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MPPT implementation and simulation using developed P&O algorithm for photovoltaic system concerning efficiency

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ABSTRACT

The great development witnessed by investments in renewable energy has made it the focus of researchers' attention in order to increase its efficiency. This is due to the increase in demand for electrical energy due to rapid technological growth, increase in population numbers, and high fuel prices that are used in the production of traditional electrical energy, but it suffers from a problem that is greatly affected by two factors, namely, the change in the intensity of solar irradiation and temperature, which makes its electrical characteristics non-linear, which causes a decrease in its efficiency. To address the efficiency problem, the researchers developed several techniques for tracking the MPP point and extracting the maximum energy from the solar panels under various measurement conditions. Maximum power point tracking technology (MPPT) is the most widely used technology in solar energy systems. MPPT technology is simulated using MATLAB/Simulink for the purposes of extracting maximum power and managing the duty cycle of a DC-DC buck converter. The performance of the photovoltaic system under various irradiance fluctuations and settings of constant temperature could well be determined using simulation results. Under standard and varied test settings, allowing the inverter to convert over 99% of the electricity provided by the solar panels.

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1. INTRODUCTION

Researchers and scientists have been forced to find alternative ways to generate electricity that are less expensive and inexhaustible as a result of the global financial crisis and the rise in fossil fuel prices, the main source of conventional electric power production, and the increase in demand for electric power. The emphasis was on renewable energy sources such as solar and wind (wind energy, thermal energy, solar energy, and ocean energy). The most widely used energy source nowadays is solar which utilized renewable energy source for producing electrical energy. It has become the focus of researchers' interest for a variety of reasons, including its availability, cheap costs, and the fact that it is an ecologically beneficial energy that does not pollute or exhaust. All of these aspects, as well as others, have made it the target of their study attention [1], [2]. Electrical energy is obtained by shining sunlight on panels prepared of semiconductors [3], that sequentially produces electrical energies. Its cost be determined by double key features: the intensity of solar irradiation and temperature [4], [5]. For this reason, its electrical properties are always non-linear, which causes the efficiency of the photovoltaic system to decrease [6]. In order to address the problem of the low efficiency of solar panels and the effect of changing the intensity of irradiation and temperature on them, several methods have been developed to control the charge and track the MPP point in addition to maximum power can be extracted with panels despite the change of weather conditions called the maximum power point tracking technology (MPPT) [7]. In the literature, many algorithms that were developed to be applied in MPPT technology are mentioned such as a fuzzy logic control (FLC) algorithm which considers a powerful and simple algorithm, and it shows less loss in tracking the MPP point in various measurement conditions and compare the simulation results with the results of applying the methods conventional perturb and observe (P&O) [8]-[10]. This research aims to simulate the photovoltaic system consisting of (a solar panel, DC-DC buck converter, and MPPT technology), where the P&O algorithm was developed and applied to track MPP and control the duty cycle of the transformer to battery charge using 48 volts voltage then compare the simulation results with simulation results conventional method (P&O) [11], [12].

The accurate evaluation of solar radiation on the location place with understanding of its parameters are required for the system designing to convert solar energy into any type of energy (thermal or electrical) [13]. Solar panels efficiency improvement as well as inverters are difficult, thus the output is limited by technology. Furthermore, the system's design may necessitate higher-performance components, resulting in significantly higher installation costs [14]. Instead, it's easier to improve MPPT using a new control method, which saves money.

Artificial intelligence (AI) is advancing at a rapid evolution across many industries and including renewable energy. AI algorithms achieve extraordinarily good in nonlinear systems, for instance photovoltaic (PV) systems, according to a literature review and research experiments. Kamran *et al*. [15] for example, provide an entirely new design approach for converting the MPPT algorithm into a buck–boost converter-based PV control system [16]. They use Bode diagrams with mode and phase conditions in their work. In incremental conductance (IC) algorithms, the design approach is used to P&O. As a consequence, the authors proved that the proposed design form may maximize energy collection, agreeing an algorithm for realizing remarkable performance in MPPT and adaptivity.

Zand *et al*. [17] designed a system of PV with MPPT and a DC-DC boost converter based on self-predictive incremental conductance. Their method beats the standard incremental conductance (I&C) algorithm, based on authors' MATLAB/Simulink simulation findings, and the output power has low ripple. Mnati *et al*. [18] used typical MPPT approaches to investigate several converter configurations for a PV system, including the P&O technique thru flexible step sizes, improved I&C. Such algorithms compare static and dynamic irradiation while taking into account algorithm properties like as fluctuations of MPP, track speed, in addition to recognition parameters.

