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Effect Of Improving Perturb And Observe Mppt Algorithm On AC Grid Connected Pv Sytems

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Abstract: *Photovoltaic energy systems have an important role in electricity generation. Although photovoltaic systems are renewable, environmentally-friendly, silent and non-fuelled, they still have various disadvantages such as high investment cost and low efficiency. In order to get highest efficiency from photovoltaic systems in different operation conditions, solar panels and arrays should be operated at maximum power points. At maximum power point, solar arrays generate the electric energy at maximum efficiency and minimum losses. Some algorithms are used in photovoltaic systems to provide maximum efficiency and minimum losses. The perturbation and observation (P&O) algorithm have been well known algorithm. Although it is an easily applicable algorithm, it has important ripple problems when it reaches to maximum power point. This paper introduces an improvement on conventional P&O algorithm to eliminate ripple problem and it applied on grid connected system. In this approach, ripples are eliminated by obtaining reference current value under variable and constant solar irradiation conditions. This algorithm proposes variable power perturbation with fill factor. In the end, it was evaluated along with simulation, experimental results.*

Keywords: *DC-AC power converters, maximum power point tracking, P&O algorithm, solar power generation*

1. Introduction

Along with the development of global industrialization, human's energy demand is increasing day by day [1]. Photovoltaic (PV) systems produce a significant amount of the electrical energy used around the world. PV modules are now commercially usable for small and large scale applications like roof mounted panels and solar farms. Similarly, the power electronic systems have been put on the market for processing the electric power generated with photovoltaic system for both on-grid and off-grid applications [2]. In recent years, studies about solar cells have focused on minimizing the costs and maximizing the conversion energy efficiency. To maximize the efficiency of photovoltaic energy conversion systems, solar panels should be operated at maximum power points. In maximum power point, solar panels generate the electric energy at maximum efficiency and minimum losses. Solar cells have variable current and voltage characteristics and maximum power point depends on solar irradiations and ambient.

Therefore a maximum power tracking control should be made rapidly in different temperatures and different solar irradiation atmospheric conditions. MPPTs are developed to capture maximum power level in variable conditions [3, 4].

In Figure 1, typical I-V and P-V curves of a solar cell are illustrated. These curves show that solar cells are the power sources dependent on solar irradiation and ambient temperature.

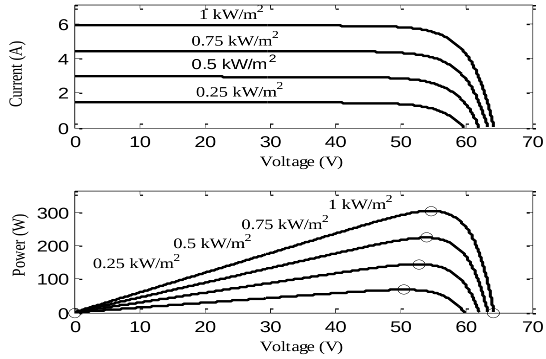

Figure 1. Typical I-V and P-V curves

Determining the suitable converter and inverter types are an important issue for MPPT design. Buck, boost and buck-boost, dual types are mostly preferred. Additionally, several converter types and inverters have been studied and proposed in literature.

In conventional PV energy conversion systems there is a serial connected solar panel, DC/DC converter and inverter with AC load as seen in Figu 2.

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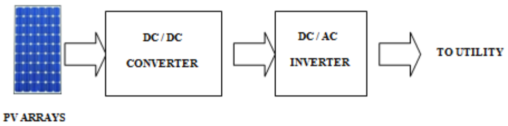


Figure 2. Conventional PV Energy Conversion System

In the literature, both converter design and MPPT algorithms have been studied and presented so far. To reach maximum power point faster, several algorithms such as perturbation and observation (P&O) [5, 6], incremental conductance [7], look-up table, current control loop [8, 9], fuzzy logic were proposed and applied.

This study go around on an optimization of P&O algorithm. Conventional P&O algorithm causes the ripples (oscillations) even if it reaches maximum power point because of its structure [10]. This difficulty increases the power losses and hardens the control actions. Hence, some calculation procedures of convantional P&O algorithm were modified and the ripples were corrected completely.

