International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-8 Issue-4S2, April 2019

Reconfiguration Method in Photovoltaic Array for Nonuniform Shading Condition

Abhronil Chaudhuri, Lakshay Gopalka

Abstract: ***The output of the photovoltaic array is directly related to the external environment and solar irradiation. Photovoltaic arrays are affected by partial shading which deviates the VI and PV curve from ideal state. This phenomenon influences the operating efficiency of Photovoltaic arrays, as generated power is reduced and hotspots are formed. One possible way to get rid of such negative phenomenon is to reconfigure the Photo voltaic arrays and another method is to operate Photo voltaic panels in peak voltage, which includes global maximum power (GMP) but it has few drawbacks like high complexity, time-consuming. This paper proposes a new methodology of reconfiguring series-parallel (SP) photovoltaic array, which is implemented on MATLAB Simulink. The scheme extracts maximum power by electrically connecting all the shaded or underperforming photovoltaic panels in a common series connection, such that the restricted flow of electricity due to shaded panels is only restricted through one part of the series-parallel photovoltaic array. This method is unlike some interconnection method as it utilizes a reconfigurable part to normalize the fixed part, it is completely adaptable. The obtained results from simulation prove the reliability and overall efficiency under partially shaded array configuration.***

Index Terms**:** ***Photo voltaic array, Reconfiguration, Shading, Irradiance.***

I. INTRODUCTION

The ever-increasing demand for clean energy due to growing concerns of increasing populations and environmental issues has made the use of renewable energy the forerunner for generation of electricity. The mass generation and consumption of electricity from solar have become common recently due to its long lasting, clean, maintenance free nature. A solar PV array uses solar energy to generate electricity.

Partial shading is due to shadows of passing clouds, trees, nearby building while the rest of the modules are fully illuminated. Partial shading causes non-uniform solar irradiance on a solar array. It also accounts for various undesired effects like local hot spots in the shaded part which can damage the solar modules and results in loss of power generation. The maximum power losses are not proportional to the shadows but magnify non-linearly [1]. Power Voltage characteristics under Partial shading have multiple peaks which are dependent on array topology. The output characteristic of PV arrays is also dependent on module temperature and solar irradiance, different orientation, panel ageing and so on. [2], [3], [4]

The PV grid system architecture uses solar modules in a fixed determined topology generally in series-parallel modules. The inverter is connected with the output to convert the DC current to AC current. This extraction is driven by algorithms like Genetic, Fuzzy but most commonly used is MPPT, Maximum Power Point Theorem. MPPT is used to extract maximum power from maximum peak voltage in solar array module.

Another solution to mitigate Partial shading condition is reconfiguration that is to change the electrical connection pattern of PV module arrangement and put them in the different sequence which is dependent on irradiance patterns. The reconfiguration is classified into two groups. The aim of the first group is the reconfiguration of PV cells in a module [5] and the aim of the second group is the optimum connection of PV modules in an array. Another viable solution is to divide the PV module into two branches with defined connections. In this paper, we focus on the new reconfiguration of modules by this method.

A lot of scientific literature and articles are found dealing with extraction of maximum power and reconfiguration algorithms and techniques. The drawback in such papers is that they do not increase the efficiency by larger quantity or they are just simulated for a single case. Hence, this paper focuses on increasing the efficiency of solar arrays by using this newly devised reconfiguration method. The dynamic reconfiguration in this technique enhances the output characteristics by means of electrical array reconfiguration by active switches in a switching array. This reconfiguration allows the PV panels to give more productive output by compromising and by mitigating Partial shading characteristics.

The strategy is based on dividing the solar modules in the array into series-parallel groups in an equal number of modules in each string. The subdivision should be such that all the partial shaded modules are in one group, this way is most effective than prevailing techniques and gives a greater output power.

II. PHOTOVOLTAIC CHARACTERISTICS

A. Effects of inhomogeneous irradiance on PV array

The main source of power losses is by partial shading in solar Photo-voltaic systems. These losses arise if a part of PV system is under the influence of shading and the remaining system is unaffected or illuminated. Open circuit voltage (V_{oc}), short circuit Current (I_{sc}), fill factor and other attributes are affected by shading in such systems [6].

Revised Manuscript Received on April 25, 2019.

Abhronil Chaudhuri, Department of Mechatronics Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, India.
Lakshay Gopalka, Department of Mechatronics Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, India.