Basha and Rani [19] have conducted extensive research on popular MPPT techniques. They are pursuing both P&O and I&C techniques in their study. As a result, they propose new modified forms of the P&O and I&C techniques to improve the techniques' inefficiency. Palanisamy *et al*. [20] propose an MPPT method that integrates fuzzy logic and neural networks, as well as an adaptive radial basis function-neural network (RBF–NN). A DC–DC boost converter is driven by the suggested method, which is coupled to a resistive load and a PV module. In terms of energy conversion efficiency, the new technique, known as I&C, outperforms the traditional P&O algorithms. Additionally, the PV panel could be strongly connected to the inverter, removing the need for a DC–DC converter thus lowering expenses and simplifying the system [21]. In addition, in grid-connected settings with further of two proportional integral (PI) controllers, the earlier work shows strategies for demonstrating the high-quality transit performance necessary.

2. RESEARCH METHOD AND MATERIAL

2.1. Modeling of the photoelectric system

The photovoltaic system that we will work on in this research consists of an array of solar panels that provide an electrical power of (945 watts) that is connected to a DC-DC buck converter that works to regulate the output voltage and maintain it at a certain level (48 volts), working on it. MPPT technology is based on the fuzzy logic controller (FLC) algorithm for converter duty cycle control and MPPT to excerpt maximum power as of solar panels under standard as well as variable test conditions [22]. Figure 1 shows the scheme of the photovoltaic system.

2.2. PV generator model

The photovoltaic cell's main function is to convert light into electrical energy using the photo-voltage effect without affecting environmental pollution or creating frustrating sound [23]. The resistances of the photovoltaic cell involve with group of panels which can be either in parallel, or in series, neither both are not included in a conventional solar cell, but they are implanted and coupled to the PV diode in a real application, the equivalent circuit of a single-diode photovoltaic panel can be shown in Figure 2 [15].

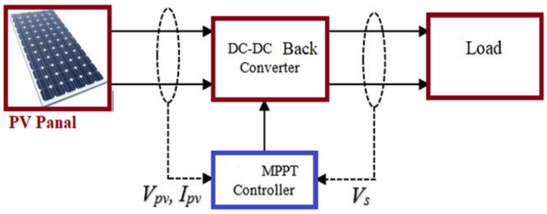


Figure 1. A schematic diagram of a PV system [13]

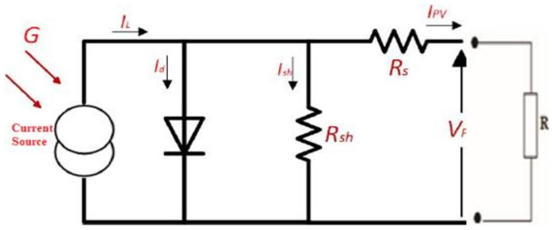


Figure 2. The corresponding cct of PV cell

This is owing to variables such as the PV semiconductor's magnitude of resistance and a non-optimal PN junction diode, which result in the implementation of series and shunt resistance, respectively. Kirchhoff's law (1) may be used to determine the current generator from a solar cell [15]:

$$IPV = IL - Id - Ish \tag{1}$$

the current generator (I_L) may be in (2):

$$I_L=G\{I_{SC}[1+k\alpha(T-T_{STC})]\} \tag{2}$$

here, the solar irradiation is G, and an ambient temperature is T of climate conditions, PV cell's short circuit current I_{SC}, *ka* is the temperature coefficient and the temperature operation T_{STC} for the PV cell within standard test conditions (STC), and PV diode current is *Id*, that is specified from Shockley's (3):

$$I_d = I_o \left(\exp(\frac{qV_d}{nKT}) - 1\right) \tag{3}$$

$$Io = (Isc + Ka(Tc - T_{ref}))/[\exp\left(q\left(Voc + \frac{Kv(Tc-T_{ref})}{NsAKTc}\right) - 1\right] \tag{4}$$

where

$$Iph = [Isc + Ka(Tc - T_{ref})] * (irr/irr_{ref}) \tag{5}$$

and T_{ref}=25 °C, irr is the irradiation [W*m^{-2}], and irr_{ref}=1000 W*m^{-2}. The PV unit's output then can be considered from current Kirchhoff's rule as:

$$I = Iph - Io\left(\exp\left(\frac{q(V+Rs*I)}{NsAKTc}\right) - 1\right) - (V + Rs * I)/Rsh \tag{6}$$

with related to MATLAB simulation model and using Suntch STP155D-12-VEC PV modules. The maximum output power is 155 watts; the characteristics of PV module can be listed in Table 1.