2. Design and Modelling of Solar Cell, Boost DC/DC Converter and Inverter

As the sun light hits on PV cells, photo-voltage and photo-current act like a forward diode on a large surface. The current expression emerging as a result of the sunlight hitting on the cell is given in Eqn (1).

$$I = I_{PH} - I_S \cdot \left\{ \exp\left[\frac{q}{A \cdot k_B \cdot T} (V + I \cdot R_L) \right] - 1 \right\} - \frac{(V + I \cdot R_S)}{R_{SH}} \quad (1)$$

In this expression, photo-current, saturation current, load resistance, series equivalent circuit resistance, parallel equivalent circuit resistance, terminal voltage, load current, diode ideality factor, Boltzman's constant and temperature of PV panel are denoted by I_{PH}, I_S, R_L, Rs, R_{SH}, V, I, A, k_B and T respectively [11].The equivalent circuit diagram for a solar cell is shown in Figure 3.

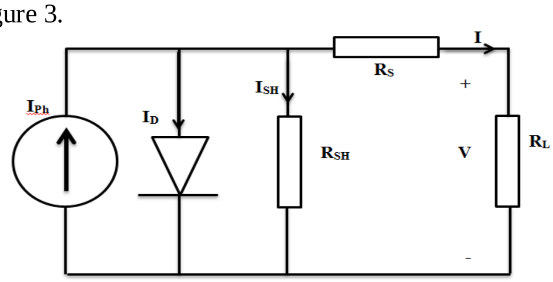


Figure 3. Equivalent Circuit Diagram for Solar Cells

PV panels are built through series or parallel connected of these solar cells.The relation between the voltage of solar cells and current switched on the load indicates I-V and P-V characteristics. Maximum power point for PV systems varies depending on atmospheric conditions, which are the amount of ambient temperature and insolation. Electrical parameters of PV array used in this study are given in Table1.

Table 1. Electrical Characteristics of PV Panel in The Simulations

Variable Name	Parameters
Maximum power at 1000W/m^2(P_{max})	85 W
Short-circuit current (I_{sc})	5.45 A
Open-circuit voltage (V_{oc})	22.2 V
Current at P_{max} (I_{mpp})	4.95 A
Voltage at P_{max} (V_{mpp})	17.2 V

Boost converter, as its name implies, is a structure that boosts the voltage. Its simplified circuit diagram is shown in Figure 4. In PV systems, input voltage defined as Vs is the voltage in the panel while output voltage, defined as Vo, is the battery or load voltage. In these circuits, conversion rate is higher than one since output voltage exceeds input voltage.

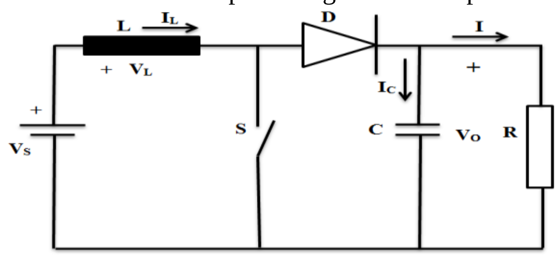


Figure 4. Circuit diagram for boost DC/DC converter

S is a switching component such as MOSFET or IGBT. d is duty cycle which denotes relative conduction time, which equals to switching element conduction time (t_{on}) divided by signal period which is the total conduction and cut-off time ($T = t_{on} + t_{off}$). d is given by Eqn (2).

$$d = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T} \quad (2)$$

The conversion is performed as follows: While switching element (S) turns on, source injects energy to inductance through driving current over inductor. So inductor stores some energy by generating a magnetic field. When S turns off, current flows to the load. But current is going to reduce as the impedance is higher. The relationship between output voltage and input voltage is as follow Eqn (3).

$$V_{PV} = Vs = \frac{1}{1 - d} \quad (3)$$

2.1. DC to AC Conversion

Inverters, known as DC/AC converters, alter the DC power output from the photovoltaic array into AC power. The general tasks that such an inverter must accomplish are two. They must alter, as efficiently as possible, DC to AC power, and they must accomplish this in away that does not expose the PV panel or array to damaging amounts of feed back from the grid connection. A wide variety of inverter designs exist, but normally contain many common components [12, 13].