Therefore, in shading scenarios, the affected cells that is shaded cells shows variation from their normal behavior. These cells show high resistance and reverse biased which causes non-uniform distribution and led to increase in temperature of the entire cell. This increase in temperature can led to breakdown in shaded cells resulting in output power losses [7].

The power loss exists in two ways, the first in which multiple power peaks are developed and only a single one among them is power peak [8]. Other way is power difference between photo voltaic arrays connected in series configuration. Power difference can be a case in photo voltaic arrays connected in series configuration when they don't have the same MPP (maximum power point) current caused by non-uniform irradiance level. Therefore, it becomes imperative to study and examine the effects of irradiance, non-uniform temperature which arise due to partial shading phenomena in Photo voltaic arrays. The output losses are caused by the variation in electrical configuration in the photovoltaic arrays [9]. The partial shading limits the current to the string in the series configuration, thus, resulting in drop of output power from the PV system,

The major phenomena affecting PV arrays when it is partially shaded are-

1. Formation of hotspots- It affects the cells and efficiency while drastically impacting performance criteria
2. The phenomenon of returning current- It affects the modules in connection and leads to power losses.

To avoid such losses due to partial shading, this research paper introduces a compelling array configuration method to increase the output characteristics of PV array modules.

B. Electric Characteristics of PV module

The key electrical characteristics of a Photo voltaic module is determined by Current-Voltage(I-V) characteristics curve of a solar cell and the arrangement of cells in the module. The output current(I) is directly related to the intensity of the solar irradiation and the operating voltage(V) is inversely related to the temperature of solar cells. The increase in irradiance increases the magnitude of photo current while an increase in the temperature of the solar cell negatively affects its voltage (V). I-V curve provide the information to operate a module as close to its optimal peak power point (MPP) as possible.

C. I-V Characteristic Curve

The figure 2 displays the I-V (Current-Voltage) plot of a conventional Photo-voltaic cell under partial shaded affected condition. We obtain the power curve for every voltage like open circuited or short circuited for a particular value of radiation. If the solar cell is in open circuited case, that means it is load free and the resulting current will be zero or negligible while the voltage will be high or maximum, which is referred as open circuited voltage. Its annotation is given by V_{oc}. On the contrary, if solar cell is in short circuited case, the current received will be high or maximum and the voltage in this situation will be zero or negligible, this is referred as short circuit current. Its annotation is given by I_{sc}. Thus, we infer from above cases is that maximum current is found at closed circuited while maximum voltage is found at open circuit but unfortunately, it doesn't help in production of power. The power is generated in between these values in the solar arrays. The maximum power output is found at the sudden turn of the plot called MPP that is maximum power point. The annotation for V and I at this juncture is given as V_{mp} and I_{mp}.

D. Array Topology

PV modules are modelled as series and parallel connection of modules. The combination and arrangement of these modules constitute various topologies. The V-I curve of a Photo Voltaic array is dependent on the single solar module V-I characteristic curve connected in the desired topology. The PV array can be connected in multiple topologies. Each topology arrangements have different functions, operating characteristics, applications and drawbacks [10]. For this purpose, several interconnections are prevalent to mitigate the effects of partial shading like series, parallel, series-parallel, total cross tied. The most commonly used for industrial applications are mentioned and illustrated below and in figure 1(a) and (b).

Series Parallel (SP) - The PV modules are connected in series and the resulting rows are associated in parallel. The main advantage of SP array is that only one row is negatively affected, compared to entire array in the series arrangement.

Total Cross Tied (TCT) - The Photo voltaic modules are connected in parallel and corresponding arrangements are tied in series in addition to SP connection. TCT arrangement connects all the modules in a row which are then connected to each module in parallel in the array configuration. The main advantage of TCT array is that shading affecting a particular cell or module does not affect the entire row or column of the array.

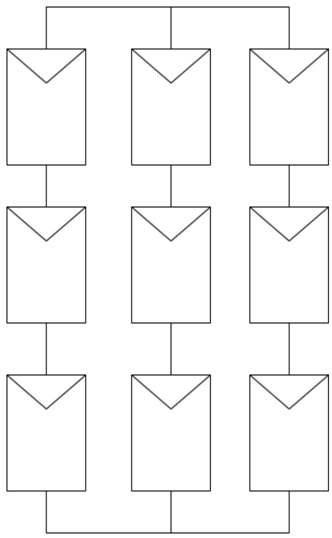

Fig.1 (a): Series Parallel Topology

As TCT interconnection is complex architecture in regards to array structure as all series parallel modules are connected in same time and number of switching elements will be increased, hence, to eliminate this, the study uses a SP interconnection reconfigurable matrix for PV arrays.