2.3. DC-DC converter

The DC-DC buck, boost, and buck-boost power converters are the most often used DC-DC converter in photovoltaic power conversion because it enables a greater maximum power transmission with lower energy losses seen between solar module panals and the load [18]. The MPPT method is used to regulate the DC-DC converter's duty ratio in addition to meeting the source voltage and the load operational points at the determined power point. In contrast to previous complicated setups, a DC-DC buck converter has been preferred for employing here to achieve a greater conversion efficiency with electrical circuit simplicity [19], and can be applied for the purposing of battery charging by voltage equal 40 volts, an output voltage from the buck converter being less than or equal to the input voltage (the voltage extracted from the solar panel) [24]. Figure 3 shows the equivalent circuit of a buck converter.

The converter considers ideal when the array voltage (Vo) is more than battery voltage (Vi), an average output voltage can be (7) [25]:

$$D = \frac{V_o}{V_i} \tag{7}$$

the dynamic model of this buck converter may be realized to [22]:

$$\frac{d}{dt}\begin{bmatrix} Vi \\ Li \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ D/L & 0 \end{bmatrix}\begin{bmatrix} V_i \\ I_i \end{bmatrix} + \begin{bmatrix} \frac{1}{C_1} & 0 & \frac{-D}{C2} \\ 0 & \frac{-1}{L} & 0 \end{bmatrix}\begin{bmatrix} I \\ V_b \\ I_b \end{bmatrix} \tag{8}$$

Table 1. General PV system main parameters

General characteristics rate	Value
Voltage at open cct (Voc)	25.4 V
Current with short cct (Isc)	8.8 A
voltage at Opt. operating (Vmpp)	17.8 V
Current at Opt. operating (Impp)	7.8 A
Current- temp. coef. Isc	(0.045±0.01)%/K
Voltage- temp. coef. Voc	0.075 mV/K

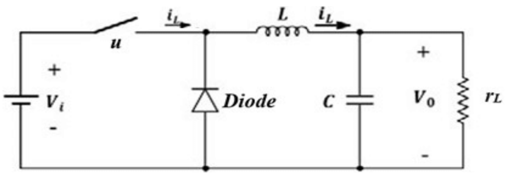


Figure 3. The DC-DC buck converter [20]

3. MPPT ALGORITHMS

Since the panel's MPP oscillates by way of irradiation level and temperature, MPPT algorithms are important in PV applications in order for acquiring a greatest power possible from solar array. An algorithms P&O in addition to I&C can be considered the best widespread algorithms meanwhile the implementation can be the easiest. PV curve with just unique maximum point under typical circumstances, thus there is no issue. Regarding the level of detail, budget, attractiveness, rapid converging, technical specifications, and plus efficiency, all of the mentioned are distinctive [26].

3.1. Perturbation and observation

Due to its ease of application and simplicity of result, the P&O algorithm is one of the most extensively used and popular ways of MPPT technology. The P&O method defines the slope of the characteristic curve as being equal to zero on MPP point and for left portion is positively (growing region), while for the right portion of MPP point is negative (reducing region) [27]. Consequently, till MPP may be attained, the oscillation process continues. The turbulence stages size is lowered to prevent oscillation, yet the process of getting to the MPP point is slowed significantly by this [28].

This approach creates a basic closed-loop regulator with only a few controllable parameters. By regularly adjusting the solar panel voltage by means of a miniscule incremental stage to lessen the fluctuation round an MPP or any intended stage, the P&O algorithm made a comparison of the power that was previously given with the one following a disruption. Because of its simplicity and the fact that it only involves a few measured parameters, such algorithm was commonly used commercialy [29]. Figure 4 depicts the P&O algorithm flowchart.

The P&O approach regularly changes the PV output voltage through the terminals then compares a former cycle strength with present one. Whether voltage and power are straight connected, so that when one rises, the second rises besides, an equipment for regulating position adapts accordingly; an operating point then exchanges to the other direction Figure 5 [30]. The existing changes at a steady pace after the current shift position is detected. This level is a variable that may be changed to apportion stability among quick feedbacks by reducing state variance.

