Experimental Verification of MPPT Algorithms for Photovoltaic systems

Sachin Angadi, Divya C. Badiger, Udaykumar R. Yaragatti, A. B. Raju

Abstract*: Changing meteorological conditions influence the output power of the Photovolataic systems, which affect the overall performance of the system, in turn reduces the overall efficiency. So, to draw maximal power from the PV system a technique called maximum power point tracking (MPPT) is incorporated. Two perturbations-based algorithms are presented in this paper are Perturb and Observe (P&O), and Modified drift-free perturb and observe (MP&O). Fixed step size duty ratio is used in both of these algorithms. The boost converter is used between the photovoltaic module and the resistive Load. The simulation and experimental results for 250W PV module are presented. The simulation studies are carried out in MATLAB SIMULINK. The algorithms are implemented using TMS320F28069M.

Keywords: Boost converter, Duty ratio, Maximum Power Point Tracking, Perturb and Observe, Modified drift-free Perturb and Observe.

I. INTRODUCTION

Due to the depletion of non-renewable energy sources, it is necessary to make efficient employment of available renewable energy sources [1]. They are used to cater to an increase in electrical energy demand. Among all the available forms of energy, solar energy is more abundant in nature, which is clean and eco-friendly [3]. The PV domain is the most efficient way of generating electricity [15], as it requires low operating costs. There is one unique point in the power versus voltage graph, where generated energy is maximum called maximum power point [6]. Maximum power point trackers are being used to make our system to operate at MPP [4].

Generally, the system will not function at MPP, where we can extract maximal power. [7] The Boost converter is adopted as an interface amid the photovoltaic module and the resistive load. It matches the load impedance to the source impedance by varying the duty ratio appropriately, so that energy transferred is maximum to the load.

Algorithms presented in this paper make use of direct duty ratio control under varying weather conditions because basic electrical quantities (Voltage, Current) of PV is given as inputs to the controller. There are many methods proposed for MPP Tracking [14].

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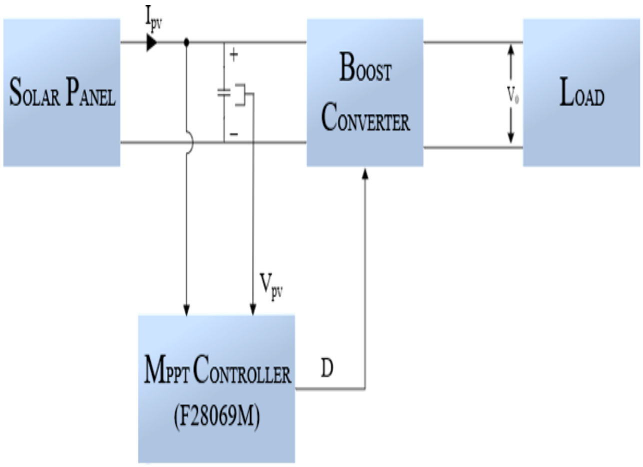


Fig. 1.Photovolatic System Block Diagram

The widely implemented algorithm is Perturb and Observe, which is the simplest and performs quick convergence. P&O algorithm involves perturbation in operating voltage [9]. There are numerous maximum power tracking methods. Constant voltage method, Fractional short circuit current, Fractional Short circuit voltage, P&O, and MP&O. The Constant voltage method is the most simple and low-cost MPPT controller [16]. It only takes PV Voltage as input, but the efficiency is very poor under varying environmental conditions, constant voltage method can be implemented in regions where there are no abrupt changes in ecological terms.

Fractional short circuit current is a fast and straightforward way of finding the MPP. But it does not track the exact MPP more accurately. The drawback of using this Algorithm is that there will be a periodic loss in power while measuring the short circuit current. Fractional Open Circuit Voltage method is similar to that of Fractional open circuit current method. It also does not track the exact MPP. There will be a power loss while measuring the open-circuit voltage.

