig. 2 (a). The novel structure of PV panel can be called PV-buck module. The proposed PV-buck module can be used to construct the required PV array with certain voltage and power.

Assuming the buck converter has no conversion loss, the individual PV-buck module's output characteristic of P-V and I-V with different irradiance condition are presented in Fig. 2(b) and Fig.2 (c). From Fig. 2(c), it can be concluded that the individual PV-buck module has different output characteristic of I-V under different duty ratio according to its irradiance. From Fig. 2(b), the characteristic of P-V for each PV-buck module is shown under different duty ratio according to different irradiance, meanwhile the maximum power can be extracted from the PV panel under different irradiance. We can find that the maximum output power is not changed under different duty ratios. Meanwhile, it is known that the traditional PV-diode module has only one output characteristic curve.

It is impossible for the PV array to make each PV panel work at its own MPP under partially shaded condition. However, if the PV-buck module is used, it is easy to make sure each PV-buck module work at MPP by controlling the buck converter as showed in Fig.1(c). The two dotted line are PV-buck module I-V curves, point a$'$ and point b$'$ are their MPP and column operating current $I = I_4$.

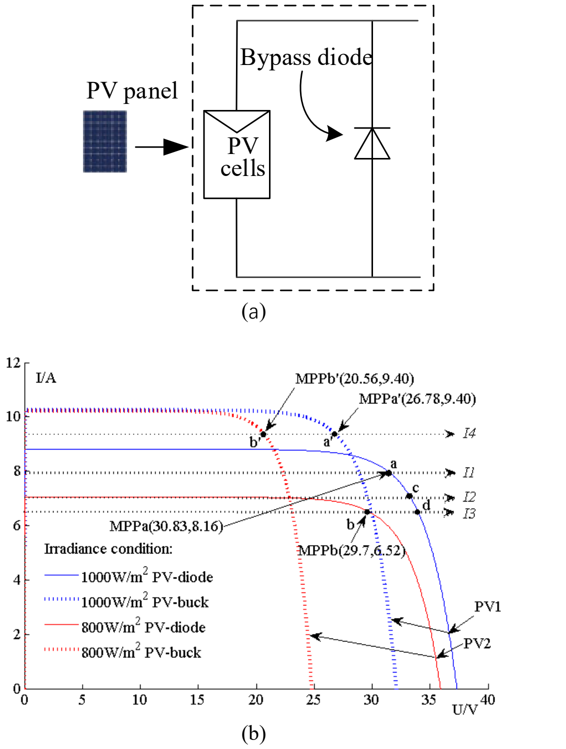

Fig. 1. (a) Traditional PV-diode module. (b) I-V curves of two PV modules in series. (Data is from the PV panel of CSUN 250-60P.)

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A k*n PV array is shown in Fig. 3 by using the proposed PV-buck module. The valuables of current and voltage are marked in the figure. The voltage and current of the buck converter in each column can be derived as (1),

$$\begin{cases} I_{1j} = I_{2j} = \cdots = I_{ij} = \cdots = I_{kj} \, (j = 1, 2 \cdots n) \\ \sum_{i=1}^{k} U_{i1} = \sum_{i=1}^{k} U_{i2} = \cdots = \sum_{i=1}^{k} U_{ij} = \cdots = \sum_{i=1}^{k} U_{in} \end{cases} \tag{1}$$

Where I_{sj} is the current of jth column.

The mean value of voltage and current in each PV-buck module can be deduced as follows:

$$\begin{cases} U_{pvij} \times d_{ij} = U_{ij} \\ I_{pvij} \div d_{ij} = I_{ij} \end{cases} (i = 1, 2, \cdots k; j = 1, 2, \cdots n) \tag{2}$$

U_{pvmij} and I_{pvmij} are assumed to be the corresponding panel voltage and current of the PV-buck module of the ith row and the jth column in the array, meanwhile the output voltage and current of the corresponding buck converter are assumed to be U_{mij} and I_{mij}. The maximum power of the column j is $P_{mj} = \sum_{i=1}^{k} P_{mij}$, where, P_{mij} is the maximum output power of the PV-buck module in the ith row of column j. If every PV component work at MPP, the voltage of parallel column must satisfy the rule of as shown in (1), then the power relation of each column can be calculated as:

$$P_{m1} : P_{m2} \cdots P_{mj} \cdots P_{m(n-1)} : P_{mn} = I_{sm1} : I_{sm2} \cdots I_{smj} \cdots I_{sm(n-1)} : I_{smn} \tag{3}$$

