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Enhancing Grid-Connected PV Efficiency with Beta MPPT under various weather conditions

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Abstract: Photovoltaic (PV) systems are progressively integrated into the electricity grid, allowing households to generate renewable energy and contribute excess power to the network. A key challenge in optimizing these systems lies in maximizing the output voltage and implementing effective Maximum Power Point Tracking (MPPT) techniques to ensure solar panels operate at their highest efficiency under varying sunlight conditions. This paper focuses on evaluating the performance of two MPPT methods: Perturb and Observe (P&O) and the Beta method. Both techniques adjust the duty cycle of a DC/DC converter to maintain optimal power extraction for the Grid. Through a comprehensive analysis of current, voltage, and power outputs, we assess which method best meets criteria such as tracking accuracy, dynamic performance, and stability. The results indicate that the Beta MPPT method excels over the P&O approach, particularly in terms of quick response and reduced oscillations, even during rapid changes in irradiation

Keywords: Photovoltaic (PV) system, DC/DC Converter, grid-connected, Beta approach, Partial Shading.

1. Introduction

To solve the environmental and health problems linked with traditional energy sources, as well as to fulfil the increasing need for energy, renewable energy sources are being used more and more over the globe [1,2]. When it comes to renewable energy sources, photovoltaic (PV) systems are among the most encouraging.

These systems are mostly used as independent power sources or as additional power sources that are connected to the main grid [3]. As solar PV systems have become more popular in homes, businesses, and utility companies, along with falling module costs and government subsidies and incentives, grid-connected PV systems have captured the attention of the government. An issue for the future is energy generation. Industrialised nations' energy demands are on the rise. More energy will be needed by developing nations as they expand. The bulk of the energy that powers our planet comes from fossil fuels. Greenhouse gas emissions and pollution are caused by the use of these sources. When we use up our natural resources too quickly, we leave less power to the generations that come after us [1] .

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Power sources that can be replenished through time include wind, solar, hydroelectric, geothermal, and biomass. Unlike fossil fuels, renewable energy sources never run out of power. Based on the energy source and the value of the recovered energy, renewable energies encompass a specific set of technological industries [4] .

For instance, photovoltaic solar energy allows those who were only ever consumers to become producers of electricity. Each installation is required to connect to the grid Due to the existing policy, this electricity is not to be used but rather integrated into the network.. Up until now, however, the networks have only been built to carry the electricity that is concentrated in large power plants and distribute it to millions of people or companies. Thus, new features and system complexity will be necessitated by this decentralisation of production associated with renewable energies. Problems with this area could significantly slow down the expansion of renewable energy sources unless they are resolved. An increasing number of photovoltaic systems are being linked to the power grid these days [5,6]. With their help, a home can generate some of its own power in an environmentally friendly manner, and then feed any surplus power back into the grid.

A solar power system's annual electricity production could be affected by a number of factors, one of which is the reliability and performance of the static converters utilised to connect the system to the grid. On the other hand, this connection can affect electrical networks in a few ways[7,8]. These include changes to power flows, voltage, protection, and the quality of the energy that is generated.

A number of studies have examined and simulated PV systems that are connected to the grid. From modelling issues [9-11], where the goal is to provide a comprehensive overview and comprehension of the features and methods for the modelling of PV systems that are connected to the grid, to evaluate performance and conduct soft computing [12-17], the topics covered are vast and varied.

Two algorithms that control the duty cycle of DC/DC converters in PV systems connected to the grid are the focus of this research: Beta and Perturb and Observe (P&O). Maximum PowerPoint Tracking is the name of the procedures used. High accuracy, few steady-state variations, rapid dynamic response, and efficient tracking of the Maximum Power Point (MPP) even when irradiation varies rapidly are some of the important performance parameters that will be used to establish the best MPPT algorithm.

To assess how well each method works, comparative research is carried out in Matlab/Simulink. The power, voltage, and current outputs from the photovoltaic systems and converters are measured and shown graphically. In addition, we talk about how PV systems are affected by partial shading.

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This paper is structured into the subsequent sections: Part 2 will centre on the approach that was used and the mathematical modeling of each component of the grid-connected photovoltaic system. Section 3 will go into further detail regarding the application of the MPPT technique that was used. Section 4 presents the results of the simulation and discusses the comparison of grid-connected Photovoltaic systems with MPPT regulators using the Beta and P&O approaches under partial shading. In the last section, we shall provide the conclusions.

2. Methodology

Our goal is to find the peak power that the DC/DC converter linked to the grid can produce by comparing two maximum power point tracking (MPPT) methods, p and o, and a beta approach for managing the duty cycle. A comprehensive representation of the methods employed is shown in Figure 1.

