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Assessing the Influence of Shading Patterns on Solar PV Panel Efficiency

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Solar energy is increasingly recognized as a key source of renewable energy, driving ongoing research into optimizing its efficiency and minimizing power generation losses. This study investigates the performance of multiple solar PV panel configurations, examining various strategies that prioritize efficiency, power output, and loss reduction. Among the configurations evaluated are Total Cross Tied (T-C-T), Series Parallel (S-P), Physical Relocation of Modules with Fixed Electrical Connections (PRM-FEC), and a novel Sudoku-inspired arrangement. The analysis is conducted using MATLAB/SIMULINK to provide a detailed examination of each configuration's impact on parameters such as output power, mismatch losses (ML), fill factor (FF), and overall efficiency. Simulation techniques are employed to explore functionality and effectiveness of these configurations. The findings of this research aim to advance the efficiency of solar power systems, aligning with the global shift toward sustainable energy sources. Additionally, the paper introduces an innovative approach to enhancing photovoltaic (PV) system efficiency through a unique Sudoku-based shading configuration. By arranging the PV panels in a pattern inspired by Sudoku, this method seeks to reduce shading effects and boost system performance.

Keywords: Mismatch Losses, PRM-FEC, PV panels, Sudoku-based shading, T-C-T.

1. Introduction

The demand for efficient power supply is increasing exponentially with the growth of technology, leading to a rise in the generation of renewable energy globally presented by K. [1-4]. Solar photovoltaic (PV) panels are becoming an increasingly popular choice for generating electricity from renewable sources by [1-8]). They are easy to install and maintain, and they provide a sustainable and cost-effective way to generate power by [9-11]. However, when it comes to shading, the configuration of the panels can make a big difference in their performance. Shading can occur in various ways, such as due to trees, buildings, or other obstructions. When a solar panel is partially shaded, it can lead to a reduction in power output given by [12-13]. This is because solar panels are made up of many cells that are connected in series, and when even one of these cells is shaded, it can cause a drop-in voltage and current output. In terms of the physical arrangement of solar panels, they can be installed on rooftops or on the ground, depending on available space and other factors by A. S. Ahmadzai [14-15]. The angle and orientation of the solar panels can also affect their performance, and adjustments can be made to optimise energy production. Overall, solar PV panel configuration is an important aspect of designing and installing a solar power system, and there are many options available to meet different energy needs and preferences.

Design and optimization of photovoltaic (PV) systems under shaded conditions have been extensively studied in the literature. Several researchers have investigated the performance of shaded PV systems and proposed various optimization techniques to improve their efficiency. In this regard, Hajimiragha [16] discussed the design and performance of shaded PV systems, while Bhatti et al. [17] focused on modelling and optimization of these systems. Phattanasak and Manzoor et al. [18-19] presented studies on the optimum configuration of partially shaded PV panels and shading effect on energy yield of PV arrays, respectively. Yaghoubi and Alavi [20] and Ajami et al. [21] investigated the shading analysis and optimization of solar PV systems and optimal configuration of PV panels in shaded conditions using particle swarm optimization, respectively. Wang et al. [22] also presented a study on shading analysis and optimal configuration for photovoltaic panels, while El-Dessouky and Sharaf [23] proposed an optimal configuration of PV modules in partially shaded conditions for maximum power point tracking. Furthermore, Zhang, Musavi et al., Hossain et al. and Zhu and Wu [24-27] presented studies on the optimal configuration of shaded PV systems based on improved particle swarm optimization, maximising the energy yield of a solar. This paper investigates performance of photovoltaic systems under conditions of partial shading hybrid optimization algorithm for optimal configuration of photovoltaic modules in partially shaded conditions, and an improved method for optimal configuration of PV modules in shaded conditions, respectively.

In addition, Authors discussed a adjective study of different solar panel configurations in partial shading [28-29], while lokesh et al. (2017) proposed an optimal photovoltaic module configuration for maximum power generation under shaded conditions[30]. In this paper [31-36] Presented the different application of photovoltaic system.

