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Comparative analysis of P&O and Incremental conductance methods for standalone PV system

H. Srinaath*, **V. Balaji**** **& A. Peer Fathima*****

Abstract**:** This paper presents the analysis and comparison of maximum power point tracking (MPPT) algorithms namely Perturb and Observe (P&O) and Incremental Conductance methods for standalone PV system. These two algorithms are compared under different step size and sampling time based on settling time and magnitude of oscillation. This type of comparison is useful in identifying the optimal value of step size and sampling time with respect to settling time. An improved circuit oriented model of PV panel along with boost converter is developed using MATLAB/SIMULINK environment to test the two algorithms. The simulation results shows that the maximum efficiency of the solar panel is achieved by using optimal values.

Keywords: maximum power point tracking (MPPT), Perturb and observe (P&O), photovoltaic (PV), power-voltage characteristics (P-V)

1. INTRODUCTION

PV panel is the only source that converts light energy directly to electrical energy. The major advantage of solar photo-voltaic panel is that they are environmental friendly. Typical conversion (light to electrical energy) efficiency of the silicon solar panel ranges between 14 to 19% according to [8], due to this low efficiency and high cost, makes it less competitive with fossil fuels. Adding to this disadvantage there is a further reduction in efficiency of the panel due to various losses like mismatch loss, heat loss, reflective loss, etc. Maximum power point tracking system is the one which improves the panel efficiency by tracking maximum operating voltage at particular irradiation and temperature. There are several MPPT algorithms in literature out of which the most popularly used algorithms are P&O and incremental conductance methods because of their simplicity [6, 9].

Electrical circuit model of *PV* panel is characterized as single diode model and two diode model. Most commonly used model is single diode model [2]. Due to non-linear characteristics, *PV* panel is modeled using numerical methods [1, 2]. But this method is tedious and gives only approximate results. *PV* panel can also be modeled by

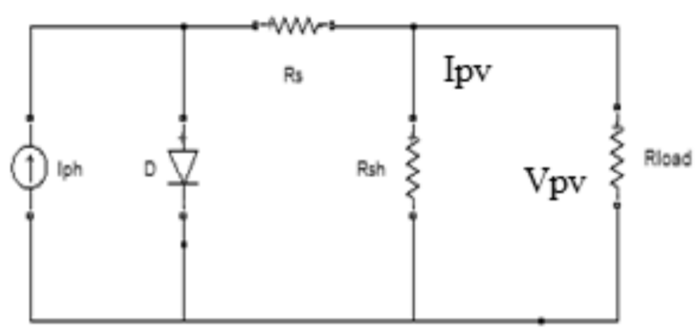

Figure 1: Equivalent circuit of PV cell

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explicit equations using lambert-*W* function [4]. The advantage of this method is that characteristics of *PV* panel can be computed directly instead of using numerical methods. The values of series and shunt resistance have been neglected in [3], this reduces the accuracy of the model. An accurate model of *PV* panel is developed in section 2. Conventional boost converter is used for analysis of two algorithms, which is described in section 3. In section 4 and 5 P & O and incremental conductance methods are compared and analyzed.

2. MODELING OF PV PANEL

The Equivalent circuit of the *PV* cell is shown in Fig.1. There are several models of solar cells in literature, out of which single diode model is most widely used. Equivalent circuit of solar cell has four elements namely current source, diode, shunt and series resistance. Purpose of the diode is to represent the *PV* panel characteristics under dark condition. *PV* panel is modeled according to equations given in [5]. Reverse saturation current of the cell is given by

$$I_{rs} = \frac{I_{scr}}{e^{\left(q*\frac{V_{oc}}{N_s*A*k*T}\right)} - 1} \tag{1}$$

Where, I_{scr} is short circuit current at Standard Test Condition (STC), V_{oc} is open circuit voltage, A is ideality factor, k is Boltzmann constant, T is module operating temperature and q is charge of an electron, N_s is number of cells in series.

