International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

Experimental Verification of Reconfiguration Techniques Applied for Partial Shading on Solar PV

Balaji Venkateswaran V, Deepali Yadav, Neeraj Kumar Sharma

Abstract*: Energy is the one of the basic requirements for sustained economic growth. To meet the growing requirement of energy, and to reduce the CO2 emission, many countries have chosen to meet its energy demand through renewable energy resources for sustainable development. Most popular renewable energy resources are solar and wind; due to the technological advancement in solar technology and its demand in the market made solar panels comparatively cheaper. One of the popular ways to extract solar power is installing solar rooftop. The main factor, which affects the performance of solar rooftop PV system, is power mismatch due to shading. In the literature, many reconfiguration methods have proposed based on electrical interconnections and physical location of the solar cell/modules. In this paper, physical-location based techniques are modified as electrical interconnection techniques and its performance is compared through experimentation at various shading patterns.

Keywords: Solar PV, Partial shading, Reconfiguration, Power mismatch, Shading loss.

I. INTRODUCTION

Energy is the key component, which is essential for the developing nations for its industrial growth. For any nation to sustain its growth, consistent and adequate energy supply becomes prime factor. In addition, the nations signed for Paris agreement has to comprehend with low carbon fuels or non – carbon fuels to meet its growing energy demand [1]. Usage of solar photovoltaic (PV) technology (being under low carbon fuel category) is increasing because of its easiness to deploy. For capacity addition of solar PV, nations have created policies, which helps in increasing the installations of solar PV. One such installation to increase the capacity as well as to decrease the transmission loss is solar rooftops. Nevertheless, the challenge in extracting energy from solar rooftop prevails because of its non-linear output characteristics, which varies mainly with temperature and irradiation. This characteristic becomes complex when it receives uneven insolation (due to trees, nearby buildings, clouds and other unavoidable structures).

Over the years, many techniques have proposed in the literature to solve power mismatch due to shading. These techniques can be categorised into two: based on electrical interconnections and physical relocation. Some of the popular reconfiguration techniques found in the literature based on electrical interconnection are series – parallel (SP), bridge – link (BL), total-cross-tied (TCT). To eliminate the power mismatch in SP configuration, by-pass diodes are used [2]–[4]. To reduce the cost associated with by-pass diode and to avoid the problems during diode failures, BL and TCT configurations came into existence [5]. Since partial shading depends on many factors, controllers have developed to sense the available irradiance and change the electrical connection (between SP, BL and TCT) to get the desired configuration with maximum power output [6].

Later, B. Indu Rani proposed a technique based on physical location, which exploits the Sudoku logic in a TCT configured solar array [7]. In a similar manner magic square based logic is also proposed to minimize the effect of shading on solar array [8]. Many authors have attempted to compare the performance of SP, BL and TCT reconfiguration techniques with and without bypass diode through simulations and experimentation[9]–[14]. In these methods, physical location is changed to minimize the power – mismatch, which is practically difficult for a solar plant which is already erected. Hence, in this paper an attempt to modify the location based techniques into electrical interconnection techniques and its performance is analysed through experimentation. The shading pattern defined in [15] is applied in this paper to verify various configurations. Section II describes shading problem and various techniques (used in the literature to solve the same) in detail. Section III describes the proposed modification. In section IV, the maximum power of all the reconfiguration techniques are analysed and compared. The performance of the reconfiguration techniques under shading conditions are analysed in section V.

II. SHADING PROBLEM

The solar photovoltaic works on the principle of junction effect. The output produced by a solar cell is proportional to the solar irradiation incident on it as evident from equation 1 [9]. A solar PV system consist of many solar panels connected in SP configuration (in general) to form solar array. Since the current produced in solar PV depends on surface irradiation, any shade created on it due to any obstacle may lead to power mismatch.

Manuscript published on 30 September 2019.
***Correspondence Author(s)**
Balaji Venkateswaran, Department of Electrical and Electronics Engineering, University of Petroleum and Energy Studies, Bidholi Campus, Dehradun, India. Email: b.venkateswaran@ddn.upes.ac.in
Deepali Yadav, Department of Electrical and Electronics Engineering, University of Petroleum and Energy Studies, Bidholi Campus, Dehradun, India. Email: dyadav@ddn.upes.ac.in
Neeraj Kumar Sharma, Department of Electrical and Electronics Engineering, University of Petroleum and Energy Studies, Bidholi Campus, Dehradun, India. Email: nksharma@ddn.upes.ac.in

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

In addition, due to electrical interconnections some solar cells/panels may not contribute for the power output even when it is unshaded.

$$I_{ph} = I_{ph}^{STC} + k\Delta T) * 0.001 * G \quad (1)$$

To address this issue many reconfiguration methods have proposed in the literature shown in figure 1. In all these configurations, bypass diode can be used.