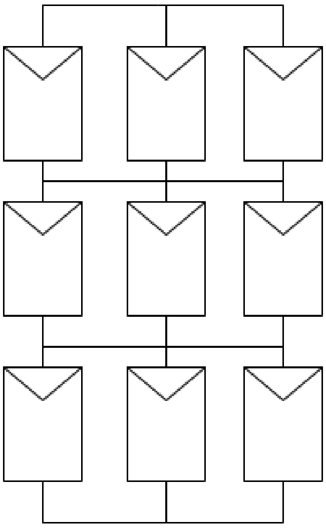

Fig.1 (b): Total Cross Tied Topology

III. DETECTION OF SHADING

The value of shading percentage significantly affects the locus of MPP curve, therefore, higher the shading percentage the PV string has, the lower V_{mp} it, figure 2 shows the change in V_{mp} with respect to shading percentage. Jieming Ma [6] in his paper described a robust method to detect shading using the terminal Voltage. The Terminal voltage of the modules is sorted in descending order and stored in an array denoted by Vs. The new array Vs is then normalized using the following function:

$$V_d[i] = \begin{cases} 1 & (V_s[i] / V_s[1]) \geq \beta \\ 0 & (V_s[i] / V_s[1]) < \beta \end{cases} \quad (1)$$

β (Given in equation 2) is the Threshold, which is used to differentiate between unshaded and shaded photovoltaic module. The 1 denotes Shaded modules and 0 denotes unshaded modules.

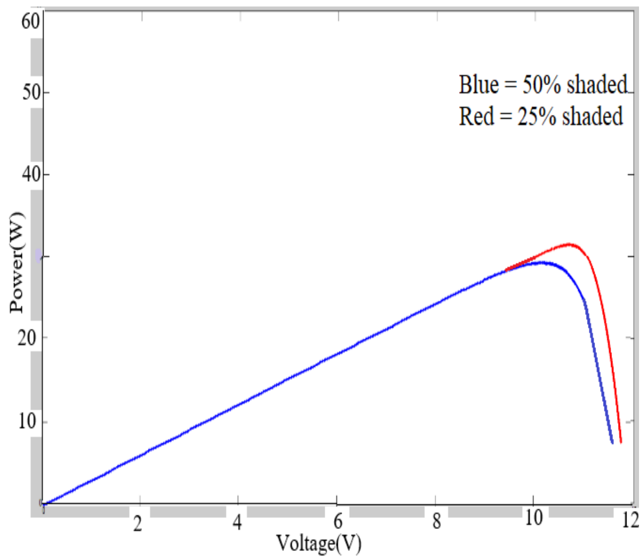

Fig.2: PV Characteristics Comparison on Different Shading Percentage

$$\beta = V_{oc,\,sh}/V_{oc,\,us} \quad (2)$$

Here $V_{oc,\,sh}$ refers open circuit voltage of the module in shaded condition and $V_{oc,\,us}$ refers open circuit voltage of the module in unshaded condition.

$$\frac{nkT}{q} ln\left(\frac{I_p}{I_0} + 1\right) \quad (3)$$

Here k denotes Boltzmann Constant, q denotes electronic charge, T is temperature of the PV module (K), I_p is photo generated current and I_0 is saturated current.

IV. RECONFIGURATION SYSTEM FOR S-P TOPOLOGY

The proposed method instead of bypassing the shaded module in a string of photovoltaic array electrically connects the affected modules in the same string of series connection. The reconfiguration methodology is dependent upon Irradiance Equalization method. Irradiance Equalization aims to obtain balanced average irradiance values in a SP topology. [11] This results in connecting modules of irradiance values which are similar to the irradiance value of other modules which were earlier having similar or different value depending upon the effect of partial shading. This is done by relocating shaded PV modules with different irradiance value within the array so that the maximum power is achieved by the application of a switching matrix. The reconfiguration method checks that least number of the parallelly connected, strings (connected in series) of modules in the SP configuration are shaded. This reduces the effective resistance of the whole array and delivers a higher output power. The block diagram of the proposed reconfiguration system for PV arrays is presented in Figure 3.

