TMP UNIVERSAL JOURNAL OF RESEARCH AND REVIEW ARCHIVES

VOLUME 3 | ISSUE 3 | YEAR 2024 | JUL - SEP 2024

RECEIVED DATE	REVISED DATE	ACCEPTED DATE
28/05/2024	20/06/2024	26/07/2024

Article Type: Research Article

Available online: www.tmp.twistingmemoirs.com

ISSN: 2583-7214

RECONFIGURATION OF SOLAR PANELS TO PRODUCE MAXIMUM POWER USING NOVEL METHOD (TOUR PUZZLE)

*[1]Sevda Rezazadeh

[1]*Department of Electrical Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran*

ABSTRACT

This paper introduces a new reconfiguration technique called tour puzzle for better shadow dispersion and obtaining maximum output power under partial shade conditions. In the presented method, partial shadows are spread in all rows and maximum power can be achieved. The puzzle tour can be applied to all kinds of PV arrays of different dimensions and sizes. Accordingly, the puzzle tour procedure is applied in several cases in the form of squares and rectangles with different dimensions and various shading conditions in each case. To directly compare and present the efficiency of the proposed method, the total cross-connection model and conventional methods such as magic Square puzzle, competence Square puzzle, Skyscraper and improved Sudoku are also implemented in the introduced cases. Finally, the evaluations emphasize the capability and efficiency of the Tour puzzle solution compared to other methods by achieving GMPP values such as 63.9 V_mI_m, 69.3 V_mI_m, 69.3 V_mI_m and 68.4 V_mI_m for cases 1 to 4, respectively. The results show that the proposed method can provide acceptable performance for solving the problem of achieving maximum power under PSC in PV.

Keywords: Renewable energy · Photovoltaic array · Reconfiguration · Partial shading conditions · Tour puzzle technique

CORRESPONDING AUTHOR

Name: Sevda Rezazadeh

Affiliation: Department of Electrical Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran

INTRODUCTION

Due to the depletion of fossil fuels and the global pursuit of low-carbon energy supply, large amounts of distributed renewable energy production sources have been installed and used in the last decade(1) . The performance of a photovoltaic (PV) array is highly dependent on partial shading conditions, which can be mitigated by careful planning and positioning of PV modules during installation to prevent self-shading (2). Increasing support for a range of policies to support renewable energy development has the potential to promote equality, health and employment, while also limiting greenhouse gas emissions (3). Solar radiation is taken into account as the main source of energy for the earth among renewable energy sources (4). The reduction of partial shading losses can be explained by using different types of connections between PV modules (5). Several configurations have been proposed for PV array reconfiguration in PSCs, including parallel (SP), total cross (TCT), bridge link (BL), and honeycomb (HC), which is the most efficient TCT configuration (6). In partial shading conditions, reconfiguring the connection of the PV modules in the photovoltaic array is one of the best methods that can be used to obtain the maximum output power (7). The reconfiguration techniques are divided into two categories: dynamic photovoltaic array reconfiguration and static photovoltaic array reconfiguration (8). The method of physical reconfiguration of PV modules can be a real alternative to the shading process of the PV array. In this paper, a new method using the Tour puzzle for PV modules reconfiguration and shadow dispersion in PV arrays is shown. The mismatch phenomenon is a common damage condition in most PV systems, which reduces the extraction of the generated power in the PV array (9). The mismatch phenomenon is caused by cracks on the modules or due to different radiations on the PV modules. The mismatch phenomenon in a PV array causes losses such as the difference between the maximum power of a PV array and the maximum power of all its modules (10). Solar energy has become a glimmer of hope, especially in the global warming and climate change issues that have intensified around the world (11). Solar panels consist of photovoltaic cells and convert sunlight into electricity with increasing efficiency (12). In the dynamic method, to increase the maximum available power, the connections of PV modules inside the PV array are changed dynamically based on the radiation level (13). The dynamic reconfiguration technique requires many high-cost sensors to detect partial shading and reconfiguration algorithms to optimize to obtain the most reliable connection to reach the maximum possible power and a switching matrix to change the connections of PV modules. The physical movement of the panel is done to provide better and more optimal results for most partial shade conditions. This method does not include any sensors, switches, complex algorithms, has a simple structure and is suitable for large installations (14, 15).

This article, the proposed method has been compared with other important in static methods such as Magic Square puzzle, Competence Square puzzle, Skyscraper and improved Sudoku, and the efficiency and maximum output power of the proposed method are well shown in the graphs and tables.

Tour puzzle technique

In this article, we discuss the tour puzzle, which is similar to sliding puzzles in different dimensions (n × m). The n × m torus puzzle consists of m n pieces numbered from 1 to m n and the pieces are placed on a board consisting by m rows of n columns. Initially, for each r ∈ {1,. . . , MN}, piece number r is placed in the p_{th} row and q_{th} column, where p = ⌈r/n⌉ and r ≡ q (mod n). In the puzzle, there are four main operations; N, S, E and W (these mean North, South, East and West).