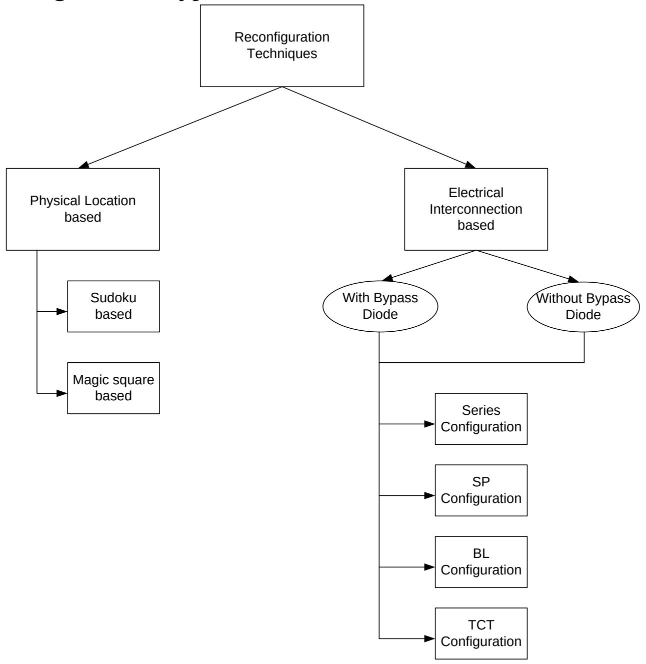


Fig. 1. Various reconfiguration techniques

A. Bypass diode configuration

In this type of configuration, a diode is connected in reverse bias fashion parallel to solar cell/module, which bypass the shaded solar cell/module. As a result, the output from the solar module will increase (in a way the diode helps to extract the energy from unshaded solar cells/modules). The application of bypass diode in series configuration is shown in figure 2. The bypass diodes can also overlap each other to achieve the desired characteristics when shading [3].

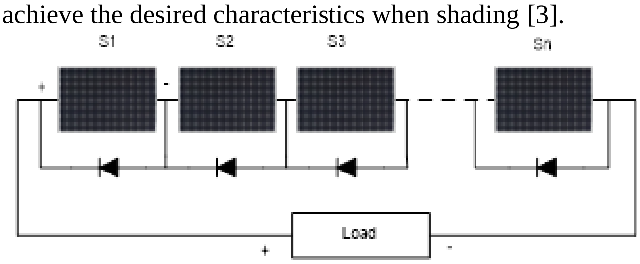


Fig. 2. Bypass diode-based Series configuration

B. SP configuration

This type of configuration is very common in any solar PV plant. In this, the solar cells/modules are connected in series and parallel combination to develop the desired value of voltage and current as shown in figure 3. The major drawback of this configuration is if one cell/module in an array is shaded, the power output is affected. This can be rectified using bypass diodes which becomes series – parallel with diode (SPD) configuration.

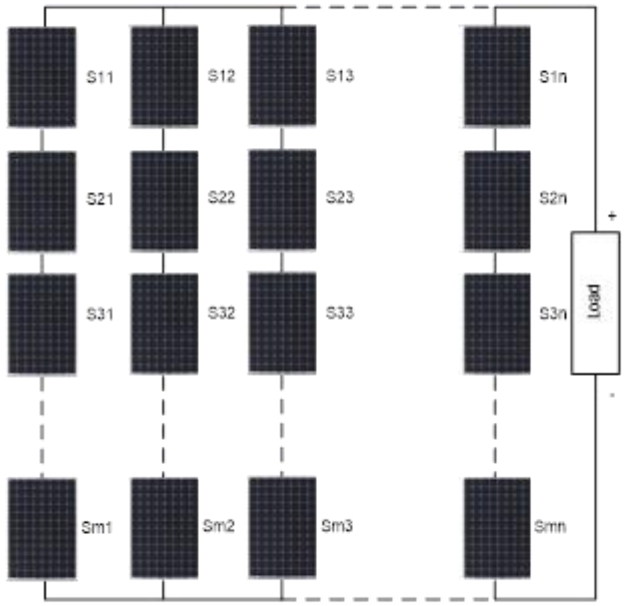


Fig. 3. Series – Parallel Configuration

C. Bridge-link configuration

In the SP configuration, if an interconnection between the columns made alternatively then this type of configuration becomes bridge link configuration. The main advantage of this over bypass diode-based SP configuration is it reduces the number of diodes and thereby decreasing the possibility of hotspot creation due to partial shading and failure of diodes.

D. Total-Cross-Tied configuration

In this type of configuration, the need for diode is avoided since all the solar cells/modules are connected as shown in figure 4, thereby creating a pathway for the current to flow even when a cell/module is shaded.

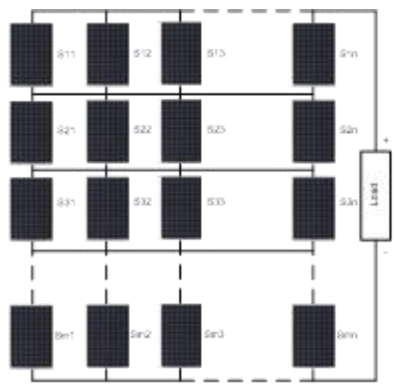


Fig. 4. Generalized TCT Configuration

In all the above-mentioned techniques with or without bypass diodes, an alternative path for the current flow have created. However, the hotspot creation due to partial shading prevails. This can be minimized by using physical relocation techniques. The relocation techniques mainly based on TCT configuration are Su-Do-Ku and magic square configuration

Retrieval Number: K22570981119/19©BEIESP
DOI: 10.35940/ijitee.K2257.0981119
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

E. Su Do Ku configuration

This type of configuration depends on Su Do Ku puzzle pattern of $m \times m$ or $n \times n$ solar array. The positions of solar cells/modules configured in TCT configuration are changed according to the solution of puzzle [7]. By this manner, the insolation is distributed over the entire solar array.

