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RESEARCH ARTICLE

Enhancing Photovoltaic Conversion Efficiency With Model Predictive Control-Based Sensor-Reduced Maximum Power Point Tracking in Modified SEPIC Converters

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ABSTRACT The objective of this paper is to propose a new technique for maximum power point tracking (MPPT) in photovoltaic (PV) systems that utilizes fewer sensors, thereby reducing the hardware cost. The technique aims to achieve efficient MPPT under various environmental conditions by employing a modified SEPIC converter and a model predictive control (MPC)-based MPPT algorithm. To achieve the objective, the proposed technique utilizes only one voltage sensor and one current sensor, significantly reducing the hardware requirements compared to traditional MPPT techniques. The modified SEPIC converter is employed to regulate the voltage and current levels in the PV system. The MPC-based MPPT algorithm is implemented to dynamically adjust the operation of the converter and track the maximum power point. The algorithm incorporates a model predictive control approach, which utilizes a predictive model of the PV system to anticipate and optimize the power output. The algorithm predicts the behavior of the PV system based on the available sensor measurements, allowing for accurate MPPT. The algorithm operates in real-time, providing instantaneous adjustments to maximize power extraction. The study demonstrates that the proposed technique effectively tracks the maximum power point of the PV system using only one voltage sensor and one current sensor, thus reducing the overall hardware cost. The MPC-based MPPT algorithm, in combination with the modified SEPIC converter, achieves efficient power extraction under various operating conditions. The simulation and experimental results indicate that the proposed technique outperforms traditional MPPT techniques in terms of cost-effectiveness and power extraction efficiency.

INDEX TERMS Model predictive control (MPC)-based MPPT algorithm, modified SEPIC converter, MATLAB simulation and hardware, voltage sensor and current sensor.

I. INTRODUCTION

Photovoltaic (PV) generation has become increasingly popular in recent years as a sustainable and environmentally friendly energy source. By harnessing solar energy and transforming it into electrical power, PV generation has the potential to revolutionize the way we consume energy. One of the key benefits of PV generation is that it is an inexhaustible source of energy. The sun is an abundant source of energy that can meet our electricity needs for an indefinite

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amount of time. Unlike fossil fuels, which are finite and will eventually run out, solar energy is a renewable resource that will be available for billions of years. As a result, generating electricity through photovoltaic systems can provide a sustainable and long-lasting solution to our energy requirements [1], [2], [3], [4]. This makes it an ideal choice for those who are concerned about the impact of their energy consumption on the planet. In addition to its environmental benefits, PV generation also has economic benefits. As the cost of solar panels continues to decrease, PV generation is becoming increasingly affordable. This means that more and more people are able to take advantage of this technology and reduce their energy bills. In addition, PV generation can also provide a source of income for those who generate excess energy and sell it back to the grid. Despite its many benefits, there are still some challenges associated with PV generation. One of the main challenges is that it is dependent on sunlight, which means that it may not be a reliable source of energy in areas with limited sunlight [5], [6], [7].

To optimize the output of a PV panel, it's necessary to utilize a dc/dc converter equipped with maximum-power-point-tracking (MPPT) control. Essentially, the role of the dc/dc converter is to convert the DC power supplied by the PV panel into a higher voltage level that's compatible with the electrical grid [8]. This is achieved by using power electronics to increase the voltage and decrease the current. In addition to voltage conversion, a dc/dc converter also provides isolation between the PV panel and the electrical grid, which is important for safety reasons. It also helps to optimize the energy output of the PV panel by ensuring that it operates at its maximum power point [9]. The use of a dc/dc converter with MPPT control offers several benefits for PV generation systems. These include: 1. Increased Energy Output: By ensuring that the PV panel operates at its MPP, more energy can be generated than would be possible without MPPT control; 2. Improved Efficiency: The use of a dc/dc converter helps to optimize the energy output of the PV panel by increasing the voltage and decreasing the current. This results in less energy being lost as heat, improving overall system efficiency; 3. Greater Flexibility: The use of a dc/dc converter with MPPT control allows for greater flexibility in system design, as it enables PV panels to be connected in series or parallel to achieve the desired voltage and current levels [10].

The maximum power point (MPP) of a PV panel is the point at which it generates the most power for a given set of conditions, such as temperature and irradiance. However, the MPP changes constantly as these conditions change. MPPT control is used to track the MPP of the PV panel and adjust the operating point of the dc/dc converter accordingly. By doing so, it ensures that the PV panel operates at its maximum efficiency, maximizing the amount of energy that can be generated [11], [12].

In the literature, various MPPT techniques are available, among which perturb and observe (P&O), incremental conductance (InCond), ripple current control (RCC), and model predictive control (MPC) are the most prevalent ones. Perturb and observe (P&O) is a widely used and straightforward MPPT technique that involves perturbing the operating point of the photovoltaic (PV) system and observing the resultant change in power output. This technique adjusts the operating voltage of the PV system until the maximum power point (MPP) is reached. Nevertheless, P&O technique has some drawbacks, including oscillations around the MPP and slow tracking speed.

Incremental conductance (InCond) is another widely used MPPT technique that is based on the observation that the slope of the PV system's power versus voltage curve is zero at the MPP. InCond continuously compares the instantaneous conductance of the PV system with its incremental conductance to determine the direction of the MPP. This technique has a faster tracking speed than P&O and can handle rapidly changing irradiance conditions.

Ripple current control (RCC) is a relatively new MPPT technique that uses a high-frequency ripple current to perturb the operating point of the PV system. The technique uses a feedback loop to adjust the ripple current until the MPP is reached. RCC has a fast tracking speed and can handle partial shading conditions.

In [13], a RBFC-based fuzzy logic controller was proposed as a new MPPT controller to extract maximum power from solar PV systems under PSCs. The controller outperformed other conventional and AI-based MPPT controllers in various categories, making it a promising choice for solar PV systems under PSCs.

In [14], a two-step system for PV modules was suggested that uses an enhanced iRCS-MPC method to track the maximum power point (MPP) efficiently. The suggested system improves on the traditional P&O and MPC methods and performs better than the traditional method in terms of overshoot, undershoot, and time required to reach a steady state.

In [15], researchers proposed a metaheuristic algorithm for maximum power point tracking (MPPT) under partial shading conditions. This algorithm effectively reduces the search space exploration and computational complexity of metaheuristic optimization algorithms. Compared to two other recent MPPT algorithms, the proposed algorithm demonstrates superior performance by achieving maximum power point more quickly and with lower power losses during tracking.