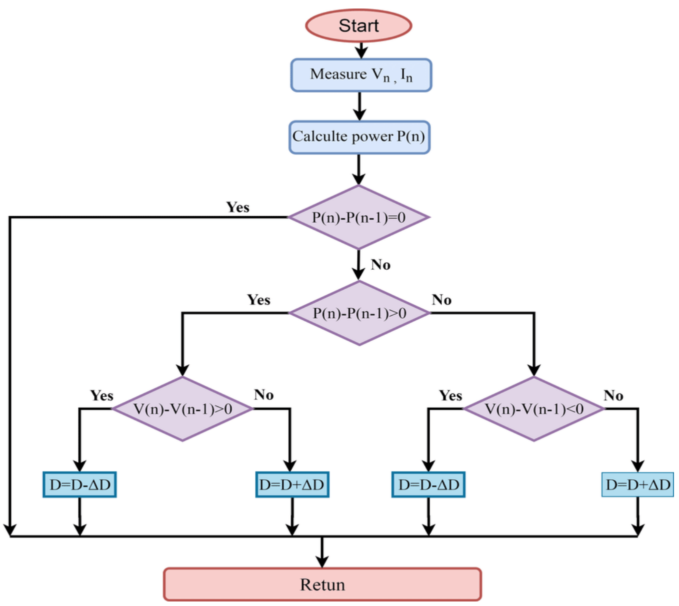


Figure 4. P&O algorithm flowchart [22]

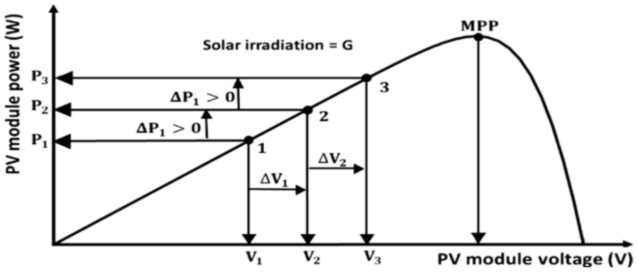


Figure 5. PV curve related to classical P&O

The common issue with the P&O method is that the array voltage level interrupts each MPPT cycle; as a result, after MPP has been achieved, output power swings on the way to an ideal due to a decrease in the plan's energy. This is especially true in instances where the environment is stable or gradually changing. Again, when the energy is moving predominantly in one direction, a sophisticated control regulation changes the scale factor of perturbation toward a widely levels due to a wide range of environmental variables, which can be utilized to remedy this issue using an improved P&O approach by adjusting the disturbance's step size.

4. SIMULATION RESULTS

The total MATLAB/Simulink execution may be seen at Figure 6, that involves PV generator represented by a group of panels connected in series and parallel, where a solar panel anof STP153D-12 is utilized, DC-DC buck converter, and MPPT algorithm which is based on the P&O technology developed for controling the converter's duty cycle, in addition to resistive load. Table 1 shows specifications of the PV panels and buck converters which were in employment. Double scenarios of changing solar irradiation are run in this section of the simulation in parallel to examine the effectiveness and precision of the suggested MPPT tactic for tracking accessible power in various insolation situations and conversion points. The suggested MPPT scheme is then associated to other well-known MPPT algorithms applied alike of P&O, I&C, besides fuzzy logic. On the basis of two cases, simulation results using such a P&O technique are also shown.

