Photovoltaic System Reconfiguration strategy for mismatch condition

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***Abstract*—Power generation efficiency of photovoltaic(PV) system is reduced significantly under partial shading or solar cell damage conditions. This efficiency losses affected by truing on bypass diode of PV panels, which called mismatch losses. Reconfiguration technology to reconfigure electrical series or parallel connection among PV panel can maximize generate power. This paper proposes a reconfiguration strategy that finds an optimal configuration among mismatched PV array in a less computational time. This algorithm is very light and suitable for embedded device. The results show that compare with existed reconfiguration method under non-uniform shadow scenario proposed algorithm computes an optimized configuration with less computational time and very high accuracy.**

***Index Terms*—Photovoltaic system, mismathed power loss, reconfiguration, dynamical reconfiguration.**

I. Introduction

As fossil energy is constantly depleted and increasing a serious pollution problem for the environment, research and utilization on a green and renewable energy have become necessary to support human existence and guarantee a sustainable human development. Photovoltaic (PV) energy has received a significant attention since it is unlimited and easy to be scaled up. Thanks to extensive technology and research on photovoltaic energy generation, large scale photovoltaic energy generation systems have been deployed into many practical applications. However, PV arrays are sensitive to shading and PV cell's fault or aging. This implies that when ~~interconnection of~~ PV cells or modules do not have identical properties or experience different conditions from one another. the PV array is in mismatch condition. The photovoltaic arrays under mismatched conditions will accelerate the aging and heating of PV cells and cause a short circuit of photovoltaic cells to further damage the PV array. In order to avoid ~~mismatch condition~~ damage PV cells, we propose an algorithm that can reconfigure photovoltaic arrays ~~to avoid mismatch damage and maximize generated power~~.

In this paper, we use non-uniform irradiance levels to represent mismatch condition and analyze the efficiency of a PV system ~~under different shaded working condition~~. Photovoltaic arrays operating in non-uniform irradiance levels may present multiple local maximum power points (MPPs) [1], which are generated by turning on bypass diodes. By changing electrical connection among the panels to prevent activate bypass diodes is a recent appealing solution [2].

The main difficulty facing the reconfiguration problem is that some or even all panels can be subjected to partial shading and there may be more than one MPP for each panel. Moreover, the panels, and not modules, reconfiguration strategy has to be realized so that modules providing the highest power could be grouped separately [3] [4].

This procedure enables to detect panel's operating conditions, in more than two-strings, receiving different irradiance levels. The reconfiguration algorithm will analyzes panels' working conditions and reorganizes panels into different strings by different irradiance levels. However, in sparse of mismatching conditions, distribution of panels among different irradiance levels are not significant. For that, by increasing number of strings in the PV array and using exhaustive search can be a solution [3]. Another approach to optimize photovoltaic arrays is using genetic algorithm [5]. However, computing cost is too significant, and this algorithm can't detect best configuration precisely. A simplest reconfiguration strategy for minimizing mismatch losses is presented in [10]. In this strategy, an algorithm gives candidates for PV array reconfiguration, for each candidates we have conduct power simulations. But some candidates are not feasible, which means there isn't any configuration for PV array can be realized. Since the power simulation is very time consuming, based on existed work we want to reduce number of candidates to accelerate overall reconfiguration algorithm. In this paper we propose an algorithm can give optimal configuration and check feasibility with less computational time and high accuracy.

II. Assumption of a PV array

In this paper, we use the following definitions of PV arrays, modules, strings and panels as showed in Fig. 1. A PV array is formed by several parallel connected (PV) strings, and a string is formed by several series-connected PV panels. For a PV panel, formed by three PV modules ($N_M = 3$) connected in series with bypass diodes.

We assume that each panel follows: The current versus voltage (*I-V*) curve is acquired and calculated by algorithm presented in [6]. That algorithm will analyzes the panel *I-V*

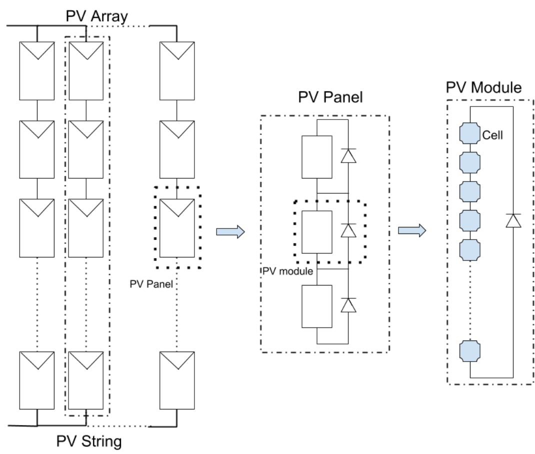


Fig. 1: PV arrays, strings, and panels.

curve sample by finding almost-constant-current and voltage regions and coordinate multiple maximum or minimum power point in the *P-V* curve if PV array is working in mismatched conditions or not.