Fig.3: Block Diagram

The MATLAB Simulation was done on 85 Watts, SP array configuration with 3 column modules, each residing 4 modules in series. The various shading scenarios are simulated with 0% shading as ideal case, 2 modules shaded, 3 modules shaded and 4 modules shaded which were simulated for a variety of configuration within the same and multiple strings. The following are the representation of 4 cases which represents the effectiveness of this method.

A. Case 1: No Shading

In this case, as shown in figure 4(a) there is no shading on arrays and the modules receive irradiance of 1000 W/m^2. For this situation, no reconfiguration is required and gives the ideal output characteristics as shown in figure 4(b). The irradiance of 1000 W/m^2 is taken in random and hence possesses no significant leverage in the working of the system.

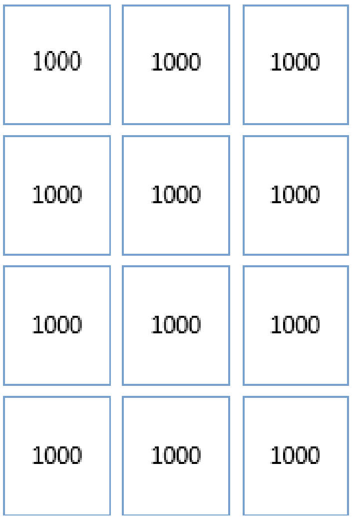

Fig.4(a): Non-Shaded Array

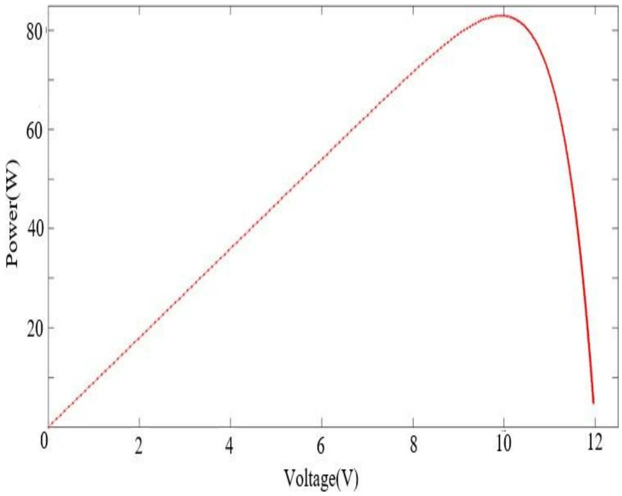

Fig.4(b): Output P-V Curve of Non-Shaded array

B. Case 2: Array with Two Column Shaded

In this case as shown in figure 5(a), modules of two different column are shaded and receive irradiance of 500W/m^2 and others modules receive irradiance of 1000W/m^2. The figure 5(b) shows the P-V curve of this case, the output from all the three shading scenarios shown in figure 5(a) gives almost similar output V_{mp} and peak power.