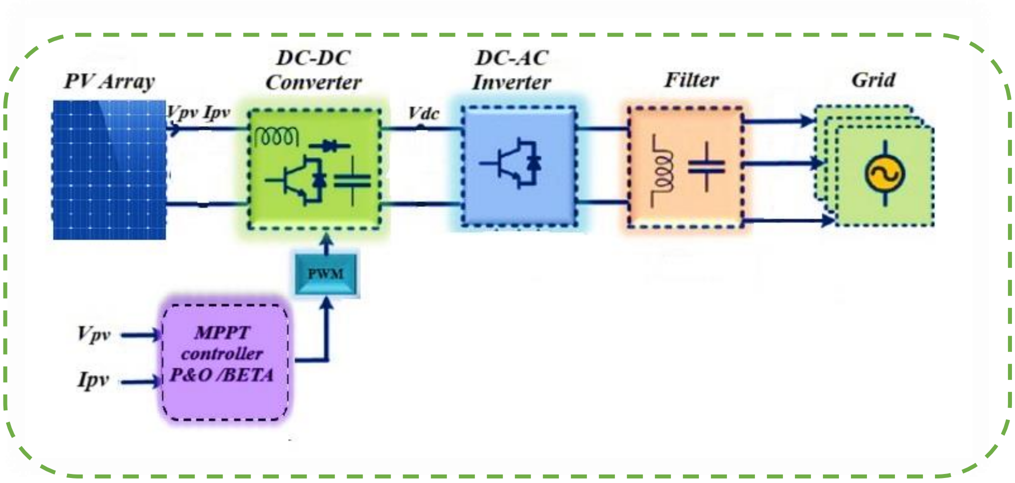

Fig.1: Methodology diagram

3. Methods Modelling of Grid-Connected Photovoltaic Systems

3.1 *The PV Module:*

Semi-conducting materials are utilised in photovoltaic panels, which are apparatuses that convert light into energy. The circuit of electricity that is equal to a photovoltaic cell that contains two diodes is depicted in Figure 2[18,19].

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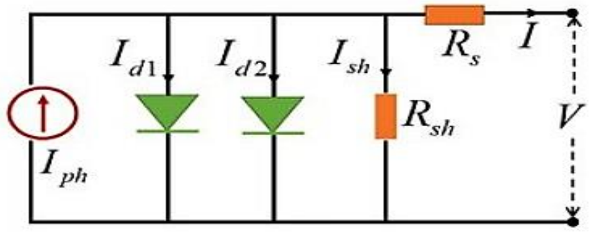

Fig.2: Solar cell model with two diodes.

The current produced by the photovoltaic panel is articulated as [20,21]:

$$I = I_{ph} - I_{d1}\,[\exp\,(\frac{q.(V+R_S\,.\,I)}{n_1.K.T}) - 1] - I_{d2}\,[\exp\,(\frac{q.(V+R_S\,.\,I)}{n_2.K.T}) - 1] - \frac{(V+R_S\,.\,I)}{R_{sh}} \quad (1)$$

where I denotes light; In Kelvin, T stands for the cell temperature. The series resistance is denoted as R_S, whereas the shunt resistance is R_{Sh}. The voltage that was discovered is denoted by V, where K is a constant that equals 1.38 × 10^-23 J/K.

3.2 Boost Converter:

Boost converter is a basic DC/DC converter because its duty cycle may be electronically modified from 0 to 1 to change the transformation ratio. Traditionally linked concepts such as an input signal, an output voltage, and a duty ratio form the basis of its design. we see the output voltage represented by the equation. (1). Its main objective is to maximise power output to the grid utility by directing the PV system to use the maximum power point tracking (MPPT) approach.

$$V_{out} = 1/(1-\alpha) \times V_{in} \quad (2)$$

Where;

V_{in}: An input voltage to the converter

V_{out}: The voltage that the converter receives as its output.

α: The switch's duty cycle 's'

The electrical circuit diagram of the boost converter is presented in Figure 3. [22].

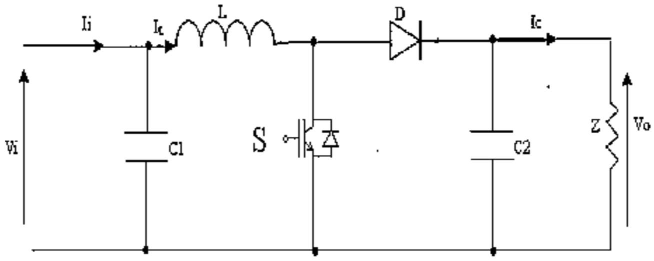

Fig.3: The boost converter.

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DC/DC power switching converters convert Direct Current power into multiple voltage levels in solar power systems. Most maximum power point trackers employ this converter to improve energy conversion.