They are switched at line frequencies. This altering is done after the MPPT converter, takes the output power from that section of the system and alters to available AC power. The basic term is to use sets of transistors paired together and fired in pulses to alter the DC into a rough AC response, in the style of a step function. Circuit diagram is given in Fig. 5.

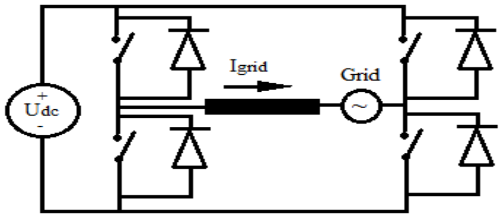


Figure 5. Circuit diagram for DC/AC converter

Particularly significant is the option of a switching rate and transformer combination. Switcing rate transistors in this kind of layout can range up to 15-20 Khz range, and as switching speeds are increased, temperature losses are introduced in the silicon transistors which are employed in almost all current inverters. Recent transistor technologies, such as SiC and GaN transistors are being developed and show promise for lower losses at higher switching speeds, but have yet to be widely deployed in commercial models. It is very important to find the switching speed for each converter design so as to maximize effiency, reduce switching and operating losses.

3. Essentials of Perturbation and Observe Algorithm

P&O algorithm is the most commonly used approach in practice owing to its applicability. It enables to make a decision through analyzing the change in output power following a tentative voltage increase and decrease in PV system [14]. This algorithm is also called as "hill climbing". P-V curve of solar panel is used in this algorithm. The amount of change (ΔP) in solar panel is measured following a deliberate slight increase. If ΔP value is positive, operating voltage is increased again, which causes PV panel operating point to reach its maximum power point. In other words, output voltage is monitored constantly and it is determined whether to decrease or increase reference after a correlation between control variable and power movements is established. This algorithm and changing values are given in Table 2.

Table 2. Summary of P&O Algorithm

Perturbation	Change in power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

As seen above, this method includes maximum power tracking through ripple around maximum power point. It is preferred due to its simple structure. P&O algorithm is a useful MPPT algorithm as far as PV energy conversion where changes in sun light radiation are constant or slowly atmospheric conditions available [14]. This problem can be solved to decrease the perturbation step; but the tracking response will be slower. In rapidly changing weather conditions, P&O algorithm can occasionally make the system operating point far from the MPP. Power reference current measured in this method is increased by a constant ΔI reference current increment and ΔI coefficient is used to determine whether the power changes or not.

It is based on the principle that an increasing in the power increases current in the same direction while a decreasing leads to a direction change, thus causing a decrease in reference current. Adding or subtracting constant coefficients leads to ripple around maximum power point. These ripple problems may be reduced by improving P&O algorithm. In the following sections, the modified algorithm will be presented. Flowchart of the conventional P&O algorithm is given in Figure 6 [7].