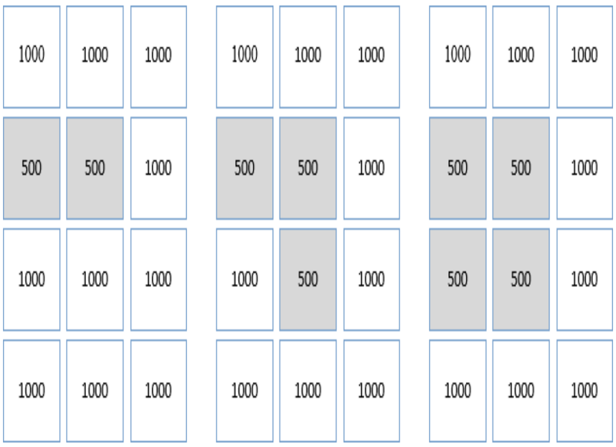

Fig.5(a): 2 Column Shaded PV Array

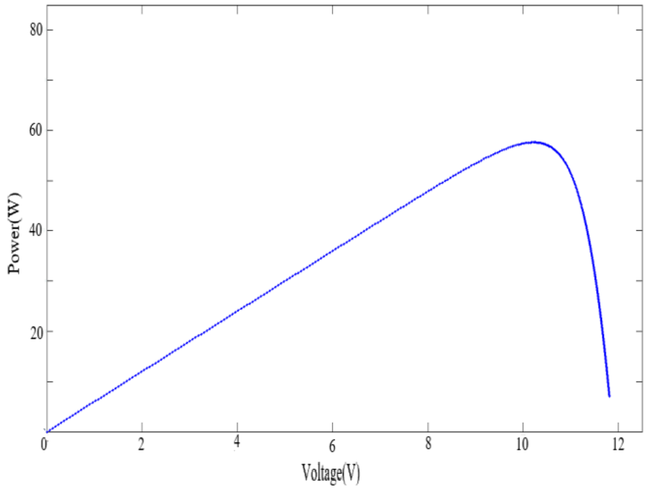

Fig.5(b): Output P-V Curve of 2 Column Shaded Array

C. Case 3: Array with Three Column Shaded

In this case as shown in figure 6(a), modules of three different column are shaded and receive irradiance of 500 W/m^2 and others modules receive irradiance of 1000W/m^2. This condition leads to maximum power loss. The figure 6(b) shows the P-V curve of this case, the output from all the two shading scenarios shown in figure 6(a) gives almost similar output V_{mp} and peak power.

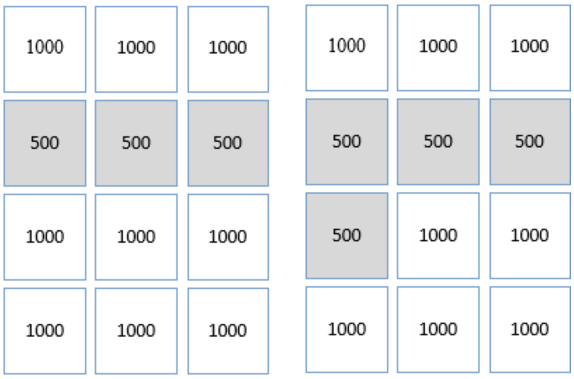

Fig.6(a): 3 Column Shaded PV Array

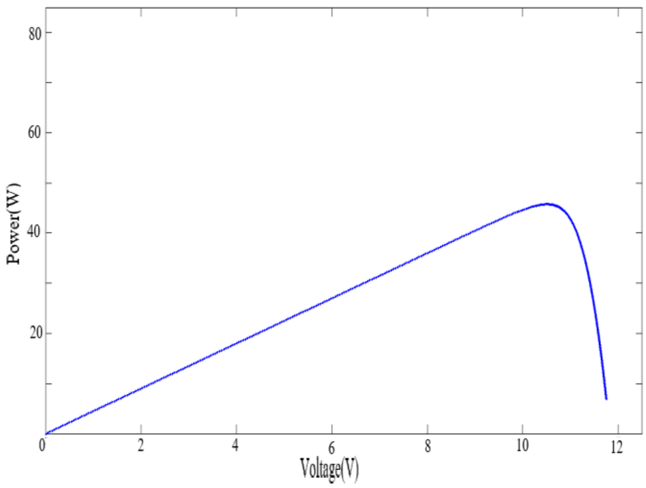

Fig.6(b): Output P-V Curve of 3 Column Shaded Array

D. Case 4: Array After Reconfiguration

The reconfiguration method can be employed to change the connection in case 2 and 3 as shown in figure 7(a). The shaded modules are connected in such a way that all shaded module reside in a single column or in least possible columns to enhance the power by drastically reducing the effective resistance of modules. The figure 7(b) shows the P-V curve of this case, the output from all the three reconfigured scenarios shown in figure 7(a) gives almost similar output V_{mp} and peak power.