4. MPPT Techniques

4.1 Perturb and Observe Method:

Solar MPPT often uses the "perturb and observe" strategy. This method involves adjusting the converter's duty cycle and measuring power output. When this happens, the duty cycle drops to MPP. The duty cycle continues at the MPP. The method's simplicity and ability to maximize solar power gathering in all weather situations make it popular. However, the P&O approach is susceptible to fluctuations and stable-state inaccuracies in rapidly changing irradiation and cannot monitor the MPP while partially shaded. [23]

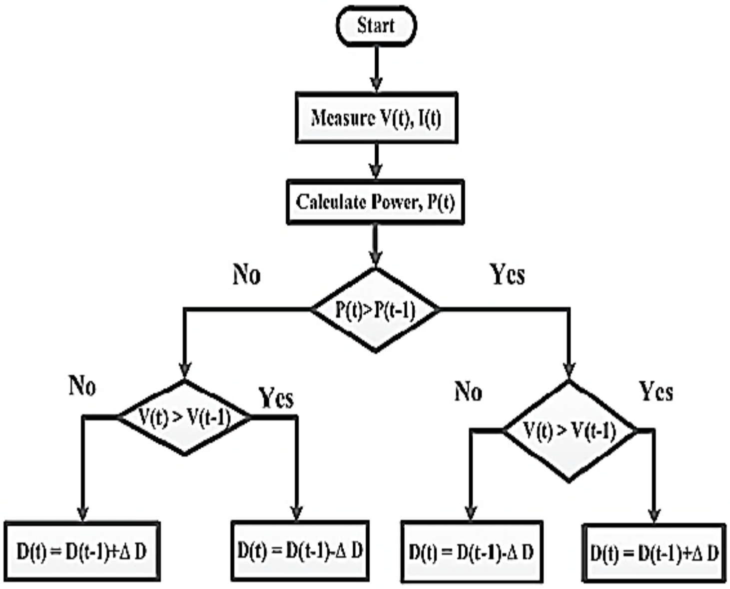

Fig.4: Flowchart of P&O Method.

4.2 Beta Method:

The researchers Jain and Agarwal [24] first proposed the Conventional Beta method. Regardless of a change in power, the basic principle of this method is to keep an intermediate variable β_a under observation. We can represent the intermediate variable β_a. using the equation that follows

$$\beta_a = \ln(I_{pv}/V_{pv}) - c \times V_{pv} \tag{3}$$

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V_{pv} represents the PV module's output voltage, and I_{pv} stands for its output current. The following is the equation for a constant diode c:

$$c = q\ (N_s.A.K.T) \qquad (4)$$

Where:

q: is defined as One electron has a charge of 1.6×10^{-19} C

K : represents 1.38×10^{-23} J/K. for Boltzmann fixed value

A : A diode's ideality factor

N_s : Amount of cells in PV module.

T: The temperature of the p-n junction (measured in Kelvin).

Two phases make up the Beta technique; one is transitional, and the other is steady-state. Both phases react to different-sized steps. To apply the Beta technique, first identify the range of β_{min} and β_{max} before calculating β_g itself. Start by measuring a PV module's voltage and current outputs and continually calculating its values. Use the P&O approach when β_a is between β_{min} and β_{max} in the Beta method to achieve the stable state phase. The Beta approach uses a guiding parameter β_g to calculate the variable step size "ΔD" in the transient stage [24].

$$\Delta D = N \times (\beta_a - \beta_g) \qquad (5)$$

The range of parameters β_{min} β_{max} and the parameter β_g are all determined by the scaling factor N. The temperature and irradiance, which are exterior factors of the PV module, determine the range of β. [25]

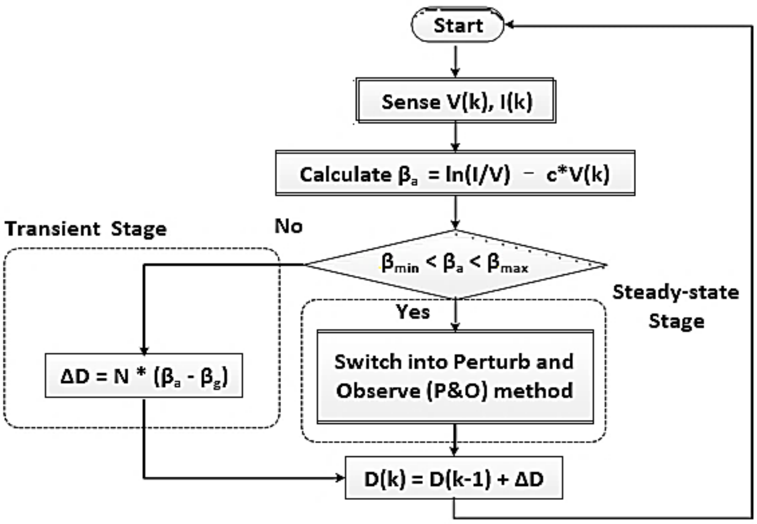

Fig.5: Flowchart of Conventional Beta Method.

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5. Results and Discussion

There are 330 modules in the PV array, all linked in series-parallel, and each one is a sunPowerSPR-305E-WHT-D. Providing 100 kilowatts of electricity, this array serves as a power source.

Furthermore, a boost converter is employed, which has a 500V output voltage.

