Multiple Solutions for Reconfiguration to Address Partial Shading Losses in Solar Photovoltaic Arrays

Nikesh Sharma¹, Smita Pareek², Nitin Chaturvedi³, Ratna Dahiya⁴

¹Department of Electrical and Electronics Engineering, BKBIET Pilani, Rajasthan, India
²Department of Electronics and Communication Engineering, BKBIET Pilani, Rajasthan, India
³Department of Electrical and Electronics Engineering, BITS Pilani, Rajasthan, India
⁴Department of Electrical Engineering, NIT Kurukshetra, Haryana, India

Abstract—Solar photovoltaic (SPV) systems are steadily rising and considered as the best alternatives to meet the rising demand of energy. In developing countries like India, SPV’s contribution being a clean energy is the most favourable. However, experiences have shown that produced power of these systems is usually affected due to day, night, seasonal variations, insolation, partial shading conditions etc. Among these parameters, partial shading causes a huge reduction in output power of PV systems. This results in lack of confidence for this technology among users. Thus, it is important and a major challenge in PV systems to minimize the effect of partial shading on their energy production. The work in this paper aims to propose solutions for reconfiguration of solar photovoltaic arrays in order to reduce partial shading losses and thus to enhance power generation.

Keywords: Array, Partial shading, Photovoltaic, Reconfiguration, Total-cross-tied interconnection.

1. Introduction

1.1 Solar photovoltaic

SPV 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, to day, night, seasonal variations, partial shading conditions etc, PS (partial shading) etc. [4-8]. Among the parameters listed above, PS causes major reduction in the output power. PS may 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 system. It is reported that shading causes a massive reduction in annual yields of large BIPV (building integrated PV) systems [9], [10].

To address this issue, this paper provides solutions for reconfiguration of modules in an array to reduce partial shading losses. The proposed solutions offers multiple reconfiguration possibilities in both HRPVA (half reconfigurable photovoltaic array) and FRPVA (full reconfigurable photovoltaic array) in comparison to the existing research [11], which provide only one solution in both the categories and that too using complex mathematical equations.

This paper is organized as follows: Section 2 discusses the partial shading effects and hot spot phenomenon. Section 3 reviews various techniques proposed to reduce PS losses. Section 4 discusses the mathematical analysis of reconfiguration technique on 4*4 TCT configured PV array. Section 5 presents three application case studies of partially shaded PV fields for various shading patterns followed by conclusion.

2. Partial shading effects

SPV panels are connected in series and parallel to obtain the load power requirement and thus, there is a chance that few of the panels are partially or completely shadowed by nearby clouds, trees, buildings, towers etc. [12, 13]. Partial shading causes the reduction in the insolation received by cell under shade compared to other 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, 15].

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 panel in a string, output of the entire string will be reduced to almost zero.

It is reported that the losses occur due to partial shading are not proportional to the PV's 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 [16].

3. Partial shading loss reduction techniques

The traditional way to reduce PS effect is to connect bypass diodes. Bypass diodes are connected in anti-parallel to PV cells/modules [17-19]. The incorporation of bypass diodes increases the complexity of the PV characteristic curve with multiple peaks under partial shading conditions and thus mislead the conventional MPP (maximum power point techniques) [20-23].
Another technique to reduce PS losses as reported in Refs.[24], in which a separate dc/dc power converter 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 [25-27] are also proposed 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. Common drawback of all above techniques is high cost because of the requirements of separate components with each module. In addition, some require independent voltage control for each PV module and also has high power loss in switching.

Another method reported to overcome the negative effects of PS is reconfiguration of PV arrays, which is also being addressed in this work with an intention to cover the limitations of the work done in this area. Although reconfiguration technique could not gather a significant attention in past, this is because of high cost and lack of suitable hardware.

The work done in this paper is extension of reconfiguration technique proposed in reference [9] to array for TCT interconnected PV arrays in order to mitigate the negative impact of partial shading on energy yield of these arrays. The results of [9] shows that connecting the shaded modules according to the proposed technique can decrease PS losses. The aim of this paper is to check the performance of proposed reconfiguration technique by implementing them on various shade scenarios which are given by various researchers. In the performed case studies, PV arrays interconnected in TCT style, a half reconfigurable photovoltaic array and a full reconfigurable photovoltaic array (FRPVA) are considered under shading pattern given in [28-29] In HRPVA, odd numbers of columns are fixed and the even numbers of columns are reconfigurable to form a half reconfigurable photovoltaic array. In FRPVA, all columns are reconfigurable. It is work to mention that according to the proposed reconfiguration technique, the shaded modules must be connected diagonally opposite to each other (if belong to different string).

