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Study on Series and Parallel Connected Solar Photovoltaic System under Shadow Conditions

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***Abstract**: The performance of a photovoltaic (PV) array is affected by temperature, solar isolation, shading and array configuration. Often, the PV arrays get shadowed, completely or partially, by the passing clouds, neighboring buildings and towers, trees, and utility and telephone poles. Under partially shaded conditions, the PV characteristics get more complex with multiple peaks. Yet, it is very important to understand and predict them in order to extract the maximum possible power. In the usual series-connected wiring scheme, the residual energy generated by partially shaded cells either cannot be collected(if diode bypassed) or, worse, impedes collection of power from the remaining fully illuminated cells (if not bypassed). Rapid fluctuation of the shading pattern makes maximum power point(MPP) tracking difficult; generally, there will exist multiple local MPPs, and their values will change as rapidly as does the illumination. In this paper, a portable solar PV system that effectively eliminates both of the aforementioned problems is described and proven. And also Parallel-configured PV systems are compared to traditional series-configured PV systems with hardware experiments.*

***Index Terms:** Complex Illumination, Maximum Tracking Power Point (MPPT), Partial Shading, Photovoltaic (PV) Solar Cell, Power Converter, Solar Array*

I. Introduction

The use of electricity generated from solar energy has become more common recently, perhaps because of the environmental threats arising from the production of electricity from fossil fuels and nuclear power. However, in many applications, such as solar power plants, building integrated photovoltaic, or solar tents, the solar photovoltaic arrays might be illuminated non-uniformly. The cause of no uniform illumination may be shadows from clouds, trees, booms, neighbor's houses, or even the shadow of one solar array on the other, etc.
In conventional solar PV plants, the designer must solve the complex problem, the tradeoff between "maximum energy output" and "minimum produced energy cost" by varying the distance between the rows for these new applications, it has been especially important to optimize performance of the arrays in shadowed conditions. Because of the nature of the electrical characteristics of solar cells, the maximum power losses are not proportional to the shadow, but magnify nonlinearly. The shadow of solar PV array can cause many undesired effects:

The real power generated from the solar PV array is much less than designed, so that the loss of load probability increases.

The local hot spot in the shaded part of the solar PV array can damage the solar Cells. There are several approaches that have been proposed to reduce the effect of shadows on a solar PV array output power:

Bypass diodes are connected across shadowed cells to pass the full amount of current while preventing damage to the solar cell. This method usually requires a great number of bypass diodes that are integrated in the solar arrays. The production of solar arrays with bypass diodes is more costly. Furthermore, the power losses of solar PV arrays are not prevented completely because there are the additional power losses when the current passes though the bypass diodes.

In large systems, each of the solar sub-modules can be connected to its own maximum power point (MPP) tracking DC-DC converter and can individually operate near its own MPP. Thus, the efficiency of the whole system is increased, but the method requires a large number of DC-DC converters (equal to the number of solar modules).

First, although partially shaded cells can still generate a certain amount of energy, that energy cannot be collected in systems of the traditional configuration. If bypass diodes are not used, any shaded cell inhibits power production from the entire series-connected string of cells. If bypass diodes are used, then the fraction of energy that could be generated by the partially shaded cells is still lost even if it does not impede collection of energy from the rest of the cells. Furthermore, in low-voltage arrays, the diode bias voltage may represent a significant fraction of the total PV source operating voltage. These issues are often not significant in high-voltage stationary systems that do not have obstructions, but they are quite significant in low-voltage systems for portable applications where partial shading occurs frequently and quite a fraction of the cells may be partially shaded at any one time. Second, rapidly changing shadow conditions increase the difficulty of

maximum power point tracking (MPPT). It is very hard to identify the global maximum power point (for diode bypassed systems) because multiple local MPPs exist, and their locations fluctuate rapidly corresponding to the changing shading conditions. Even if at some instant one could know where the global maximum is, it would probably change before it was possible to shift the MPP tracker to that operating point. In other words, very fast tracking speeds and good control stability are particularly required for a MPP tracker to work in this situation.
Addressing these problems, this paper describes and validates a highly parallel configured PV system that operates effectively in rapidly varying shaded conditions. Series connections of cells, if necessary, are limited only to the minimum necessary to present an adequate input voltage (V) to the step-up converter connected at the output of the PV array, and by considerations of ohmic losses in the bus work. For Si cells, we are typically considering just two or three cells, but for multijunction PV cells that produce higher voltages, we could use single cells. It is noted that in, PV modules rather than PV cells are connected in parallel and shown to demonstrate better performance in shaded conditions. Each PV module is treated as one unit that tracks its own MPP. Therefore, when a module is shaded, the degradation of performance will not propagate to other modules. The work we report here extends the concept to the micro scale appropriate for portable applications at low power and low voltages. The proposed PV system adopts the parallel configuration at the individual cell level, so that every cell in the PV panel can achieve its MPP under nonideal conditions. In contrast to the electric utility scale applications where one needs as many power converters as PV modules, in the low-power case, only a single low cost converter is required. This paper shows specifically the performance gain of this arrangement and the efficacy in real world conditions, and it validates the real-world experiments with simulation data.