I_{smj} is the current of jth column when each PV-buck operates under MPP. Therefore, the duty ratio d_{mij} of each buck converter can be written as:

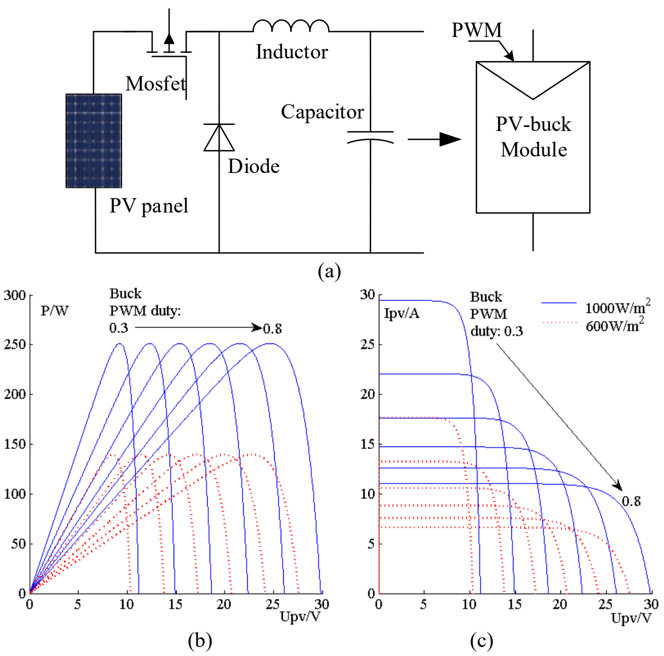


Fig. 2. (a) PV-buck module. (b) and (c) are P-V and I-V curves for PV buck module under different duty ratio. (Data is from the PV panel of CSUN 250-60P.)

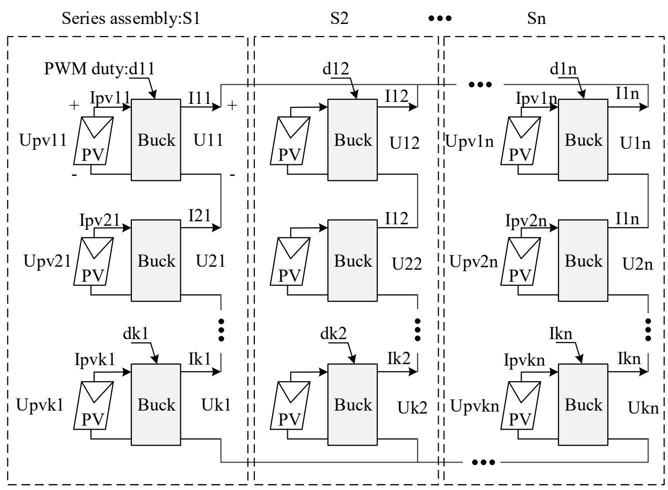


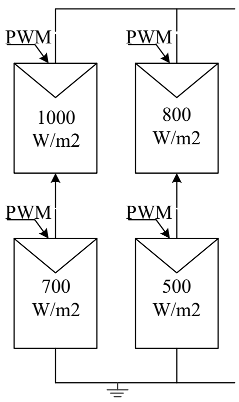
Fig. 3. k*n PV array with PV-buck module

$$d_{mij} = I_{pvmij} \div I_{ij} = I_{pvmij} \div I_{smj} \, (j = 1, 2, \cdots n) \tag{4}$$

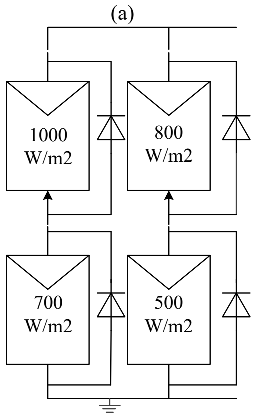
Therefore, in the jth column, d_{mij} can be achieved in each buck converter to extract the maximum power from the ith row PV panel. d_{mij} can be found by the traditional P&O[3].