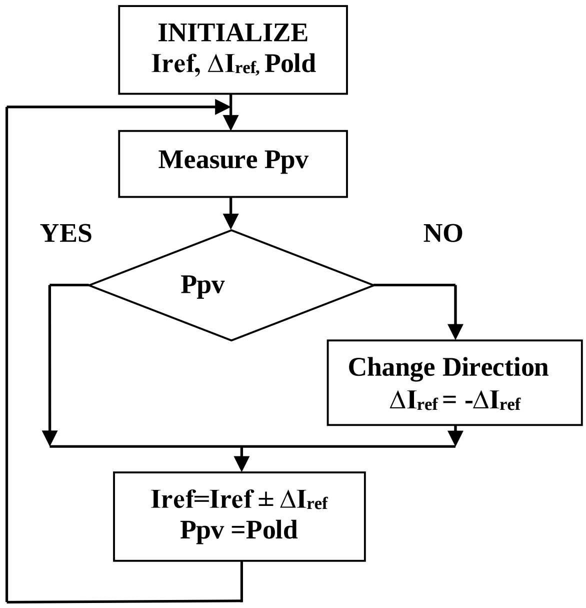


Figure 6. Basic flowchart implementing the conventional P&O Algorithm

4. Proposed P&O Algorithm Modification

In the proposed algorithm, ΔP (denoting amount of power change) and k (fill factor of solar cell; the ratio of maximum obtainable power to the product of the open-circuit voltage and short-circuit current) are used in order to attain maximum power point in proportion to an increase or decrease instead of constant ΔI coefficient. In other words, a parallel coefficient was provided for power change to faster identify maximum power point. In case of no power change (ΔP=0) or ΔP ≤ Ɛ, no iteration was performed and ripple was minimized. Conductance error is a (Ɛ) of the present measurement and the recorded conductance G_{mpp} is characterized in $\mathcal{E} = i/v - G_{mpp}$[14] and value of Ɛ is too close zero. This Ɛ value can generate ripple under the variable solar irradiation [15]. If I_{ref} is > I_{refH} or if $I_{ref} < I_{refL}$ then P_{old} is to be equaled to P_{new}. (I_{refH} and I_{refL} are reference current limits of the DC/DC boost converter). Flowchart of proposed modification is seen in Figure 7.

Fill factor (k) also determines the quality of solar cell. In PV system design, solar cells must have at least 0.7 of fill factor or above. Mathematically, fill factor can be expressed by the following Eqn (4) [16].

$$\text{Fill Factor (k)} = \frac{V_{mpp} I_{mpp}}{V_{oc} I_{sc}} \qquad (4)$$

The proposed approach is designed in order to prevent ripple emerging during attempts to identify maximum power point of the conventional algorithm and to faster identify this point following significant power changes.

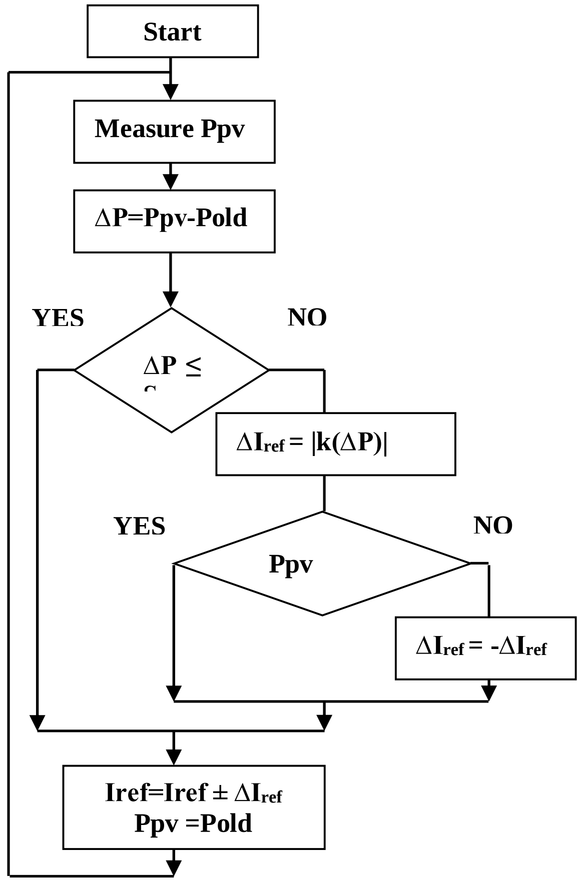


Figure 7. Flow Chart for Proposed P & O Algorithm

The proposed approach is designed in order to prevent ripple emerging during attempts to identify maximum power point of the conventional algorithm and to faster identify this point following significant power changes. In this approach, $\Delta P = P_{pv} - P_{old}$ denotes power change. When reference current of panel and converter is increased or decreased in accordance with this power change, it is found out in the simulation results that ripple is reduced and reference current at maximum power point is identified sooner. In case of no power changing, no iteration is performed. In this case, ripples around maximum power point are eliminated.