The drawback of this Algorithm is, it does not make an accurate decision under varying weather conditions [11]. The operating point is made to vacillate, around the peak point. The modified drift-free P&O Algorithm with experimental proof is presented to address the weaknesses of the P&O algorithm [5], [10], [12]. Modeling and simulation are carried, on MATLAB SIMULINK.

In section III, the modeling of photovoltaic, P&O, and MP&O is explained with relevant mathematical equations. The experimental setup is described in section IV. In section V, implementations of the MPPT algorithm are discussed to choose the best algorithm for MPPT tracking. The conclusion is given in the conclusion section VI.

II. SYSTEM SPECIFICATIONS

The PV system block diagram is illustrated in Fig.1. It comprises of PV module, boost converter, MPPT controller, and the resistive load. The module generates electrical energy by the application of solar light on its surface. The electrical quantities such as voltage and current from the PV module are

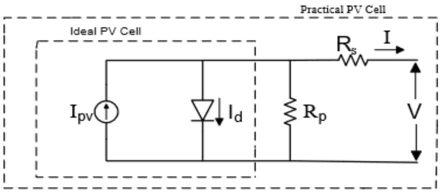


Fig. 2. PV cell Equivalent circuit

given as inputs to the MPPT controller. The controller decides the duty ratio, to where the maximum amount of power can be generated. The duty ratio is given as an input to the dc-dc converter.

III. MATHEMATICAL MODELING

A. Mathematical Modeling of PV Cell

A Fig. 2 represent the ideal and practical PV cell. The solar PV system is composed of photovoltaic cells. Cells are arranged to form panels, and panels are grouped to constitute an array [8]. The mathematical equations are defined below. The PV cell equation is given in (1).

$$I = I_{ph} - I_0\left(\exp\left(\frac{V + I.R_S}{V_T}\right) - 1\right) - \left(\frac{V + I.R_S}{R_P}\right) \tag{1}$$

I_{ph} = Insolation current [A]
I = Total current of the cell [A]
I_o = Reverse saturation current [A]
V = Total Voltage of the cell [V]
R_s and R_p = Resistances [ohms]
V_T = Thermal Voltage [V]
The Total Current I is given by (2)

$$I = Iph - I_D - I_{RP} \tag{2}$$

Where I_{RP} is the current through resistance R_p. The diode current is given by,

$$I_D = \left(\exp\left(\frac{V + I.R_s}{V_T.N_s}\right) - 1\right)I \tag{3}$$

Where N_s = Total cells connected in series.
Shunt resistance current is given by (4),

$$I_{RP} = \left(\frac{V + I.R_S}{R_P}\right) \tag{4}$$

Insolation current is given by (5),

$$I_{ph} = [\mu_{sc}(T_c - T_{ref} + I_{sc})]G_{pu} \tag{5}$$

Where, μ_{sc} Coefficient of short circuit,

T_c : Operating condition temperature,

T_{ref} : Temperature of reference

The reverse saturation current is given by (6):

$$I_o = I_{sc} / \exp\left(\frac{q.V_{oc}}{\eta.K.T_c.V_T}\right) \tag{6}$$

K : Boltzmann's constant ($1.381\text{x}10^{-23}$) [J/K]

q : Charge of an electron ($1.602\text{x}10^{-19}$) [C]

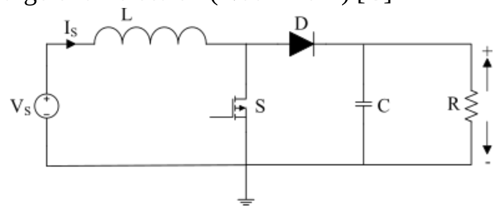


Fig. 3. Schematic of Boost Converter

B. Boost Converter

Fig. 3 gives the schematic of the PV fed boost converter. It boosts the voltage at the output terminal. For charging applications boost converters are being used. It is also called a step-up transformer. The boost converter is employed to transfer maximal amount power to the load [2].