In the proposed method, the puzzle provided for arranging the solar panels is derived from the tour puzzle. The proposed method in this article is that the north side is rearranged first, then the south side, the east side and the west side respectively. That is, by applying E (in the order of W) to the row $r = (p_2, p_3, \dots, p_n, p_1)$and r converted to $(p_1, p_2, \dots, p_{n-1}, p_n)$ (respectively, $((p_n, p_1, \dots, p_{n-2}, p_{n-1}))$) where A^{tr} represents the displacement of a matrix A. Similarly, operation N (in S order) rotates in a row $(p_1, p_2, \dots, p_{m-1}, p_m)^{tr}$ to $(p_2, p_3, \dots, p_m, p_1)^{tr}$ (respectively, $(p_m, p_1, \dots, p_{m-2}, p_{m-1})^{tr}$).

After performing a series of basic operations, the configuration of the array will be significantly different from the initial configuration. The purpose of the tour puzzle is to create the most suitable configuration for rearranging the solar panels. On the other hand, if we do not reach the ideal configuration after running the tour puzzle, we can rotate the matrix clockwise. Given an array of N rows and N columns, we can rotate the matrix 90 degrees clockwise (16).

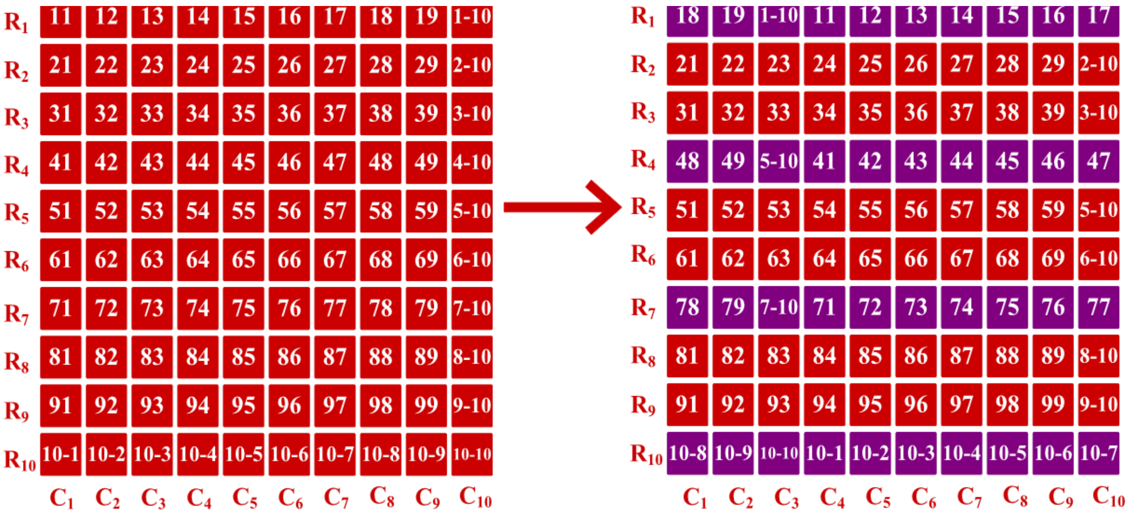


Fig1: Step 1 Rearrangement of solar panels by tour puzzle method

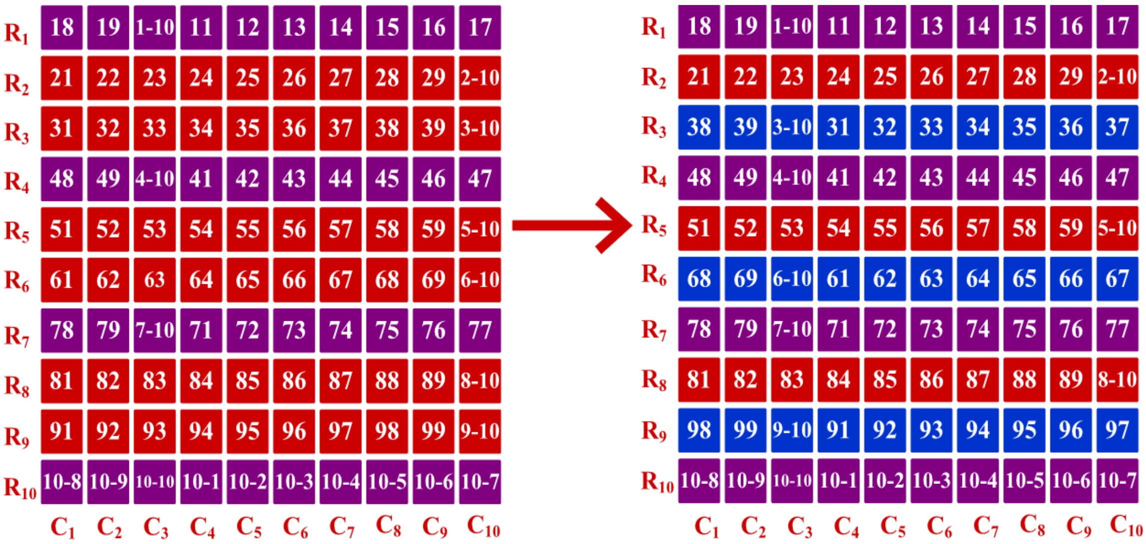


Fig 2: Step 2 Rearrangement of solar panels by tour puzzle method

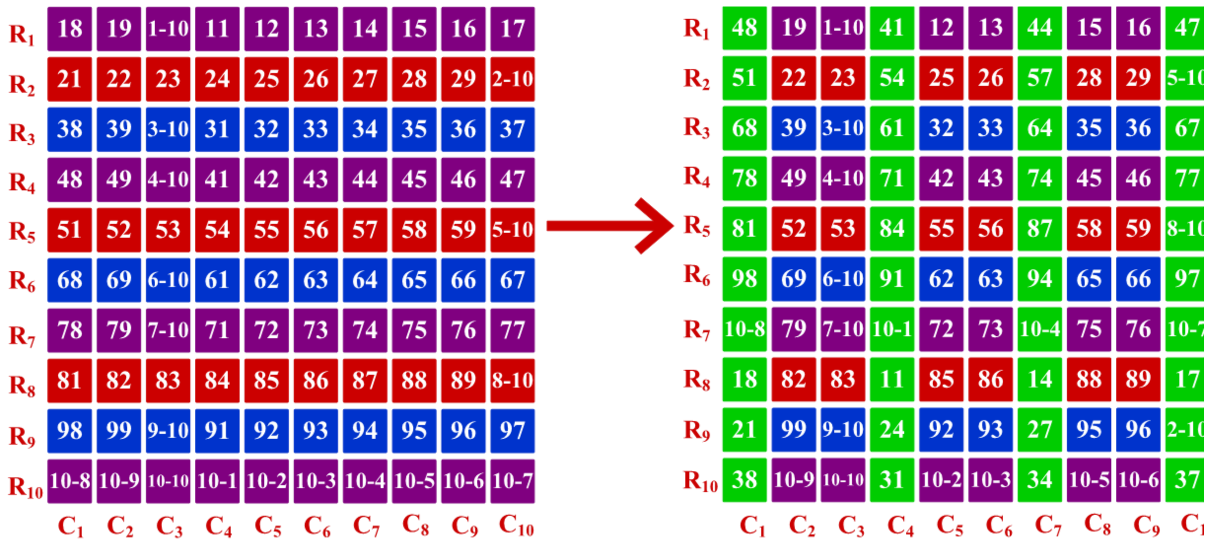


Fig 3: Step 3 Rearrangement of solar panels by tour puzzle method