Reference [16] describes an adaptive block that estimates solar irradiance and PV I-V curve circuit parameters based on output current and voltage measurements from the PV panel. This algorithm eliminates the need for costly solar irradiance sensors, which are typically required by trackers that rely on measured solar irradiance.

In [17], researchers developed and comparatively analyzed five MPPT controllers for PV systems that utilize artificial intelligence techniques. Among these, the PID-based MPPT controller is notable for its relatively low cost, ease of implementation, good balance between transient state speed and steady state accuracy, and robustness against parameter changes.

In [18], a new ABC based MPPT algorithm for PV systems under partially shaded and dynamic weather conditions was suggested. It has been compared with PSO based MPPT algorithm and simulation results have shown that the suggested ABC-based MPPT algorithm provides better tracking performance to find the global MPP under partially shaded and dynamic weather conditions than PSO-based MPPT algorithm.

Reference [19] proposes a MPPT algorithm for PV systems with DC regulation that is based on the Monod equation. This new algorithm has lower implementation complexity and computational requirements, making it easier and cheaper to implement using low-cost controllers and processors.

Reference [20] introduces a new MPPT technique for PV systems that experience rapidly changing partial shading conditions. This method utilizes a skipping mechanism to avoid certain areas of the search space and a scheduling process to reduce voltage tracking.

In [21], a framework was developed to estimate the remaining useful life of a wind turbine and determine the root cause of any faults using machine learning techniques. The suggested framework was validated through experiments on real-world wind turbine data and showed superiority in terms of accuracy and efficiency.

In [22], a method for detecting and diagnosing faults in wind turbines using machine learning techniques was suggested. The method involves gathering data from various sensors installed on the wind turbine and using it to train a machine learning model. The results of the study show that the suggested method is effective in detecting faults in wind turbines and can help improve their reliability and reduce maintenance costs.

Model predictive control (MPC) is a more advanced MPPT technique that uses a mathematical model of the PV system to predict its behavior under different operating conditions. The technique uses an optimization algorithm to determine the optimal operating point of the PV system that maximizes its power output. MPC has a high tracking accuracy and can handle complex environmental conditions [23].

Model Predictive Control based maximum power point tracking(MPC-MPPT) is a sophisticated MPPT technique that has gained popularity in recent years due to its ability to achieve high tracking accuracy. This technique is particularly effective in controlling the operating point of photovoltaic (PV) panels to track the Maximum Power Point (MPP) [24].

The basic principle behind MPC-MPPT is to predict the future behavior of the PV panel and then use this information to control the operating point of the panel. The prediction is based on a mathematical model of the PV panel that takes into account various parameters such as temperature, irradiance, and panel characteristics. The model is then used to predict the voltage and current that will result in maximum power output from the panel [25].

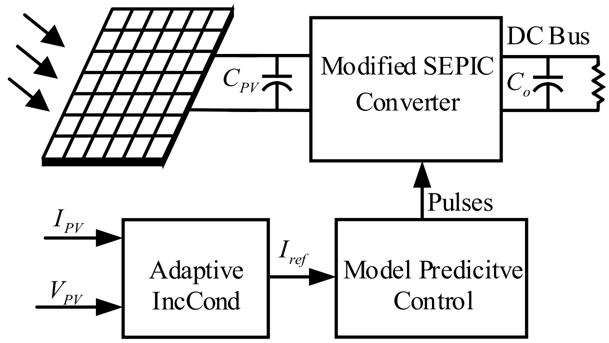

FIGURE 1. The structure of an innovative photovoltaic (PV) generation system incorporates a modified SEPIC converter and utilizes a model predictive control (MPC)-based maximum power point tracking (MPPT) control algorithm.

Once the future behavior of the panel is predicted, the MPC-MPPT controller adjusts the operating point of the panel to track the predicted MPP. This is achieved by continuously adjusting the voltage and current of the panel to maintain the output power at its maximum level. The controller does this by solving an optimization problem that takes into account the predicted behavior of the panel and the desired output power.

One of the advantages of MPC-MPPT over other MPPT techniques is its ability to handle dynamic changes in the environment. For example, if there is a sudden change in irradiance or temperature, the MPC-MPPT controller can quickly adjust the operating point of the panel to track the new MPP. This is because MPC takes into account the future behavior of the panel and can anticipate changes in the environment [26].

This paper contributes a novel model predictive control (MPC)-based maximum power point tracking (MPPT) technique for photovoltaic (PV) systems that utilizes fewer sensors. Figure 1 shows the system structure that is under investigation in this paper. The proposed technique necessitates only one voltage sensor and one current sensor, in contrast to traditional MPC-based MPPT techniques for PV dc/dc converters, which require two voltage sensors and one current sensor. This reduces the overall system's hardware cost. The proposed technique can operate with both fixed and adaptive step sizes and can effectively track the maximum power point under a variety of environmental conditions. A modified SEPIC converter is used in the power stage due to its advantages such as high step-up ratio, high efficiency, and low voltage stresses. The operation principles of the modified SEPIC converter and the MPC-based MPPT technique are explained in detail.

II. MODIFIED SEPIC DC–DC CONVERTER ANALYSIS

Figure 2 shows the structure of a transformerless modified SEPIC converter with high gain, which was proposed in [27]. The converter has two inductors, two diodes, three capacitors, and a single power switch. This paper designs the converter to work in continuous conduction mode. The switch status,

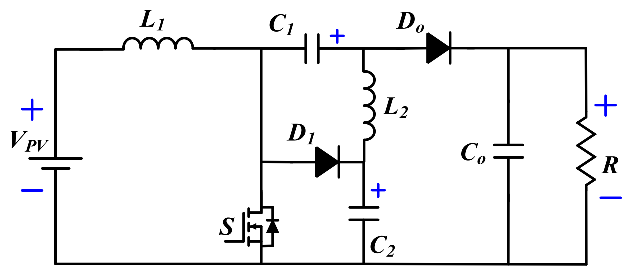

FIGURE 2. Layout of the updated SEPIC Converter [27].

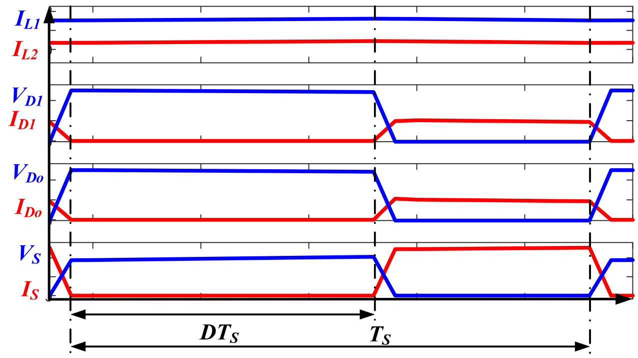

FIGURE 3. Behavior graphs for updated SEPIC converter.

