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Inverter based implementation of maximum power point techniques

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ABSTRACT

The utilization of renewable energy sources is being pushed by both greater environmental consciousness and expanding demand. Recently, solar photovoltaic technology has found increased use for a broader range of applications. This may be ascribed to solar energy's extensive availability as well as its long-term viability and low cost. According to the global photovoltaic (PV) industry, 594 gigawatts (GW) of PV capacity were installed in 2019, with the objective of replacing conventional source-based generating facilities. The major problem in PV production, however, is identifying the maximum power point tracking (MPPT) systems that are currently in use to compute peak output. For 1240 W PV power plants, this article compares perturb & observe MPPT approaches with incremental conductance MPPT techniques. The MATLAB Simulink program was utilized to conduct the study, which was based on many factors such as voltage, current, and output power under various weather conditions. When these MPPT algorithms are applied to solar trackers, the efficiency, reaction time, and steady-state oscillations all improve.

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1. INTRODUCTION

Renewable energy is used to produce "green energy". The most promising renewable energy generating technique is presently solar energy generation utilizing photovoltaic (PV) technology. PV generating is becoming more popular because to its environmental benefits, ample supply, and economic efficiency. PV cells directly convert solar energy into electricity. Because the power generated is direct current (DC), it must be converted to alternating current (AC) at an acceptable frequency before being sent to the loads. Power converters are thus used to link PV installations to grids. PV system power must be provided to diverse loads through grids via inverters. The primary challenges in integrating a PV system with a grid are the operating characteristics of the load corresponding to the PV array [1]. The intersection of the PV array's I-V curves and the load, which is not always stable, provides the highest power point. On the system, maximum power point techniques are employed to generate a stable and maximum power point (MPP) on the I-V curve. The PV array is modeled for irradiance and temperature data before obtaining the MPP. Since manual calculations are impractical, many software applications are available to calculate different elements such as irradiance and temperature [2]. So, these computer-based methods are centered on creating the algorithm that extracts the greatest electricity from the PV system.

As a consequence, MPPT techniques depend on predetermined algorithms to extract as much power as possible by attaining the MPP. As a consequence of continuous study in this sector, several MPPT algorithms have been proposed. MPPT techniques are used to extract the most power from a PV module depending on the positioning of different PV panel characteristics. The interface between the load and the module is provided by a DC-DC converter [3]. It helps to transmit the maximum quantity of power produced by the solar panel to the load. Peak power and load matching are obtained by varying the duty cycle of the DC-DC converter. As a consequence, numerous MPPT methodologies are used to maintain the MPP of PV modules, including perturb & observe (P&O), inc. conductance, fuzzy logic method, and ripple correlation method [4], [5]. This research has produced the two most reliable ways, P&O and the inc. conductance method. The paper is split into four sections. First, the characteristics of PV cells and PV system modeling are being explored. In the second part, the algorithms for the P&O and Inc conductance techniques are described. The MPPT processes are covered in the third section. In the fourth section, the simulation results of both methodologies are shown using MATLAB Simulink. The fifth section has a conclusion.

2. MODELLING OF PV CELL AND ITS CHARACTERISTICS

A photovoltaic cell, which is also known as a photoactive P-N junction diode, is the primary component that is responsible for converting the solar energy into the usable form of electrical energy. Creating what are known as PV cell panels requires connecting a number of photovoltaic cells in series and in parallel. This is done with the intention of increasing the quantity of power that may be generated. When light energy is absorbed by free electrons in semiconductors, the light energy is then used to excite those free electrons, which causes the free electrons to transition from a low energy band to a high energy band [6]. Free electrons may also be excited by other free electrons. Additional electron hole pairs are generated within a photovoltaic (PV) cell whenever light is shined on the cell. Because of this, the p-n junction behaves as if it were a short circuit, which in turn triggers the passage of an electric current across the circuit [7].

