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Enhanced power generation of partial shaded photovoltaic fields by forecasting the interconnection of modules

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ABSTRACT

SPV (solar photovoltaic) systems are often partially shadowed by passing cloud, neighboring building, chimney, tree, telephone pole etc. As a result, their produced power is lower than the expected value despite their size. This reduction in produced power is dependent on area of PVs under shade, shade scenario, module interconnection styles and also on the connection of shaded and non-shaded modules. This paper presents a novel method to forecast the interconnection of modules in a TCT (total-cross-tied) connected PV (photovoltaic) array. In this approach, the placement of shaded and non-shaded modules in array are done in such a way so as to distribute the shading effects evenly in each row thereby enhance the PV array power. The performance of this method is investigated for different shading patterns which are the approximations for the most common partial shading scenarios in PV fields and the results show that it can provide multiple solutions for reconfiguration of photovoltaic array to improve energy yield under partial shading conditions. In addition, the power–voltage characteristic curve of these reconfigurable PV arrays are much smoother than that of TCT (total-cross-tied) configured PV arrays and thus ease the work of MPP (maximum power point) techniques. Also this method can easily be implemented for the design of large photovoltaic structures without tedious mathematical formulation.

1. Introduction

SPV (solar photovoltaic) is steadily rising as a source of renewable energy. This is because of the depletion of fossil fuels, their negative effects on environment, noticeable decrease in the cost of solar panels and other associated advantages. However, according to the reports [1–3], there is a lack of confidence for this technology among users. The output power of SPV cells depends on insolation, temperature gradient, reflection, tilt, mismatch among modules, PS (partial shading) etc. [4–15]. Among the parameters listed above PS causes the major reduction in the output power. PS (partial shade) can be explained as when some modules in an array are receiving less insolation than others due to shading. It is a frequent phenomenon and ruins the energy yield of entire PV (photovoltaic) system. It is reported that shading causes a massive reduction in annual yields of large BIPV (building integrated PV) systems [16]. To address this issue, this paper proposes a novel method to configure the modules in such a manner that can significantly reduce partial shading losses. The proposed method guarantee to provide a complete base for connection of shaded and non-shaded modules in case of large partially shaded photovoltaic fields for enhanced power generation and can also be used for fully reconfigurable and partial reconfigurable PV arrays. In addition, this method offers multiple reconfiguration possibilities in both HRPVA (half reconfigurable photovoltaic array) and FRPVA (full reconfigurable photovoltaic array) categories in comparison to the existing research [56], which provide only one solution in both the categories.

This paper is organized as follows: Second 2 discusses the partial shading effects and hot spot phenomenon. Section 3 reviews the different techniques that are proposed to reduce the PS losses. Section 4 will be briefly discussing the different interconnections styles. In section 5, modeling of PV module and array is given. This section also deals with the investigation of small partially shaded TCT (total-cross-tied) configured PV fields (2*2 and 3*3) and based on the results, certain conclusions are drawn in terms of connection law and implementation of these results on large PV fields (4*4 and

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Nomenclature

SPV	solar photovoltaic
PS	partial shading
PSC	partial shading conditions
BIPV	building integrated PV
BL	bridge-linked
SP	series-parallel
TCT	total-cross-tied
IRA	arrays' total irradiance level (W/m^2)
FRPVA	full reconfigurable photovoltaic array
HRPVA	half reconfigurable photovoltaic array
MPP	maximum power point
MPPT	maximum power point technique
G	reference irradiance level (W/m^2)
PA	array's output power (W)
P_{dc}	array's dc power rating (W)
PR	performance ratio
RPVA	reconfigurable photovoltaic array

above) shows that by connecting the shaded and unshaded modules according to the derived connection law can decrease PS losses and thus enhance power generation. However, the results of large PV fields (4*4 and above) are not shown due to limited space. Section 6 presents the application case studies of partially shaded PV fields for different shading patterns to verify the proposed connection law, followed by conclusion.