4. Mathematical analysis of reconfiguration technique on 4*4 TCT configured PV array

The dependency of the output power on the location of shaded modules is illustrated by a 4*4 TCT configured PV array as shown in Figure 1.
(a) Under uniform irradiance

All modules will conduct same current and it is assumed that peak current and peak voltage of all
modules will be equal to $I_m$ and $V_m$ respectively.

In row 1, four modules are connected in parallel, thus the peak current generated by row 1 comprising
of four modules will be $I_{row1} = 4*I_m$

The peak voltage of row 1 will be equal to the peak voltage of single module, as voltage in parallel
remain same, thus, $V_{row1} = V_m$

TCT configured array peak power, which has four such rows in series connected, under uniform
irradiance is given by

$$P_{array} = V_{array}*I_{array} = 4*(V_m)*(4*I_m) = 16V_m*I_m = 16P_m$$

Next, the array is considered less than three different shade scenarios i.e. horizontal shade, vertical shade
and diagonal shade scenario as shown in Figure 2.

(a) Horizontal shade pattern

Case 1

When array current is less than the current generated by the shaded module

Shaded modules will also contribute power and peak current generated by both shaded and non-shaded
row shaded is determined by the peak current of shaded row, as all rows are in series

Shaded row, non-shaded row = $4*0.2*I_m = 0.8*I_m$ (as one row is comprising of four such modules and
the peak current of shaded module is $0.2*I_m$)
The voltage of shaded and non-shaded rows is same as that of peak voltage of single module, thus, shaded row, non-shaded row = \( V_m \)

The peak generated by the array comprising of four rows will be

\[ P_{array} = 4 \times (0.8 \times I_m) \times V_m = 3.2 \times I_m \times V_m = 3.2 \quad (1) \]

Case 2

When string current is greater than the current generated by the shaded module (i.e. 0.2\( \times I_m \))

Shaded modules will be bypassed by bypass diode; hence shaded row will not contribute power. The peak power generated by three non-shaded rows will be given by

\[ P_{array} = V_{array} \times I_{array} = 3 \times (V_m) \times (4 \times I_m) = 12 \times V_m \times I_m = 12 \text{pm} \quad (2) \]

According to equation (1) and equation (2), it may be concluded that the PV curve will show two peaks, one at 3.2\( \text{pm} \) and other at 12\( \text{pm} \). Since peak power (\( \text{pm} \)) of single module is 197.78W, therefore two peaks will be at 632.896W (=3.2\( \text{pm} \)=3.2\( \times 197.78 \)) and 2373.36W (=12\( \text{pm} \)=12\( \times 197.78 \)). The results obtained is in close agreement with the simulated results, since the PV curve of horizontal shade pattern shows two peak with approximately the same value as obtained.

(b) Vertical and diagonal shade pattern

In these shade patterns, all rows comprises of one shaded module and three non-shaded modules, thus the peak current of each row is the given by \( I_{row} = I_m + I_m + I_m + 0.2 \times I_m = 3.2 \times I_m \)

The peak power generated by four such rows is given by

\[ P_{row} = 4 \times V_{row} \times I_{row} = 4 \times (V_m) \times (3.2 \times I_m) = 12.8 \times V_m \times I_m = 12.8 \text{pm} \quad (3) \]

Since peak peak power (\( \text{pm} \)) of single module is 197.78W, therefore PV curve will have only one peak at 2532.74W (=12.8\( \text{pm} \)=12.8\( \times 197.78 \)). The results obtained is in close agreement with the simulated results, since the PV curve of vertical and diagonal shade pattern shows only one peak with approximately the same value as obtained.

5. Application & Example [28], [29]

5.1 Hypothetical Shading-I on 6*4 PV Array

The PS situation as shown in Figure 3 is applied to TCT connected PV array, HRPVA and FRPVA. Some of the possible HRPVA and FRPVA solutions are shown in Figure 4 and Figure 5 respectively. Since ten modules are shaded, thus parallel connection of four shaded modules cannot be avoided.
For this shading, PA is equal to 2758.2 W for TCT, 3724.8 W for HRPVA and FRPVA.