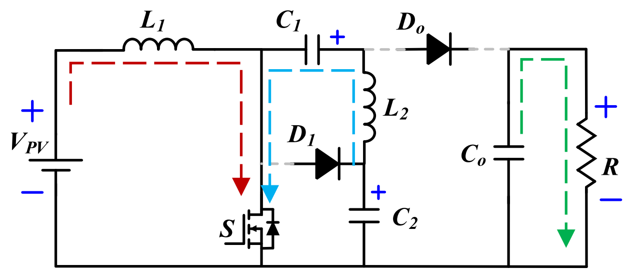

FIGURE 4. Performance assessment of the revised SEPIC converter, Mode I.

S={0 or 1}, determines the two modes of operation of the converter. The following paragraphs explain the operation modes with ideal characteristics of the circuit components. Figure 3 displays the operating waveforms of the converter.

The converter has two modes of operation:

Mode 1: When $S = 0$, the switch is off and the circuit is reconfigured as a boost converter. The input voltage is transferred to the output voltage through the inductors and capacitors.

Mode 2: When $S = 1$, the switch is on and the circuit is reconfigured as a buck converter. The output voltage is transferred to the input voltage through the inductors and capacitors.

The converter can be operated in either mode to achieve the desired output voltage. The choice of mode depends on the specific application. Figure 3 shows the operating waveforms of the converter in Mode 1 and Mode 2. The waveforms show that the converter can achieve a high gain, which is the ratio of the output voltage to the input voltage.

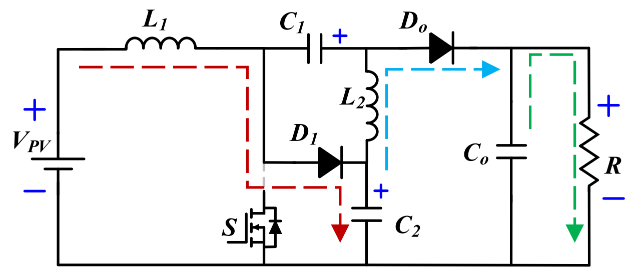

FIGURE 5. Performance assessment of the revised SEPIC converter, Mode II.

A. MODE I

When the switch is triggered by a high pulse signal, it comes on. This is demonstrated in Figure 4, where diodes D_1 and D_2 are off when the switch is on. In this mode, inductor L_1 draws energy from the dc source and inductor L_2 draws energy from capacitor C_2. The equations that represent this mode are:

$$\begin{cases} v_{L1}(\mathrm{t}) = \mathrm{V}_{PV} \\ i_{PV}(\mathrm{t}) = C_{PV}\dfrac{dV_{PV}}{dt} + i_{L1} \\ v_{L2}(\mathrm{t}) = V_{C2} - V_{C1} \\ C_o\dfrac{dV_o}{dt} = i_{Co} = -V_o/R \end{cases} \tag{1}$$

B. MODE II

When the switch is switched off by a low pulse signal, it shuts off. This is Mode II. Fig.5 displays that diodes D_1 and D_2 are on when the switch is off. They allow the inductors to empty their energy. During operation, the energy stored in inductor L_1 is transferred to capacitor C_2, while inductor L_2 delivers its stored energy to the output capacitor. The mathematical equations that define the characteristics of this mode are:

$$\begin{cases} v_{L1}(\mathrm{t}) = \mathrm{V}_{PV} - V_{C2} \\ i_{PV}(\mathrm{t}) = \mathrm{C}_{PV}\dfrac{dV_{PV}}{dt} + i_{L1} \\ v_{L2}(\mathrm{t}) = -\mathrm{V}_{C1} \\ C_o\dfrac{dV_o}{dt} = i_{Co} = i_{L2} - V_o/R \end{cases} \tag{2}$$

C. STEADY STATE ANALYSIS

By utilizing the principles of inductor volt-second balance and capacitor charge-balance, the following results can be obtained:

$$\begin{cases} \langle v_{L1}(\mathrm{t})\rangle = 0 \\ \langle v_{L2}(\mathrm{t})\rangle = 0 \\ \langle i_{Co}(\mathrm{t})\rangle = 0 \end{cases} \tag{3}$$

TABLE 1. Voltage stress on components of the modified SEPIC converter.

Device	Voltage Stress
Switch S	$\frac{V_o}{1+D}$
Diode D1	$\frac{V_o}{1+D}$
Diode Do	$\left(\frac{1-D}{1+D}\right)V_o$

Equations (1)-(3), can be used to derive the relationships among the output voltage, input voltage, and capacitors,

$$V_{C1} = \left(\frac{D}{1-D}\right) V_{PV} \tag{4}$$

$$V_{C2} = \left(\frac{1}{1-D}\right) V_{PV} \tag{5}$$

$$V_o = \left(\frac{1+D}{1-D}\right) V_{PV} \tag{6}$$

The converter's voltage gain is indicated by equation (6), where D signifies the converter's duty cycle. Table 1 illustrates the voltage stress across each switching component. This converter has low voltage stress levels, which permits choosing switching devices with low ratings. Choosing low rating devices is a vital factor in diminishing switching and conduction losses, and thus increasing the system's overall efficiency.

III. AN INNOVATIVE MPC BASED PV MPPT METHOD FOR OPTIMAL POWER TRACKING

Model predictive control (MPC) is an advanced control technique that can be used to control a wide variety of systems. MPC works by using a model of the system to predict its future behavior. The model is used to calculate a control input that will minimize a cost function, which is typically a measure of the error between the system's output and a desired reference. The control input is then applied to the system, and the process repeats.

MPC has several advantages over other control techniques, including:

- MPC can handle systems with multiple state variables.
- MPC can take into account constraints on the system.
- MPC can be used to control systems that are difficult to control with other control techniques.

Here is a more detailed explanation of the steps involved in MPC, see Figure 6:

- Modeling: The first step in MPC is to develop a model of the system to be controlled. The model can be linear or nonlinear, and it can be deterministic or stochastic.
- Prediction: Once the model has been developed, it can be used to predict the system's future behavior. The prediction is typically done over a finite horizon, which is the number of steps into the future that the controller will look.
- Optimization: an optimization problem needs to be solved to obtain the control input that would minimize the cost function. The optimization problem is typically solved using a numerical method, such as the simplex algorithm or the interior point method.
- Control input: The control input that is found in the optimization problem is then applied to the system.
- Repeat: The process then repeats, with the controller using the updated model to predict the system's future behavior, solving the optimization problem to find the control input, and applying the control input to the system.