2.1. PV array modelling

Figure 1 presents a single-diode equivalent circuit that may be used for the purpose of analyzing the properties of a PV cell. MATLAB may be used to explore the ideal I-V characteristics of a PV cell by using fundamental semiconductor equations [8], [9]. The Photo current of PV cell is given by (1):

$$I_{ph} = [I_{sc} + K_i(T - 298)] \times Ir/1000 \quad (1)$$

I_{ph}: photo-current (A); I_{sc}: short circuit current (A); K_i: short-circuit current of the cell at 25 °C and 1000 W/m^2; T: operating temperature (K); Ir: solar irradiation (W/m^2). PV cell reverse saturation current I_{rs}.

$$I_{rs} = I_{sc} /[exp(qVOC/NSknT) - 1] \quad (2)$$

Here in (2), q: electron charge, = 1.6 × 10^{-19}C; V_{oc}: open voltage (V); N_s: number of cells connected in series, n: the ideality factor of the diode; k: Boltzmann's constant, $= 1.3805 \times 10^{-23}$J/K.

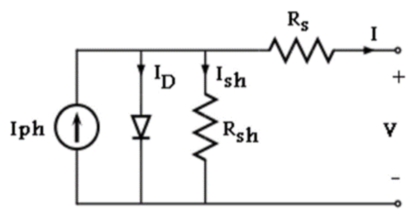

Figure 1. PV cell equivalent circuit

PV cells are the finished product that results from the combining of series and parallel cell configurations [10], [11]. The voltage will increase when the cells are connected to one another in series. However, the current will grow when the cells are linked in parallel to one another. A schematic representation of a circuit that is analogous to the one found in a perfect photovoltaic cell may be seen in Figure 1. The following equation demonstrates its series resistance, Rs, as well as its parallel resistance, Rsh:

$$I = I_{pv} - Io\left[\exp\left(V + \frac{IR_s}{V_t \cdot a}\right) - 1\right] - V + I\,R_s/R_{sh} \quad (3)$$

where $V_t = N_s kT/q$ is the thermal voltage of the array with $'N_s'$ cells are connected in series. Cells connected in parallel increase the current. V and I are the terminal voltage and current [12].

2.2. PV array characteristics

The I-V characteristics of PV cells, arrays, and modules offer the energy conversion capacity and efficiency of the process of converting solar power into usable energy. The solar radiation that hits the PV module, which governs the current (I), and the rise in temperature on the cell, which influences the voltage, are the parameters that are stated (V) [12]. Therefore, the I-V characteristics of a solar cell are the graphical description of the current and voltage relationship for the existing conditions of irradiance and temperature, which provides information about the optimal peak power [13]. For I-V characteristics, it is always suggested to keep the value of the series resistance Rs very low, and the parallel resistance Rsh to be high as compared to the forward resistance of the diode [14], [15]. This is because keeping the value of the series resistance Rs very low allows for more accurate measurements of the I-V characteristics. This is due to the fact that the magnitude of the series resistance, denoted by Rs, has an effect on the way in which the diode responds in terms of current and voltage. The characteristics include the open circuit voltage (VOC), as well as the short circuit current (ISC), at the maximum power point (MPP) for the given temperature and levels of irradiance that are displayed in Figure 2.