Saturation current is given by

$$I_o = I_{rs} * \left(\frac{T}{T_r}\right)^3 * e^{\left(\frac{q*Eg}{A*k}\right)*\left(\frac{1}{T_r} - \frac{1}{T}\right)} \tag{2}$$

Where, E_g is Band gap for silicon, T_r is module temperature at STC. Photocurrent of the cell is given by

$$I_{ph} = [I_{scr} + \alpha_i * (T - 298)] * G \tag{3}$$

Where, α_i is temperature coefficient of current and G is irradiation level. Output current of the *PV* module is given by

$$I_{pv} = I_{ph} - I_o\left(e^{\frac{V_{pv}+IR_s}{AV_t}} - 1\right) - \frac{V + IR_s}{R_{sh}} \tag{4}$$

Where, N_p is number of cells in parallel, R_s is series resistance and R_{sh} is shunt resistance. Solar module consists of number of cells and array consists of number of modules as shown in Fig 3. To obtain the equivalent model for the panel from cell model, following relations are used

$$V_{pv} = N_s * V_{cell} \tag{5}$$

$$I_{pv} = N_p * I_{cell} \tag{6}$$

The above relations are justified by the fact that cells in series adds up the voltage whereas cells in parallel adds up the current. The equations (1) to (6) are used to model PV panel in MATLAB/SIMULINK as shown in Fig. 2

Specification of solar *PV* panel considered for modeling as shown in Table 1. Two strings of panels are connected in parallel while each string has two panels in series as shown in Fig. 3. Panel rating is specified under STC condition (temperature at 25 °C and irradiation at 1000 W/m^2). In order to get accurate simulation

Table 1
PV panel specification

Power	10 W
Open circuit voltage	21 V
Short circuit current	0.7 A
Voltage at maximum power	16.4 V
Current at maximum power	0.610 A

results, values of three important parameters are to be found namely ideality factor, series resistance and shunt resistance. Shunt resistance is assumed to be infinite and values of remaining two parameters are found by following equations

$$A = \frac{\alpha_v - \frac{V_{OC}}{I_{stc}}}{N_s V_{tstc}\left(\frac{\alpha_i}{I_{ph}} - \frac{3}{T_{stc}} - \frac{E_{GAP}}{kT_{stc}^2}\right)} \tag{7}$$

$$R_S = \frac{n_s A V_{tstc} \ln\left(1 - \frac{I_{mp}}{I_{sh}}\right) + V_{oc} - V_{mp}}{I_{mp}} \tag{8}$$

Where V_{tstc} is thermal voltage at STC and α_v temperature coefficient of voltage, I_{mp} is maximum current and V_{mp} is maximum voltage of PV panel.

P-V & I-V curve for constant and different irradiation levels are shown in Fig. 4 and 5 respectively. It is observed that variation in short circuit current is larger than the variation in open circuit voltage and hence PV cell is modeled as current source