2. PV MODULE MODELLING

PV module modelling is the process of simulating the behaviour of a photovoltaic module under different operating conditions. This includes understanding the performance of the module under varying levels of irradiance, temperature, and load conditions. The most common approach to PV module modelling is to use mathematical models that describe the physical behaviour of the module. These models use a set of equations that take into account various factors that affect performance of the module, such as properties of semiconductor materials used in the module, the angle and orientation of the module, and the spectral content of the sunlight (Fig.1).

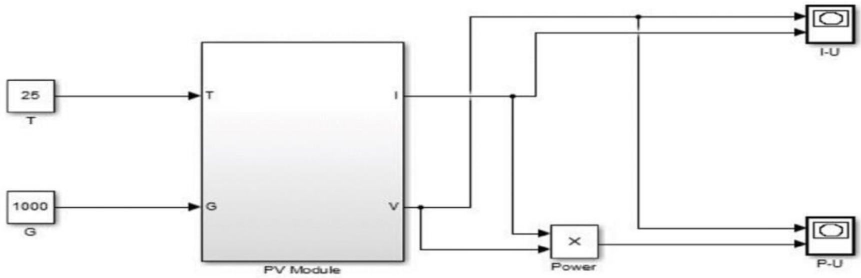

Fig.1: represents the PV module modelling in MATLAB Simulink.

Photo current:

Jph = Jsc + KI (T - To)/1000 G………………………………………………………… (1)

Where, the context of photovoltaic (PV) cells, Jsc refers to short-circuit current density in units of A/cm^2 at reference conditions shown in Equation 1. These conditions usually correspond to standard test conditions (STC), which entail an irradiance of 1000 W/m^2, cell temperature of 25°C, and air mass of 1.5. KI represents short-circuit current temperature coefficient, which is typically around -0.3%/°C for crystalline silicon PV cells. T refers to operating temperature of the cell in degrees Celsius, while to denotes the reference temperature of 25°C. Finally, G represents irradiance in units of W/m^2.

Saturation current:

Io = Irs * (T/Tn)^3 * e^(qVd/kT)…………………………………………………………(2)

Where, the context of diode analysis, Io represents the reverse saturation current. Irs denotes reverse saturation current at a reference temperature Tn shown in Equation 2. T refers to temperature in Kelvin. Q represents elementary charge, Vd is the voltage across the diode, and K denotes Boltzmann constant.

Reverse saturation current:

Irs = Isc / e^(q * Voc / kT)……………………………………………………………….(3)

Where, the context of diode analysis, IRS refers to the reverse saturation current, ISC is short-circuit current of diode, and VOC is open-circuit voltage of diode shown in Equation 3. T denotes the temperature in Kelvin.

Current through shunt resistor:

In the context of shunt resistors, Ish denotes the current flowing through the resistor, while V refers to the voltage across the load that is connected in parallel with the shunt resistor. IRs represents voltage drop across shunt resistor that results from the current flowing through it (Ish). Finally, Rsh denotes the resistance of shunt resistor.

Output current:

I = Iph - Io*[exp((q*(V+IR))/(nkT))-1] …………………………………………………. (4)

Where, the context of solar cells, I represent the output current of the cell, while Iph denotes the photocurrent generated by the cell due to incident light shown in Equation 4. Io refers to the reverse saturation current of the cell, which represents the current that flows in the absence of light. Q represents elementary charge, V is voltage across cell, and IR represents current flowing through an external load resistor connected to cell. Here, n is ideality factor that considers non-ideal behaviour of the cell.

One of the most widely used PV module models is the single-diode model, which uses a single diode to represent the electrical behaviour of the module. This model is relatively simple and can be used to predict current-voltage characteristics of module under different condition. V module modelling is a crucial step in designing and optimising photovoltaic systems, and mathematical models are commonly used to simulate the behaviour of the modules.