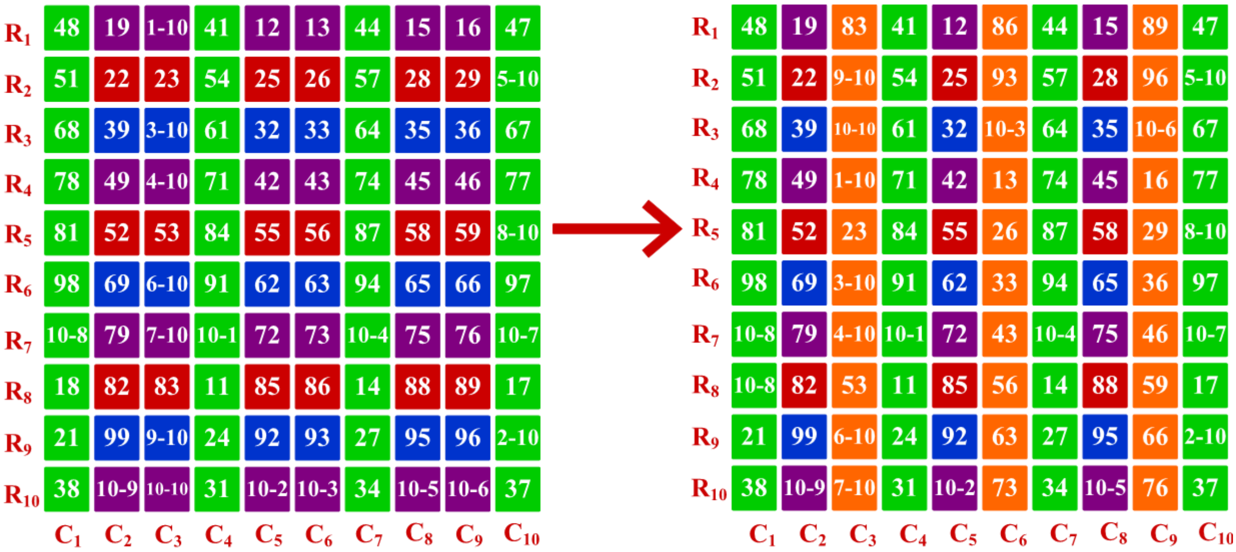


Fig 4: Step 4 Rearrangement of solar panels by tour puzzle method

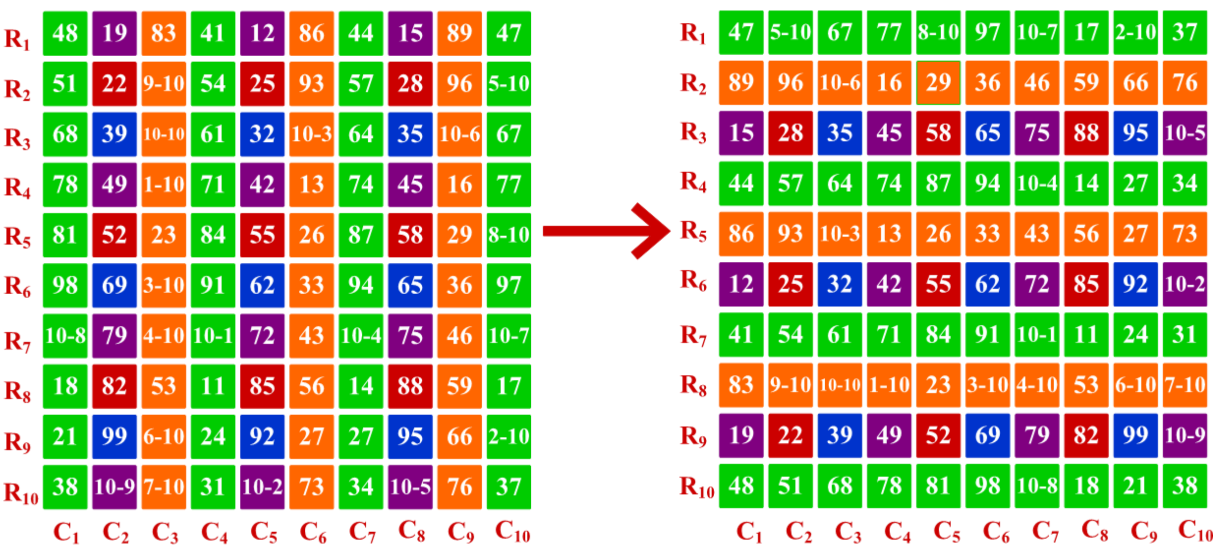


Fig 5: Step 5 Rearrangement of solar panels by tour puzzle method

In the following figures, the proposed method is rearranged along with other important static methods on solar panels. The distribution of the shade on the solar panels is shown and in the tables the improvement of the output power is calculated by the proposed method

Case 1:

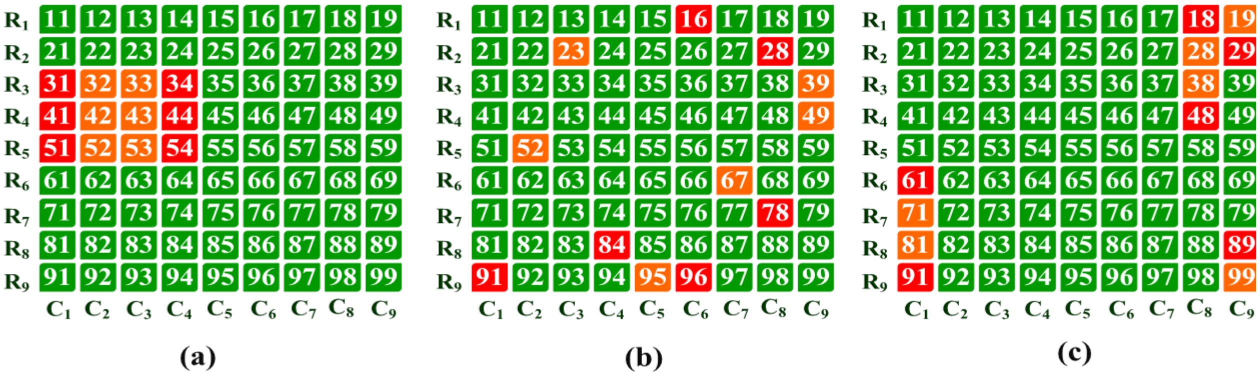


Fig 6. Rearrangement of solar panels using TCT, magic Square and competence Square methods

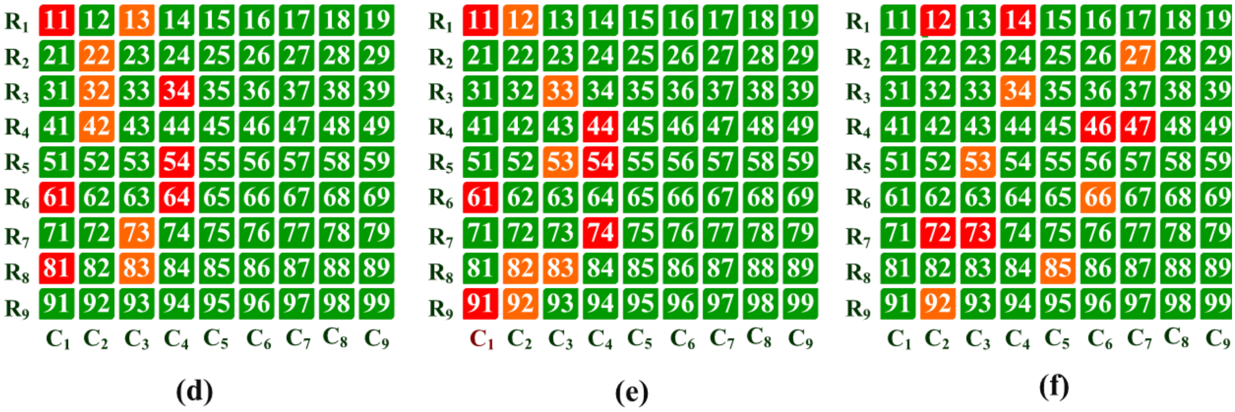
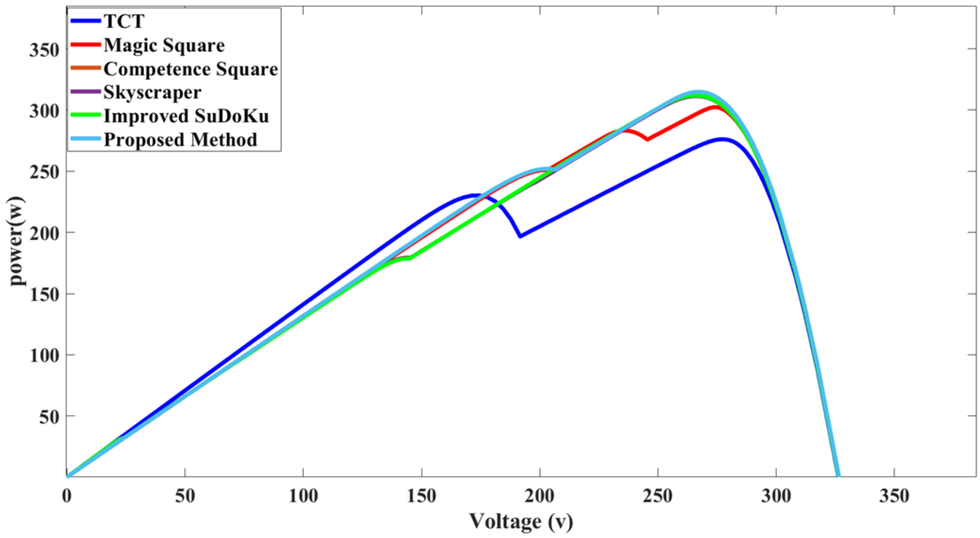