All the panels in PV array have the same number (*N*) of modules. For particular module, using (V_{mpp_n}, I_{mpp_n}) to identify voltage and current values on different maximum power point by index *n*. Those parameters can be directly estimated by the prosess provided in [7].

Furthermore, it is also assumed that for each string it has same number of panels. Means every string in PV array have same length. String's length are identical based on when they connected in parallel, a string has more panels may cause current back flow into other strings which have less panels [8].

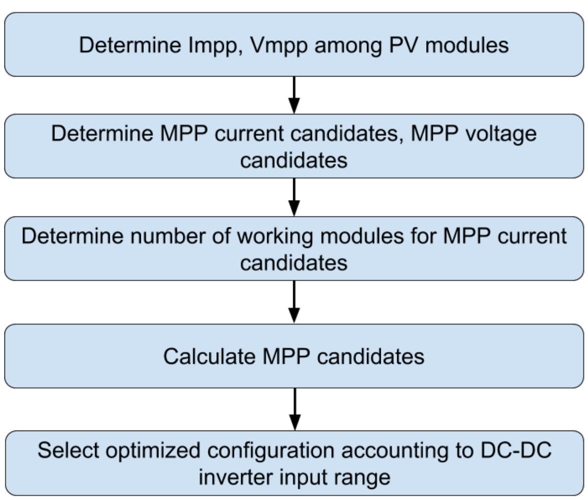


Fig. 2: Flowchart of reconfiguration algorithm in [10].

III. Reconfiguration Algorithm

To reconfigure a large scale partial shading PV array, an example refers to 9 panels which have been connected in 3 strings. In this example, mismatching conditions presented in Table I. Each panel made of 3 identical PV modules (*N=3*), dataset in Table I are provide by method in [6] [7]. As described in [10], the Fast reconfiguration strategy firstly determine V_{mpp} and I_{mpp} for each PV module by using the algorithm in [7] [9]. Then determine MPP current and voltage candidates among PV array. Calculate MPP candidates matrix by multiplying the current and voltage candidates. Using the number of working modules (Q_{M_n}) for each MPP current candidates to determine MPP candidates. Finally the Fast reconfiguration strategy gives MPP candidates for reconfiguration, which specifies a current value and minimum number of working modules for each string in PV array. The general steps of Fast reconfiguration strategy as showed in Fig. 2. Due to a PV panel can not be used into different string, those MPP candidates may have some un-feasible configurations. Our proposed algorithm based on the method in [10] to calculate MPP candidates and using unique panel selection technology to give optimal reconfiguration solution among partial-shading PV array.

In this example, though the procedure in Fast reconfiguration strategy, MPP candidates are presented in (1) and number of working modules in MPP candidates are presented in (2), respectively.

TABLE I

DATASET OF PARTIAL-SHADING PV ARRAY

Panels	Vmpp(V)	Impp (A)	MPP(W)
P1	[0, 2.9, 11.4]	[0, 0.5, 2]	[0, 1.5, 22.8]
P2	[2.9, 17.1, 17.1]	[0.5, 3, 3]	[1.5, 51.3, 51.3]
P3	[2.9, 2.9, 2.9]	[0.5, 0.5, 0.5]	[1.5, 1.5, 1.5]
P4	[0, 11.4, 11.4]	[0, 2, 2]	[0, 22.8, 22.8]
P5	[0, 2.9, 11.4]	[0, 0.5, 2]	[0, 1.5, 22.8]
P6	[2.9, 11.4, 11.4]	[0.5, 2, 2]	[1.5, 22.8, 22.8]
P7	[2.9, 11.4, 17.1]	[0.5, 2, 3]	[1.5, 22.8, 51.3]
P8	[11.4, 11.4, 11.4]	[2, 2, 2]	[22.8, 22.8, 22.8]
P9	[2.9, 11.4, 17.1]	[0.5, 2, 3]	[1.5, 22.8, 51.3]

$$MPP\ candidates = [\{0.5, 0.5, 2\}, \{0.5, 2, 2\}, \{2, 2, 2\}, \{2, 2, 3\}] \tag{1}$$

$$Q_{M_n} = [\{8, 8, 8\}, \{7, 7, 7\}, \{5, 5, 5\}, \{4, 4, 4\}] \tag{2}$$

A. Feasibility

The feasibility of configuration based on the assumption of section II, each string in PV array must have same number of panels. Definition of feasibility in (3). When a configuration needs panels in a string (NP_n) are over maximum number of panels per-string(NP_{stMAX}) this configuration is unfeasible.

$$\begin{cases} NP_n > NP_{stMAX} & \text{Unfeasible} \\ NP_n \leq NP_{stMAX} & \text{Feasible} \end{cases} \tag{3}$$

For the first MPP candidate {0.5, 0.5, 2} need 8 modules for each string. According to Table I, for a string current on 2A at least need 4 panels and didn't meet feasible requirement, thus, algorithm terminate. The second MPP candidate {0.5, 2, 2} as same as previous one also not feasible.