We want to put several MPPT algorithms to the test to see how much power grid-connected PV systems can produce. The MATLAB/Simulink program is used to run the simulation. To determine the optimal technique, we compare the two regularly employed MPPT algorithms, p and o, and the beta method, under both clear and partially cloudy skies. We will provide the components used for simulation in the following. Initially, we utilised a photovoltaic (PV) array consisting of 66 parallel strings, with 5 modules linked in series for each string.

Figure 6 displays the I-V and P-V characteristics of the panel. Our plotted features for various irradiation values are shown in this figure.

In accordance with STC, the following are the module specifications: [64.2v, 5.96A, 54.7v, 5.58A]. With regard to one module, the model parameters are as follows: [R_S, R_p, I_{sat}, I_{ph}, Q_d] are [0.037998Ω, 993.51Ω, 1.1753e-08A, 5.6902A, 1.3] in that order.

We have also made use of a boost converter, which generates the duty cycle through the use of MPPT techniques. the primary goal is to keep the DC bus voltage (V) at 500V.

To change direct current (DC) voltages into alternating current (AC), VSCs are put to use. In order to convert 500 volts DC into 260 volts AC, it employs a VSC average model. By averaging the AC voltage throughout one switching frequency cycle, the average model treats boost and VSC converters as if they were identical voltage sources.

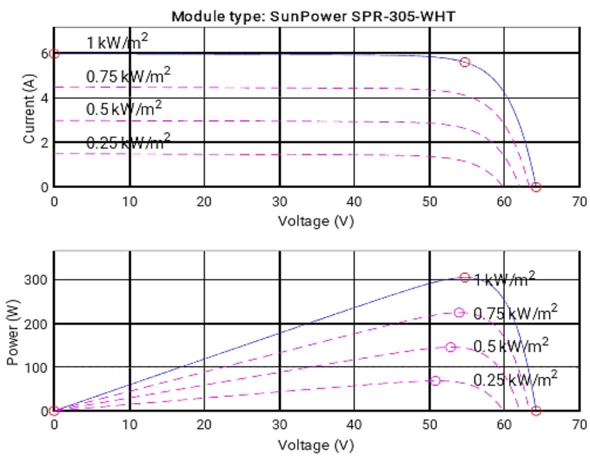

Fig.6: The P-V and I-V The PV module's features. during the 25°C measurement with varying levels of irradiation.

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The electric power grid, seen in Figure 7, consists of distribution feeders operating at 25 kilovolts and a transmission system that is 120 kilovolts equivalent., and is fed by a three-phase coupling transformer with a 400 kVA 260V/25 kV rating.

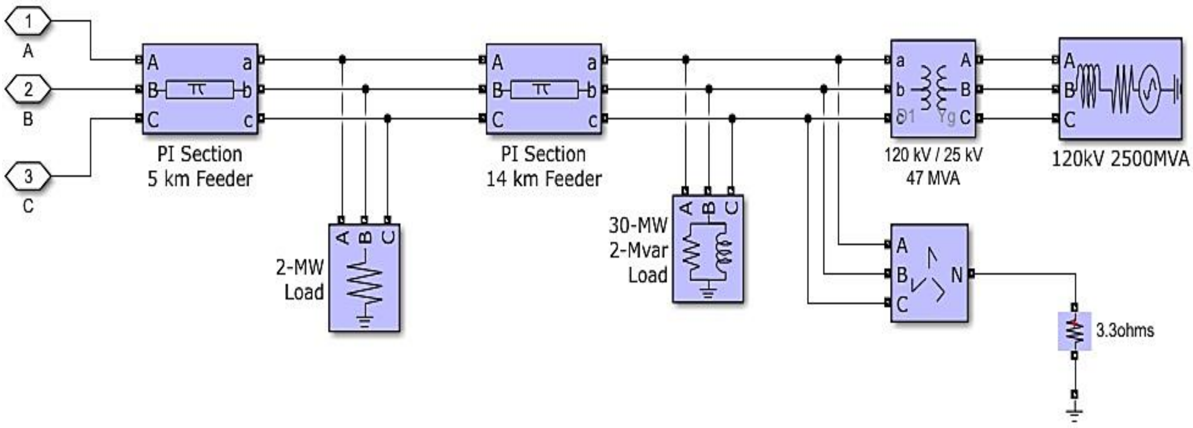

Fig.7: Schematic of the utility grid in use

5.1 Case 1 without shading

Here, we employ a continuous irradiation of 1000 w/m^2 at 25°C.

Additionally, the PV array's response to changes in duty cycle, output power, and voltage is displayed in Figure 8. Here we can observe that the output voltage is 300 V and the constant power is 100 kW. In addition, the p and o MPPT algorithm causes slight oscillations in the duty cycle, which is otherwise nearly identical. The power outputs obtained using the Beta and P&O techniques were 100 kW and 98 kW, respectively. According to the findings, the Beta approach was more efficient than the P&O method. Nevertheless, the P&O approach is susceptible to visible oscillations during transient stages, which can result in power loss and fluctuations. The study found that the Beta MPPT method was the most effective in identifying MPPs. It has the lowest power loss, the maximum tracking accuracy, and the smallest fluctuations during brief periods near the MPP, with the shortest MPP tracking time.