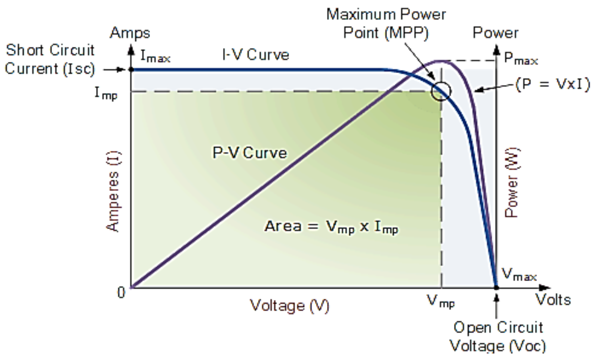

Figure 2. PV cell I-V characteristics

3. MAXIMUM POWER POINT TECHNIQUES

Techniques for tracking the maximum power point are approaches that may be used in any environment to collect the maximum amount of power from a photovoltaic array. The module power point tracker (MPPT) contributes to an improvement in the PV array's efficiency, which is determined by the radiation of the sun that falls on the PV module, the temperature, and the electrical load characteristics that are linked to the system. MPPT devices or methods are incorporated by means of a power electronic converter system. This system is utilized to convert the voltage and current to a needed value after filtering and control in order to drive various applications including power grids, batteries, and motors [16], [17]. The inverter changes the DC power into the AC power and integrates MPPT to acquire the needed MPP for the attained maximum voltage (VMP) and current (IMP) by applying the appropriate load. The inverter also transforms the DC power into the AC power. In this article, the emphasis is on conventional techniques for extracting the maximum amount of electricity from a PV array while maintaining a consistent environment. The impact that partial shadowing has on a photovoltaic array is another topic that is covered in length in [18].

3.1. Perturb and observe (P&O) technique

The approach known as "perturb and observe" is a straightforward method that calls for the use of a control variable, such the voltage, current, or duty ration of the power converter, in order to cause a disturbance in the direction of maximizing available power. Because the current control variable has a very poor transient reaction to changes in irradiance and temperature, the perturb and observe technique often uses voltage as the control variable [19]. This is due to the fact that the transient response of the current control variable is quite poor. This technique combines the data obtained from the direction of the perturbation with the information obtained from the change in power for the value that was disturbed. When the power is at its maximum point of potential, the voltage derivative of the power should be zero. When the derivative is larger than zero, the most probable path is to the left of the origin. In the event that the derivation is negative, the MPP will be located on the right. Figure 3 depicts the flowchart for P&O, and in (4)-(6) determine where MPP falls on the IV characteristics of the PV array. These equations establish the location of MPP.

$$\frac{dP}{dV} > 0, M_{pp} \text{ lies on the left} \tag{4}$$

$$\frac{dP}{dV} = 0, M_{pp} \tag{5}$$

$$\frac{dP}{dV} < 0, M_{pp} \text{ lies to the right} \tag{6}$$

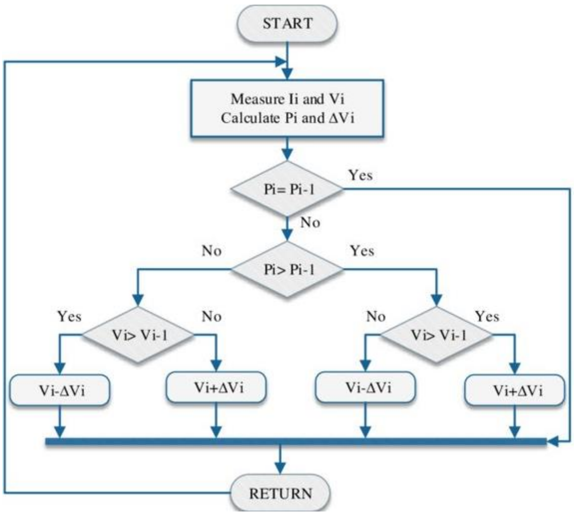

Figure 3. Flowchart P&O technique

The method is commonly used to extract the maximum power because of its simplicity and low cost under stable environment conditions, though rapid change in temperature gives poor results in extracting the power. The main drawback of the approach includes large oscillations and slow convergence for the selected step size. Therefore, a variable step size is proposed to reduce transients and to achieve steady state [20]. Although variable step size affects the performance of the system. Thus, for adaptive control & perturbation PI controller-based P&O technique have been implemented to get better performance of the system [21].

3.2. Incremental conductance technique

The incremental conductance approach is another straightforward procedure that evaluates changes in power in relation to shifts in voltage and current. This analysis is performed using the incremental conductance technique. The flowchart for the incremental conductance approach is shown in Figure 4, and the equation illustrates how the increment of power relates to the change in the instantaneous values of voltage and current.

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \sim I + V\Delta I/\Delta V \tag{7}$$

$$\frac{\Delta I}{\Delta V} > -I/V\ , M_{pp} \text{ lies to the left} \tag{8}$$

$$\frac{\Delta I}{\Delta V} = -I/V, M_{pp} \tag{9}$$

$$\frac{\Delta I}{\Delta V} < -I/V\ , M_{pp} \text{ lies to the right} \tag{10}$$

The incremental conductance is observed to operate in the same conditions as of P&O and has very similar performance characteristics. It would not be used for steady state oscillations as of P&O although its tracking speed is higher due its dependency on two different variables. It is also a very robust technique and its performance can be enhanced by PI controller. The (9) and (10) gives the position of MPP on IV characteristics of PV array.