2. PS (partial shading) effects

Generally SPV panels are connected in series and parallel to meet the load power requirement and thus, there is a chance that some of the panels are often partially or completely shadowed by nearby buildings, trees, chimneys, clouds, towers etc. [17,18]. Partial shading causes the reduction in the insolation received by cell under shade compared to other non-shaded cells. The short circuit current of solar cells depend on the insolation received and thus shaded cells have less current compared to non-shaded cells. Since in a series connected string, the string current must equally flow through cells, the result is that shaded cells operate in reverse bias region to conduct same current as that of non-shaded cells. The shaded cell will then consume power as it is operating in reverse bias region. This may lead to high bias voltage and breakdown of the shaded cell which in turn create hot-spot [14,19–21].

The effect of partial shading is such severe that it need not to fall on an entire panel to deteriorate its output. Rather it is something that if blocks or cast on even small portion of the panels in a string, the output of the entire string will be reduced to almost zero. However, if there is another string which is non-shaded, then this string will continue to produce power. It is reported that the losses occur due to partial shading are not proportional to the of PV's area under shade but also depends on the shading pattern, array interconnection style like SP (series-parallel), TCT (total cross tied), BL (bridged linked)etc. and the location of shaded and non-shaded module within the array [22–24].

3. PS loss reduction techniques

PS losses can be reduced by the addition of bypass diodes. This is the conventional way to reduce the destructive effects of PS. Bypass diodes are connected in antiparallel to PV cells/modules [25–28]. However, the incorporation of bypass diodes increases the complexity of the PV characteristic curve with multiple peaks and thus mislead the conventional MPP (maximum power point) techniques [29,30]. In addition a) the PV cells with bypass diode do not produce any power under PSC (partial shading conditions) because of being bypassed; b) the production of SPVA (solar photovoltaic array) with bypass diodes is costly and c) not applicable for low voltage applications.

Although several techniques has been reported to find global MPP out of all local MPPs but the operator may face a challenge when choosing the most suitable technique among them. All techniques differ in terms of accuracy, tracking speed, total cost, number and type of sensors required (complicated measuring system for the insolation, open circuit voltage, short circuit current etc.), complexity of the algorithm. Further some techniques works for a particular shading patterns and fails for other shading patterns [31,32].

Another technique to reduce PS losses is reported in Refs. [33–39] in which a separate dc/dc power convertor with MPP controller is combined to each PV module in order to extract maximum power from each module thus enable module level MPPT. AC modules [40–43] have also been used to reduce the PS losses by providing separate dc-to-ac conversion to each module and thus the shading of any module only affects its output power. In addition, there are also other advantages associated with this technique like a) the DC installation is replaced by an AC installation thus there is reduced danger of arcs, b) simple plug and play device because of standardized AC output (220 V), c) easily upgradeable etc. In other works, short strings operating separately [1], parallel connection of modules [44], multi-level converters [45–48], multi-input converter [49,50] are preferred to reduce the negative effects of PSC. The common drawback of all above techniques are high cost because of the requirements of separate components with each module. Also, some techniques works only for low power applications [1,44], some require that modules should be connected in parallel connection and are mostly used in portable applications [49,50], some require independent voltage control for each PV module and also has high power loss in switching [45–48].

Another method reported to overcome the negative effects of PS is reconfiguration of PV arrays [51–54], which is also being addressed in this work, with an intention to cover the limitations of the work done in this area. Although this technique could not

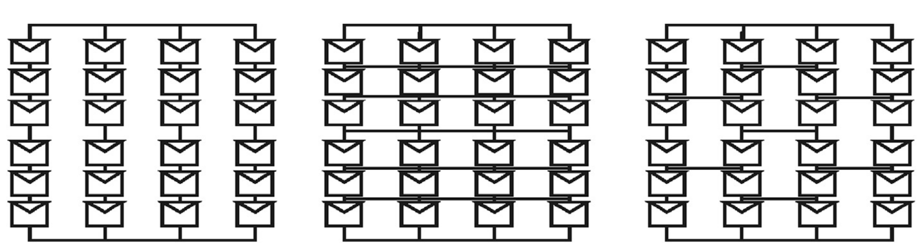

Fig. 1. Interconnection styles for a 6*4 PV field. (a) SP interconnection (b) TCT interconnection (c) BL interconnection [61].