The voltage, current, and output power of the DC/DC boost are displayed in Figure 9. A steady 500 V DC output voltage is produced by the two techniques, demonstrating that the MPPT methods are functioning properly. The conclusions reported before are further supported by comparing the electricity used by the grid.

Figure 10 shows that the beta technique produces the best outcomes. The response time and a few variations are different because of the perturb and observe tracking algorithm

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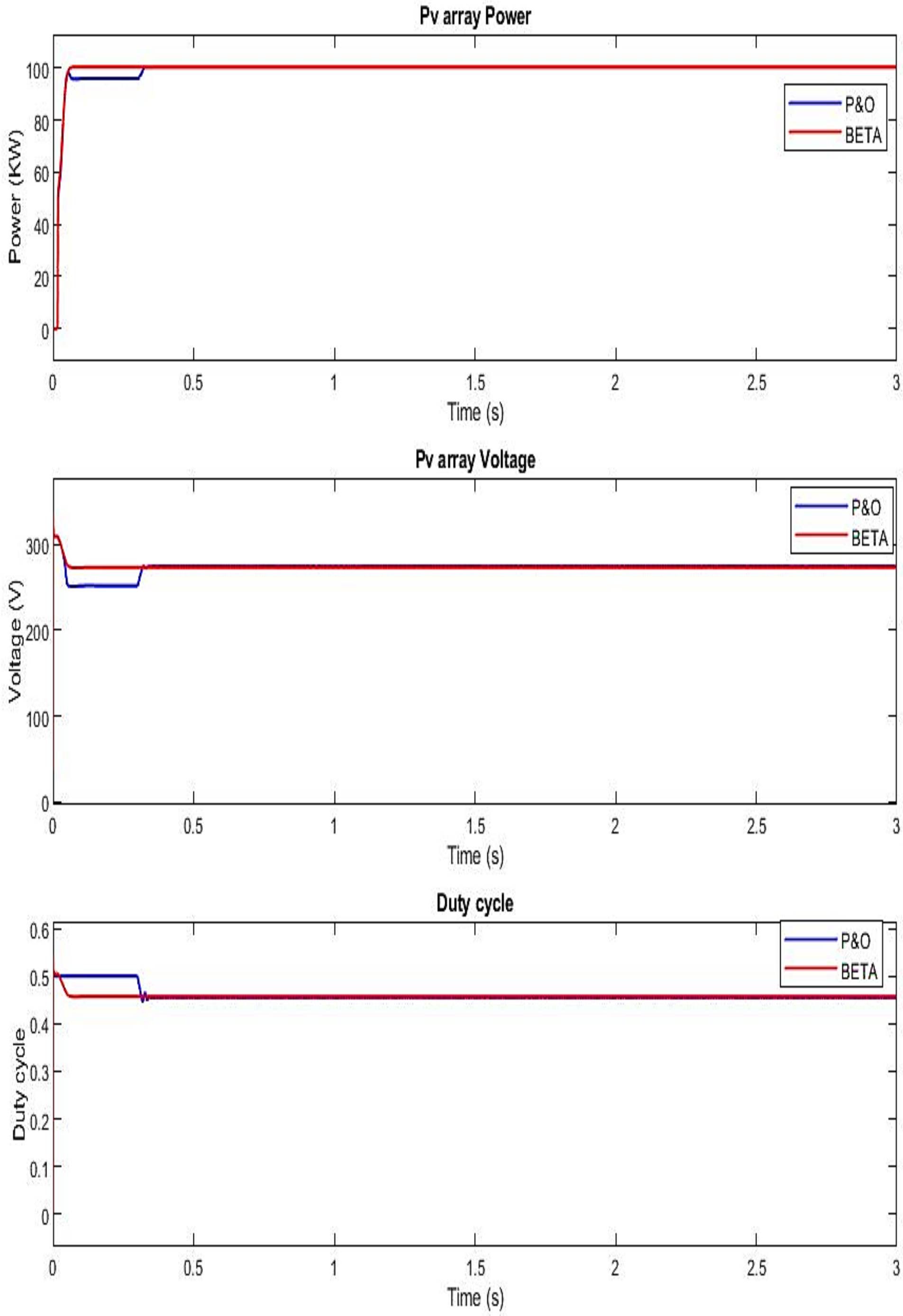

Fig.8: Without shading solar radiation, PV power production, voltage, and duty cycle