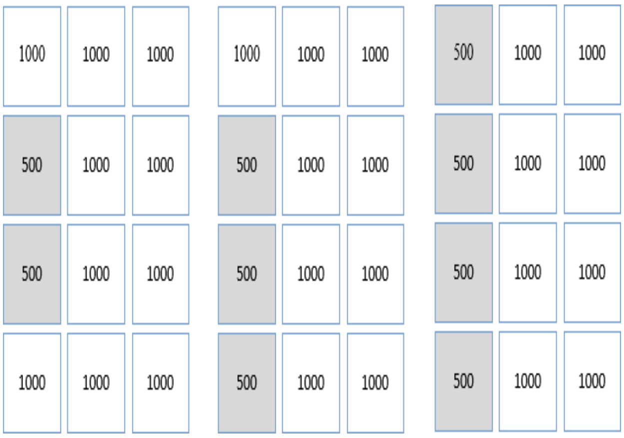

Fig.7(a): Shaded PV Array After Reconfiguration

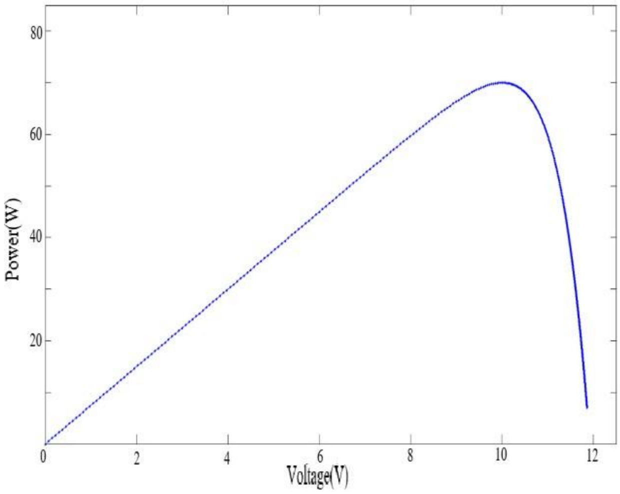

Fig.7(b): Output P-V Curve of Reconfigured Array

V. OBSERVATION

The shading conditions were implemented and tested on various arrays in MATLAB and for different array configuration with numerous diffrent irradiance and panel characteristics. It was observed when the proposed reconfiguration method was implemented, the output power displayed a significant improvement when compared to similarly shaded PV array of series-parallel topology. The intensity and pattern of shaded modules was varied for this study to give a comprehensive result. The different patterns of shading were used so the connection of modules were interchanged accordingly to give the enhanced output and validate this reconfiguration method. The following sections present the change in irradiance level in modules from 1000 W/m^2 to 500 W/m^2 in various arrays and strings. The findings of the experiment are shown in table 1.

Table 1: Comparision of Output Power For Different Cases

CASE	NO. OF SHADED PANELS	OUTPUT POWER (W)
1	0	85
2	2	58
2	3	58
2	4	56
3	3	45
3	4	45
4	2	70
4	3	68
4	4	65

VI. SIMULATED RESULT

The system is simulated in MATLAB-Simulink in SP topology using an array of 85 W with a total of 12 modules in which 4 modules are in the individual string connected in series with each other and in parallel connection to other strings. The results of the simulation show that reconfiguring the partially shaded Photo voltaic array according to the proposed method increase the array's output power in comparison to other interconnection methods and also decrease the number of interconnections in comparison to TCT topology. The experimental results show an appreciable difference in the total power output of SP, interconnection as summarized in Table 1 for the number of cases. The total power of the Photo voltaic array is calculated by multiplying the terminal voltage and output currents of the strings and then adding powers of all the strings.

The SP interconnection by this method has increased the output power by 14-35% which could be vital for any solar panel applications, especially in large Solar Grids which deals in Mega Watts (MW). The proposed reconfiguration method significantly improves the Maximum power point in comparison to other method and also requires fewer interconnection in between modules as compared to TCT, reducing complexity. Therefore, proposed reconfiguration method yields more power and simultaneously have fewer interconnections. The proposed reconfiguration technique can be applied to any Photo voltaic array consisting of any number of Photo voltaic modules.

Table 1 shows the value of maximum output power obtained from different shading scenario as shown in figure 4(a), 5(a), 6(a) and also shows the reconfigured array of those shading case as shown in figure 7. The results show that the reconfiguration method has been able to improve power output in various cases by a drastic amount.

P-V characteristic curves for arrays for different shading scenarios, before reconfiguration are displayed in figure 5(b) and 6(b) and after reconfiguration have been displayed in figures 7(b).

The sample results are provided as representatives for the model's performance in a simulation. However, the model is applicable to any geographical location and irradiance profile.

VII. CONCLUSION

The focus of this study lies on the adverse effects of shading on PV arrays output performance. In this study, SP interconnection is employed for reconfiguration method to improve the output power generation. Based on the result obtained after the simulation, the proposed reconfiguration method interconnection was able to limit the losses.

