EFFECTS OF PARTIAL SHADING ON DIFFERENT STRUCTURE OF SOLAR PHOTOVOLTAIC ARRAYS

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Abstract

The most promising source of renewable energy is solar photovoltaic (SPV) generation. These SPV modules facing issues with varying environs as well as Partial shading conditions (PSC) of cells in the modules. Normally, for varying PSC of single SPV module maximum power point tracking (MPPT) techniques is quite adequate to overcome these issues. But in practice, SPV modules are interconnected and formed as SPV arrays and these are used for SPV generation in large scale applications. So these arrays are facing the PSC which results in multiple peaks in the P-V curves. This paper investigates the behaviour of three different structures of SPV arrays which gives rise to multiple peaks due to PSC. In this paper, SunPower SPR-X20-250W-BLK module data is used to form SPV array and it is examined under PSC conditions with different irradiance (G) and temperatures (T) values. The electrical performance characteristics under PSC with three different structures of SPV array is obtained using Matlab/Simulink and are examined to get a clear idea to choose which style of connection is better for PSC.

Keywords: SPV Module, Partial shading conditions (PSC), MPPT, SPV Arrays, SCS, PCS, CTS.

I. Introduction

Day to day power intake to the grid from all power generating sources was increasing and the fact that due to the modernization of all the industrial and home applications which are now majorly operated on electricity\(^[V]\). So that to feed the grid and come across the demand non-conventional energy sources comes into action in that SPV is the major source. Due to this reason mainly researches essences on SPV systems in the recent years\(^[XVI]\), so SPV systems were focused and some of the downsides of SPV are addressed in order to extract peak power from the system for that MPPT algorithms are used for better yielding of output power\(^[XIV]\). The conventional MPPT algorithms which only operates for a single peak in the P-V curve i.e. for constant insolation conditions. But for PSC numerous peaks will occur where conventional algorithms miss the mark and we have to trace the global peak in the P-V curve by using advance algorithms\(^[VI,VII,XI]\). To trace the global peak the complete characteristics of SPV array were examined and decide the global peak which depends on the style of connecting the modules in the SPV array\(^[I,II,III,IV,VIII,IX,X,XII,XIII,XV]\).

This paper mainly intensive on the extraction of the electrical characteristics of the SPV array under PSC. This paper categorizes as follows: section II offers different
structures of SPV array, section III provides simulation results of different structures by considering three different case studies and section IV concludes the paper.

II. Structures of SPV Arrays

The basic formation of SPC array is shown in Fig. 1. The basic block diagram representation of different connection structures of SPV arrays are shown in Fig. 2, Fig. 3, and Fig. 4 along with the simulation circuit, and are classified as follows

- Series connected structure (SCS).
- Parallel connected structure (PCS).
- Cross Tied structure (CTS).

![Fig. 1. SPV Array formation structure.](image)

2.1. SCS

The SPV modules are allied in series to get a single a current to flow in this SCS and output loads are placed across both terminals. This structure is the simplest as there are no cross-links among adjacent columns having an increased voltage and same current as that of single SPV module. The simplicity of the connection is one of the few benefits in SCS. The block diagram of SCS and its simulation of 4x1 in structure is shown in Fig. 2. Despite the merits, the major downfall of SCS is the distribution of losses i.e. if one SPV module faces PSC remaining modules in the SPV array also gets affected. Out of all the structures of SPV array, SCS is having poor performance characteristics without bypass diodes.
2.2. PCS

In this type of SPV array has 4 modules are used all the positive ends are linked at one end to form a positive terminal and all negative terminals are linked at one end to form a negative terminal for which loads are placed among them. The PCS gives rise to increased current at the output end and same voltage as that of a single SPV module. The block diagram of PCS and its simulation of 4x1 in structure is shown in Fig. 3. This structure has low power losses than SCS, due to PCS is more efficient than the SCS.
2.3. CTS

In CTS all the SPV modules are allied in parallel to which the row they exist and in series with the other rows. Every node in the CTS is connected to all the SPV modules in the row and series to the all other rows. The block diagram of CTS and its simulation of 2x2 in structure is shown in Fig. 4.
III. Simulation Results

For simulating the SPV array SunPower SPR-X20-250W-BLK modules are used and the datasheet is given in Table. I.

Table. I SunPower SPR-X20-250W-BLK SPV Module dataSheet

| Parameters                        | Ratings     |
|-----------------------------------|-------------|
| Peak Power (W<sub>p</sub>)        | 250W        |
| Voltage at W<sub>p</sub> (V<sub>mp</sub>) | 42.8V       |
| Current at W<sub>p</sub> (I<sub>mp</sub>) | 5.84A       |
| OC voltage of Module (V<sub>oc</sub>) | 50.93V      |
| SC current of Module (I<sub>sc</sub>) | 6.2A        |
| Coefficient of temperature at I<sub>sc</sub> (k<sub>i</sub>) | 0.07%/°C    |
| Coefficient of temperature at V<sub>oc</sub> (K<sub>v</sub>) | -0.35602%/°C |
3.1 SCS under PSC

For the simulation of SCS, it has four modules used in it named as SPV Module 1 to 4 as seen from Fig. 2. Considering the case:I of SCS under Standard test conditions (STC) all the modules are given with a constant G of 1000 W/m², T of 25 °C. For case:II PSC of SCS the values of four modules from 1 to 4 was taken as G of 1000, 800, 500, 300 W/m², and T of 25 °C for all SPV modules. Similarly for case:III of SCS first three modules are having STC conditions and the fourth SPV module is taken as 100% PSC that means it has a G of 0 W/m² and T of 25 °C. Finally the electrical characteristics of the case:I is presented with a green colour curve in Fig. 5 and Fig. 6, case:II is presented with a blue colour curve in Fig. 5 and Fig. 6 and case:III is presented with a maroon colour curve in Fig. 5 and Fig. 6.