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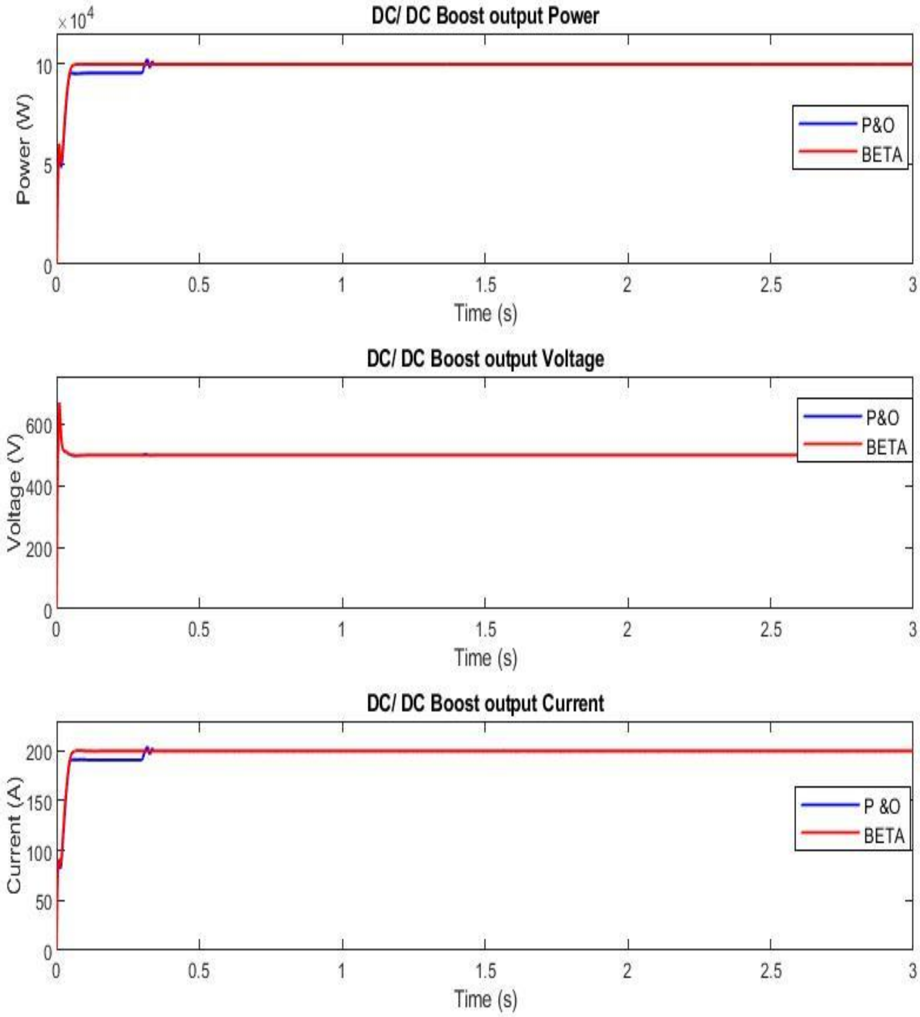

Fig.9: Power output, voltage, and current of the DC/DC converter in shade

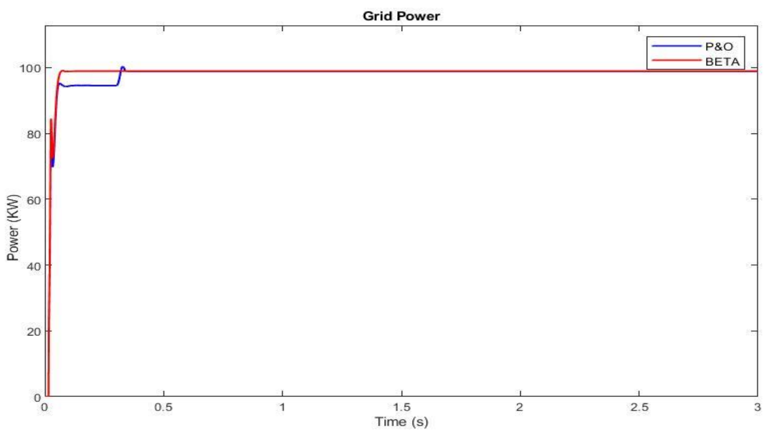

Fig.10: Power generation for the grid in the absence of shading

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5.2 *Case 2: including shading*

Instead of using constant sun irradiation, we have implemented shaded PV arrays here. Figure 11 shows the scenario that is proposed to achieve this goal—the simulation of a discrete shade section—during the course of the simulation. Furthermore, the duty cycle, PV array output voltages, and power are all shown in this picture. The outcomes are consistent with what was seen in scenario 1 when shading was not present. The beta method consistently outperforms the p and o method.

Results from P&O and Beta MPPT techniques during varying irradiance conditions (1000 to 250 W/m²) are shown in Figures 12 and 13, respectively. With the Beta technique, convergence is quicker and there is no overshoot., but both approaches accurately track the MPP in real-time. The P&O approach, on the other hand, shows a large overshoot and large variability close to the MPP. One major issue with the P&O algorithm is how it handles variations in light intensity.

According to Figure 13, which shows the outputs of the boost converters, the MPPT approach is working properly since the DC output voltage remains constant at 500V regardless of the change in irradiation for both methods. The stability of the current and power outputs is best provided by beta, as compared to P and O.