If changing in power increases, iteration coefficient will increase. Otherwise, iteration coefficient decreases. The direction of algorithm is defined by $\Delta I_{ref} = -\Delta I_{ref}$. On the left side of MPP, if current increases, power will increase and if current decreases, power will decrease, too. Oppositely, on the right side of MPP, when current increases, power will decrease and when current decreases, power will increase, too. Therefore, when reference current is changed,(if there is an increasing in power) changing on same way should be kept on (ΔI_{ref} which equals absolute value ΔP should be added). If there is a decreasing in power, changing should be continued in an inverse way. (ΔI_{ref} should be subtracted). Thus, a more determined algorithm is developed.

In Figure 8, MPPT block structure where simulation is performed. MPPT is a power tracking system which enables to obtain maximum power from PV panels. In MPPT block, DC/DC converter is controlled by P&O algorithm through producing reference current. As a result, the maximum power level from PV panel is reached.

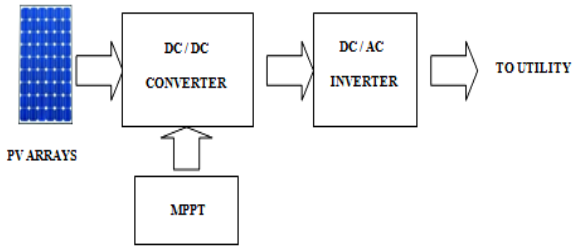


Figure 8. Essential block of studied system with MPPT

5. Comparison of Conventional and Proposed P&O Algorithms

In simulations, three cases are considered to compare both algorithms. In the first one, outputs of PV panels are considered when insolation increases. In the second one, the same parameters are also considered with output of inverter when insolation constant.

Case I; Results obtained from the modeling in Matlab are presented in case I. Solar irradiation is 980W/m^2 at starting point. Irradiation is increased to 995 W/m^2 linearly until 8th second.

A linear increase was simulated in the system as seen in Figure 9(a). A solar irradiation is changed from 980W/m^2 to 995 W/m^2 during eight seconds linearly. Figure 9(b) and 9(c) show the results of conventional and proposed methods. Ripples in reference current are eliminated as seen in Fig 9(b).

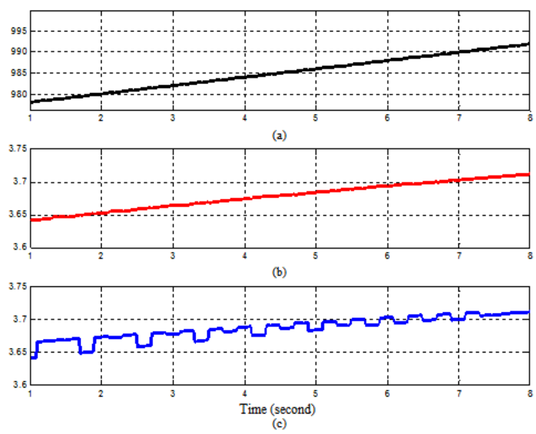


Figure 9. (a) Solar insolation (b) reference current in proposed method (c) reference current in conventional method for Case I

It can be clearly seen from Figure 9 that the modified P&O algorithm removes ripples around the MPP under various insolation levels for output current of PV panels which are connected series.

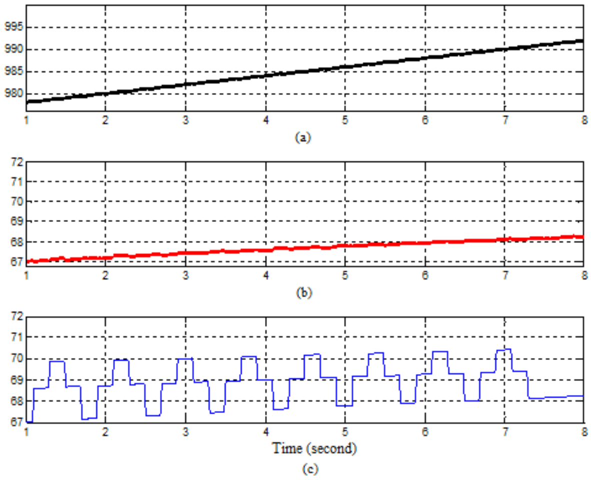


Figure 10. (a) Solar insolation (b) array voltage in proposed method (c) array voltage in conventional method for Case I

Similarly, Figure 10 shows us the success of proposed method. Although voltage ripples (Fig. 10c) are much more than current (Fig. 9c) in conventional method, the voltage ripples are eliminated successfully too. Power variations for case I are also given in Figure 11. The same results are obtained from the power.