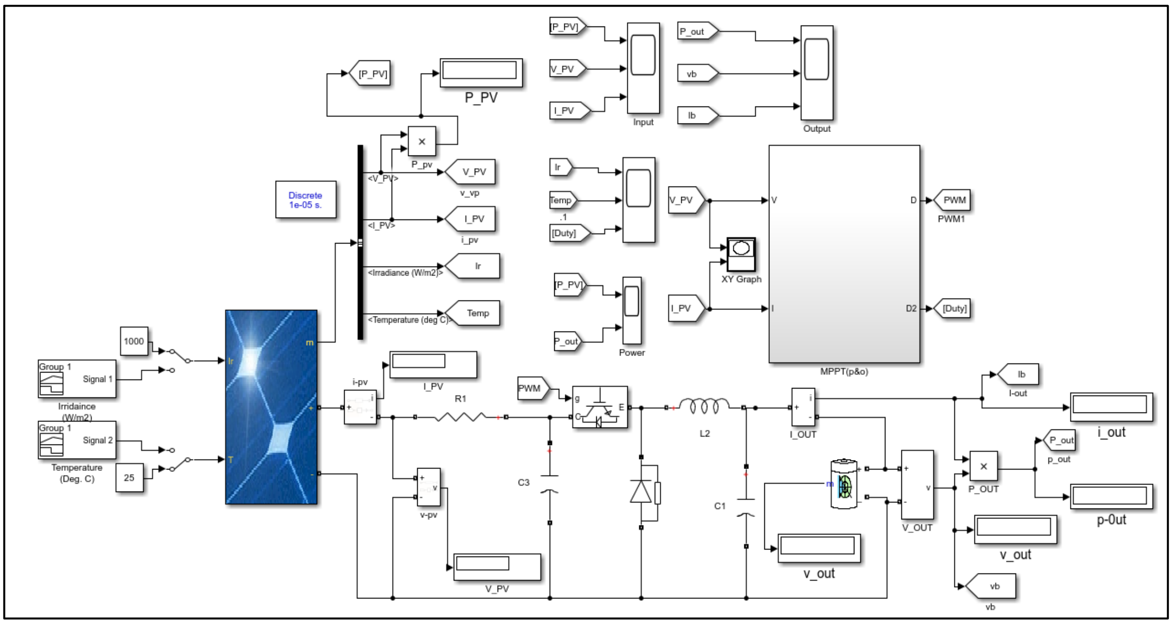
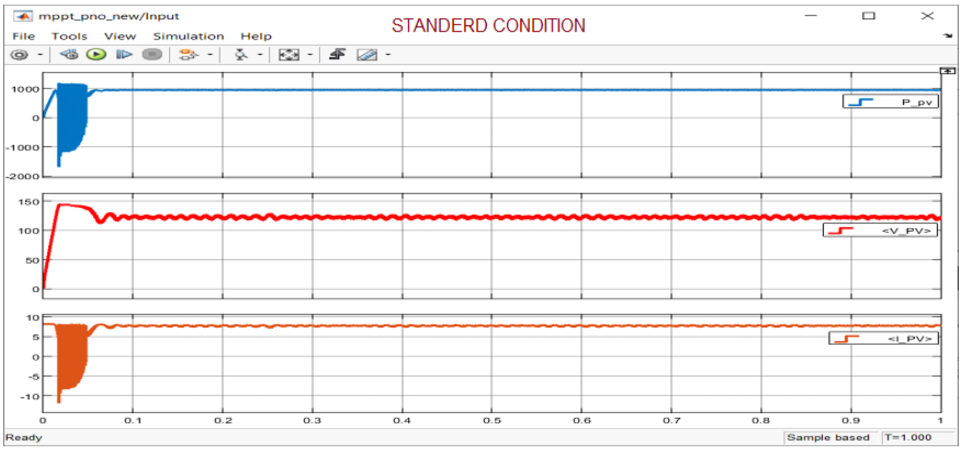