Fig 7. Rearrangement of solar panels using skyscraper, improved Sudoku and Tour puzzle methods



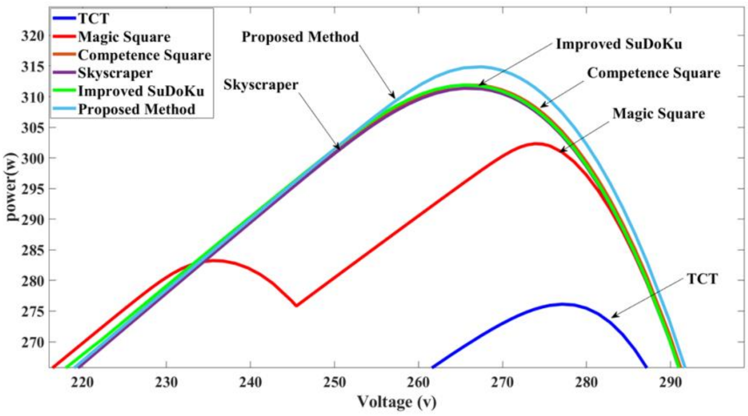


Fig 8. Voltage-power diagram (1)

TCT interconnected				Magic Square puzzle				Competence Square Puzzle			
Row bypassed	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power
Irow9	$9I_m$	$5V_m$	$45V_mI_m$	**Irow9**	$9I_m$	$5V_m$	$45V_mI_m$	**Irow9**	$8.1I_m$	$8V_m$	$64.8V_mI_m$
Irow8	$9I_m$	$5V_m$	$45V_mI_m$	**Irow8**	$9I_m$	$5V_m$	$45V_mI_m$	**Irow8**	$8.1I_m$	$8V_m$	$64.8V_mI_m$
Irow7	$9I_m$	$5V_m$	$45V_mI_m$	**Irow7**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow7**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**
Irow6	$9I_m$	$5V_m$	$45V_mI_m$	**Irow6**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow6**	$8.1I_m$	$8V_m$	$64.8V_mI_m$
Irow5	$9I_m$	$5V_m$	$45\backslash V_mI_m$	**Irow5**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow5**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**
Irow4	$9I_m$	$5V_m$	$45V_mI_m$	**Irow4**	$9I_m$	$5V_m$	$45V_mI_m$	**Irow4**	$8.1I_m$	$8V_m$	$64.8V_mI_m$
Irow3	$6.8I_m$	$9V_m$	**$61.2V_mI_m$**	**Irow3**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow3**	$8.6I_m$	$7V_m$	$60.2V_mI_m$
Irow2	$6.8I_m$	$9V_m$	**$61.2V_mI_m$**	**Irow2**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow2**	$9I_m$	$5V_m$	$45V_mI_m$
Irow1	$6.8I_m$	$9V_m$	**$61.2V_mI_m$**	**Irow1**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow1**	$9I_m$	$5V_m$	$45V_mI_m$

Skyscraper Puzzle				Improved Sudoku Puzzle				Proposed Method			
Row bypassed	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power
Irow9	$9I_m$	$5V_m$	$45V_mI_m$	**Irow9**	$9I_m$	$5V_m$	$45V_mI_m$	**Irow9**	$8.6I_m$	$8V_m$	$68.8V_mI_m$
Irow8	$9I_m$	$5V_m$	$45V_mI_m$	**Irow8**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow8**	$8.1I_m$	$9V_m$	**$72.9V_mI_m$**
Irow7	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow7**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow7**	$8.1I_m$	$9V_m$	**$72.9V_mI_m$**
Irow6	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow6**	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow6**	$8.6I_m$	$8V_m$	$68.8V_mI_m$
Irow5	$8.6I_m$	$7V_m$	$50.4V_mI_m$	**Irow5**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow5**	$8.1I_m$	$9V_m$	**$72.9V_mI_m$**
Irow4	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow4**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow4**	$8.1I_m$	$9V_m$	**$72.9V_mI_m$**
Irow3	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow3**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow3**	$8.6I_m$	$8V_m$	$68.8V_mI_m$
Irow2	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow2**	$9I_m$	$5V_m$	$45V_mI_m$	**Irow2**	$8.1I_m$	$9V_m$	**$72.9V_mI_m$**
Irow1	$7.7I_m$	$9V_m$	**$69.3V_mI_m$**	**Irow1**	$9I_m$	$5V_m$	$45V_mI_m$	**Irow1**	$8.1I_m$	$9V_m$	**$72.9V_mI_m$**