The grid output power shows that the Beta technique delivers the most power in the circumstance of partial shading. The results demonstrate that the Beta algorithm surpasses P&O technique in power extraction, stability, and minimum power oscillations, even in the presence of rapid variations in irradiance (as shown in Figure 14).

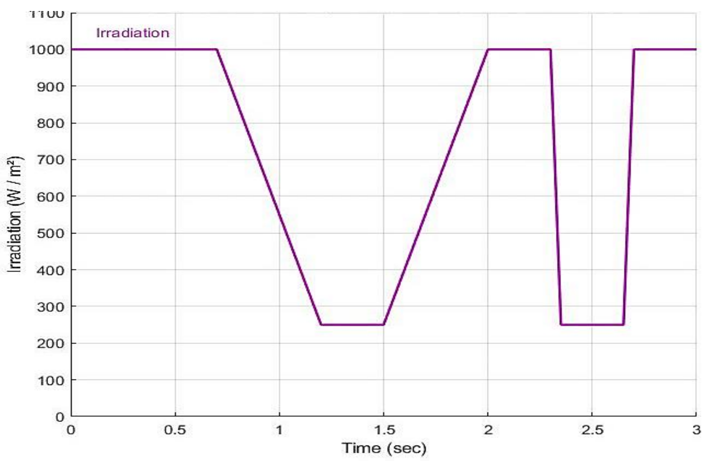

Fig.11: Changing of Radiation

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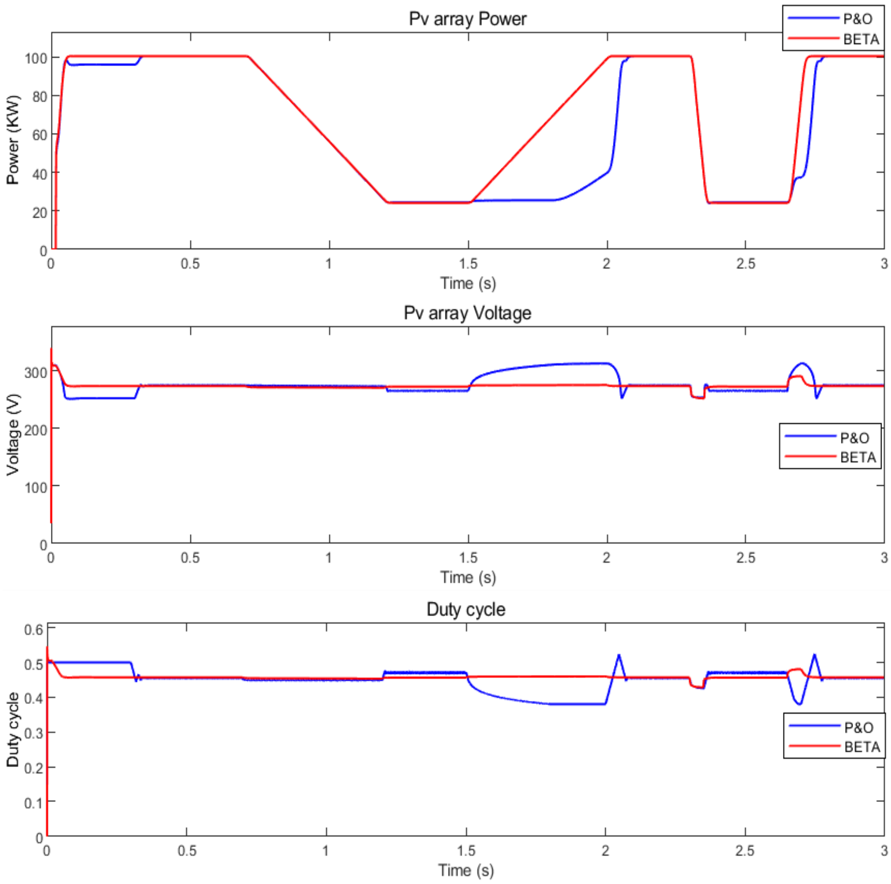

Fig.12: PV power generation, voltage, and duty cycle under abrupt irradiance change