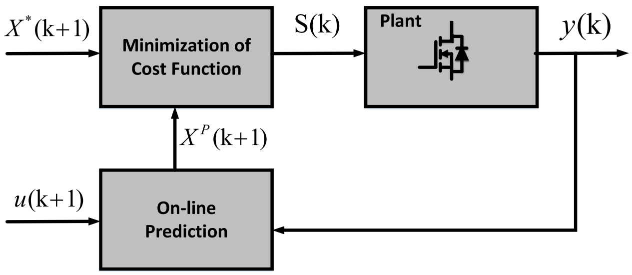

FIGURE 6. Model predictive control block diagram.

TABLE 2. Components main specifications.

Component	Value
DSPACE 12012	Main control device
Ts Sampling time	10 us
Switches type	IRFP27N60KPBF
Diode type	MUR860 — 8 A / 600 V

The modified SEPIC converter's discrete time model is obtained by utilizing the forward Euler method on equation (1) during switch on mode and equation (2) during switch off mode

$$I^1_{PV}(\mathrm{k}+1) = \left(\frac{T_S}{L_1}\right) \mathrm{V}_{PV} - I_{PV}(\mathrm{k}) \tag{7}$$

$$I^0_{PV}(\mathrm{k}+1) = \left(\frac{T_S}{L_1}\right) (V_{PV} - V_{C2}) - I_{PV}(\mathrm{k}) \tag{8}$$

Here T_s, L, V_{PV}, $I_{PV}(K)$, V_{C2}, V_{PV}, $I^0_{PV}\ (k+1)$, $I^1_{PV}\ (k+1)$ stand for sampling time, inductance, PV current and voltage, capacitor C2 voltage, and predicted PV current with switch off and on conditions, respectively. Equations (7) and (8) show that three sensors are needed to estimate the next PV current value. This adds to the system cost and size. To eliminate one voltage sensor, equation (5) is used to substitute the value of V_{C2}. This way, one sensor is saved.

The final step in model predictive control (MPC) is to find the control input that minimizes the error between the actual and desired system states. This is done by solving an optimization problem, which minimizes a cost function. The cost function is typically a quadratic function that penalizes

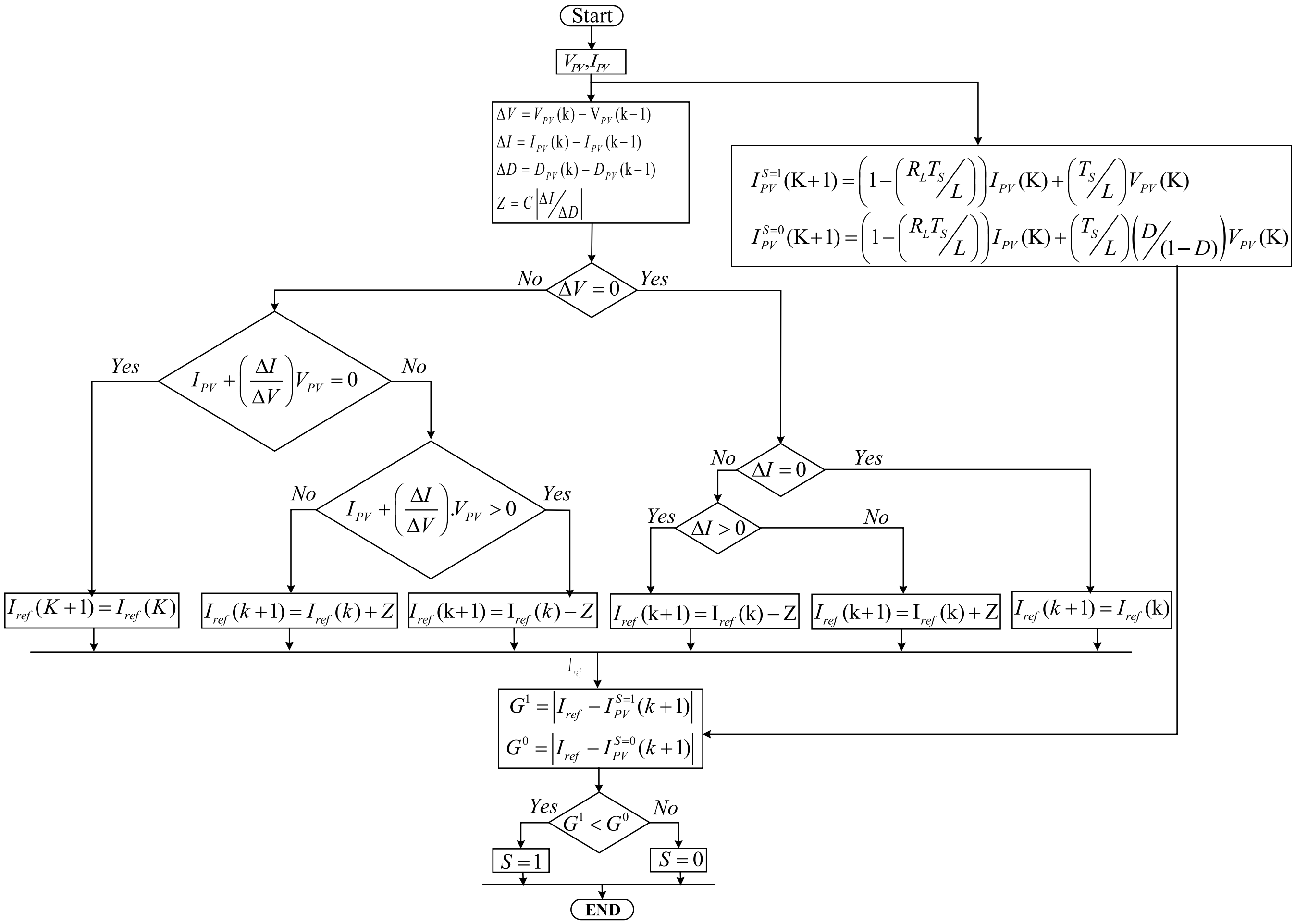

FIGURE 7. The diagram depicting the proposed method for tracking the maximum power point (MPP) using model predictive control (MPC) with fewer sensors.