By understanding the performance of the module under different conditions, engineers and designers can optimise the design of the system and predict its energy output. PV module modelling is important for designing and optimising PV systems, as it allows engineers and designers to predict the performance of system under different operating conditions. This information can be used to optimise design of system, choose the most appropriate modules, and predict the energy output of the system.

Other models, such as the double-diode model, take into account more complex behaviour such as the effects of recombination and shunt resistance. These models are more complex but can provide more accurate predictions of module performance.

Module rating for modelling in Simulink:

Table 1. Specification of PV module

Rated power (W)	200
Voltage at maximum power (V)	26.4
Current at maximum power (A)	7.58
Open circuit voltage (V)	32.9
Short circuit current (A)	8.21
Total number of cells in series (Ns)	54
Total number of cells in parallel (Np)	1

Equation used for PV module modelling:

$$\mathrm{Io} = \mathrm{Irs} * \left(\frac{\mathrm{T}}{\mathrm{Tn}}\right)^3 * \exp\left(\mathrm{q} * \mathrm{Eg} * \frac{\frac{1}{\mathrm{Tn}} - \frac{1}{\mathrm{T}}}{\mathrm{n} * \mathrm{K}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

In the given Equation 5, Io refers to the reverse saturation current of the module at a specific temperature. Io_ref denotes the reference reverse saturation current at a reference temperature, while T represents the actual temperature of the module. Tn typically refers to the nominal temperature of 25°C. Q represents electronic charge, Eg is bandgap energy of the semiconductor material, and k_B denotes the Boltzmann constant. Finally, the term 'exp' refers to the exponential function.

Power losses for Photovoltaic array:

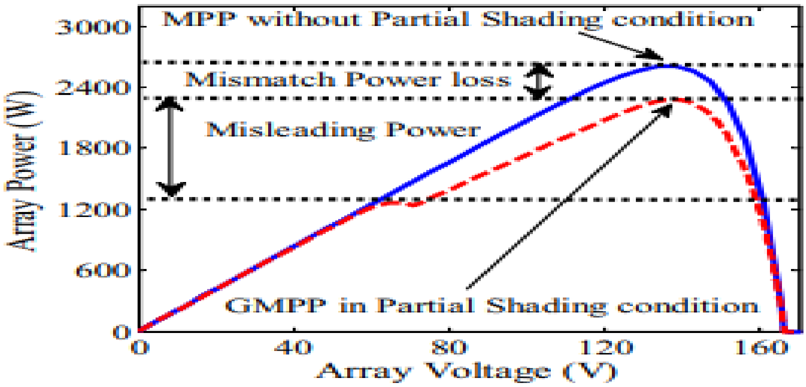

Fig.2: Power Losses for photovoltaic array

After simulation in MATLAB we can see the IV cure and PV curve (Fig.2, Fig.3 & Fig.4).