The equation that connects input (V_S), output voltage (V_o), and the duty ratio is computed as:

$$Vo = \frac{Vs}{(1-D)} \tag{7}$$

Inductance minimum value is:

$$L_{min} = \frac{(1-D^2)DR}{2f} \tag{8}$$

where, D = Duty ratio
R = Resistance of Load [Ω]
f = Switching frequency [Hz]
Capacitance minimum value is given by (9),

$$C = \frac{D}{R\left(\frac{\Delta Vo}{Vo}\right)f} \tag{9}$$

The Relation between the Duty ratio, R_{mpp}, R_{load} is given by (10).

$$R_{mpp} = \frac{R_{load}}{(1-D^2)} \tag{10}$$

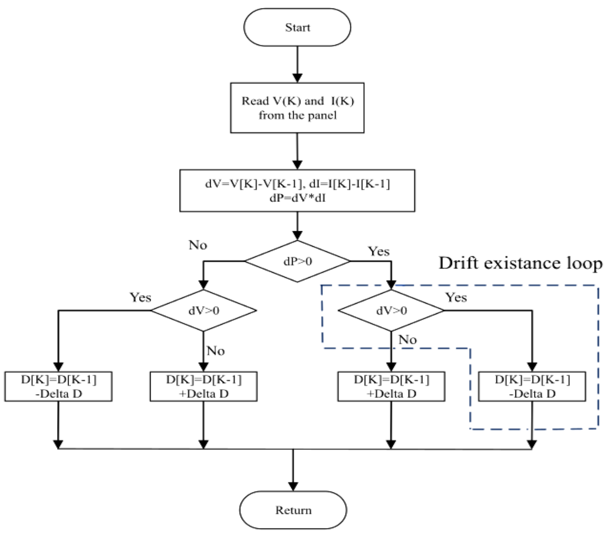


Fig. 4.P&O Algorithm Flowchart

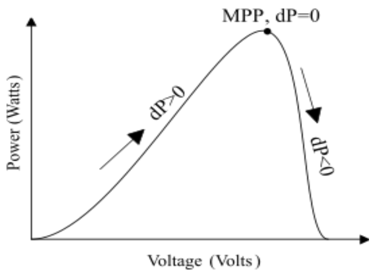


Fig. 5.P-V Characteristics of P&O Algorithm

C. Perturb and Observe

P&O is the primary algorithm employed in the MPPT algorithm (Fig. 4). The power versus voltage characteristics is given in Fig.5. It perturbs the voltage under changing environmental conditions. The dP increases at the left side of maximum power point decreases at the right side of maximum power point and is zero at maximum power point. Power changes with changes in irradiance and temperature values, with changes in power, duty ratio, adjust itself accordingly. The duty ratio fluctuates around the MPP. The dV and dP, are obtained by calculating the Variation between the voltage and power values at K^{th} instant to that of the $(K+1)^{th}$ instant. In this algorithm, it examines the power and voltage values at two different instants and makes the decision.

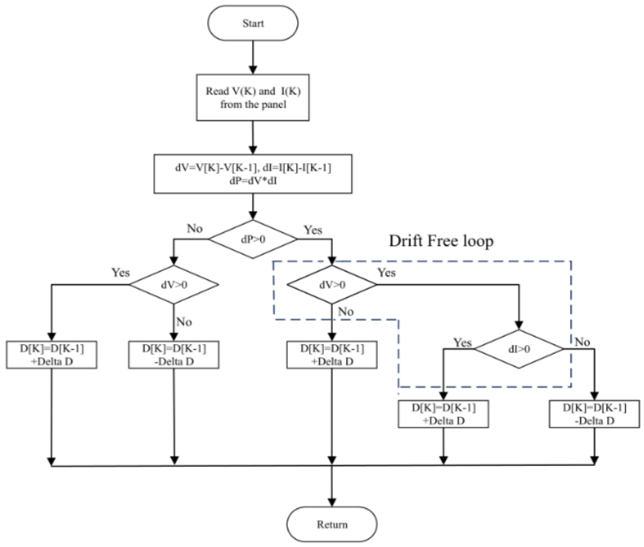
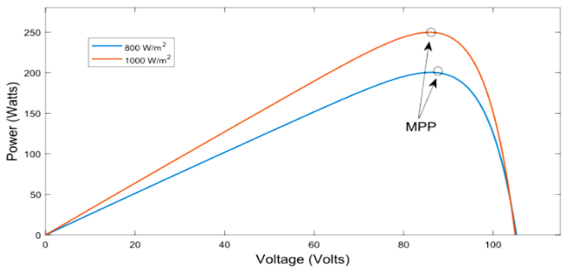