Total irradiance on array = 14 * 1000 + 10 * 500 = 19000

IRA can be calculated as

\[
IRA = \frac{\text{Total irradiance on array}}{\text{Total modules in array}} = \frac{19000}{24} = 791.67 \text{ W/m}^2
\]

Thus, PR of TCT can be given as

\[
PR = \frac{2758.2}{791.67} \times \frac{1000}{24 \times 202.44} = 0.72
\]

PR of HRPVA and FRPVA can be given as

\[
PR = \frac{3724.8}{791.67} \times \frac{1000}{24 \times 202.44} = 0.97
\]
As shown in Table 1, HRPVA and FRPVA have increased the generated power from 2758.2 W to 3724.8 W and percentage increase in power is 35.04 % when compared to TCT. Also the shaded modules are able to contribute power rather than dissipating. The PV characteristics of both reconfigurable arrays are smoother compared to TCT and has only one peak as shown in Figure 6, thus simplifying the task of MPPT algorithm.

| Array and modules’ MPP powers |
|-------------------------------|
| Individual module’s MPP (W) | Array’s MPP (W) | PR | Power change w.r.t. TCT (%) |
|-------------------------------|----------------|----|---------------------------|
| TCT 96.95 96.95 96.95        | 196.48         | 2758.2 | 0.72 -                   |
| 96.95 96.95 96.95             | 96.95          | 96.95 | -                         |
| 96.95 96.95 96.95             | 96.95          | 96.95 | -                         |
| 96.95 96.95 96.95             | 96.95          | 96.95 | -                         |
| HRPVA (for solution a) 98.6 200.83 98.6 | 200.83 | 3724.8 | 0.97 35.04 |
| 98.6 200.83 98.6             | 98.6           | 200.83 | -                         |
| 192.07 89.11 192.07          | 192.07          | 192.07 | -                         |
| 200.83 200.83 98.6           | 98.6           | 200.83 | -                         |
| 192.07 89.11 192.07          | 192.07          | 192.07 | -                         |
| FRPVA (for solution a) 98.6 200.83 98.6 | 200.83 | 3724.8 | 0.97 35.04 |
| 98.6 200.83 98.6             | 98.6           | 200.83 | -                         |
| 192.07 192.07 89.11          | 192.07          | 192.07 | -                         |
| 200.83 98.6 200.83            | 98.6           | 200.83 | -                         |
| 192.07 89.11 192.07          | 192.07          | 192.07 | -                         |
5.2 Hypothetical Shading-II on 6*4 PV Array

The PS situation as shown in this Figure 7 is applied to TCT connected PV array, HRPVA and FRPVA. Some of the possible HRPVA and FRPVA solutions are shown in Figure 8 and Figure 9 respectively. Since eleven modules are shaded, thus parallel connection of five shaded modules cannot be avoided.

![Figure 6: Arrays’ P-V characteristics](image)

![Figure 7: Hypothetical shading-II irradiance levels](image)

![Figure 8: Some HRPVA solutions of hypothetical shading-II](image)

![Figure 9: Some FRPVA solutions of hypothetical shading-II](image)
For this shading, PA is equal to 2801.8 W for TCT, 3666.4W for HRPVA and FRPVA; G is equal to 1000W/m².

Total irradiance on array = 13 * 1000 + 11 * 500 = 18500

IRA can be calculated as

\[
IRA = \frac{\text{Total irradiance on array}}{\text{Total modules in array}} = \frac{18500}{24} = 770.83 \text{ W/m}^2
\]

\[\text{Pdc} = \text{Number of modules in array} \times \text{MPP power of single module} = 24 \times 202.44 \text{ W}\]

Thus, PR of TCT can be given as

\[
PR = \frac{2801.8}{770.83} \times \frac{1000}{24 \times 202.44} = 0.748
\]