the error and the rate of change of the error:

$$g^{\sigma=\{0,1\}} = \left| I_{ref} - I_{PV}^{\sigma} \right| \tag{9}$$

The objective function and the current reference are denoted by g and *Iref*, respectively. The current reference Iref is obtained by using the incremental conductance method. The flowchart of the proposed MPC-MPPT technique is shown in Figure 7. The figure shows that the PV current and voltage are the only measurements required by the MPC-MPPT method. It uses an incremental conductance approach to generate the reference current that matches the maximum power operation. Then, the converter is controlled by the MPC method to track the reference current. The capacitor's voltage sensor is replaced by the voltage observer, as discussed in the previous section. The perturbation step size, denoted by Z, in the flowchart can be either fixed or adaptive. A fixed step size MPC-MPPT can be implemented by assigning a constant value to Z. Alternatively, Z can be designed adaptively by using the following equation:

$$Z = C. \left| \frac{\Delta I}{\Delta D} \right| \tag{10}$$

A scaling factor, denoted as C, is used in conjunction with the difference between the current and previous values of both the PV current and reference current, ΔI and ΔD, respectively.

IV. RESULTS AND DISCUSSION

One of the most important factors in the effective use of photovoltaic generation is to efficiently track the maximum power point. However, in some countries with sandy weather, such as the Middle East, solar panels often face partial shading conditions due to dust and sand. Therefore, it is essential to have an efficient MPPT tracker to improve the economic performance of the photovoltaic system under various operating conditions.

This paper aims to develop an efficient tracker that can improve the overall efficiency of PV plants in different situations. The proposed algorithm is simulated using the MATLAB platform and then implemented with the DSPACE DS1202. An 85W PV module that produces current and voltage at maximum power of 4.9 A and 17.8 V respectively (at nominal radiation and temperature of Gn=1000 and Tn=25°C) is used for the experiment.

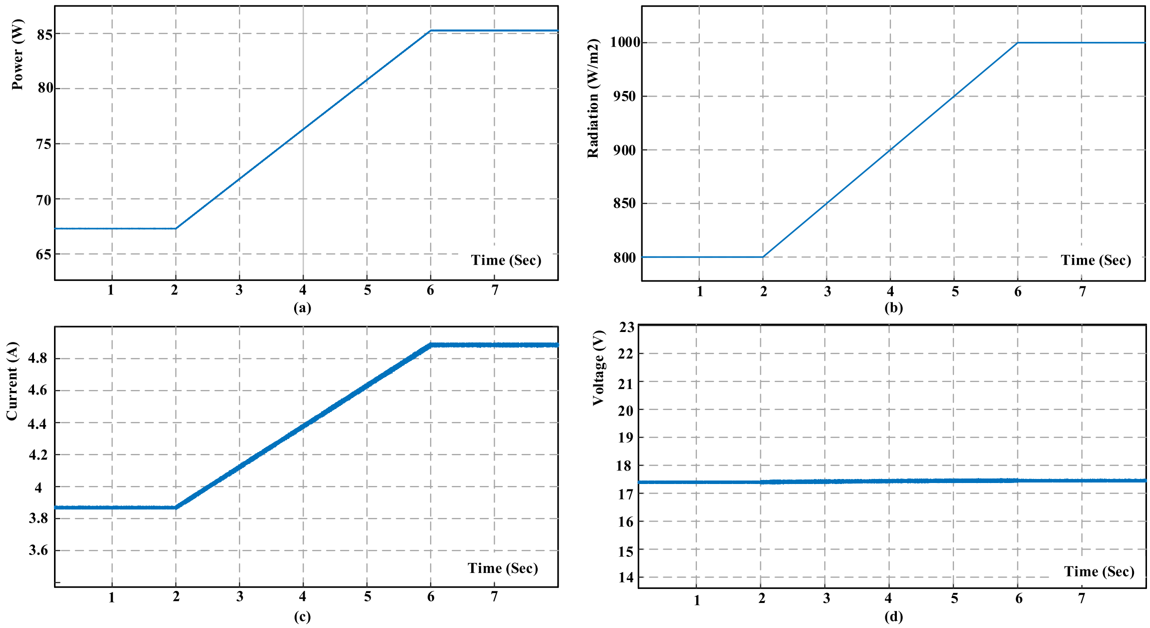

FIGURE 8. PV Output characteristics with gradual variation in solar radiation(a) Photovoltaic Power Generation, (b) Solar Irradiance, (c) Photovoltaic Current, and (d) Photovoltaic voltage.

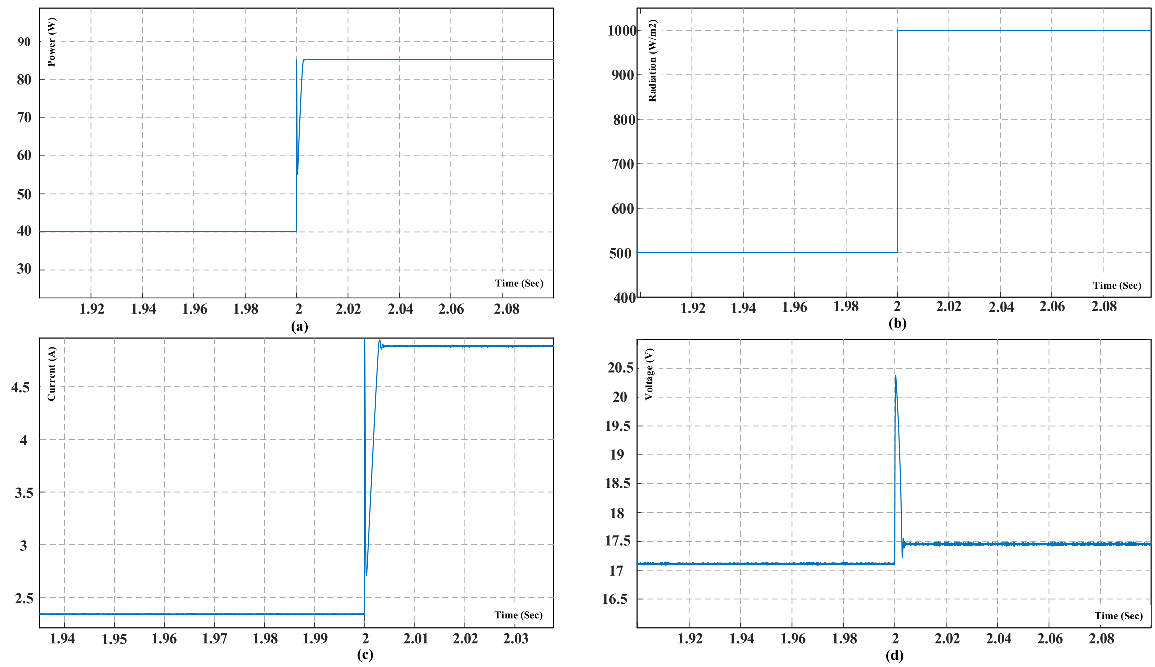

FIGURE 9. PV Output characteristics with abrupt variation in solar radiation(a) Photovoltaic Power Generation, (b) Solar Irradiance, (c) Photovoltaic Current, and (d) Photovoltaic voltage.