II. System Configuration

Parallel Connected System:

The proposed configuration consists of an array of parallel-connected PV cells, a low-input-voltage step-up power converter, and a simple wide bandwidth MPP tracker. Each PV module considered in this paper 24-PV cells connected as 2 cells in series, and 12 such series are connected in parallel. The model diagram of parallel connected solar PV panel is shown in fig .1 .The open circuit voltage (v_{oc}) = 3 V and short circuit current (I_{sc}) =5.4A

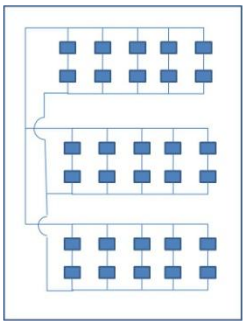


Fig.1.parallel connected system

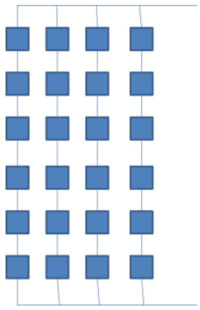


Fig.2.series connected system

Series Connected System:

The proposed configuration consists of an array of series -connected PV cells, a step-down power converter, and a simple wide bandwidth MPP tracker. Each PV module considered in this paper 24-PV cells connected as 6 cells in series, 4 strings in parallel. The model diagram of series connected solar PV panel is shown in fig.2 .The open circuit voltage (V_{oc}) =12V and short circuit current (I_{sc}) =2.7A

III. Experimental Results

Two hardware tests were carried out to validate the performance of the described approach. The first test compared the conventional configuration to the parallel configuration under complex illumination conditions; the other test verified the feasibility of wide bandwidth MPPT. For convenience, in the following, the conventional configuration is referred to as the series configuration and any mostly parallel configuration is referred to as the parallel configuration even if it contained two or three series cells in each parallel branch.

Performance Of Parallel Configuration And Series Configuration

The series configuration yielded an open circuit voltage around 12 V which was then reduced to 5 V by a buck converter; the parallel configuration yielded an open circuit voltage around 3 V which was then increased to 5 V by a step-up converter. Voltage was converted to 5 V in each case to provide power suitable for consumer electronics using typical two cells of NiMH batteries. The 5 V was conveniently chosen here for the purpose of comparison, but could otherwise have been any voltage between the lowest or highest voltages produced by the parallel and series arrays, respectively. Both of the power converters are commercial products (as shown in Table I) for general dc–dc power managements with typical efficiency around 90%, two cells of ultracapacitors were connected in series and served as the energy repository. The integrated control algorithms in both of the converters were not designed to track the MPP of the PV arrays because, for the series configuration implement any MPPT under rapidly changing shadow conditions. For the parallel configuration, the MPPT can be implemented and will be detailed in the second experiment; however, in this first experiment, no MPPT was integrated in order to generate results that were directly comparable to results from the series configuration.