The results are validated by performing several simulations on Photo voltaic arrays which consisted of various scenarios to proof the validity of the method. The improvement in the P-V curve is being demonstrated in SP topology compared to existing interconnections. This reconfiguration method is fairly simpler to use and reduces complexity compared to TCT interconnection. This study of reconfiguration is valid for all PV arrays with PV modules and also useful in various implementation applications like agricultural fields or buildings which have irregular shading patterns. Additionally, the study could be used by designers to check the performance of PV arrays to improve design and efficiency. Hence, partially shaded PV panels connected in SP topology using reconfiguration interchanging connections method results in improvement of output characteristics like power, intensity and voltage compared to any existing interconnection method.

REFERENCES

1. S. H. Raushenbach, "Electrical output of shadowed solar arrays," IEEE Transaction Electronic Devices, vol. 18, p. 483, Aug. 1971.
2. K. Ding, X. Bain and H. Liu, "Matlab-Simulink Based Modelling to Study the Influence of Nonuniform Insolation Photovoltaic Array," Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific, Wuhan, 2011, pp. 1-4.
3. A. N. R. Ahmed, K. Nowaz, J. Tasnim and N. Afroze, "A complete modeling and analysis of solar system (cell/module/array) based on MATLAB, "International Conference on Electrical & Electronic Engineering (ICEEE), Rajshahi, 2015, pp. 149-152.
4. K. Biju and R. Ramchand "Modeling and simulation of a novel solar PV/ battery hybrid energy system with a single phase five level inverter," 2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), Kozhikode 2015, pp.1– 5.
5. Mehdi Zarei Tazehkand, S. Hamid Fathi, Aref Eskandari, Jafar Milimonfared, Optimal Reconfiguration of PV Modules in an Array without any Constraint on Structure by the Use of Genetic Algorithm, 2018 9th Annual Power Electronics, Drives Systems and Technologies Conference (PEDSTC).
6. Jieming Ma, Member, IEEE, Xinyu Pan, Ka Lok Man, Xingshuo Li, Huiqing Wen, Member, IEEE, and Tiew On Ting, Member, IEEE, 'Detection and Assessment of Partial Shading Scenarios on Photovoltaic Strings', IEEE transactions on industry applications, vol. 6, no. 1, january 2017.
7. Fawzan Salem, Mohamed A.Awadallah, Detection and assessment of partial shading in photovoltaic arrays, Journal of Electrical Systems and Information Technology, Volume 3, Issue 1, May 2016, Pages 23-32.
8. Yousef Mahmoud, Senior Member, IEEE, and Ehab F. El-Saadany, Senior Member, IEEE, Enhanced Reconfiguration Method for Reducing Mismatch Losses in PV Systems, IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 7, NO. 6, NOVEMBER 2017.
9. Guillermo Velasco-Quesada, Member, IEEE, Francisco Guinjoan-Gispert, Member, IEEE, Robert Piqué-López, Member, IEEE, Manuel Román-Lumbreras, Member, IEEE, and Alfonso Conesa-Roca, Electrical PV Array Reconfiguration Strategy for Energy Extraction Improvement in Grid-Connected PV Systems, IEEE transactions on industrial electronics, vol. 56, no. 11, november 2009 4319.
10. Dr. Mahmoud Amin, Jelani Bailey, Cesar Tapia, Vineeth Thodimeladine, Comparison of PV Array Configuration Efficiency under Partial Shading Condition, The 2016, 43rd IEEE Photovoltaic Specialists Conference (PVSC 2016), Portland, OR.
11. Moein Jazayeri, Kian Jazayeri, Sener Uysal, Adaptive photovoltaic array reconfiguration based on real cloud patterns to mitigate effects of non-uniform spatial irradiance profiles, Solar Energy 155 (2017) 506–516.

AUTHORS PROFILE

Abhronil Chaudhuri received his Bachelors degree in Mechatronics Engineering from SRM Institute of science and Technology in 2019. He will join Anand Group as an Engineering in fall of 2019. His research areas are in field of electronics and Machine learning.

Lakshay Gopalka received his Bachelors degree in Mechatronics Engineering from SRM Institute of science and Technology in 2019 and he will start his MS in Robotics engineering at WPI for fall, 2019. His research areas are in field of electronics, robotics and control systems on the area like Photovoltaic cells, Continuum robots, Path planning and AI.