PR of HRPVA and FRPVA can be given as

\[
PR = \frac{3666.4}{770.83} \times \frac{1000}{24 \times 202.44} = 0.98
\]
Table 2: Array and modules’ MPP powers

| TCT | Individual module’s MPP (W) | Array ’s MPP (W) | PR | Power change w.r.t. TCT (%) |
|-----|-----------------------------|------------------|----|-----------------------------|
| 152.11 | 152.11 | 152.11 | TCT | 2801.8 | 0.748 | - |
| 193.87 | 193.87 | 152.11 | 152.11 | 90.56 | 90.56 |
| 186.81 | 12.54 | 87.61 | 92.54 |
| 3.3 | 3.3 | 3.3 | 3.3 |
| 90.56 | 90.56 | 193.87 | 193.87 |
| HRPVA | 202.14 | 98.81 | 202.14 | 98.81 | 3666.4 | 0.98 | 30.86 |
| (for solution a) | 190.2 | 87.61 | 190.2 | 202.14 |
| 202.14 | 202.14 | 98.81 | 98.81 |
| 202.14 | 202.14 | 98.81 | 202.14 |
| 98.81 | 202.14 | 98.81 | 98.81 |
| 98.81 | 202.14 | 202.14 | 98.81 |
| FRPVA | 98.81 | 202.14 | 98.81 | 202.14 | 3666.4 | 0.98 | 30.86 |
| (for solution a) | 202.14 | 98.81 | 202.14 | 98.81 |
| 190.2 | 190.2 | 87.61 | 190.2 |
| 202.14 | 98.81 | 202.14 | 98.81 |
| 98.81 | 202.14 | 98.81 | 202.14 |
| 202.14 | 98.81 | 202.14 | 98.81 |

Shaded module location

As shown in Table 2, the HRPVA and FRPVA both has increased the generated power from 2801.8 W to 3666.4 W and percentage increase in power is 30.86% when compared to TCT. The PV characteristics of both reconfigurable arrays are smoother as compared to TCT configuration as shown in Figure 10, thus simplifying the task of MPPT algorithm. Also the shaded modules are delivering more power compared to TCT configuration in HRPVA and FRPVA.

Figure 10: Array’s P-V characteristic
5.3 Double-row shading on 4*3 PV array:

The PS situation (as shown in Figure 11), is now considered on 4*3 PV array, where numbers in the boxes indicate modules’ irradiance levels in W/m²).

Figure 11: Double-row shading on 4*3 PV array

5.4 Half Reconfigurable Photovoltaic Array:

By applying the proposed rules for shaded modules interconnections, there is one possible HRPVA solution (Figure 12), which yields more MPP power compared to TCT interconnections and also reported in [29]. The locations of shaded modules can be (1*2) and (2*2).

Figure 12: Possible HRPVA solution of 4*3 PV array

5.5 Full Reconfigurable Photovoltaic Array:

In FRPVA, all columns may be reconfigured and thus many FRPVA solutions are possible. Some of the possible FRPVA solutions are given in Figure 13.

Figure 13: Some of the possible FRPVA solutions
The array and module’s MPP power are as shown in Table 3 together with the array’s overall performance ratio (PR). For single row shading, PA is equal to 1308.5 W for TCT, 1694.6 W for HRPVA and FRPVA.

**Total irradiance on array**

\[
\text{IRA} = \frac{(\text{Number of non shaded modules} \times 1000) + (\text{Number of shaded modules} \times 500)}{\text{Number of modules in array}} = \frac{9000}{12} = 750 \text{W/m}^2
\]

**IRA** can be calculated as

\[
\text{IRA} = \frac{\text{Total irradiance on array}}{\text{Total modules in array}} = \frac{9000}{12} = 750 \text{W/m}^2
\]

\[P_{dc} = \text{Number of modules in array} \times \text{MPP power of single module} = 12 \times 202.44 \text{W}\]

Thus, PR of TCT can be given as

\[
PR = \frac{1308.5}{750} \times \frac{1000}{12 \times 202.44} = 0.718
\]

PR of HRPVA and FRPVA can be given as

\[
PR = \frac{1694.6}{750} \times \frac{1000}{12 \times 202.44} = 0.93
\]

| Table 3: | Array and modules’ MPP powers |
|----------|-------------------------------|
| Individual module’s MPP (W) | Array ‘s MPP (W) | PR | Power change w.r.t. TCT (%) |
| TCT | 123.52 | 123.52 | 123.52 | 1308.5 | 0.718 | - |
| | 123.52 | 123.52 | 123.52 | | | |
| | 94.71 | 94.71 | 94.71 | | | |
| | 94.71 | 94.71 | 94.71 | | | |
| HRPVA (for solution a) | 183.44 | 82.25 | 183.45 | 1694.6 | 0.93 | 29.5 |
| | 183.44 | 82.25 | 183.45 | | | |
| | 98.71 | 201.24 | 98.71 | | | |
| | 98.71 | 201.24 | 98.71 | | | |
| FRPVA (for solution a) | 183.44 | 85.63 | 183.44 | 1694.6 | 0.93 | 29.5 |
| | 183.44 | 85.63 | 183.44 | | | |
| | 98.71 | 201.24 | 98.71 | | | |
| | 98.71 | 201.24 | 98.71 | | | |