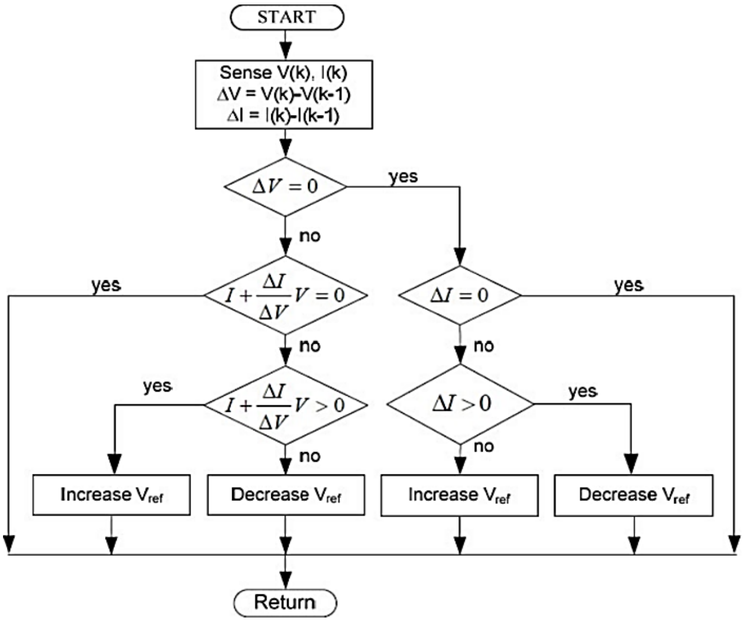

Figure 4. Flowchart incremental conductance technique

4. SIMULATION & RESULTS

The PV array modelling and its characteristics are simulated in MATLAB software. The Shunt resistance is taken as negligible for the open circuit PV voltage V_{oc} and to obtain I_{sc} short circuit current, the series resistance of very value is connected to the circuit. Table 1 are various parameters to be considered for the modelling of 1240 watt PV panel in MATLAB. Figure 5 shows the simulation model of 360 cells PV array in MATLAB with irradiance of 1000 W/m^2 and temperature of 25 °C.

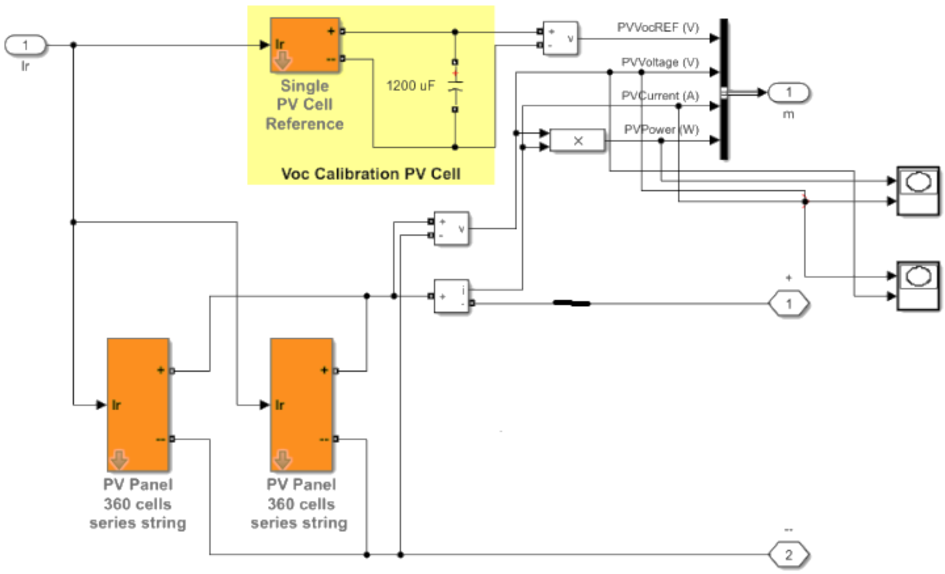

Figure 5. Simulation model for PV array for 360 cells in string

Table 1. Parameter specifications of 1240 w PV module

Parameters	Specifications
Open circuit voltage V_{oc}	230 V
Short circuit current I_{sc}	7 Amps
Maximum output power	1240 Watts
Open circuit voltage V_{oc}	230 V
Short circuit current I_{sc}	7 Amps