F. Magic Square configuration

In this type of configuration, the idea of distributing the shaded area over the entire region of solar array have taken into consideration. The location of solar cells/modules with TCT configuration is replaced according to magic square [8].

III. DESCRIPTION OF PROPOSED TECHNIQUE

The proposed technique is a modified version of physical location-based reconfiguration. Here, both the modified methods are elaborated using 5×5 PV system.

A. Proposed configuration based on Su Do Ku puzzle

Su Du Ku is a number placement puzzle based on a logic. The Su Do Ku puzzle pattern for 5×5 is based on the logic as explained in figure 5 and the same puzzle pattern is considered for the study. Using Su Do Ku puzzle shown in figure 5, two configurations: C-Sudoku and R-Sudoku have developed as shown in figure 6 and figure 7 respectively.

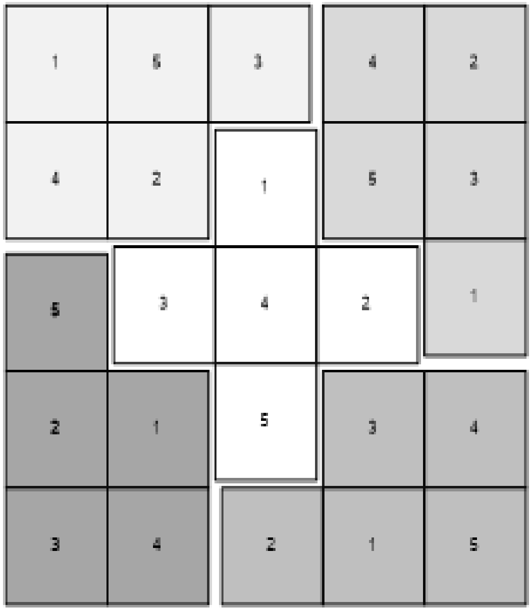


Fig. 5. Sample solution of 5 x 5 Su Do Ku puzzle

Here, the TCT configured (as shown in figure 4) 5×5 solar array is electrically interconnected with a configuration shown in figure 6 and figure 7 representing R – Sudoku and C – Sudoku respectively. The electrical interconnection of the same is shown in figure 8 and figure 9 respectively.

B. Proposed configuration based on Magic Square matrix

Magic square matrix of a given dimension $(m \times m)$ is an arrangement of m^2 numbers, such that addition of all row elements, column elements, and both diagonal elements has same constant called magic constant. This magic constant of order m is given by equation 2.

$$M_c = m * \frac{m^2+1}{2} \tag{2}$$

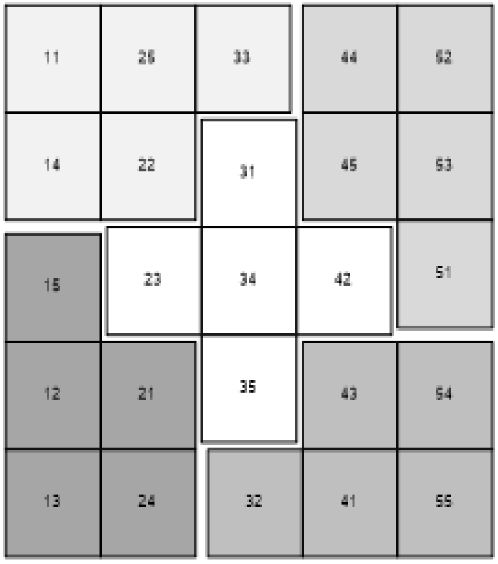


Fig. 6. R – Sudoku Configuration

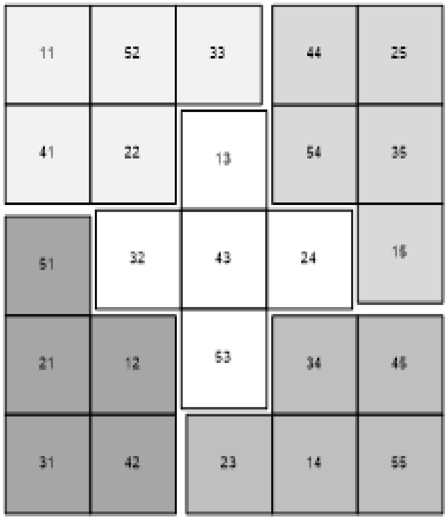


Fig. 7. C – Sudoku Configuration

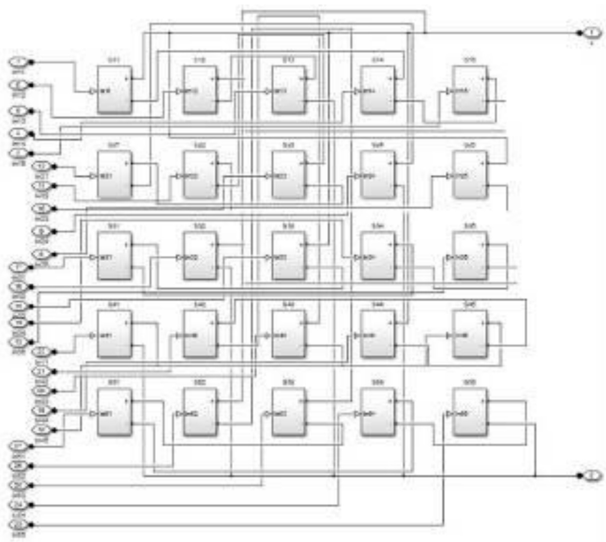


Fig. 8. Electrical interconnection of R – Sudoku Configuration

Retrieval Number: K22570981119/19©BEIESP
DOI: 10.35940/ijitee.K2257.0981119
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