The simulation results from the MATLAB platform are shown in Figures 8 and 9, while the implementation results from the DSPACE DS1202 are presented in Figures 10-12. As mentioned earlier in this paper, the output characteristics of PV panels depend mainly on solar radiation and ambient temperature, with solar radiation being the most influential factor.

The proposed algorithm is able to track the maximum power point efficiently under different operating conditions, including partial shading. This results in an improvement in the overall efficiency of the PV plant. The simulation and implementation results show that the proposed algorithm is a promising solution for improving the economic performance of PV plants in sandy weather conditions.

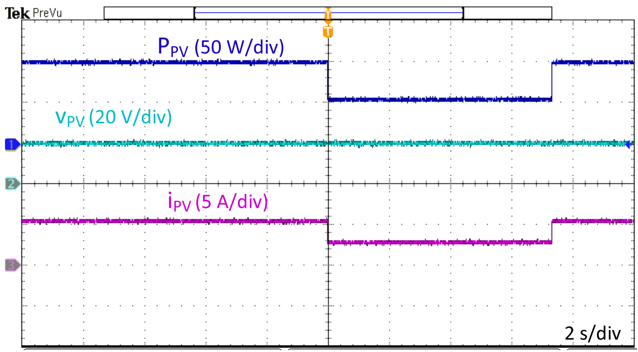

FIGURE 10. The electrical properties of the photovoltaic (PV) output are shown as the radiation levels vary from 1000 to 500 and subsequently back to 1000 [W/m2].

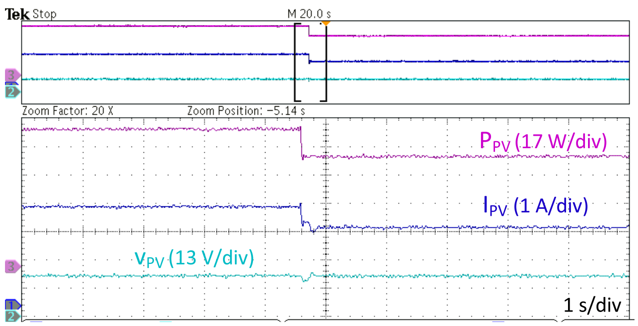

FIGURE 11. The electrical properties of the photovoltaic (PV) output are displayed as the radiation levels fluctuate between 1000 and 800 [W/m2].

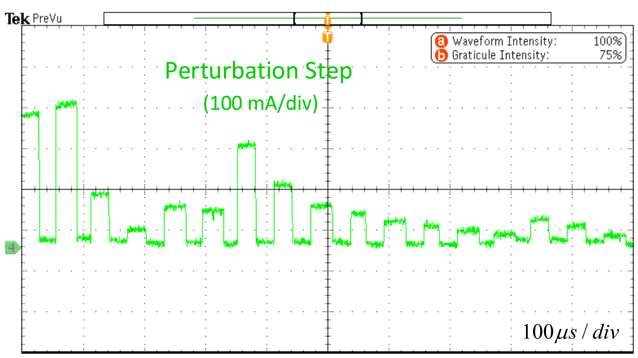

FIGURE 12. Adaptive perturbation step size.

One of the most important factors in the effective use of photovoltaic generation is to have an effective maximum power point tracking (MPPT) system. In some regions with sandy weather, such as the Middle East, solar panels often face partial shading conditions due to dust and sand. This can cause the MPP to shift, and if the MPPT system is not able to track the MPP accurately, then the solar panel will not produce the maximum amount of power.

This paper aims to develop an MPPT system that can improve the overall efficiency of PV plants under various operating conditions. The proposed algorithm is simulated using the MATLAB platform and then implemented with the DSPACE DS1202. An 85W PV module is used for the

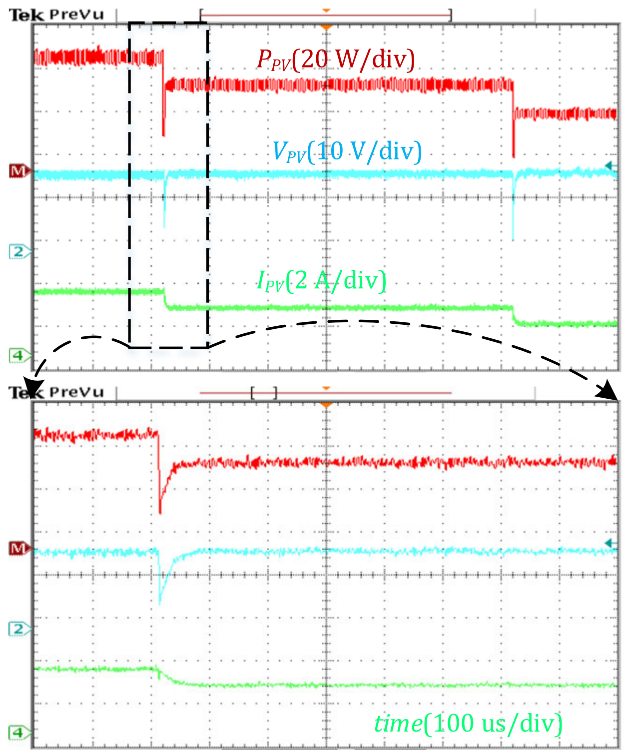

FIGURE 13. The electrical properties of the photovoltaic (PV) output are demonstrated as the radiation levels vary from 1000 to 900 and then further to 800 [W/m2].

experiment, which produces current and voltage at maximum power of 4.9 A and 17.8 V respectively (at standard radiation and temperature of Gn=1000 and Tn=25°C).

Figures 8 and 9 show the results obtained from the MATLAB platform, while Figures 10-12 present the results obtained from implementation using the DSPACE DS1202. As previously noted in this paper, the output characteristics of PV panels are primarily affected by solar radiation and ambient temperature, with solar radiation having a greater impact than temperature.