Figures 6 and 9 represents the block diagram of MPPT techniques in MATLAB. The output waveforms for implementation of both the techniques P&O and Incremental conductance has been shown in Figures 7, 8, 10 and 11. Figures 7 and 10 shows the results of PV array & DC output voltage, current & power i:e V_{PV}, V_{DC}, I_{PV}, I_{DC}, P_{PV} & P_{DC}. Figures 8 and 11 shown output waveforms from inverter i:e output volatge (V_{abc}Inv) and power (P_{abc}Inv) for three phases. The magnitudes of output voltage, current & power from PV array is given in Table 2.

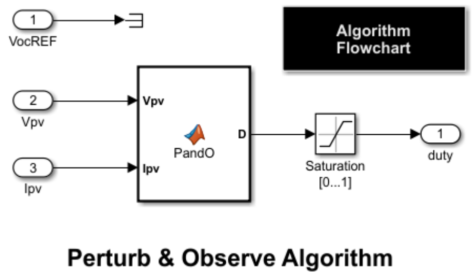

Figure 6. P&O Technique MPPT MATLAB simulation diagram

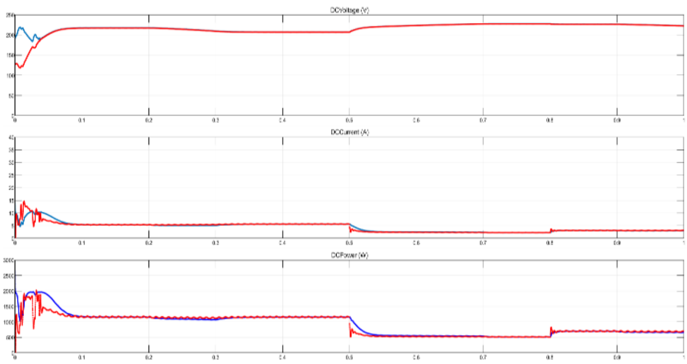

Figure 7. Output voltage, current and power of PV array with P&O MPPT technique

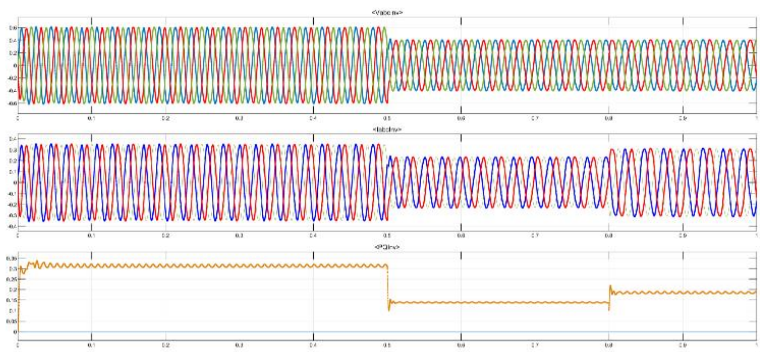

Figure 8. Inverter output voltage, current and power in P.U P&O MPPT technique

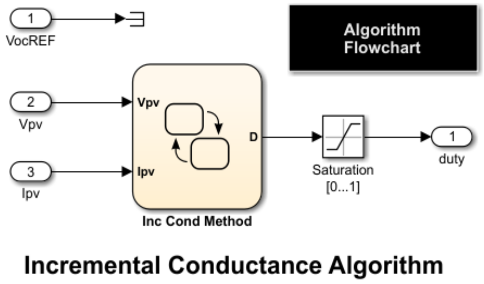

Figure 9. Incremental conductance technique MPPT MATLAB simulation diagram

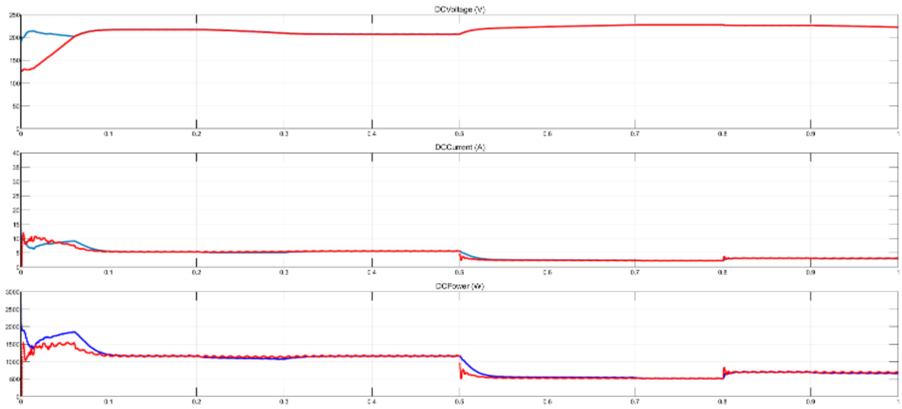

Figure 10. Output voltage, current and power of PV array with incremental conductance technique MPPT technique