Fig. 6.Modified drift-free P&O Algorithm Fowchart

D. Modified drift-free P&O

The P&O algorithms shortcoming is its tracking ability under varying environmental conditions and poor dynamic performance when a level variation in irradiance value occurs.

Flowchart of modified P&O algorithm given in Fig.6. The algorithm overcomes the problem of drift by comparing the voltage and current values and accurately adjusting the duty ratio. The conventional algorithm compares voltage and power and takes the decision, but in this algorithm, if the voltage and power condition in the flowchart is true, it also examines the current to make a decision [13].



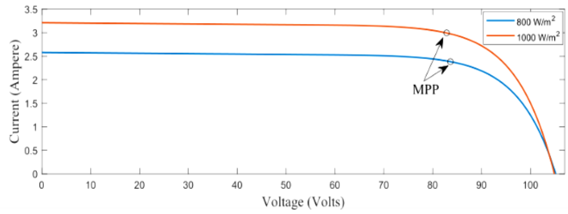


Fig. 7.Current versus Voltage curve

Fig. 8.Power versus Voltage curve

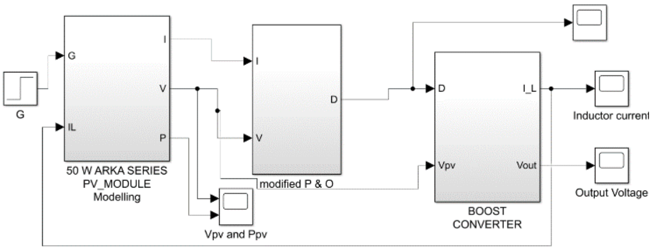


Fig. 9.Fig. 9.Simulink model of MPPT system

Table- I: Solar PV module specifications

Parameters	Values
Maximum System Voltage	1000 V
Open Circuit Voltage V_{oc}	21.0 V
Short Circuit Current I_{sc}	3.17 A
Maximum Power P_{max}	50.0 W
Current at $Pmax$ (I_{max})	2.94 A
Voltage at $Pmax$ (V_{mpp})	17.0 V
Load Resistance R_{load}	250 Ω