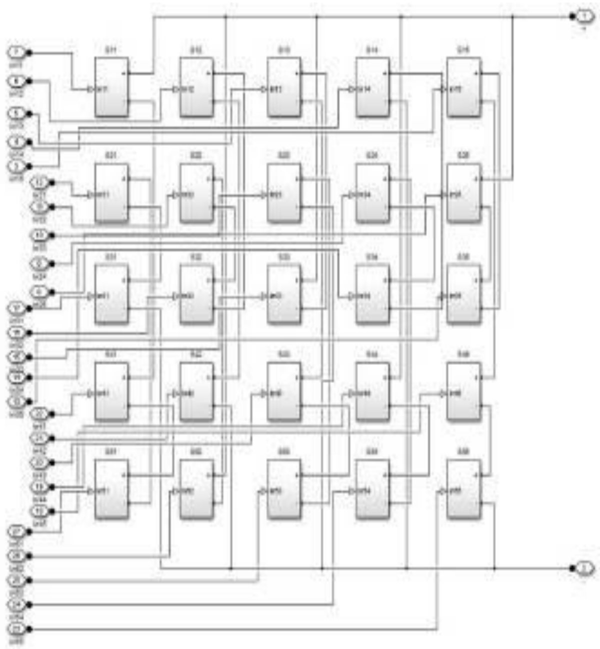


Fig. 9. Electrical interconnection of C – Sudoku Configuration

The magic matric for 5 × 5 array is shown in figure 10 and the same is considered for the study. The magic square configuration proposed in this article follows the physical location of conventional TCT configuration as shown in figure 11 and the electrical interconnections are made with respect to figure 10. The electrical interconnection of magic square configuration is shown in figure 12.

17	24	1	8	15
23	5	7	14	16
4	6	13	20	22
10	12	19	21	3
11	18	25	2	9

Fig. 10. Magic Square Configuration

IV. COMPARISON OF VARIOUS RECONFIGURATION TECHNIQUES

In this section a comparison is made between all the configuration techniques based on maximum power delivered by solar array during unshaded condition. The comparison is done based on the results obtained from experimental setup. The experimental setup used is shown in figure 13 (a). The specification of the equipments used to perform experiment is shown in Table 1. The experimentation is performed at an irradiance level of 150 Btu/(ft^2 – h) with a variable load of 1.2 $k\Omega$

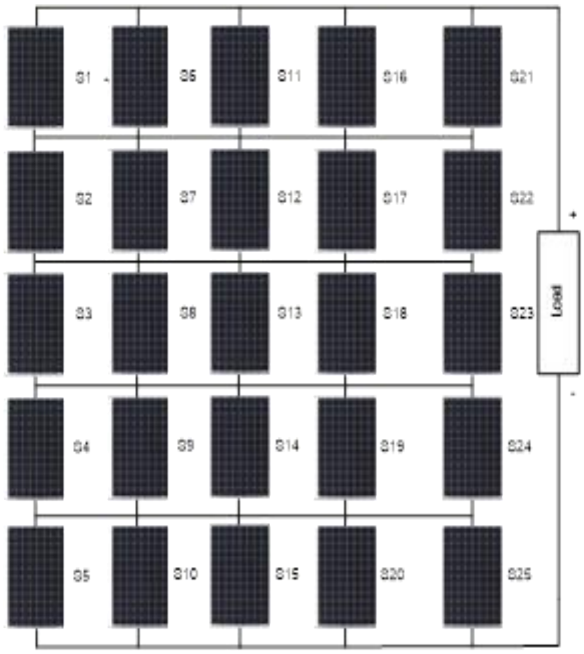


Fig. 11. TCT Configuration

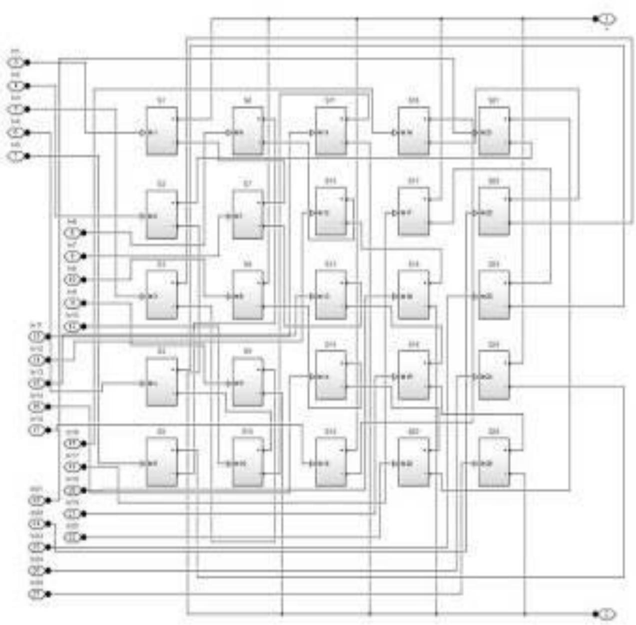


Fig. 12. Electrical interconnection of Magic Square Configuration

The I-V and P-V characteristics for various configuration have obtained through experimentation are shown in figure 14 and figure 15 respectively.