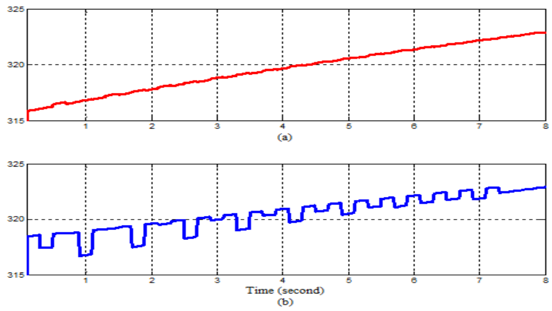


Figure 11. PV panels output power in (a) proposed, (b) conventional P&O algorithm for Case I

Case II; In case II, a constant insolation was applied in the system at 1000 W/m^2. In view of this value, the convantional P&O algorithm and response of identical system operated by modified method were compared for output voltage and power of PV panels. Voltage and power responses are compared in Figures 12 and 13.

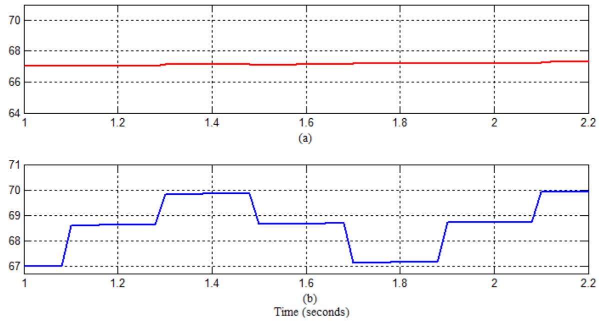


Figure 12. Panel voltage (V) in (a) proposed, (b) conventional P&O algorithm for Case II

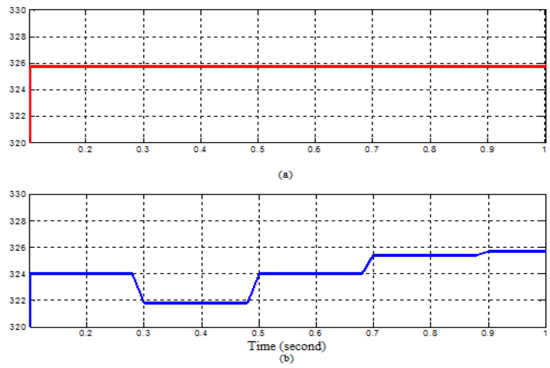


Figure 13. PV panels output power in (a) proposed, (b) conventional P&O algorithm for Case II

It can be clearly seen from Figure 12 that the proposed algorithm (a) removes the ripples around the MPP under constant insolation levels for output voltage of PV panels.

As it is seen in Figure 13, While the proposed algorithm reached the maximum power instantly, which is close 326 W, the conventional algorithm reached less power at 0.9th second. As it can be seen here, the proposed algorithm reached maximum power point in a shorter time with a higher rate of power under constant insolation.

Case III; In this case III, a constant insolation was applied in the system at 1000 W/m^2 similar to previous case. In this case, a DC/AC inverter is added to simulation and filtered AC side waveforms are obtained.

The control variable for the DC/AC inverter [17] is the RMS current reference I_{RMSref} and the inverter output current $I_{ac}(t)$ is controlled so that it is in phase with the load voltage $V_{ac}(t)$ and so that its RMS value equals the reference current from P&O algorithms.