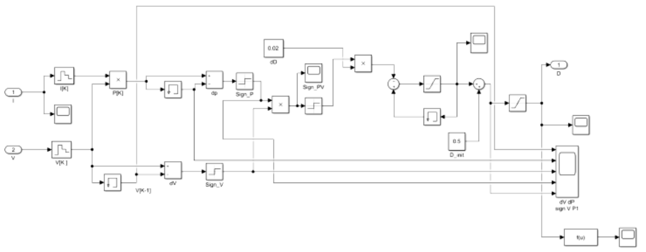


Fig. 10. Fig. 10. P&O Algorithm SIMULINK model

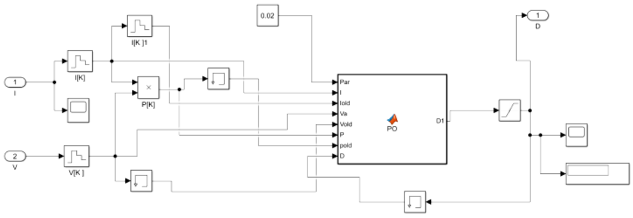


Fig. 11. Fig. 11. Modified P&O SIMULINK model

IV. RESULTS AND DISCUSSIONS

A. Simulation studies

Fig. 7 & 8 give the I-V and P-V characteristics respectively for 800 W/m² and

1000 W/m^2 irradiance values. The PV system Simulink model is given in Fig. 9. The data in Table- I indicates the PV module specifications. In this paper, the value of one inductor is 560μH. Six such inductors are connected in series which will sum up to 3.36mH. Input capacitance of 1250μF is chosen to extract V_{pv} from the PV system. Output capacitance is 2350μF. The Simulink model of both the presented algorithms is given by in Fig. 10 & 11 respectively.

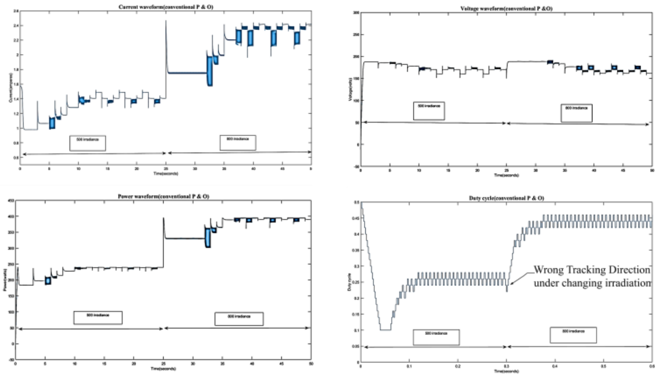


Fig. 12. Fig. 12: Current, voltage power and duty cycle waveforms for Conventional P&O MPPT at irradiance values from 500 W/m2 – 800 W/m2

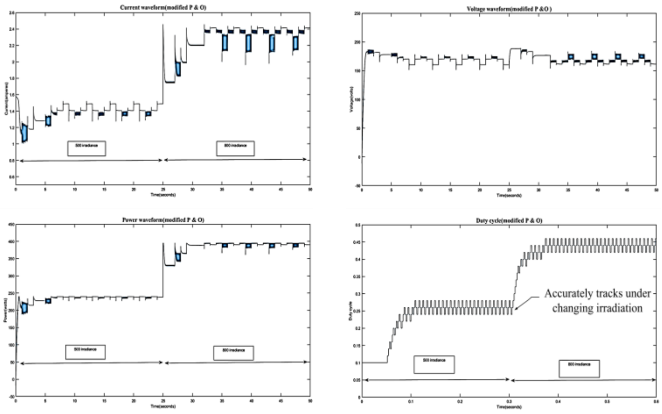


Fig. 13. Fig. 13: Current, voltage power and duty cycle waveforms for modified drift free P&O MPPT at irradiance values from 500 W/m2 – 800 W/m2

The simulation results of both algorithms are presented in Fig.12 and Fig. 13 respectively.

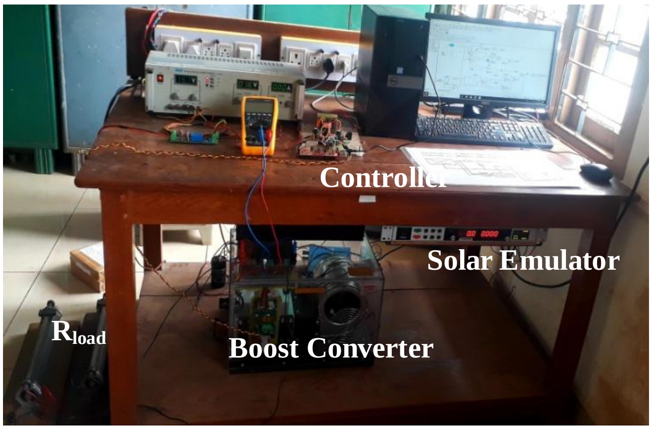


Fig. 14. Fig. 14. Hardware setup of MPPT system

Table- II: Hardware Component specifications

Parameters	Values
PCV-2-564-08L (Inductor)	560 μ *Henry*
SKC 3M3-45A-3 (Capacitor)	1250 μF, 2350 μF
Current sensor (LA25-P)	-
Voltage sensor (LV25-P)	-
F28069M microcontroller	-
IGBT (SKM200GB1234)	-
Load Resistance R_{load}	200 Ω