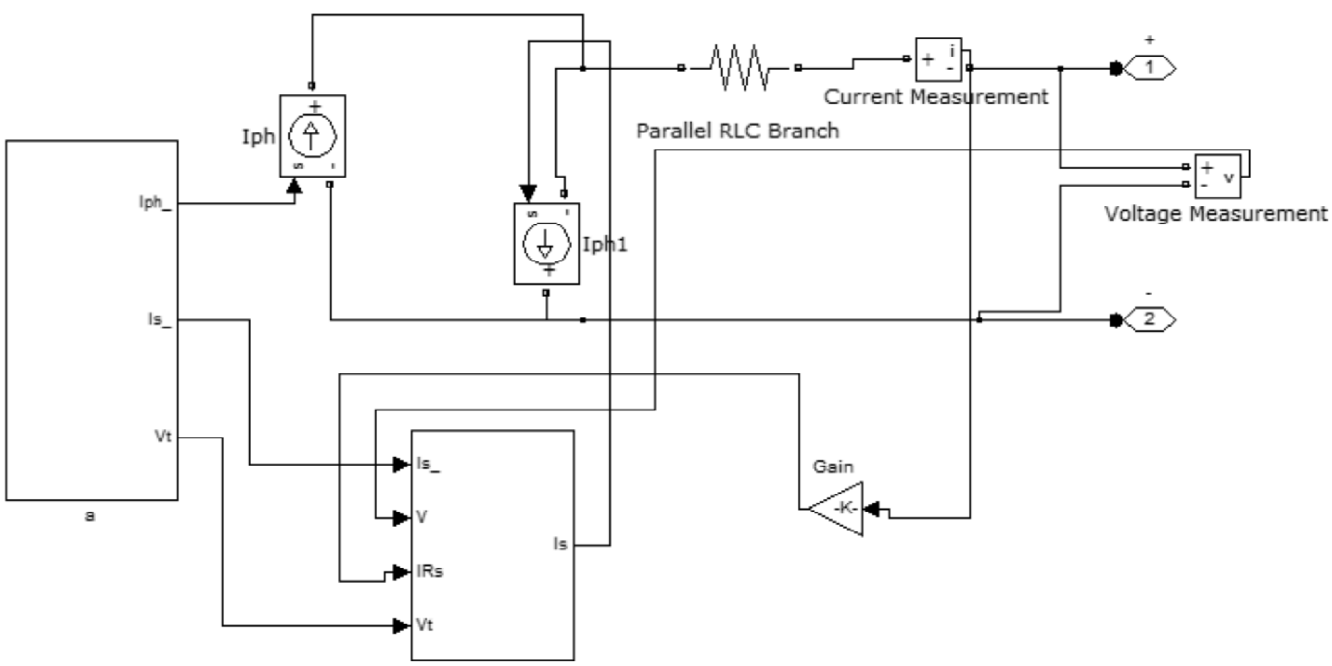


Figure 2: Circuit oriented model of PV panel