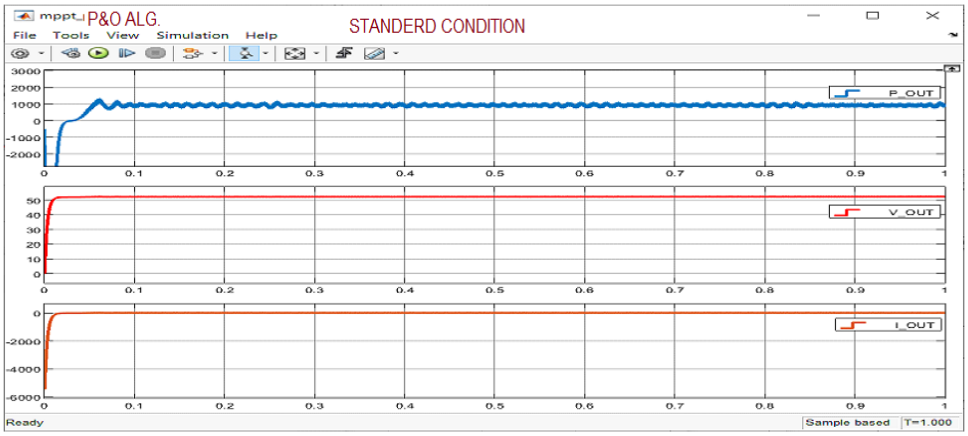
Figure 6. MPPT simulation of P&O

4.1. Scenario 1: standard condition

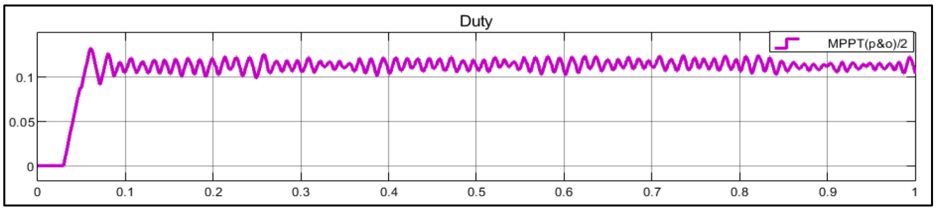
The photovoltaic system test was simulated with MPPT technology created at P&O algorithms in standard test conditions during a period 1 sec time simulation, an obtainable result shown in Figure 7(a) for the electrical signals received from the solar panels for (voltage, current, and power) in addition to Figure 7(b) for the electrical output signals from a buck converter as well as Figure 7(c) indicating the duty cycle for P&O algorithms.



(a)



(b)



(c)

Figure 7. Output characteristics of (a) solar panels when Ir is 1000 W/m^2 & 25 °C temp. at P&O algorithm, (b) a buck converter when irr=1000 W/m^2 & T=25 °C with P&O algorithm, and (c) the duty cycle for P&O algorithm

As can be seen in Figure 7 by the output power, voltage curves for the P&O method. The curve appears smoother and contains a lot more ripple content, as observed in the simulation using the back converter. The STC was being used to produce this curve while maintaining the irradiance constant.

4.2. Scenario 2: section 1

When the solar irradiation intensity varies while the temperature remains constant. In this section, solar irradiation was varied (200, 500, 750, and 1000 W/m^2) in this region, as indicated in Figure 8, at a constant temperature of 25 °C. Figure 9(a) depicts the electrical signals (voltage, current, and power) received from the solar panels, as well as the electrical output signals from a buck converter for P&O algorithms Figure 9(b). Figure 9 depicts the three main parameters collected as of solar panel as the intensity of the irradiation changes while the temperature is constant. The current and power are the characteristics that change the greatest in relation to irradiation fluctuation, as can be shown. The voltage, on the other hand, remains practically constant.

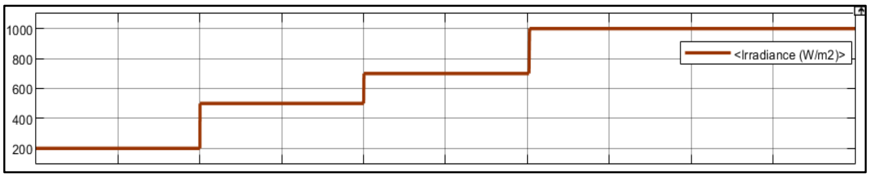
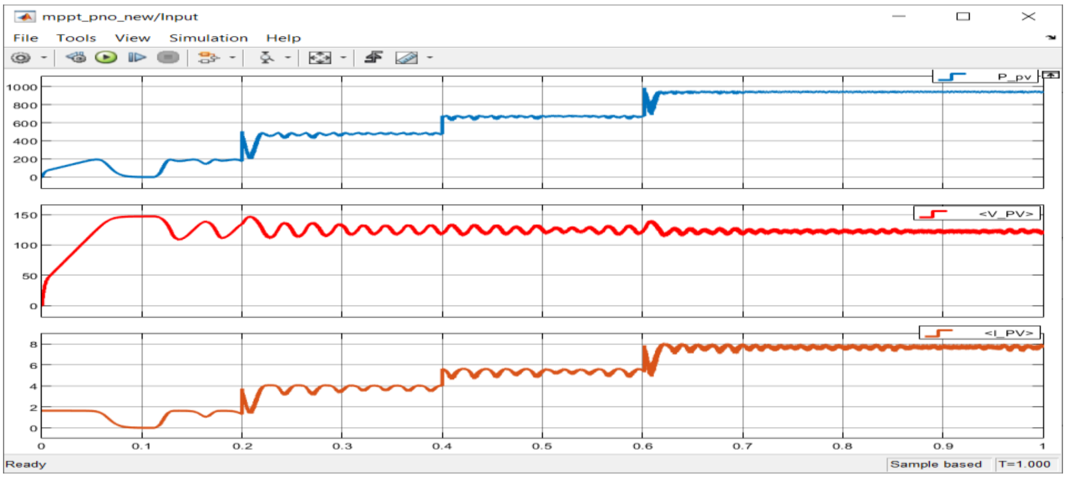
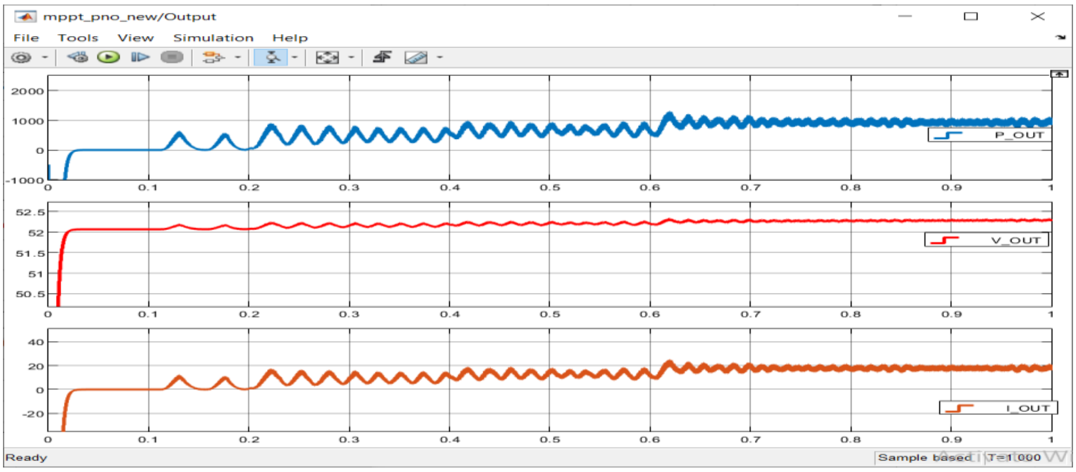