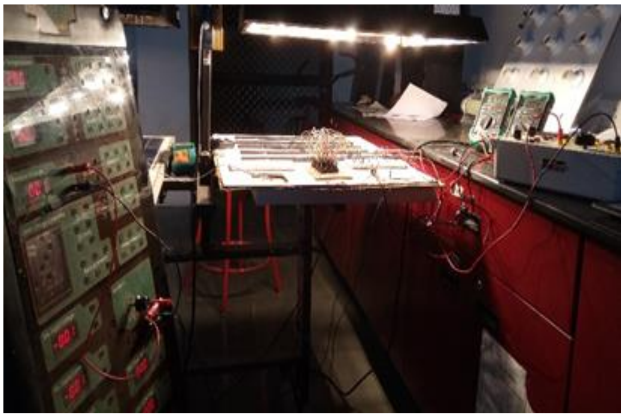
Table- I. Specification of Solar Cell at 140 Btu/(ft^2 – h)

Solar Cell Power	0.1 W
Open Circuit Voltage	6.5 V
Short Circuit Current	16 mA

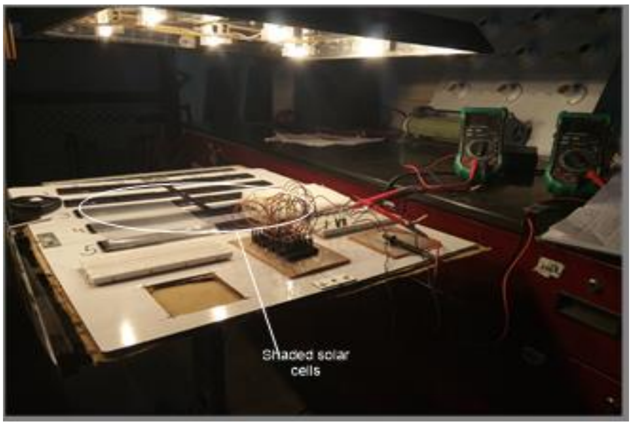
Retrieval Number: K22570981119/19©BEIESP
DOI: 10.35940/ijitee.K2257.0981119
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019



(a)



(b)

Fig. 13. (a) Experimental Setup. (b) Short wide Shading pattern

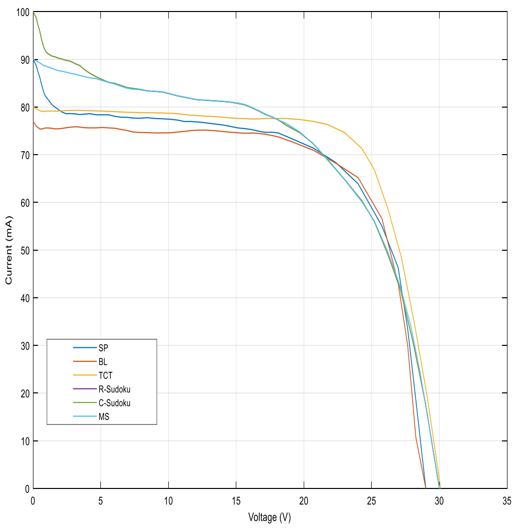


Fig. 14. I-V characteristics of various reconfigurations techniques

Following are the observations from figure 14 and figure 15:

1. TCT configuration gives maximum output compared to other configuration techniques during unshaded conditions.
2. Both the sudoku configurations and the magic square configuration almost follow the same characteristics.
3. Uptil half the open circuit voltage, the sudoku configuration and MS configuration have maximum power out compared all the other configurations.

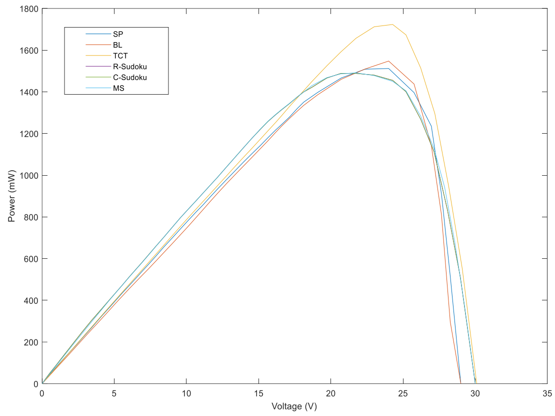


Fig. 15. P-V characteristics of various reconfigurations techniques

V. PERFORMANCE ANALYSIS OF VARIOUS RECONFIGURATION TECHNIQUES UNDER SHADED CONDITION

A. Shading Pattern

Four shading patterns namely short wide (SW), long wide (LW), short narrow (SN) and long narrow (LN) have considered in the experiment to obtain the performance of solar array. The shading patterns applied to 5 × 5 solar array is shown in figure 16. The partially shaded solar cells according to the shaded pattern described in figure 16 (a) applied in the experiment is shown in figure 13 (b).