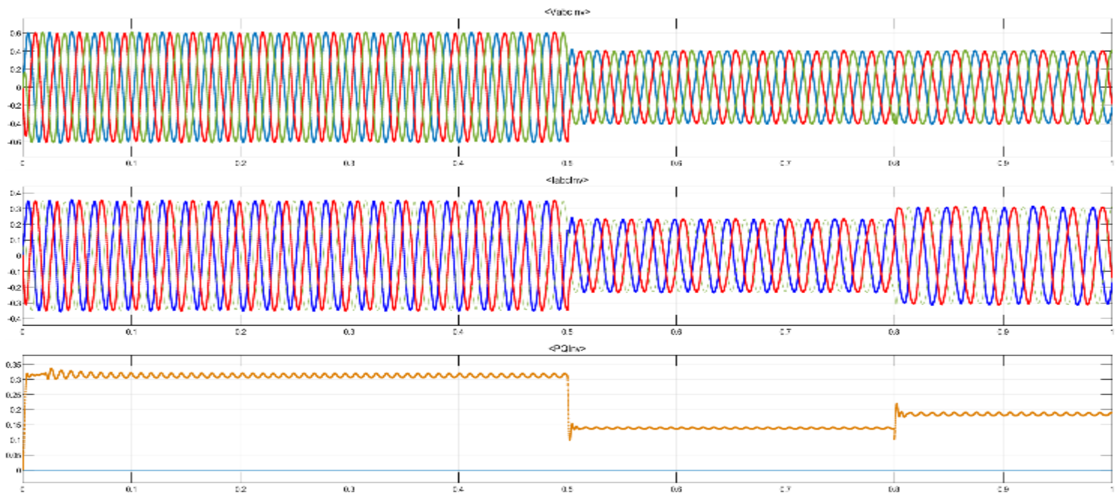

Figure 11. Inverter output voltage, current and power in p.u incremental conductance technique-MPPT technique

Table 2. Simulation results of MPPT techniques

MPPT technique	V_{pv}(V)	V_{dc}(V)	I_{pv}(A)	I_{DC}(A)	P_{pv}(W)	P_{DC}(W)
P&O	222.5	222.2	2.987	3.124	664.3	669.3
INC conductance	222.5	222.3	3.1	3.123	694.6	694.3

5. CONCLUSION

Simulations of MPPT algorithms in MATLAB with an inverter show that incremental conductance is better than perturb & observe (P&O) in terms of both dynamics and steady-state performance. The experimental results show that incremental conductance methods are better than the P&O method as it determines the maximum power point without oscillating around its value due to a decrease in sampling frequency. The only disadvantage of the incremental method is that it behaves unpredictably under rapid changes in environmental conditions. These methods are easy to use and can only be looked at in terms of things like sensors, cost, convergence speed, and effectiveness range.

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