Tables 1,2: Calculation tables of current, voltage and power in all rows of the methods mentioned in case 1

Case2:

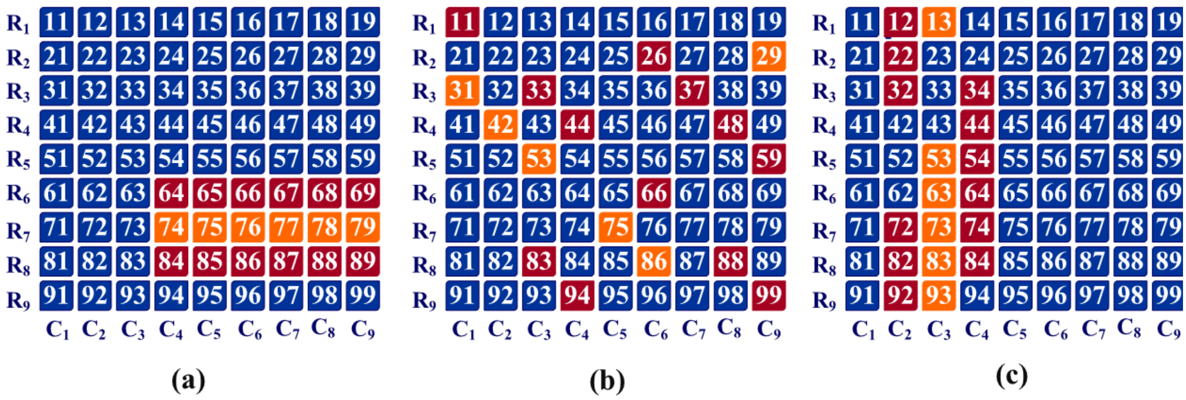


Fig 9. Rearrangement of solar panels using TCT, magic Square and competence Square methods

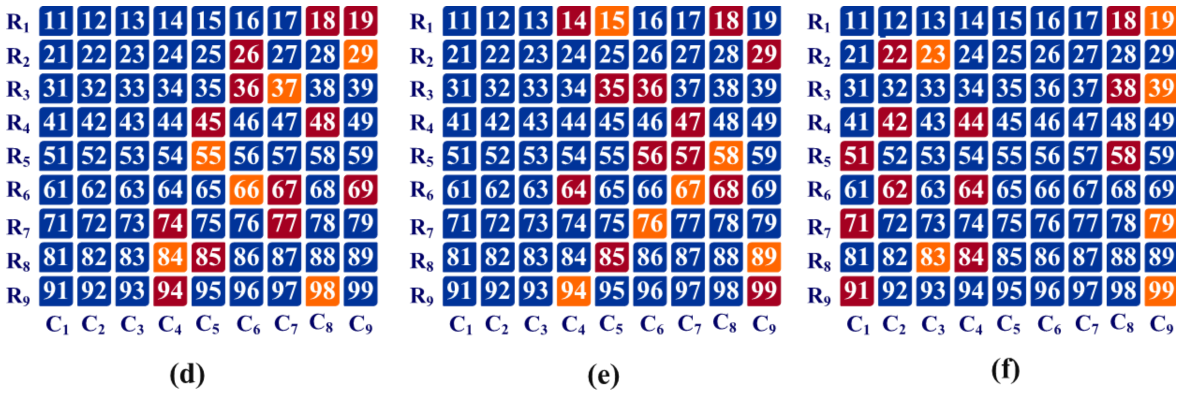
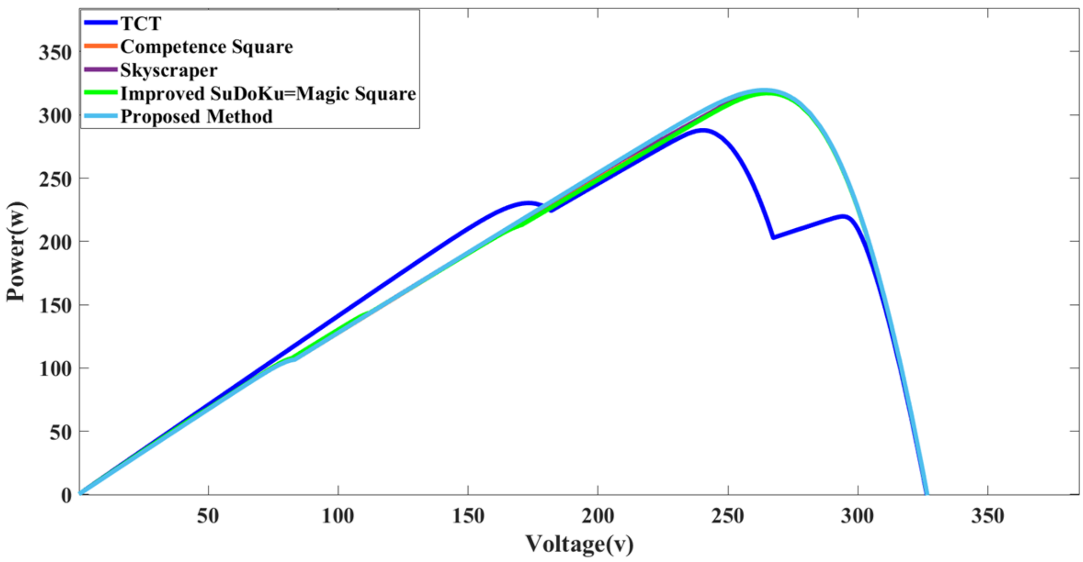