Figure 8. change in the intensity of solar irradiation (200, 500, 700, and 1000 W/m^2)



(a)



(b)

Figure 9. Output characteristics with P&O algorithm of (a) solar panels when irr = (200, 500, 700, and 1000 W/m^2) and T=25 °C and (b) a buck converter when the intensity of solar irradiation is variable and the temperature is constant

4.3. Section 2: an adjustable temperature and constant irradiation intensity

Here, variable temperature like (15 °C, 25 °C, 35 °C, and 50 °C), with constant irradiation of 1000 W/m^2 as in Figure 10, while Figure 11(a) displays the outcomes expected for PV system parameters (power, voltage, and current) at a period 1 sec time and the characteristics of a buck converter for adjustable temperature and an intensity of solar irradiation is constant P&O algorithm shown in Figure 11(b). In each temperature level, the P, V, and I are extracted with P&O at a time interval of 0 to 1 s, with higher oscillations around MPP. The PV output power of the P&O method at 1000 W/m^2 with varying temperature is shown in

Figure 11. The P&O algorithm's PV output power and voltage are (950-1000) W/m^2 and 125 V, respectively. The efficiency of the P&O method is higher than that of the other traditional approach because there is some fluctuation near the maximum power point. Furthermore, as compared to the intelligent algorithm utilized as an MPPT control mechanism, the P&O algorithm showed more substantial oscillations around the MPP in the steady state.