B. Panel Selection Strategy

In order to give more precise reconfiguration strategy. Our proposed algorithm firstly sort panels in a particular order for MPP candidates. For the example of fourth MPP candidate $\{2, 2, 3\}$, by giving dataset in Table I generate a selection matrix in (4) that each column indicate panel's number and each row indicate to string number. Element in the matrix corresponding to number of module which be able to working on string current.

	P1	P2	P3	P4	P5	P6	P7	P8	P9
St1	1	2	0	2	1	2	2	3	2
St2	1	2	0	2	1	2	2	3	2
St3	0	2	0	0	0	0	1	0	1

(4)

Then calculate number of module difference among string currents. For panel 1, difference between string 3 and string 2 is 1 ($Diff_1 = 1$) and difference between string 2 and string 1 is 0 ($Diff_2 = 0$). Sort panels in lexicographic order by $Diff_1$ and $Diff_2$. As showed in matrix (5).

	P2	P3	P1	P5	P7	P9	P4	P6	P8
St1	2	0	1	1	2	2	2	2	3
St2	2	0	1	1	2	2	2	2	3
St3	2	0	0	0	1	1	0	0	0
$Diff_1$	0	0	1	1	1	1	2	2	3
$Diff_2$	0	0	0	0	0	0	0	0	0

(5)

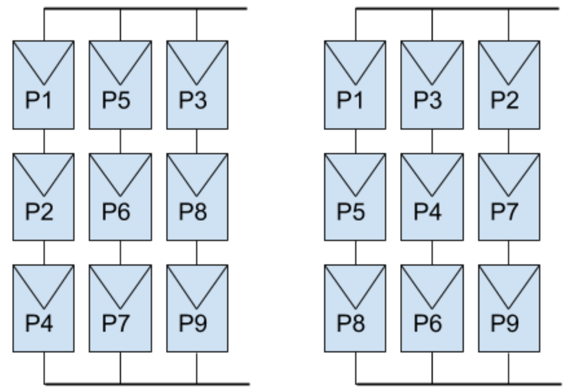
To find the best PV configuration, following steps are required:

1- Select panels in matrix (5) from left side to right.
2- If the element in matrix is 0, release corresponding panel
3- Replace selected panels if summations of selected panels' contain modules are equal to unselect panel. As the example of string 2, selected panels are [Panel 1, Panel 5], these panels contain modules are equal to next unselect panel [Panel 4]. Then swap [Panel 1, Panel 5] and [Panel4], release [Panel 1, Panel 5].
4- If replacement approved, step 3 will be repeated till summations of selected panel contain modules are large or equal to Q_{M_n}.
5- Otherwise, none of the replacement will be approved. Evaluate selected panels with feasibility requirement and compare selected modules with the requirement of Q_{M_n}.
6- If there remain any unselect panel, set unselect panel to a string with minimum length.

C. Panel Replace Strategy

In the section III-B, to obtain optimal panel selection need swap undesired panel. Based on section II, each panel only contain three identical PV modules. So the element in selection matrix in the range of 0 to 3. The replacement policy follows priorities are:

(1) Swap a panel contain 3 working modules to **three** panels each contain 1 working module.
(2) Swap a panel contain 3 working modules to **one** panel contain 1 working module and **one** contain 2 working modules.



(a) MPP candidate 3 (b) MPP candidate 4

Fig. 3: Configuration of partial-shading PV array

(3) Swap a panel contain 2 working modules to **two** panels each contain 1 working module.

By inspecting the features of each module in Table I, there are no configuration for MPP candidate 1 and MPP candidate 2. Configuration for MPP candidate 3 is that first string include Panel 1, Panel 2 and Panel 4; the second string include Panel 5, Panel 6 and Panel 7; the third string include Panel 3, Panel 8 and Panel 9. Configuration for MPP candidate 4 is that first string include Panel 1, Panel 5 and Panel 8; the second string include Panel 3, Panel 4 and Panel 6; the third string include Panel 2, Panel 7 and Panel 9. Optimal configuration for this partial-shading PV array as showed in Fig. 3.

IV. EVALUATION OF OPTIMIZATION ALGORITHM

Although the pilot example refers to three strings only, the extension of the method to any number of parallel connected strings is the same. This section verifies the effectiveness of proposed algorithm using Matlab simulation. With pilot example presented in last section, shading scenario as showed in Fig.4a. To minimize power loss, the proposed algorithm, as described, is applied to reconfigure the system. The resulting configuration is depicted in Fig.4b and Fig.4c.