Fig 10. Rearrangement of solar panels using skyscraper, improved Sudoku and Tour puzzle methods



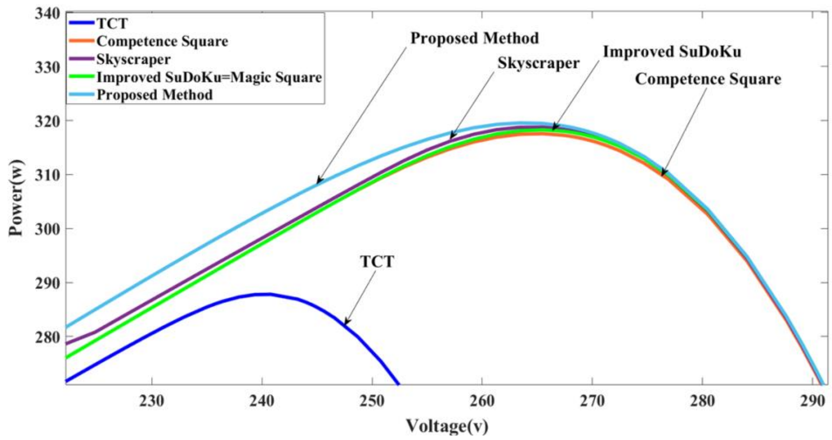


Fig 11. Voltage-power diagram (2)

TCT interconnected				Magic Square puzzle				Competence Square Puzzle			
Row bypassed	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power
Irow9	$9I_m$	$5V_m$	$45V_mI_m$	**Irow9**	$8.6I_m$	$6V_m$	$51.6V_mI_m$	**Irow9**	$8.1I_m$	$8V_m$	$64.8V_mI_m$
Irow8	$7.8I_m$	$8V_m$	$\mathbf{62.4V_mI_m}$	**Irow8**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$	**Irow8**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$
Irow7	$4.8I_m$	$9V_m$	$43.2V_mI_m$	**Irow7**	$8.3I_m$	$7V_m$	$58.1V_mI_m$	**Irow7**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$
Irow6	$7.8I_m$	$8V_m$	$\mathbf{62.4V_mI_m}$	**Irow6**	$8.8I_m$	$5V_m$	$44V_mI_m$	**Irow6**	$8.1I_m$	$8V_m$	$64.8V_mI_m$
Irow5	$9I_m$	$5V_m$	$45V_mI_m$	**Irow5**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow5**	$8.1I_m$	$8V_m$	$64.8V_mI_m$
Irow4	$9I_m$	$5V_m$	$45V_mI_m$	**Irow4**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$	**Irow4**	$8.8I_m$	$6V_m$	$52.8V_mI_m$
Irow3	$9I_m$	$5V_m$	$45V_mI_m$	**Irow3**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$	**Irow3**	$8.6I_m$	$7V_m$	$60.2V_mI_m$
Irow2	$9I_m$	$5V_m$	$45V_mI_m$	**Irow2**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow2**	$8.8I_m$	$6V_m$	$52.8V_mI_m$
Irow1	$9I_m$	$5V_m$	$45V_mI_m$	**Irow1**	$8.8I_m$	$5V_m$	$44V_mI_m$	**Irow1**	$8.1I_m$	$8V_m$	$64.8V_mI_m$

Skyscraper Puzzle				Improved SuDoKu Puzzle				Proposed Method			
Row bypassed	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power	**Row bypassed**	Current	Voltage	Power
Irow9	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow9**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow9**	$8.1I_m$	$9V_m$	$\mathbf{72.9V_mI_m}$
Irow8	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow8**	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow8**	$8.1I_m$	$9V_m$	$\mathbf{72.9V_mI_m}$
Irow7	$8.6I_m$	$6V_m$	$51.6V_mI_m$	**Irow7**	$8.3I_m$	$7V_m$	$58.1V_mI_m$	**Irow7**	$8.1I_m$	$9V_m$	$\mathbf{72.9V_mI_m}$
Irow6	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$	**Irow6**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$	**Irow6**	$8.6I_m$	$8V_m$	$68.8V_mI_m$
Irow5	$8.3I_m$	$7V_m$	$58.1V_mI_m$	**Irow5**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$	**Irow5**	$8.6I_m$	$8V_m$	$68.8V_mI_m$
Irow4	$8.6I_m$	$8V_m$	$51.6V_mI_m$	**Irow4**	$8.8I_m$	$5V_m$	$44V_mI_m$	**Irow4**	$8.1I_m$	$9V_m$	$\mathbf{72.9V_mI_m}$
Irow3	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow3**	$8.6I_m$	$6V_m$	$51.6V_mI_m$	**Irow3**	$8.1I_m$	$9V_m$	$\mathbf{72.9V_mI_m}$
Irow2	$8.1I_m$	$8V_m$	$64.8V_mI_m$	**Irow2**	$8.8I_m$	$5V_m$	$44V_mI_m$	**Irow2**	$8.1I_m$	$9V_m$	$\mathbf{72.9V_mI_m}$
Irow1	$8.6I_m$	$6V_m$	$51.6V_mI_m$	**Irow1**	$7.9I_m$	$9V_m$	$\mathbf{71.1V_mI_m}$	**Irow1**	$8.1I_m$	$9V_m$	$\mathbf{72.9V_mI_m}$