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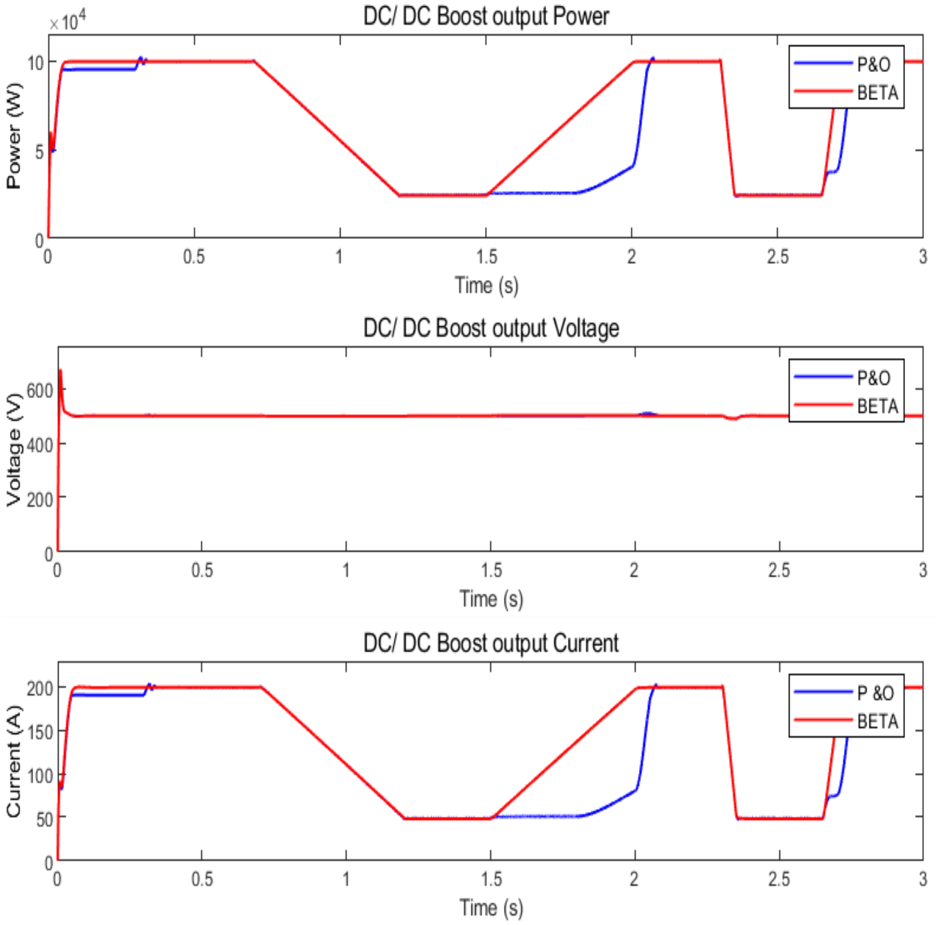

Fig.13: Power, voltage, and current of shaded DC/DC converter

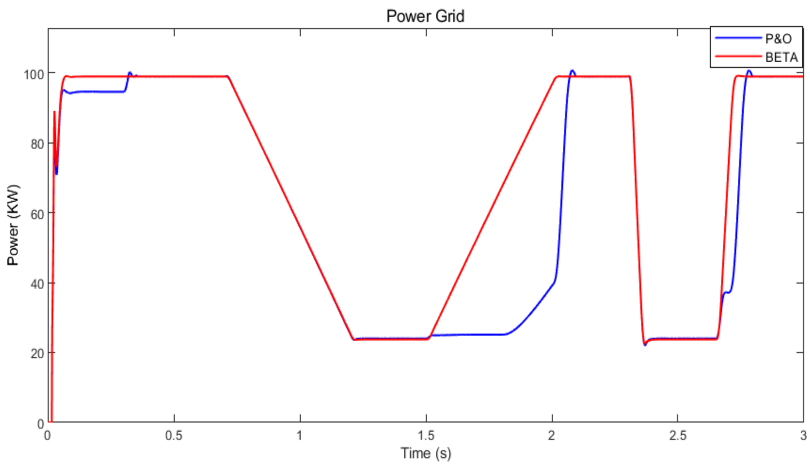

Fig.14: Shaded grid power generation

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6. Conclusion

This study compared the beta approach and P&O algorithm in grid-connected systems to optimise solar panel power extraction. Shade and unshadowed contrast. The results show that BETA is more efficient, accurate, and performs better than p. and o. It oscillates less. Our investigation found that Beta MPPT outperforms P&O. Even when confronted to unexpected irradiation changes, it follows the MPP quickly and with little oscillations, demonstrating its supremacy. Beta MPPT strikes a compromise between computational load, accuracy, steady-state fluctuations, and dynamic responsiveness to avoid previous MPPT difficulties. This suggests its potential utility in real-world PV systems. This research lays the groundwork for a more secure and efficient power conversion mechanism in grid-connected renewable energy systems. The Beta MPPT method is a major advancement in solar energy technology that should improve system reliability and energy gathering.

Solar energy system research and development can help us understand and address solar power grid integration issues, assuring their feasibility and sustainability in varied situations.

Our method considerably improves the efficiency of PV systems operating in partially shadowed conditions, but its constraints must be acknowledged, especially when utilising the beta method. Scaling factor N affects steady-state and transient performance. Environmental considerations greatly affect this factor's performance. Although parameter sweeping is advised for optimisation, it is only useful in particular situations and has limited generalisability. Optimisation does not eliminate steady-state oscillations, indicating further refinement is needed. These limits underscore the necessity for continual progress, especially when adapting the beta method to new environments .Research in the future should be concentrated on adapting this method with algorithms or integrating it with other optimisation methodologies.

Conflict of interest: We know of no conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome. As the corresponding Author, I confirm that the manuscript has been read and approved for submission by all the named authors.

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