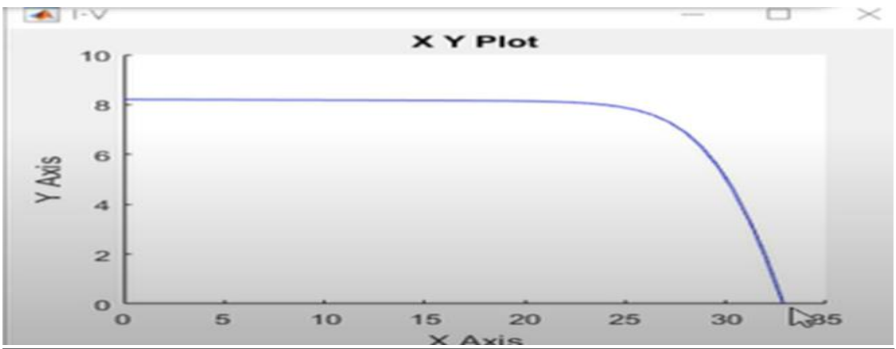

Fig.3: I-V curve

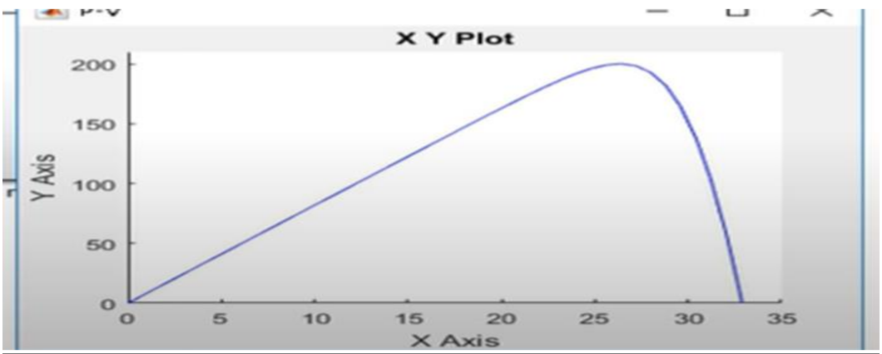

Fig.4:P-V curve

3. SHADOW CHARACTERISTICS

Shadowing is a common problem in solar PV systems, as even partial shading can significantly reduce power output of system. Shadowing can be caused by various factors, including trees, buildings, and other obstructions. Configuration of solar PV panels can also affect impact of shading on system (Fig.5).

One of the key factors affecting shadow characteristics is tilt angle of the solar panels. Tilt angle determines orientation of panels relative to sun, and can significantly affect the amount of shading that occurs. Panels that are mounted flat on a roof or ground-mounted at a low angle are more susceptible to shading, as even small obstructions can cast shadows across a large portion of the panel.

In addition to the tilt angle and spacing, the shading characteristics of solar PV panels can also be affected by the use of bypass diodes. Bypass diodes are electronic components that can help to minimise impact of shading on overall performance of system. When a panel is shaded, the bypass diode allows current to flow around the shaded cells, which can help to maintain the overall power output of the system.

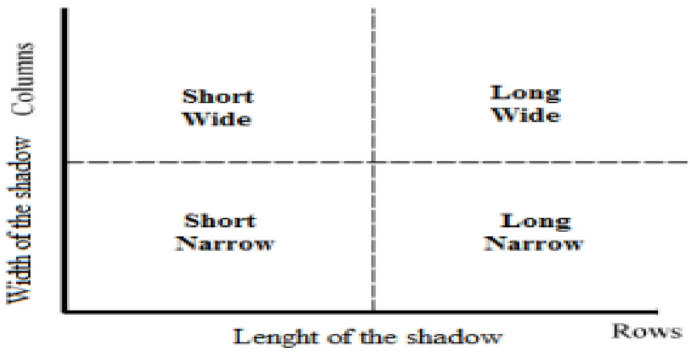

Fig.5: Shading Pattern Types

To minimise the impact of shading on solar PV systems, it is important to carefully consider configuration of the panels, including tilt angle, spacing, and use of bypass diodes.

By selecting the right configuration for your particular application, you can help to ensure that your solar PV system operates at maximum efficiency and produces the desired amount of electrical power.

4. COMPARISON GRAPH

Efficiency, current, miss match losses, fill factor, power& voltage of various Sudoku-based shading configuration under different shading pattern shown in Fig.6.