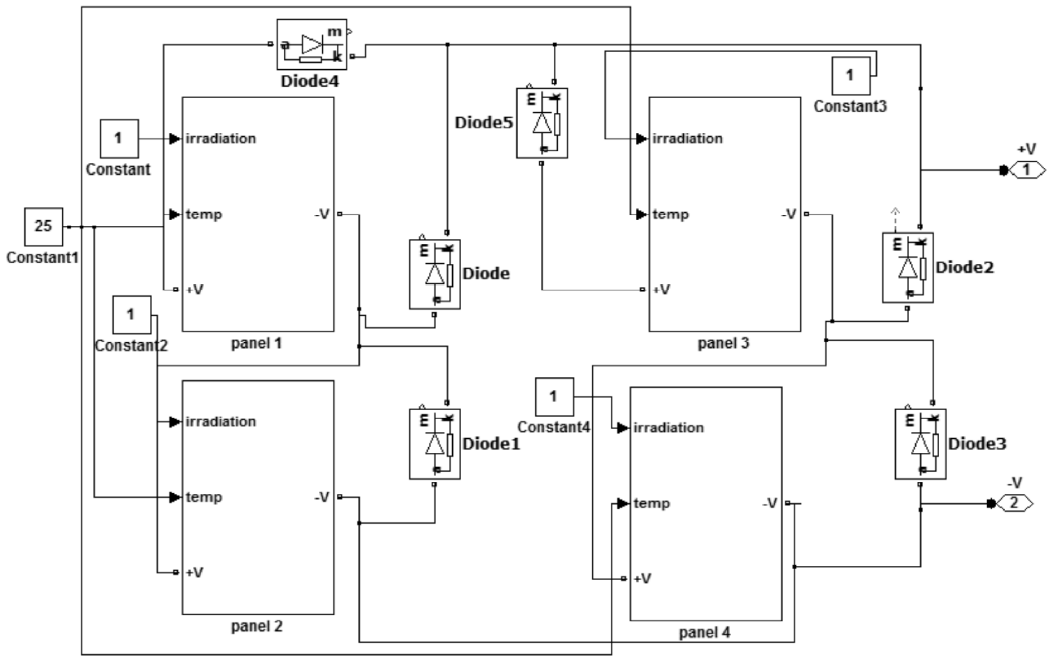
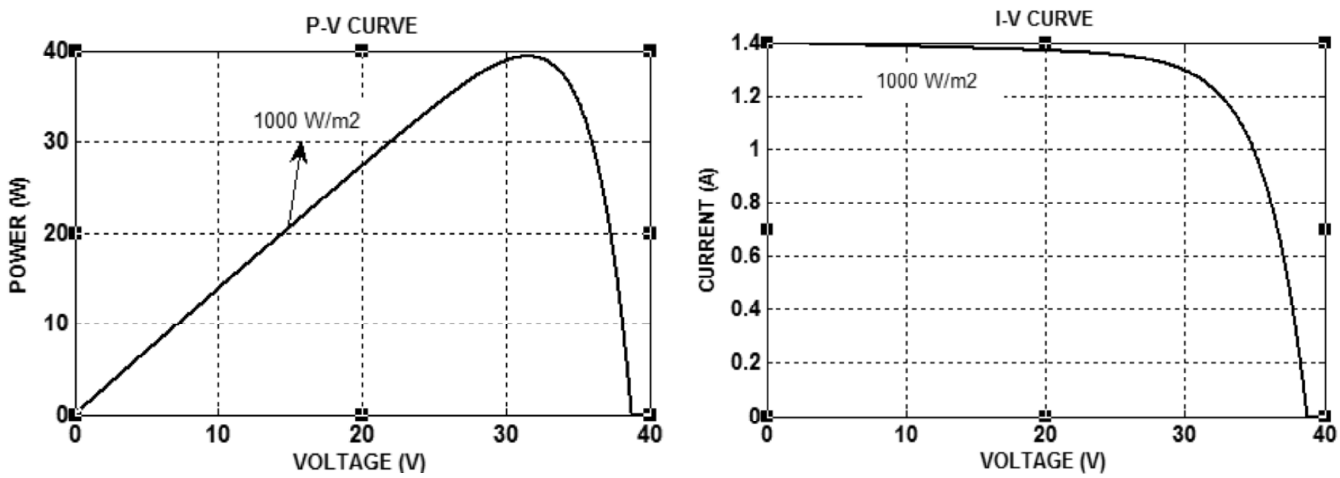
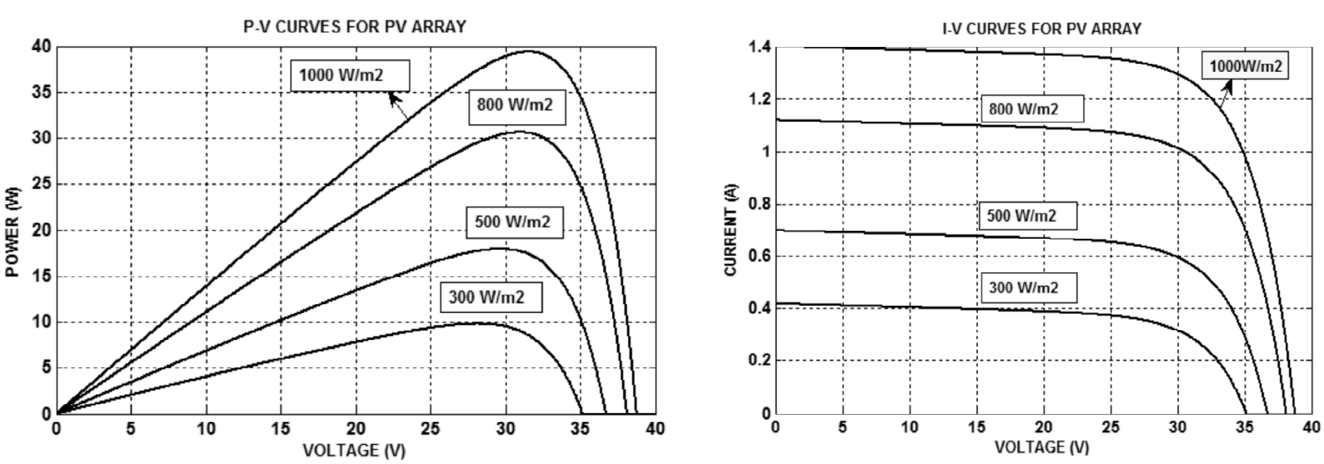