B. Solar array characteristics

A solar array consisting of 5×5 solar cells is created with respect to SP, SPD, BL, TCT, RS, CS and MS configurations. The results and a comparative analysis of various shading pattern is discussed below:

1) SW shading pattern

In this case, total of twelve cells are shaded having four different insolation levels as shown in figure 16 (a). The I – V and P – V characteristics of all the configurations are shown in figure 17 (a) and figure 17 (b). It is evident from figure 17 (b) that CS configuration generates more power output compared to other configurations.

2) LW shading pattern

In this case, total of sixteen cells are shaded having four different insolation levels as shown in figure 16 (b). The I – V and P – V characteristics of all the configurations are shown in figure 17 (c) and figure 17 (d). It is evident from figure 17 (d) that MS configuration generates more power output compared to other configurations.

3) SN shading pattern

In this case, total of eight cells are shaded having four different insolation levels as shown in figure 16 (c). The I – V and P – V characteristics of all the configurations are shown in figure 17 (e) and figure 17 (f). It is evident from figure 17 (f) that CS configuration generates more power output compared to other configurations.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

4) LN shading pattern

In this case, total of eight cells are shaded having four different insolation levels as shown in figure 16 (d). The I – V and P – V characteristics of all the configurations are shown in figure 17 (g) and figure 17 (h). It is evident from figure 17 (h) that MS configuration generates more power output compared to other configurations.

From the above results, following conclusions are made:

1. For SW and SN shading pattern, SP configuration and C – Sudoku gives maximum power output respectively.
2. For LW and LN shading pattern, MS configuration gives maximum power output.

The above observations are indicated in Table 2 with respect to open circuit voltage (V_{oc}), short circuit current (I_{sc}), and maximum power output (M_P) with respect to best configuration among all. These two conclusions are valid only if the voltage across the load is maintained at the rated level

(26 V in the experimental condition). If there is any voltage drop in the load end then, other configurations may give maximum power output.

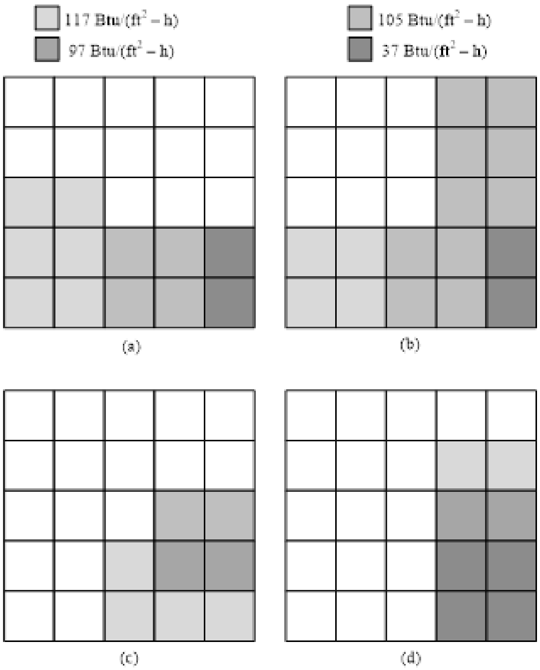


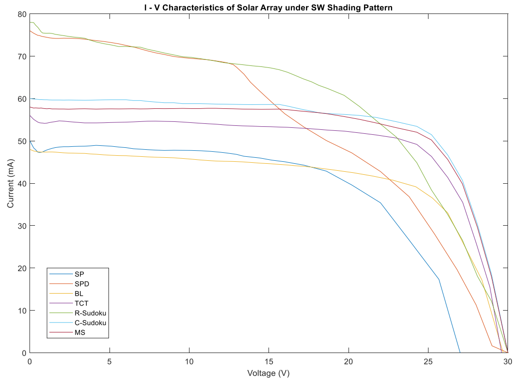
Fig. 16. Various shading patterns. (a) Short wide. (b) Long wide. (c) Short Narrow. (d) Long Narrow.

Table- II. Consolidated results under various shading patterns indicating V_{oc}, I_{sc}, M_P

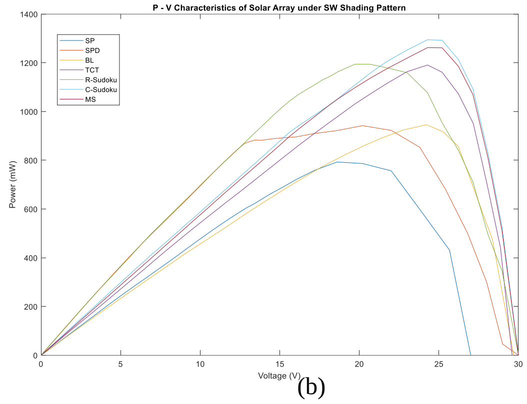
Shading Pattern	*Best Configuration*	*V_{oc} in volts*	*I_{sc} in mA*	*M_p in mW*
SW Configuration	SP Configuration	27	50	858
LW Configuration	MS Configuration	30	57	1392
SN Configuration	CS Configuration	30	68	1595
LN Configuration	MS Configuration	30	59	1385