III. Simulation Results

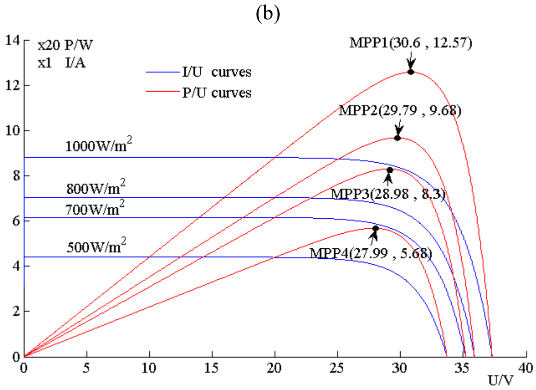
In order to verify the feasibility and high efficiency of PV array constructed by PV-buck modules, two simulation models are built in Matlab/Simulink, as shown in Fig. 4(a) and Fig. 4(b). CSUN 250-60P polysilicon PV component is used. Under standard test condition, the key parameters of PV are: Maximum Power $P_{\max}$ =250W; Open circuit voltage U_o =37.3V; Short-circuit current I_{sso} =8.81A; Voltage at MPP $U_{\max}$ =29.9V; Current at MPP $I_{\max}$ =8.36A. In addition, the practical parameters of the active switches and diodes are used in the simulation.



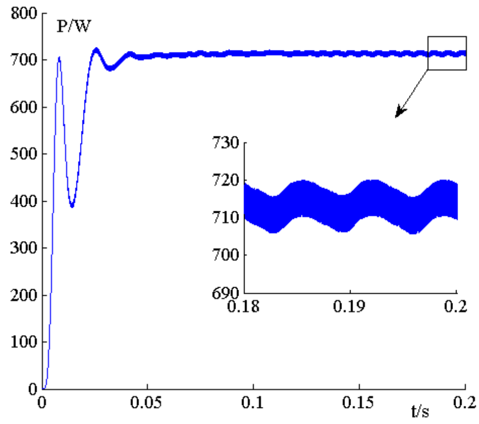
(a)



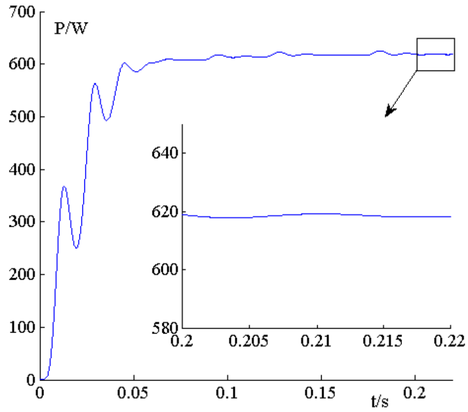
(b)



(c)



(d)



(e)

Fig. 4. (a) 2 series & 2 parallel PV-buck array. (b) 2 series & 2 parallel PV-diode array. (c) Four theoretical I-V & P-V curves under different isolation. (d) The output power of PV-buck array power. (e) The output power of PV-diode array power.

Fig. 4. (c) shows the theoretical I-V and P-V curves for the PV panel under four different irradiance conditions.

From Fig. 4(c), the theoretical maximum power of four PV panels with different irradiance condition can be calculated, which is P_{max} = (12.57+9.68+8.3+5.68) $\times$ 20=724.6W. From Fig. 4(d), the maximum power from the PV-buck module array is $P_{\max}' \approx 715\,\mathrm{W}$ and it is almost the same as the calculated value. However, from Fig. 4(e), the maximum power from the PV-diode module array is about 620W. The PV array constructed by the PV-buck module can produce 15% more power than the traditional PV array in the above assumed insolation condition.

IV. Experimental Results

In order to verify the effectiveness of PV array improving output power and efficiency under partially shaded condition, we built the experimental platform based on the AMETEK TerraSAS ETS60 PV simulator. Due to the limit of laboratory condition, we just prepared two simulators. The largest open voltage of single machine is 60V. The resistor is the load.

This control software of simulator which called TerraSAS can record the data of output power in real time. All of the following power waveforms are the data recorded in the background. The simulator setting parameters are shown in Tab.1.