**Shaded module location**
It may be seen that the HRPVA and FRPVA has increased the generated power by 29.5 % when compared to TCT. Further, the performance ratio has also increased from 0.718 to 0.93 from TCT configuration to HRPVA and FRPVA configurations. These increments are because these configurations prevent bypass diodes from turning ON, which would short the 500 W/m² modules. The PV characteristics of TCT, HRPVA and FRPVA configurations are shown in Figure 14. The characteristics of reconfigurable arrays are smoother as compared to TCT configuration, thus simplifying the task of MPPT algorithm. The array’s MPP power obtained for this partial shading situation has increased from 1308.5 for TCT to 1694.6 W for both HRPVA and FRPVA.

![Array’s P-V characteristics](image)

**Figure 14:** Array’s P-V characteristics

### 6. Conclusion
In this paper multiple solutions for reconfigurations of PV array are given. As verified by three case studies, the proposed solutions are capable to reduce partial shading losses when compared to TCT configurations. The reconfiguration technique also results in a smoother P-V array characteristic with less number of local maxima, thus simplifying the task of MPPT. In addition, the proposed reconfiguration technique is not restricted to the case studies performed but are also valid for any partial shading PV array of any size and consisting of any number of shaded modules. Thus these partial shading losses reduction reconfiguration solutions may easily be implemented for the design of large photovoltaic structures without tedious mathematical formulation (If it is possible to connect shaded modules diagonally) to improve energy yield under partial shading conditions. The solutions also reduces the losses in bypass diodes during their ON time and forces the shaded modules to produce more power in comparison to TCT interconnections and is capable to provide a complete base for the interconnection of modules in partial shaded photovoltaic arrays.
References