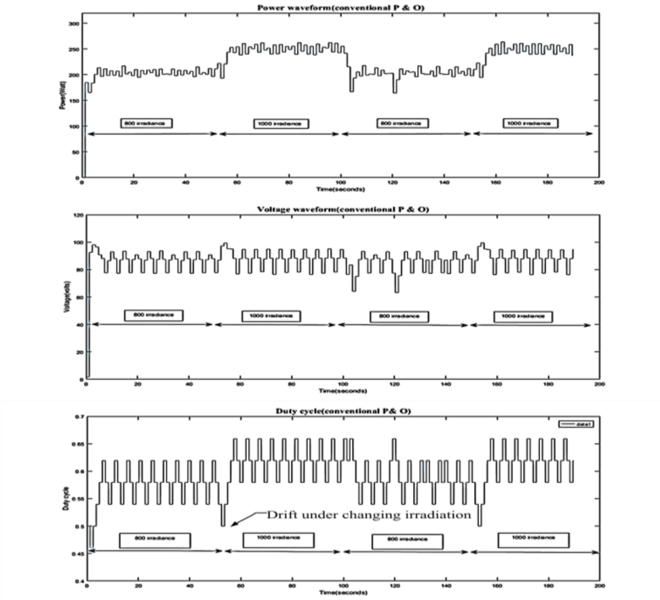


Fig. 15. Fig. 15: Current, voltage, and duty cycle waveforms for Conventional P&O MPPT at irradiance values from 500 W/m2 – 800 W/m2

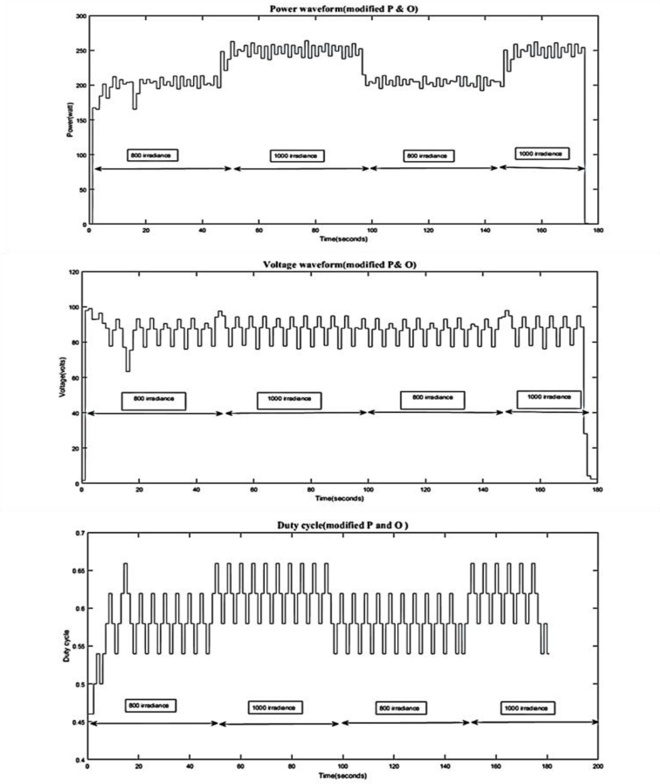


Fig. 16. Fig. 16: Current, voltage, and duty cycle waveforms for modified drift free P&O MPPT at irradiance values from 500 W/m2 – 800 W/m2

B. Experimental Setup and Results

Fig. 14 shows the complete Hardware setup consisting of R_{load}, boost converter, solar emulator, and TMS320F28069M microcontroller. The data in Table- II indicates the hardware specifications. The power, voltage, and Duty ratio graphs of conventional and modified algorithms are shown in Fig. 15 & 16 respectively. The step size was chosen to be 0.02. Modeling of the algorithms was made such that it adjusts duty ratio under varying environmental conditions.