Retrieval Number: K22570981119/19©BEIESP
DOI: 10.35940/ijitee.K2257.0981119
Journal Website: www.ijitee.org

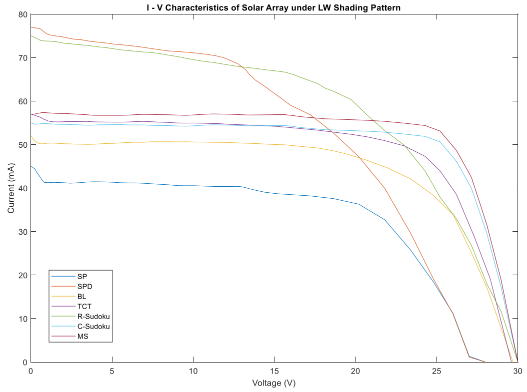
Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)
© Copyright: All rights reserved.



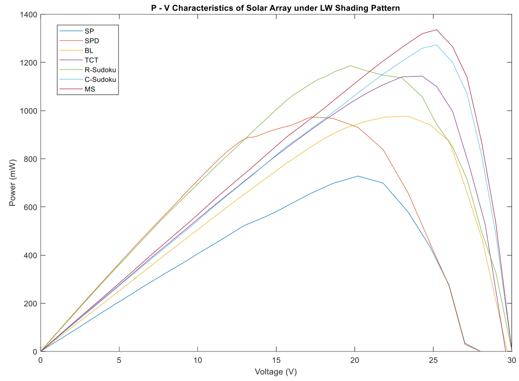
(a)



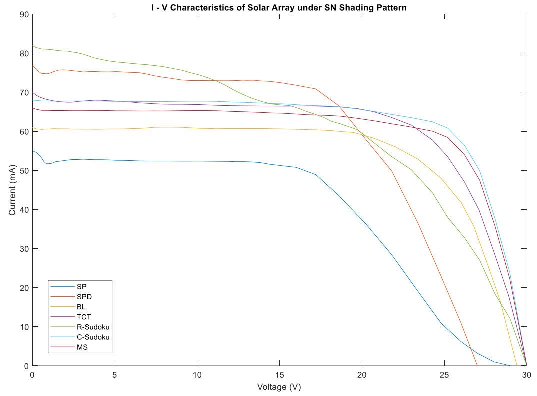
(b)



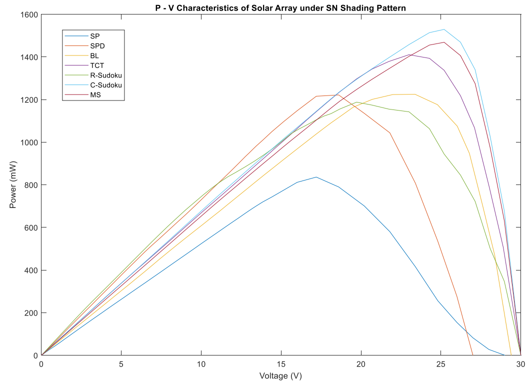
(c)



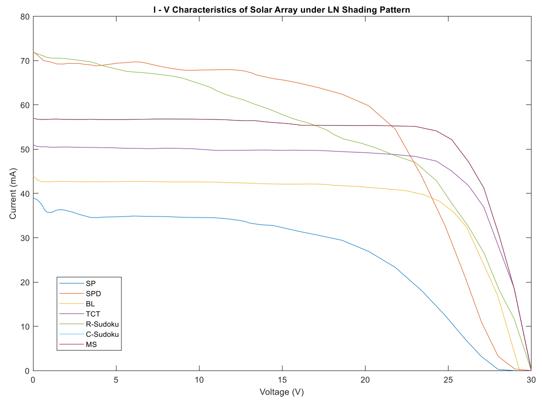
(d)



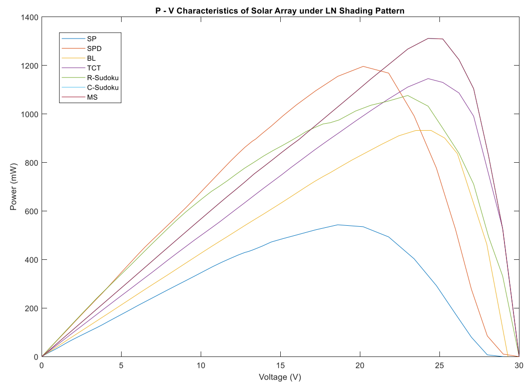
(e)



(f)



(g)



(h)

Fig. 17. Solar Array characteristics under various shading patterns

.

Retrieval Number: K22570981119/19©BEIESP
DOI: 10.35940/ijitee.K2257.0981119
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

VI. CONCLUSION

In this paper, the physical location-based reconfiguration techniques are modified into electrical interconnection techniques. Then, all the configurations are created in 5 × 5 solar array format and is tested under various shading patterns. From the practical results, it is evident that the performance of the proposed technique is better in most of the shading patterns considered compared to other reconfiguration techniques.