Tables 3,4: Calculation tables of current, voltage and power in all rows of the methods mentioned in case 2.

CONCLUSION

Various studies have been conducted in this survey. From the literature review, it can be concluded that short narrow wide, long narrow, and long wide are the most common shading patterns used for analysis. The tour puzzle method shows superiority over other static reconfiguration methods by moving panels in rows. In order to demonstrate a comparative method in each case, the TCT connection model and other conventional methods such as magic Square puzzle, competence Square puzzle, Skyscraper and improved Sudoku to extract the maximum power. However, the use of puzzle tour technique for real-world PV arrays can play an important role in reducing partial shading losses and generating maximum power from PV arrays.

REFERENCES

1. Fang, X., & Yang, Q. (2024). Dynamic reconfiguration of photovoltaic array for minimizing mismatch loss. Renewable and Sustainable Energy Reviews, 191, 114160.
2. Krishna, G. S., & Moger, T. (2019). Improved SuDoKu reconfiguration technique for total-cross-tied PV array to enhance maximum power under partial shading conditions. Renewable and Sustainable Energy Reviews, 109, 333-348.
3. Mirza, Z. T., Anderson, T., Seadon, J., & Brent, A. (2024). A thematic analysis of the factors that influence the development of a renewable energy policy. Renewable Energy Focus, 100562.
4. Gonzalo, A. P., Marugán, A. P., & Márquez, F. P. G. (2019). A review of the application performances of concentrated solar power systems. Applied Energy, 255, 113893.
5. Rezazadeh, S., Moradzadeh, A., Pourhossein, K., Akrami, M., Mohammadi-Ivatloo, B., & Anvari-Moghaddam, A. (2022). Photovoltaic array reconfiguration under partial shading conditions for maximum power extraction: A state-of-the-art review and new solution method. Energy Conversion and Management, 258, 115468.
6. Kadhim, N. A., Obed, A. A., Abid, A. J., Kotb, H., & Emara, A. (2024). Optimal PV Reconfiguration Under Partial Shading Based on White Shark Optimization. IEEE Access.
7. Rezazadeh, S., Moradzadeh, A., Hashemzadeh, S. M., Pourhossein, K., Mohammadi-Ivatloo, B., & Hosseini, S. H. (2021). A novel prime numbers-based PV array reconfiguration solution to produce maximum energy under partial shade conditions. Sustainable Energy Technologies and Assessments, 47, 101498.
8. Ajmal, A. M., Babu, T. S., Ramachandaramurthy, V. K., Yousri, D., & Ekanayake, J. B. (2020). Static and dynamic reconfiguration approaches for mitigation of partial shading influence in photovoltaic arrays. Sustainable Energy Technologies and Assessments, 40, 100738.
9. Rezazadeh, S., Moradzadeh, A., Pourhossein, K., Akrami, M., Mohammadi-Ivatloo, B., & Anvari-Moghaddam, A. (2022). Photovoltaic array reconfiguration under partial shading conditions for maximum power extraction: A state-of-the-art review and new solution method. Energy Conversion and Management, 258, 115468.
10. Lal, P., Alavalapati, J. R., & Mercer, E. D. (2011). Socio-economic impacts of climate change on rural United States. Mitigation and Adaptation Strategies for Global Change, 16, 819-844.
11. Masson, V., Bonhomme, M., Salagnac, J. L., Briottet, X., & Lemonsu, A. (2014). Solar panels reduce both global warming and urban heat island. Frontiers in Environmental Science, 2, 14.
12. Li, X., He, Z., Xia, S., & Yang, Y. (2024). Greenness change associated with construction and operation of photovoltaic solar energy in China. Renewable Energy, 120461.
13. Krishna, G. S., & Moger, T. (2019). Reconfiguration strategies for reducing partial shading effects in photovoltaic arrays: State of the art. Solar Energy, 182, 429-452.
14. La Manna, D., Vigni, V. L., Sanseverino, E. R., Di Dio, V., & Romano, P. (2014). Reconfigurable electrical interconnection strategies for photovoltaic arrays: A review. Renewable and Sustainable Energy Reviews, 33, 412-426.
15. Matam, M., Barry, V. R., & Govind, A. R. (2018). Optimized Reconfigurable PV array based Photovoltaic water-pumping system. Solar Energy, 170, 1063-1073.
16. Amano, K., Kojima, Y., Kurabayashi, T., Kurihara, K., Nakamura, M., Omi, A., ... & Yamazaki, K. (2012). How to solve the torus puzzle. Algorithms, 5(1), 18-29.