As shown, working module on each string are large or equal than required Q_{M_n}, which means mismatched power loss are minimized. The *P-V* curve for this PV array before and after reconfiguration are showed in Fig.5. It can be seen that after reconfiguration maximum power (!!!!!!!!!! W and !!!!!!W) are significantly higher than before reconfiguration maximum power (!!!!!!!!W).

To evaluate the performance of proposed algorithm, we compare the propose algorithm with exhaustive search algorithm for 300 different partial-shading PV arrays. For each PV array, contain 2$\sim$15 PV panels connected into 2$\sim$5 strings. The PV panels will have contain 2$\sim$20 different current candidates.

The computational time required to find the best configuration and accuracy of configuration in the proposed and exhaus-

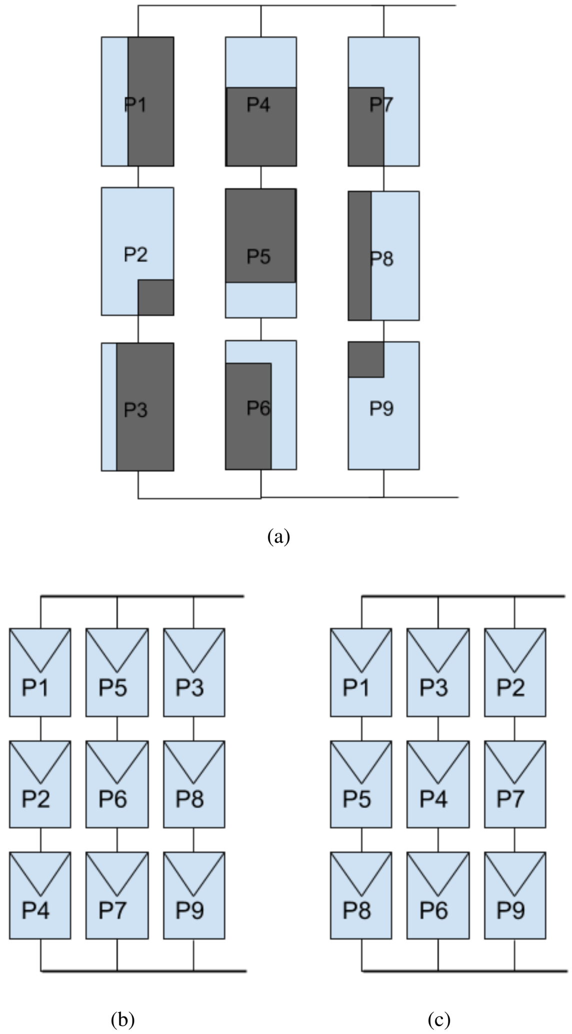


Fig. 4: The PV system under shading scenario (a) before reconfiguration, (b) after reconfiguration for MPP candidate $\{2, 2, 2\}$ and (c) MPP candidate $\{2, 2, 3\}$

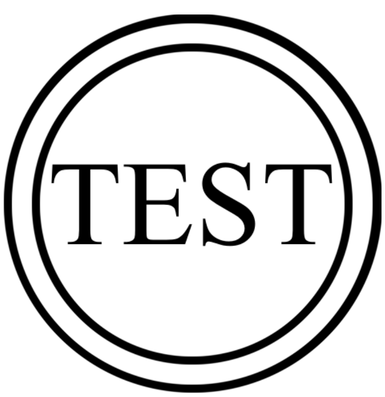


Fig. 5: The *P-V* curves for the PV system under first shading scenario before and after reconfiguration.

tive search algorithm are compared and summarized in Table II. As shown in Table II, proposed algorithm achieved high accuracy and less computing time compare with exhaustive search algorithm and methods described in [10].

TABLE II

COMPARISON BETWEEN EXISTED METHODS AND PROPOSED ALGORITHM

Methods	Computational time	Accuracy
The method in [10]		
Exhaustive search Algorithm		
Proposed Algorithm		

The calculation time used by the proposed algorithm for one MPP candidate was !!!!! ms, which is significantly lower compared with exhaustive search (!!!!!!!time) and accuracy are higher than methods proposed in [10] [12].

V. CONCLUSIONS

The existing PV reconfiguration methods either have high accuracy but suffer from long computational time such as exhausted searching algorithm or GA, or they have short computational time but do not guarantee the best configuration as described in [10] [11] [12]. This paper proposed a new PV system reconfiguration algorithm with feasibility check function and have high accuracy and less computational time. Proposed algorithm's effectiveness has been validated using Matlab simulation. The algorithm was tested though un-uniform shadow distribution among PV array and shows its effectiveness in finding optimal configuration. The proposed algorithm also compared with existed method in terms of accuracy and computational time. The result shows that proposed algorithm has high accuracy and less computational time.

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