REFERENCES

1. UNFCCC, "Paris Agreement," Conf. Parties its twenty-first Sess., no. December, p. 32, 2015.
2. S. Silvestre, A. Boronat, and A. Chouder, "Study of bypass diodes configuration on PV modules," Appl. Energy, vol. 86, no. 9, pp. 1632–1640, 2009.
3. E. Díaz-Dorado, A. Suárez-García, C. Carrillo, and J. Cidrás, "Influence of the shadows in photovoltaic systems with different configurations of bypass diodes," in SPEEDAM 2010 - International Symposium on Power Electronics, Electrical Drives, Automation and Motion, 2010, pp. 134–139.
4. H. Ziar, S. Mansourpour, E. Afjei, and M. Kazemi, "Bypass diode characteristic effect on the behavior of solar PV array at shadow condition," in 2012 3rd Power Electronics and Drive Systems Technology, PEDSTC 2012, 2012, vol. 01, pp. 229–233.
5. D. Picault, B. Raison, S. Bacha, J. Aguilera, and J. De La Casa, "Changing photovoltaic array interconnections to reduce mismatch losses: A case study," in 2010 9th Conference on Environment and Electrical Engineering, EEEIC 2010, 2010, pp. 37–40.
6. A. Bidram, A. Davoudi, and R. S. Balog, "Control and circuit techniques to mitigate partial shading effects in photovoltaic arrays," IEEE J. Photovoltaics, vol. 2, no. 4, pp. 532–546, 2012.
7. B. I. Rani, G. S. Ilango, and C. Nagamani, "Enhanced power generation from PV array under partial shading conditions by shade dispersion using Su Do Ku configuration," IEEE Trans. Sustain. Energy, vol. 4, no. 3, pp. 594–601, 2013.
8. S. M. Samikannu, R. Namani, and S. K. Subramaniam, "Power enhancement of partially shaded PV arrays through shade dispersion using magic square configuration," J. Renew. Sustain. Energy, vol. 8, no. 6, 2016.
9. K. Ishaque, Z. Salam, and Syafaruddin, "A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model," Sol. Energy, vol. 85, no. 9, pp. 2217–2227, 2011.
10. M. M. A. Salama, M. Z. Shams El-Dein, and M. Kazerani, "Optimal Photovoltaic Array Recon fi guration to Reduce Partial Shading Losses," IEEE Trans. Sustain. ENERGY, vol. 4, no. 1, pp. 145–153, 2013.
11. S. Pareek, R. Runthala, and R. Dahiya, "Mismatch losses in SPV systems subjected to partial shading conditions," in Proceedings of the 2013 International Conference on Advanced Electronic Systems, ICAES 2013, 2013, pp. 343–345.
12. R. Ramaprabha, "Selection of an Optimum Configuration of Solar PV Array under Partial Shaded Condition Using Particle Swarm Optimization," Int. J. Electr. Comput. Energ. Electron. Commun. Eng., vol. 8, no. 1, pp. 96–103, 2014.
13. S. Vijayalekshmy, S. Rama Iyer, and B. Beevi, "Comparative Analysis on the Performance of a Short String of Series-Connected and Parallel-Connected Photovoltaic Array Under Partial Shading," J. Inst. Eng. Ser. B, vol. 96, no. 3, pp. 217–226, 2015.
14. O. Bingöl and B. Özkaya, "Analysis and comparison of different PV array configurations under partial shading conditions," Sol. Energy, vol. 160, no. November 2017, pp. 336–343, 2018.
15. L. F. L. Villa, D. Picault, B. Raison, S. Bacha, and A. Labonne, "Maximizing the power output of partially shaded photovoltaic plants through optimization of the interconnections among its modules," IEEE J. Photovoltaics, vol. 2, no. 2, pp. 154–163, 2012.

AUTHORS PROFILE

Balaji Venkateswaran V received the B. E and M. Tech degrees from Anna University, Chennai and SRM University, Chennai in 2011 and 2013 respectively. Certified Trainer for Distribution Engineer issued by Ministry of Skill Development Corporation. He is currently working as Assistant Professor in Dept. of Electrical and Electronics Engineering at University of Petroleum and Energy Studies. His area of research includes renewable energy, grid integration of renewables and power system analysis.

Deepali Yadav received the B. Tech and M. Tech degrees from Uttaranchal University, Dehradun and PEC, Chandigarh in 2012 and 2015 respectively. Certified Trainer for Distribution Engineer issued by Ministry of Skill Development Corporation. She is currently working as Assistant Professor in Dept. of Electrical and Electronics Engineering at University of Petroleum and Energy Studies. Her area of research includes power electronics and drives.

Neeraj Kumar Sharma received the B. Tech and M. Tech degrees from UPTU, Lucknow and IIT, Kanpur in 2009 and 2015 respectively. Certified Trainer for Distribution Engineer issued by Ministry of Skill Development Corporation. He is awarded by POSOCO in the year 2016 for his research in master category. He is currently working as Assistant Professor in Dept. of Electrical and Electronics Engineering at University of Petroleum and Energy Studies. His area of research includes power system, power electronics and renewable energy.

Retrieval Number: K22570981119/19©BEIESP
DOI: 10.35940/ijitee.K2257.0981119
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.