1. BalasubramanianIndu Rani, SaravanaIlangoGanesan and NagamaniChilakapati, "Impact of partial shading on the output power of PV systems under partial shading conditions," IET Power Electronics, vol. 73, pp. 657-666, 2014.
2. Subudhi Bidyadhar and Raseswari Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," IEEE transactions on Sustainable Energy, vol. 1.4, pp. 89-98, 2013.
3. Pareek Smita, DahiyaRatna. Simulation and performance analysis of individual module to address partial shading cum parameter variation in large photovoltaic fields. J Energy 2015;2(3):99-104.
4. Pareek, S., Dahiya, R., 2014. Power output maximization of partially shaded 4/4 PV field by altering its topology. Energy Procedia 50, 71–78.
5. Pareek, S., Runthala, R., Dahiya, R., 2013. Mismatch losses in SPV systems subjected to partial shading conditions. In: International Conference on Advanced Electronic Systems (ICAES), pp. 343–345.
6. Purohit, J., Naveen, S.P., 2016. Comparison of various techniques to mitigate the effect of partial shading on solar PV systems. IJREEIECE 4 (8), 88–91.
7. Pareek, S., Dahiya, R., 2016. Series-connected Shaded Modules to Address Partial Shading Conditions in SPV Systems. AIP Publishing, 1715, 020020
8. Pareek, S., Dahiya, R., 2015. Power optimization of TCT conFig.d PS-PV fields by forecasting the connection of modules. In: Annual IEEE India Conference (INDICON), pp. 1–6.
9. Pareek, S., Chaturvedi N., Dahiya, R., 2017. Optimal interconnections to address partial shading losses in solar photovoltaic arrays, “Solar Energy, vol. 95,pp. 561–572.
10. Celik Berk, EnginKaratepe, Santiago Silvestre, Nuri Gokmen and AissaChouder, "Analysis of spatial fixed PV arrays configurations to maximize energy harvesting in BIPV applications," Renewable Energy, vol. 75, pp. 534-540, 2015.
11. Pareek, S., Dahiya, R., 2016. Enhanced power generation of partial shaded photovoltaic fields by forecasting the interconnection of modules. Energy 95,561–572.
12. Bastidas-Rodriguez, Juan David, Elisa Franco, Giovanni Petrone, Carlos Andres Ramos-Paja and Giovanni Spagnuolo, "Maximum power point tracking architectures for photovoltaic systems in mismatching conditions: a review," IET Power Electronics, vol. 7, no. 6, pp. 1396-1413, 2014.
13. Bai Jianbo, Yang Cao, YuzheHao, Zhen Zhang, Sheng Liu and Fei Cao, "Characteristic output of PV systems under partial shading or mismatch conditions,” Solar Energy, vol., 112, pp. 41-54, 2015.
14. Dolara Alberto, George Cristian Lazaroiu, Sonia Leva and Giampaolo Manzolini. "Experimental investigation of partial shading scenarios on PV (photovoltaic) modules," Energy, vol. 55, pp. 466-475, 2013.
15. Kotti R. and W. Shireen, "Efficient MPPT control for PV systems adaptive to fast changing irradiation and partial shading conditions," Solar Energy, vol. 114, pp. 397-407, 2015.
16. Villa Luiz Fernando Lavado, Damien Picault, Bertrand Raison, Seddik Bacha and Antoine Labonne, "Maximizing the power output of partially shaded photovoltaic plants through optimization of the interconnections among its modules," IEEE Journal of Photovoltaics, vol. 2, no. 2, pp. 154-163, 2012.
17. Pareek Smita and Ratna Dahiya, "Output Power Comparison of TCT & SP Topologies for Easy-to-Predict Partial Shadow on a 4x4 PV Field," In Applied Mechanics and Materials, vol. 612, pp. 71-76, 2014.
18. Libing Bai, "An improved MPPT controller for photovoltaic system under partial shading condition," IEEE Transactions on Sustainable Energy, vol. 5, no. 3, pp. 978-985, 2014.
19. Tey Kok Soon and Saad Mekhilef, "Modified incremental conductance algorithm for photovoltaic system under partial shading conditions and load variation," IEEE Transactions on Industrial Electronics, vol. 61, no. 10, pp. 5384-5392, 2014.
20. Hiren Patel and Vivek Agarwal, "Maximum power point tracking scheme for PV systems operating under partially shaded conditions," IEEE Transactions on Industrial Electronics, vol. 55, no. 4, pp. 1689-1698, 2008.
21. Rani B. Indu, G. Saravana Ilango and Chilakapati Nagamani, "Enhanced power generation from PV array under partial shading conditions by shade dispersion using Su Do Ku configuration," IEEE Transactions on Sustainable Energy, vol. 4, no. 3, pp. 594-601, 2013.
22. Ishaque Kashif and Zainal Salam, "A review of maximum power point tracking techniques of PV system for uniform irradiation and partial shading condition," Renewable and Sustainable Energy Reviews, vol. 19, pp. 475-488, 2013.
23. Qi Jun, Youbing Zhang and Yi Chen, "Modeling and maximum power point tracking (MPPT) method for PV array under partial shade conditions," Renewable Energy, vol. 66, pp. 337-345, 2014.
24. Bidram Ali, Ali Davoudi and Robert S. Balog, "Control and circuit techniques to mitigate partial shading effects in photovoltaic arrays," IEEE Journal of Photovoltaics, vol. 2, no. 4, pp. 532-546, 2012.
25. Rodriguez Cuauhtemoc and G. Amarathunga, "Long-lifetime power inverter for photovoltaic AC modules," IEEE Transactions on Industrial Electronics, vol. 55,7, pp. 2593-2601, 2008.
26. Ji Young-Hyok, Doo-Yong Jung, Jae-Hyung Kim, Chung-Yuen Won and Dong-Sung Oh, "Dual mode switching strategy of flyback inverter for photovoltaic AC modules," IEEE International Power Electronics Conference (IPEC), pp. 2924-2929, 2010.
27. E. Roman, R. Alonso, P. Ibanez, S. Elorduizapatarietxe and D. Goitia, “Intelligent PV module for grid-connected PV systems,” IEEE Transaction on Industrial Electronics, vol. 53, no. 4, pp. 1066–1073, June 2006.

28. Malathy S. and R. Ramaprabha, "A static PV array architecture to enhance power generation under partial shaded conditions," IEEE 11th International Conference on Power Electronics and Drive Systems (PEDS), pp. 341-346, 2015.

29. El-Dein, MZ Shams, Mehrdad Kazerani and M. M. A. Salama, "An optimal total cross tied interconnection for reducing mismatch losses in photovoltaic arrays," IEEE Transactions on Sustainable Energy, vol. 4, no. 1, 99-107, 2013.