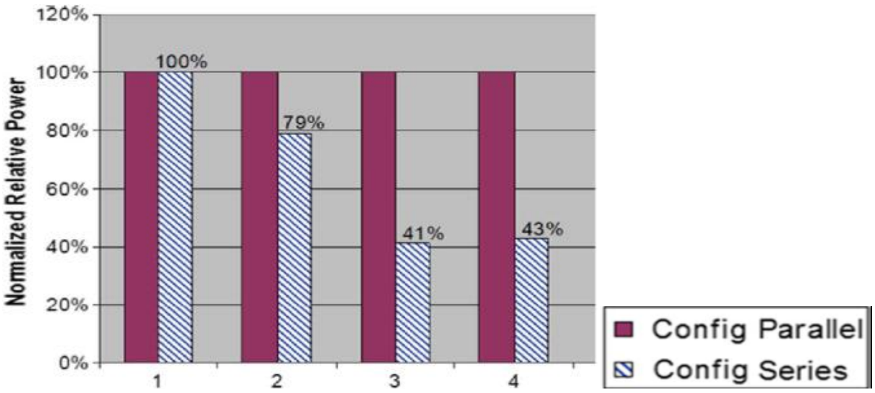


Fig 3 Comparision of power generation between two

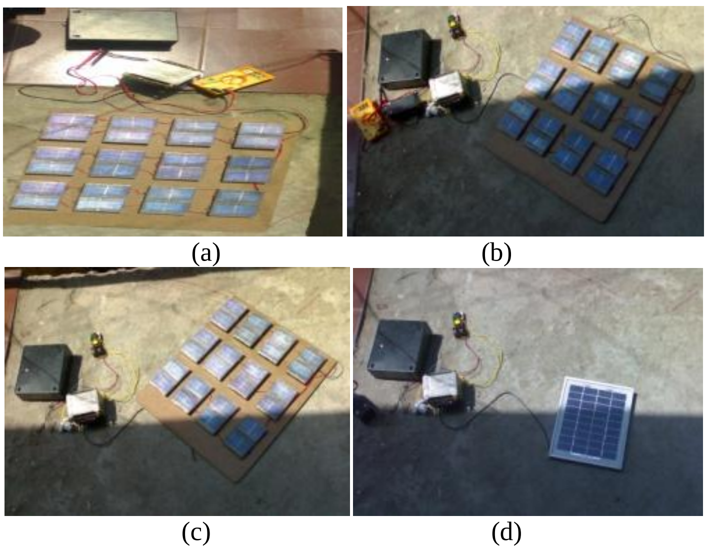
PV systems

Desciption Of Test Condition

	TEST DESCRIPTION
1	Area has no shade
2	Area shaded by trees
3	Area shaded by small plants
4	Area shaded by railing

Table 1

Both of the PV systems were tested in an outdoor environment. At the beginning and the end of each test, the terminal voltages of the ultracapacitors were measured. These voltages were used to calculate the energy charged into the ultracapacitor, and hence, the average power produced by each PV panel.

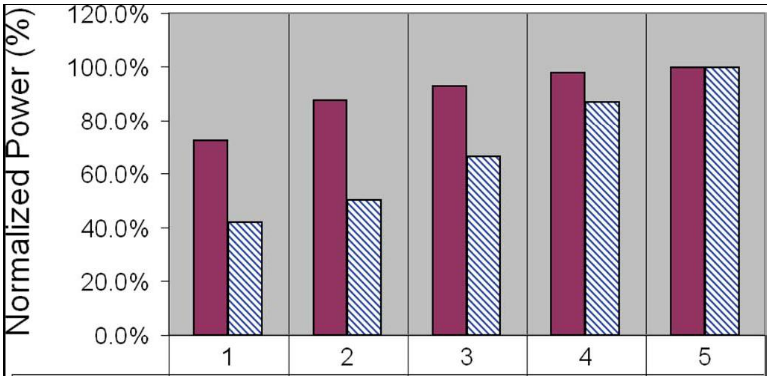


(a) (b)

(c) (d)

Fig.4. Experimental tests under different conditions

The ultracapacitor packs were precharged to 2.2 V to simulate two depleted secondary battery cells (e.g., NiMH or NiCd batteries). Four tests in total were conducted, in each test power generated by the parallel configuration was first normalized to 100%, and then it was used as reference to calculate the relative power generated by the series configuration. It can beseen, from Fig. 3, that the parallel configuration showed better performance and its power generation capability was greater, typically by a factor of two, in partially shaded conditions.



Shaded Area	50.0%	25.0%	12.5%	5.0%	0.0%
Parallel	72.4%	87.7%	92.8%	97.8%	100.0%
Series	41.9%	50.3%	66.5%	86.8%	100.0%

Fig.5 performance comparison of different shading conditions

The performance of parallel connected solar PV system and series connected solar PV system under different shadow conditions are experimentally examined and graphs are showed in Fig.6.

IV. Conclusions

This paper has described the configuration of a portable PV power system that produced maximum power under rapidly changing partial shading conditions such as would be encountered in portable applications. Under complex irradiance conditions, the power generating capability of the proposed PV system was approximately twice that of a conventionally configured series system. The developed approach is broadly applicable, but is perhaps most valuable in PV systems having high single-cell voltages where direct input to a high-efficiency converter is most practical.

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