Figure 8 depicts a sudden change in solar radiation, with the radiation level varying from 500 to 1000 W/m2. Figures 8(a)-(d) show the corresponding PV output power, output current, output voltage, and solar radiation. The proposed MPPT controller is able to track the maximum power under all conditions with an efficiency of over 99.5%. However, in most real-world scenarios, solar radiation changes gradually due to factors such as passing clouds or sand accumulation. Figure 9 simulates this gradual change in solar radiation.

The proposed MPPT system is capable of efficiently tracking the MPP under various operating conditions, including partial shading. This leads to an overall improvement in the efficiency of the PV plant. Simulation and implementation results demonstrate that the proposed MPPT system is a promising solution for enhancing the economic performance of PV plants in sandy weather conditions.

Further validates the performance of the proposed system, it was tested and implemented using the DSPACE DS1202

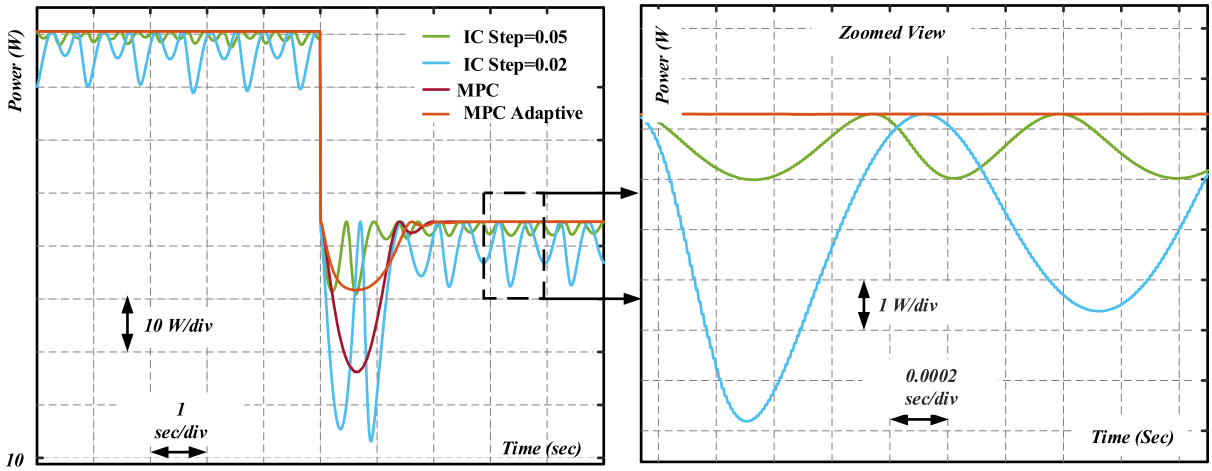

FIGURE 14. Performance comparison of proposed and other MPPT techniques under abrupt radiation change.

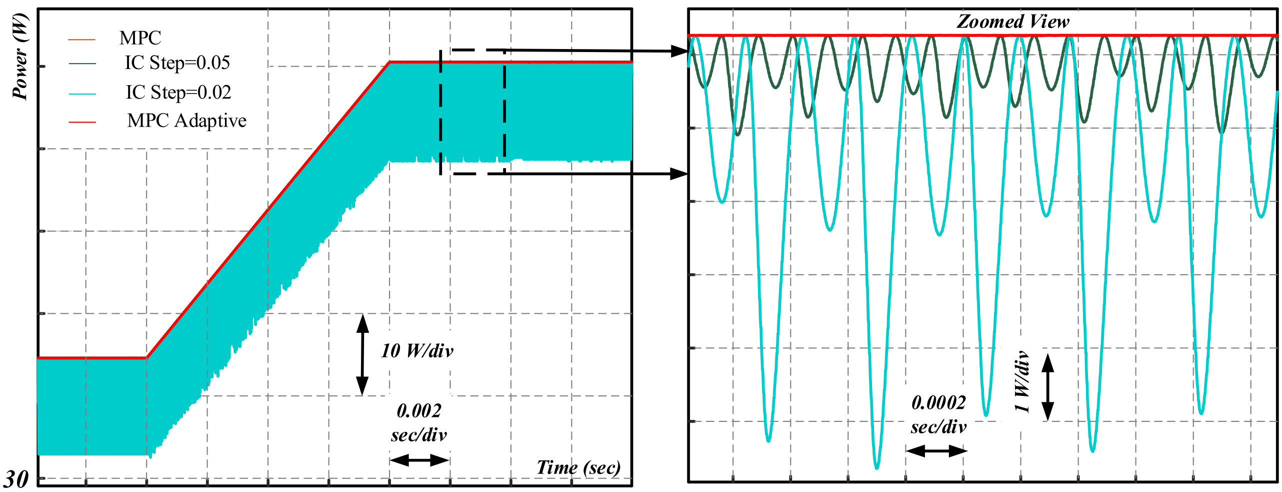

FIGURE 15. Performance comparison of proposed and other MPPT techniques under gradual radiation change.

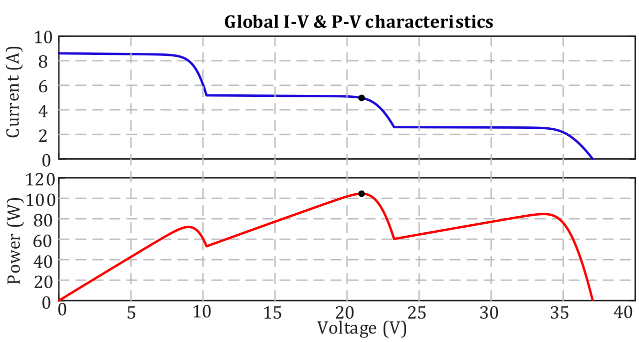

FIGURE 16. Partial shading case of study, global I-V and P-V characteristics.

and the hardware data in Table 1. This paper introduces the MPC_MPPT algorithm, which is designed to function with both fixed and adaptive step sizes. The algorithm was tested under different weather conditions, including normal and varying conditions.

Most of the existing MPPT methods in the literature depend on the step size for the MPPT controller operation. For example, the P&O, hill climb, and IncCond algorithms use a small perturbation step to achieve accurate tracking of the maximum power, but this results in slow tracking speed and sometimes failure to track the maximum power. A large perturbation step enhances the tracking speed but lowers the tracking efficiency.