Tab.1 The key parameters of PV Simulator

parameters	value	
	1000W/m^2	800W/m^2
open-circuit voltage U_{oc}/V	35.53	34.11
short-circuit current I_{sc}/A	9.653	7.415
maximum power point U_m/V	28.55	28.21
maximum power current I_m/A	8.933	6.862
maximum power P/W	255.04	193.58
fill factor FF	0.816	
influence of voltage and temperature factor β_V / (% / °K)	-0.36	
the temperature effect of power factor β_P / (% / °K)	-0.5	

According to Tab.1, when the irradiance is 1000W/m2 and 800W/m2, the maximum output power of PV simulator is 255.04W and 193.58W, the parameters are basically consistent with those of CSUN 250-60P model polysilicon subassembly.

The array structure shown in above was initiated experimental verification under two conditions: no shadow and partial shadow. Fig.5 shows the experimental platform.

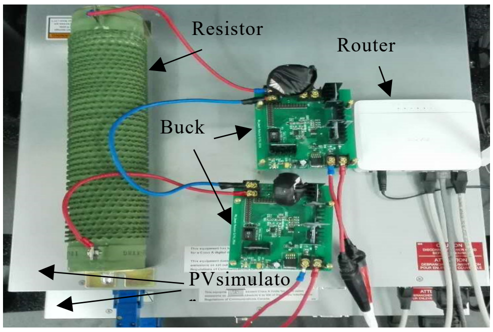


Fig.5. The photo of experimental platform

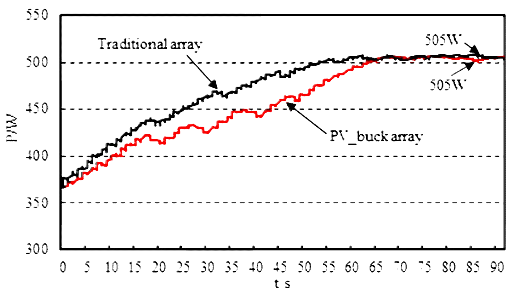


Fig.6. The output power of 2*1 string PV-buck array and the traditional array without partially shaded condition

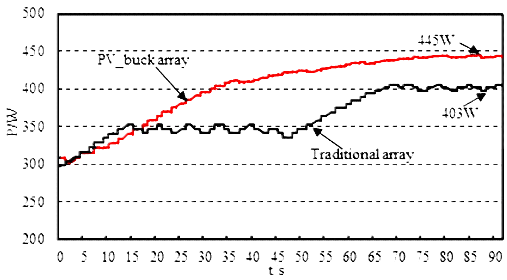


Fig.7. The output power of 2*1 string PV array under partially shaded condition

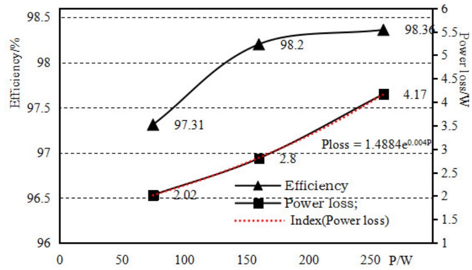


Fig.8. The efficiency of buck converter

Under no shaded condition, S1=S2=1000W/m2, the theory maximum output power of simulator is 510.08W , we can know from Fig.6, two kinds of array output power are 505W, MPPT precision is 99%. Under partially shaded condition, S1=1000W/m2, S2=800W/m2, the theory maximum output power of simulator is 448.62W, Fig.7 show us that the output power of PV-buck photovoltaic array is 445W, MPPT precision is 99.2%. While the traditional array output power is only 403W, the power promotion is about 10.42%.

The experimental results show that the conclusions are basically consistent with the simulations, moreover in accordance with the results of theoretical analysis. When partial shadow appears, PV-buck array will output more power than traditional string array, which can ensure that the maximum power can be extracted from all PV component. However, the traditional array cannot simultaneously ensure individual PV component of different radiation intensity to achieve the maximum power output. Fig.8 shows that when the buck works at rated power, the efficiency can reach 98.3%. In this experiment, when the power loss of the buck converter is about 4.1W, the group array of PV-buck can effectively improve the 33.6W power, which is about 8.4%.

The experimental results verify the effectiveness of the PV-buck PV array in improving the power generation efficiency of PV panels in local shadows. It should be pointed that it is important to reduce the cost of the buck converter.

V. Conclusions

According to the theoretical analysis, simulation and experimental results, the advantage of the new PV array connection method using PV-buck is verified. The maximum output power of PV array under partially shaded condition is increased greatly than the traditional PV array structure. Although the use of this method will increase the cost, but after mass production, the cost will be greatly reduced.

VI. Acknowledgment

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