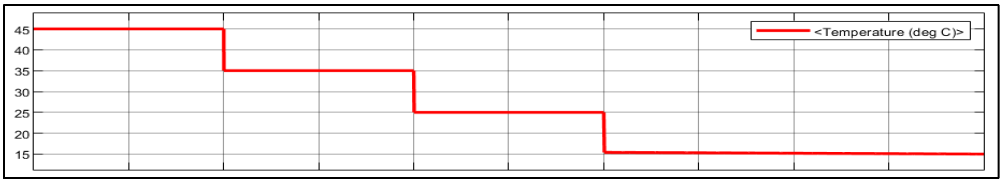
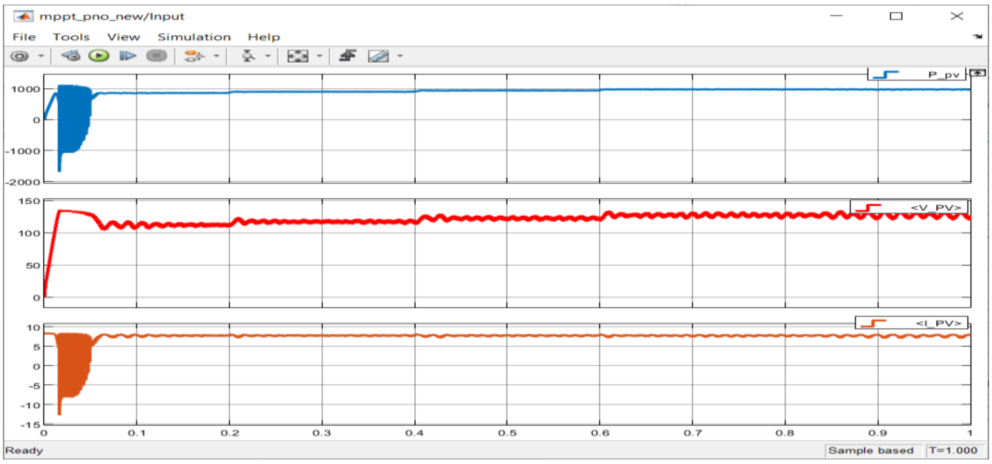
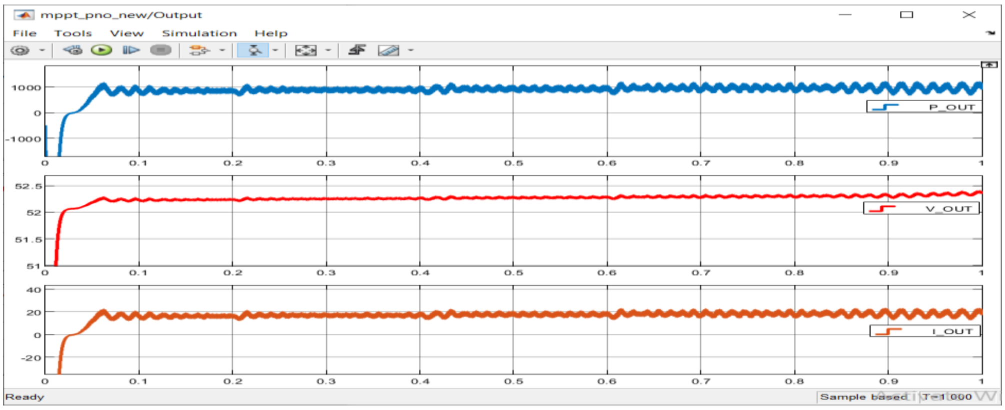


Figure 10. Temperature change (45 °C, 35 °C, 25 °C, and 15 °C)



(a)



(b)

Figure 11. Output characteristics with P&O algorithm of (a) PV module with irr=(1000 W/m^2) & T=(45 °C, 35 °C, 25 °C, and 15 °C) and (b) a buck converter at flexible temperature and the intensity of solar irradiation is constant

Table 2. Displays the measurements of the main parameters taken for solar panel under typical settings

algorithms	$P_{I/P}$ (W)	$V_{I/P}$ (V)	$I_{I/P}$ (A)	Efficiency of extracting power (%)	$P_{O/P}$ (W)	$V_{O/P}$ (V)	$I_{O/P}$ (A)	MPPT technology efficiency (%)
Under standard test conditions								
P&O	943.4	124	7.605	99.83	793.6	52.33	15.16	84.21
Under volatile weather conditions (change of irradiation intensity)								
P&O	943.8	123.8	7.627	99.87	832.8	52.28	15.93	88.23
Under volatile weather conditions (temperature change)								
P&O	959.9	133.7	7.18	97.62	832.1	52.36	15.89	86.68

5. CONCLUSION

The principal goal of this work is to provide a proposed simulated model intended for a solar PV system that uses the P&O technique for MPPT that focuses on building an effective as well as optimization scheme was achieved. The MPP tracker must match its load to the maximum available power from the most electrically efficient PV generator. P&O algorithms were integrated into the MPPT controller to achieve this. The aforementioned algorithm controls the buck converter's duty. The position MPP of a PV module varies when solar radiation and module temperature increase. In a MATLAB/Simulink environment, the typical technique is implemented. The P&O controllers improves a normal P&O regulator in terms of MPP performance. It has the ability to decrease disturbed voltage once it is recognized. Many nations in the globe are positioned in the tropical and temperate belts, somewhere sunshine intensity can approach 1000 W/m^2. The preeminence of a P&O algorithm may be observed from the outcomes displayed in results by way of simulated features might also show the effect of environmental conditions such as temperature and irradiance fluctuations and compared to the conventional approach P&O, attained greater efficiencies of 88%.

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