The proposed algorithm was evaluated with fixed perturbation step size and with adaptive perturbation step size. Figure 10 shows the radiation (W/m2) changing from 1000 to 500 and then back to 1000. The PV output voltage, current, and power are shown. The controller reacts to the radiation change in an excellent way and efficiency is above 99.5%. Another case is shown in Figure 11, where radiation (W/m2) changes from 1000 to 800. Adaptive perturbation step is shown in Figure 13.

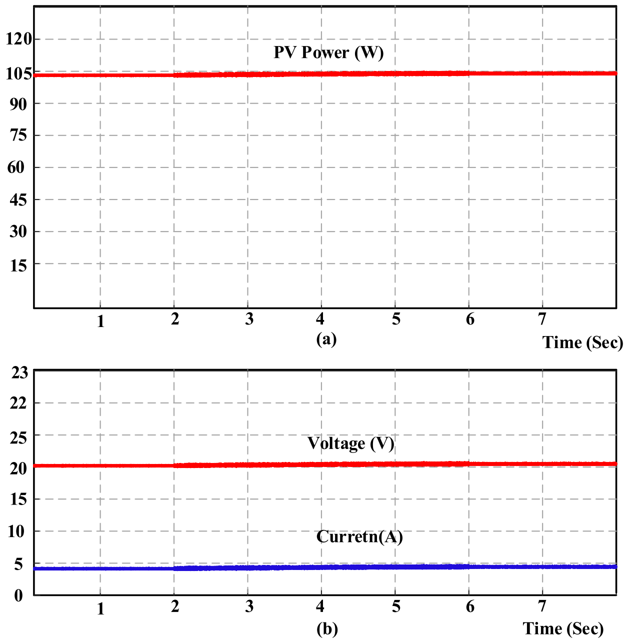

FIGURE 17. PV module output characteristics, voltage, current and power.

Figures 15 and 16 present a comparison of the proposed MPC_MPPT algorithm with both fixed and adaptive step sizes, as well as the widely used IncCond algorithm at various step sizes. The comparison is conducted for sudden and gradual changes in solar radiation. Specifically, Figure 15 depicts the comparison of MPPT methods under sudden radiation changes, while Figure 16 illustrates the comparison among different techniques for gradual radiation changes.

The IncCond algorithm is a commonly used technique in PV applications that operates on the principle that the slope of the PV curve is zero at the maximum power point. Two perturbation step sizes of 0.02 and 0.05 were chosen for the IncCond algorithm.

As shown in Figure 14, when the solar radiation (W/m2) drops suddenly from 1000 to 800, all the MPPT methods can track the MPPT. The proposed system maintains its performance regardless of the step size being adaptive or fixed. It can achieve the maximum power under any condition with an efficiency above 99.5%.

However, the IncCond method is highly sensitive to the step size. IncCond has larger oscillations with a step size of 0.02 than 0.05 and its efficiency decreases. This can affect the profitability and viability of large-scale systems.

Figure 15 illustrates the gradual change in solar radiation. The proposed system outperforms the others, with similar performance for both adaptive and fixed step sizes, while the IncCond algorithm relies heavily on the step size.

Using a step size of 0.02 results in more oscillations and less efficiency than using a step size of 0.05. Some of the main factors that influence the choice of an MPPT technique are its complexity, efficiency, tracking ability, tracking speed, and reliability.

In the case study depicted in Figure 13, the solar radiation levels exhibited a sudden change, fluctuating from 1000 to 900 and then further to 800 W/m2. Under these conditions, the PV module employed in the experiment was anticipated to generate 55W of power. The proposed algorithm, however, was able to effectively track the maximum power point at all three levels of radiation. Moreover, the algorithm exhibited a transient time of approximately 50 microseconds, indicating its fast response to changes in environmental conditions.

The successful implementation of the algorithm under such conditions highlights its robustness and reliability, and underscores its potential for use in real-world applications.

Partial shading represents a significant challenge for photovoltaic (PV) systems, as it can lead to control failures due to the presence of multiple peaks. Various techniques have been proposed in the literature to address this issue and mitigate the effects of partial shading.

In the past decade, researchers have compared various MPPT techniques, including P-V characteristics, models, and methods to track the maximum power of PV modules/arrays under partial shading conditions (PSC). Research on PV output characteristics analyzes failure, power loss, and voltage variations in the MPPT method under PSC, while research on PV models focuses on a unified model of the PV array and an accurate model of the PV unit under complex environments. The results of these studies are significant for updating the GMPPT algorithm for PV system applications. The three categories of maximum power tracking algorithms are traversing all maximum points, determining the region of maximum power, and using heuristic and intelligent optimization algorithms. Each has advantages and disadvantages [28], [29].

To accurately simulate the effects of partial shading, the cells of the PV module are divided into three distinct groups, each experiencing a specific level of radiation. In order to ensure uninterrupted current flow in the event of partial shading, each group is equipped with bypass diodes. The radiation levels assigned to the three groups are 1000 W/m2, 300 W/m2, and 600 W/m2 respectively. The resulting output power of the studied system is depicted in Fig. 16.

The algorithm we have put forward is designed to track the global maximum power point for the system in question. The operating point for the system, as governed by the proposed control methodology, is depicted in Fig.17.

V. CONCLUSION

This paper presents a reliable technique for finding the maximum power point (MPP) of a photovoltaic (PV) system using model predictive control (MPC) and only two sensors. The voltage sensor is replaced by an observer derived from the converter analysis. The algorithm can work with either a fixed or adaptive step size. The algorithm has been demonstrated to achieve the MPP under harsh environmental conditions.

The proposed control algorithm is explained in detail in the paper. The algorithm was tested under various conditions to confirm its effectiveness. The algorithm performed equally well with both fixed and adaptive perturbation step sizes.

The paper also discusses a modified SEPIC converter for PV applications. This converter has several advantages, including: high voltage gain, low voltage stress, and high efficiency.

The system was implemented using the DSPACE DS1202 to verify and validate its operation. The results showed the excellent performance of the algorithm, including fast tracking and high efficiency.

Here is a more detailed explanation of the proposed technique:

- The MPC algorithm uses a model of the PV system to predict the MPP in the future.
- The algorithm then calculates the optimal control input to track the MPP.
- The control input is applied to the PV system to track the MPP.
- The algorithm is repeated continuously to track the MPP as it changes.
- The proposed technique has several advantages over other MPP tracking techniques:
- It is reliable and can track the MPP under harsh environmental conditions.
- It is efficient and can extract the maximum power from the PV system.
- It is simple to implement and can be used with only two sensors.

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