C. Comparison of Experimental results of Conventional P&O and Modified drift-free P&O algorithm

The modified drift-free P&O is tested for a varying irradiance from 800 to 1000 W/m^2. Both the algorithms are efficiently tracking their corresponding MPP, due to drift in P&O algorithm its accuracy reduces. Duty ratio comparison of both the explained algorithms is shown in Fig. 17. Whenever there in change in irradiance occurs, the P&O is tracking in the wrong way and adjusts itself in the right direction after some time, which may lead to power loss. At the same time, drift-free algorithm tracks the MPP accurately. Likewise, the voltage and power comparison of both the algorithms is shown in Fig.18 & 19 respectively.

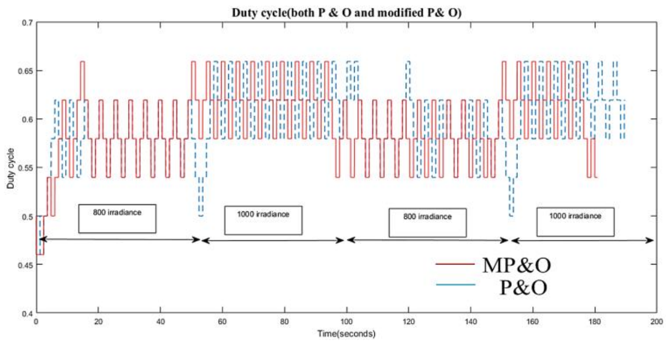


Fig. 17. Fig. 17.Duty ratio comparison

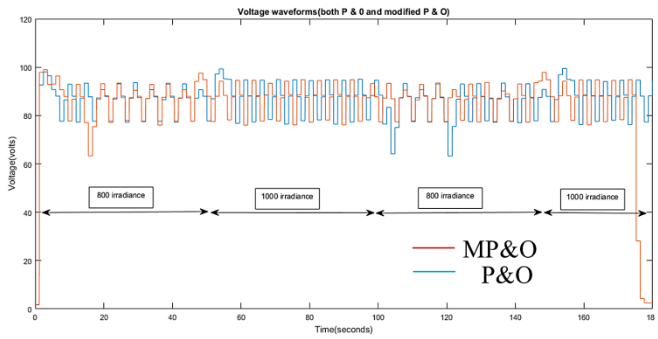


Fig. 18. Fig. 18.Voltage comparison

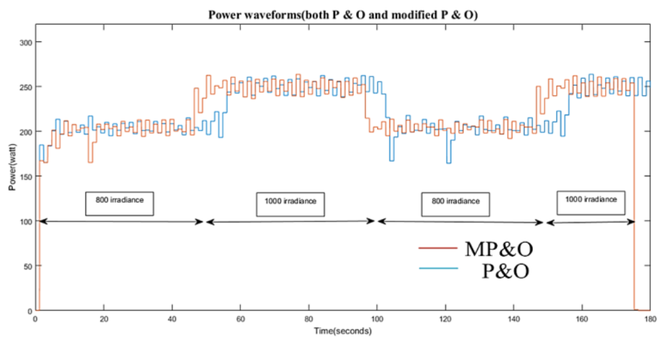


Fig. 19. Fig. 19. Power comparison

V. CONCLUSIONS

The perturbation based MPPT techniques for PV Systems to track MPP were presented in this paper. The perturb and observe and modified drift-free perturb and observe algorithms are modeled using MATLAB SIMULINK. An MPPT algorithm with a DC-DC boost converter is discussed, fixed iteration step size is used for these algorithms.

P&O Algorithm suffers from drift under varying irradiance and temperature values. Simulated MP&O algorithm tracks the MPPT more accurately, and examined for all the irradiance values by overcoming the problem of drift. The hardware results are very much complying with the simulation results.

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