![I-V plot of SCS](image1)

![P-V plot of SCS](image2)

Fig. 5. I-V plot of SCS.  
Fig. 6. P-V plot of SCS.

For SCS in case:I the electrical characteristics indicates that there are no multiple peaks in the curve as that it operates in STC. For case:II under PSC the electrical characteristics becomes poor and it has multiple peaks in the outputs. For case:III the electrical characteristics do not have any multiple peaks, but due to 100% PSC at SPV Module-4 the voltage of array gets reduced as seen in Fig. 5 and Fig. 6. These curves clearly stating that the current is same as of single module but voltage gets increased due to SCS and for PSC the array has major effects on it, it gives rise to multiple peaks at the outputs. To overcome this advanced MPPT algorithms must be used like PSO and cuckoo[5], [6].

3.2 PCS under PSC

For the simulation of PCS, it has four modules used in it named as SPV Module 1 to 4 as seen from Fig. 3. Considering the case:I of PCS under Standard test conditions (STC) all the modules are given with a constant G of 1000 W/m², T of 25 °C. For case:II PSC of PCS the values of four modules from 1 to 4 was taken as G of 1000, 800, 500, 300 W/m², and T of 25 °C for all SPV modules. Similarly for case:III of
PCS first three modules are having STC conditions and the fourth SPV module is taken as 100% PSC that means it has a G of 0 W/m² and T of 25 °C. Finally the electrical characteristics of the case:I is presented with a green colour curve in Fig. 7 and Fig. 8, case:II is presented with a blue colour curve in Fig. 7 and Fig. 8 and case:III is presented with a maroon colour curve in Fig. 7 and Fig. 8.

For PCS in case:I the electrical characteristics indicates that there are no multiple peaks in the curve as that it operates in STC. For case:II under PSC the electrical characteristics of output current only gets reduced due to this Maximum peak of Power gets reduced, but it doesn’t have any multiple peaks in the outputs. For case:III also the electrical characteristics does not have multiple peaks but due to 100% PSC at SPV Module-4 the current gets reduced significantly in the array as seen in Fig. 7 and Fig. 8. This mode clearly shows that voltage remains same as of single module but currently gets increases due to PCS and it has improved performance than the SCS and does not have the multiple peaks even though there are PSC exists in the Array.

For the simulation of CTS, it has four modules used in it named as SPV Module 1 to 4 as seen from Fig. 4. Considering the case:I of CTS under Standard test conditions (STC) all the modules are given with a constant G of 1000 W/m², T of 25 °C. For case:II PSC of CTS the values of four modules from 1 to 4 was taken as G of 1000, 800, 500, 300 W/m², and T of 25 °C for all SPV modules. Similarly for case:III of CTS first three modules are having STC conditions and the fourth SPV module is taken as 100% PSC that means it has a G of 0 W/m² and T of 25 °C. Finally the electrical characteristics of the case:I is presented with a green color curve in Fig. 9 and Fig. 10, case:II is presented with a blue color curve in Fig. 9 and Fig. 10 and case:III is presented with a maroon color curve in Fig. 9 and Fig. 10.
For CTS in case:I the electrical characteristics indicates that there are no multiple peaks in the curve as that it operates in STC. For case:II under PSC the electrical characteristics becomes poor and it has multiple peaks in the outputs. For case:III the electrical characteristics still poor and it has multiple peaks due to 100% PSC at SPV Module-4 as seen in Fig. 9 and Fig. 10. These curves clearly stating that the current and voltage gets increased due to CTS and for PSC the array has major effects on it, it gives rise to multiple peaks at the outputs. To overcome this advanced MPPT algorithms must be used like PSO and cuckoo.

Table. II provides the simulation outcomes of SCS, PCS and CTS structure with all case studies. The case:1 of Table. II shows that all the three structures generate the almost same amount of maximum power, but due to the style of connection, it generates the voltage and current correspondingly. From the case:II in Table. II clearly tells us PCS is best suitable for PSC. From the case:III in Table. II states that for either SCS or PCS is almost suitable if any one of the modules in the array completely undergoes into PSC.

### TABLE. II. Simulation outcomes of SCS, PCS, and CTS with PSC.

| Type of Structure | Case: I  | Case: II | Case: III |
|------------------|---------|----------|-----------|
|                  | V_{pv} (V) | I_{pv} (A) | P_{pv-max} (W) | V_{pv} (V) | I_{pv} (A) | P_{pv-max} (W) | V_{pv} (V) | I_{pv} (A) | P_{pv-max} (W) |
| SCS              | 203.8   | 6.2      | 999.8     | 199.5   | 4.023     | 411.6         | 151.8     | 6.2      | 745.1        |
| PCS              | 50.8    | 23.29    | 999.6     | 50.8    | 14.89     | 644.6         | 50.23     | 17.61    | 743.8        |
| CTS              | 101.8   | 11.73    | 999.6     | 99.75   | 7.83      | 575.9         | 100.3     | 9.327    | 534.2        |

IV. Conclusion

This paper presents the SCS, PCS, and CTS of SPV array operating under PSC. The electrical characteristics and the output current, voltage and powers of these structures operating under PSC with three different cases are obtained using Matlab/Simulink. From the results, it is clear that for high current applications PCS is used, for high voltage application SCS is used under STC and for PSC conditions PCS is a best suitable one. The SCS and PCS are also suitable when any one of the modules in the array completely undergoes into PSC. The CTS is best suitable for medium current and medium voltage applications. In concluding that based on the
applications only the different structures of SPV array is chosen, but out of three structures discussed above PCS is the having the better electrical characteristics under PSC for the taken case studies.

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