As given in Figure 14, RMS currents of inverter in conventional and proposed algorithms have 4.80 ampere and 4.96 ampere respectively. Similarly, in the proposed method output power reaches to 727.5W while conventional method reaches to 714.5W as seen in Figure 15.

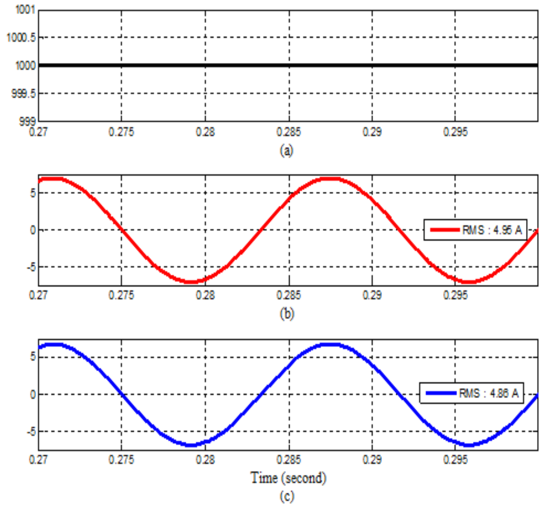


Figure 14. (a) solar insolation (b) ac side current in modified algorithm (c) ac side current in conventional algorithm for Case III

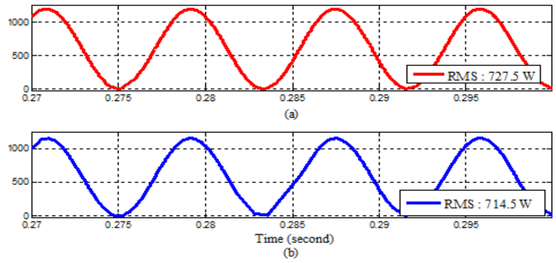


Figure 15. (a) AC side instantaneous power in modified algorithm (b) AC side instantaneous power in conventional algorithm for Case III

The results obtained from the three cases above show that both algorithms reach assumed values at the end of this process. Additionally, in conventional algorithm, some ripples occur and maximum power point is attained slightly later with less power value. Particularly, it is seen from Figures 9-13, current, voltage, power ripples continued for a specific period of time. These ripples affected total efficiency of the system negatively, too. Losses may be encountered due to changing parameters as a result of ripples.

As these results also suggest, ripples persist in conventional methods. These ripples pose disadvantages because they affect total efficiency of the panel and extend MPPT identification time.

6. Comparing the success of both methods according to step sizes under variable solar irradiation conditions

In this section, effects of iteration step sizes on performances of proposed and conventional methods are investigated. In the proposed algorithm, there was adopted ΔP with fill factor (k) in order to attain the maximum power point instead of a constant step size. When it is reached to the maximum power point, the iteration, which causes power loss, has been impeded In this case; maximum power point has been attained more quickly and with a higher power performance.

In Figure 16 and 17 the variable step size used in proposed algorithm has been compared with constant small and large step sizes used in conventional algorithm under variable insolation conditions.

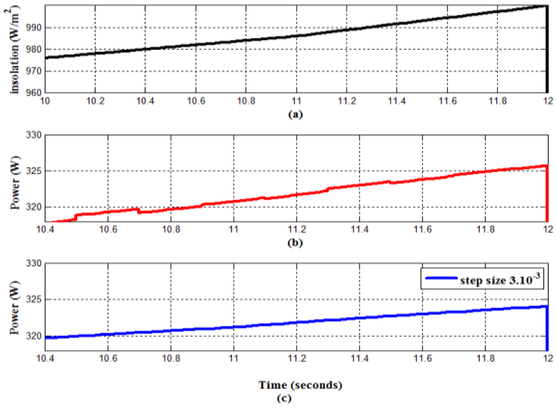


Figure 16. (a) Solar insolation (b) DC side power for variable step size in proposed method (c) DC side power for constant step size in conventional method