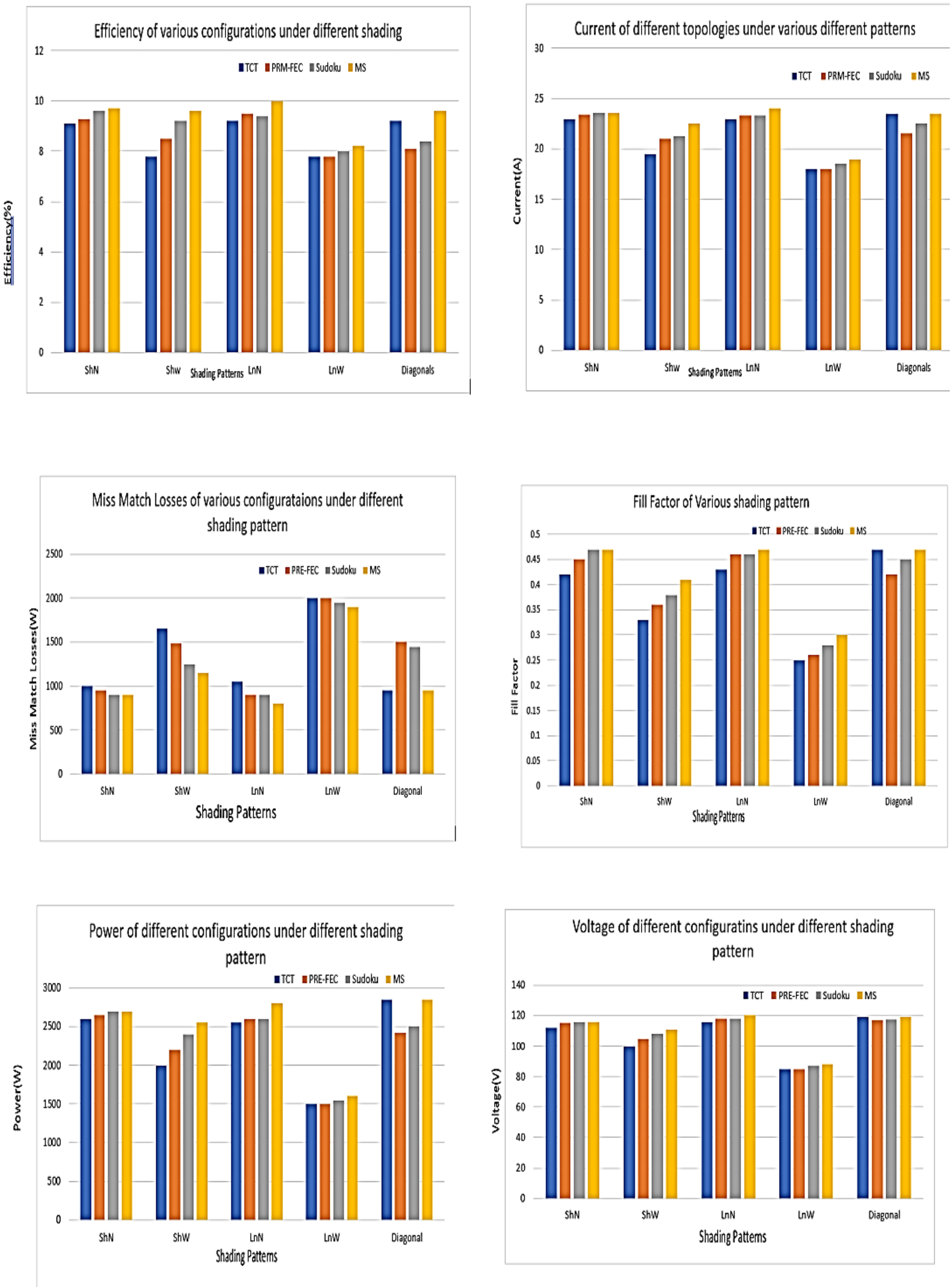

Fig.5: Efficiency, current, miss match losses, fill factor, power& voltage of various Sudoku-based shading configuration

5. CONCLUSION

The study examined and analysed the performance of 5x5 arrays using various configurations, including TCT, PRM-FEC, SuDoKu, and MS, through MATLAB/SIMULINK simulations. The analysis focused on current, voltage, power, ML, FF, and efficiency as the main performance parameters.

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