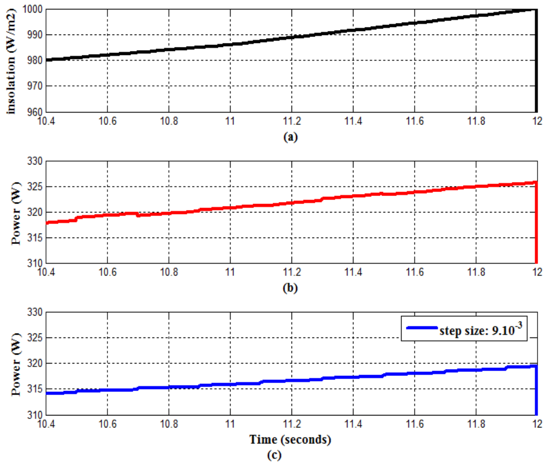


Figure 17. (a) Solar insolation (b) DC side power for variable step size in proposed method (c) DC side power for constant step size in conventional method

Similarly, when Figure 16 and 17 are observed, it is seen that the modified method reached a higher rate of power in a shorter time when compared with constant small and large step sizes used in conventional method.

7. Experimentals Results

The experimental setup used in this paper included a PV panel, a boost DC/DC converter, a microcontroller board (Arduino Uno) and battery. The PV panel is 10Wp TPS 105 monocrystalline module. Experimental setup is pictured in Figure 18.

Experimental setup is explained as follows :

- The rate of the duty cycle produced by the algorithm that is transmitted into Arduino Uno is taken from the PWM exit and this way boost DC/DC converter is controlled.
- The current data is provided through MAX4173H current sensor and voltage data is provided by voltage divider resistors.
- PWM signal is obtained by transmitting current and voltage data through Arduino board.
- The processor (ATmega328) in Arduino board controls the DC/DC converter by generating a PWM signal that switches the MOSFETs at a 50 kHz frequency.

- On the left side of the experiment setup, there is a PV panel input while on the right side of it there is a DC output that recharges the battery (load).

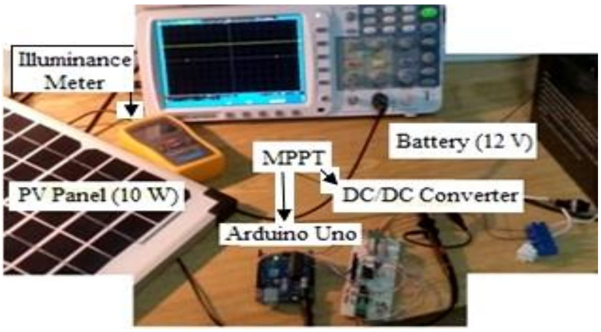
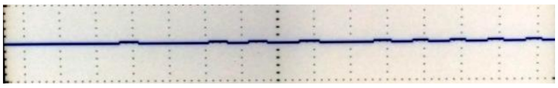


Figure 18. Experimental setup for the proposed PV system

Conventional and proposed algorithms produce output voltage as seen in Figure 19 under constant insolation. it gets clear that the modified P&O algorithm has done better in eliminating ripple than conventional P&O algorithm.

The experimental and simulation output voltages are similar in Figure 19 and Figure 12 respectively under the same conditions.

(a)



(b)

Figure 19. Scope screen belongs to output voltages in (a) conventional, (b) proposed algorithm (illuminance: 729 W/m^2, Time/div:1 Gs)

8. Conclusion

Photovoltaic energy is a wide kind of green energy, PV system efficiency have a low and depends on many equipment and parameters. Additionally, efficiency and losses in converter circuit and algorithms that set the basis for MPPT are among factors which may negatively influence total efficiency. Slow response rate of the algorithm and as stated in this paper, ripples are also important problems.

This study presented on improving algorithm and eliminating ripple problems in P&O algorithm. As a result of this study, it got observable the ripple problem was eliminated as well as a higher power value was obtained on grid system. An improved P&O algorithm is used to modulate the duty cycle of the boost DC-DC converter, inverter, and thus, the tracking speed increased. It is concluded that the proposed algorithm shows better performance than conventional P&O algorithm under changing conditions and it reduces the power losses.

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