Figure 3: Solar PV array



(a) **(b)**

Fig. 4. a P-V curve for solar PV array, b I-V curve for solar PV array.



(a) **(b)**

Figure 5: a P-V curves for different irradiation, b I-V curves for different irradiation

3. DC-DC CONVERTER

The Conventional DC-DC boost converter is considered in this paper. Parameters of boost converter are modeled according to equations (9) to (11)

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \tag{9}$$

$$L_c = \frac{D(1-D)R}{2f} \tag{10}$$

$$C_c = \frac{D}{2fR} \tag{11}$$

Where, V_o-output voltage, V_{in}- input voltage, D-duty ratio, L_c-critical value of inductance, R-output resistance, f-switching frequency, C_c-critical value of capacitance. Boost converter can be operated in continuous conduction mode or in discontinuous conduction mode. Continuous conduction mode is the one in which current does not goes to zero level whereas in discontinuous conduction mode current comes to zero value. Fig. 6 shows the simulink model of boost converter. Table 2 shows the calculated values of boost converter. Apart from boosting the voltage, boost converter also act as impedance matching device. Impedance matching is the one in which load impedance is made equal to source impedance so that maximum power is transferred from source to load. State space analysis of Boost converter [7] reveals that when variable voltage source like PV panel is connected to boost converter, it creates ripple in the voltage

4. MPPT ALGORITHM

The Maximum power point tracking methods considered in this paper are online methods namely perturb & observe method and incremental conductance method.

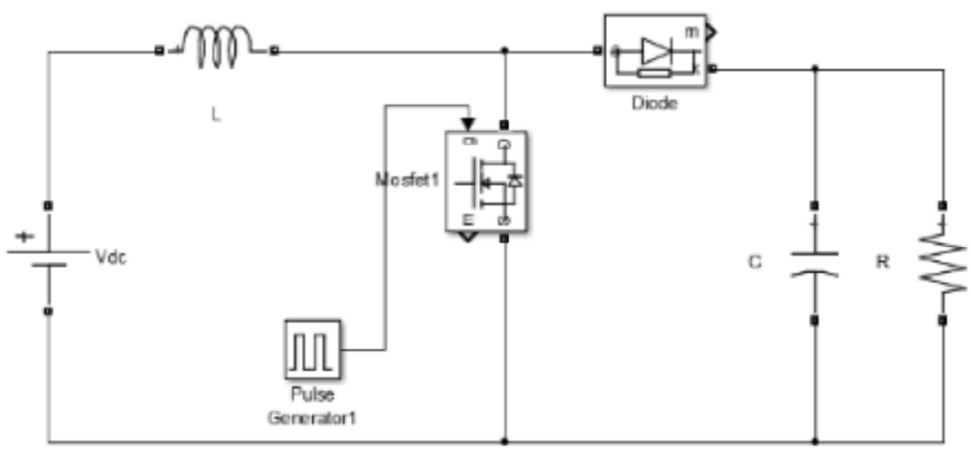


Figure 6: Simulink model of Boost converter

Table 2
Boost converter specification

Parameters	*Inductance (μH)*	*Capacitance (μF)*	*Resistance (Ω)*
Critical values	500	28.2	70
Values chosen for continuous conduction mode	750	42	70

4.1. Perturb And Observe Method

P&O is one of the simplest online methods. In this method, *PV* operating point is perturbed periodically by changing the voltage, and after each perturbation, the control algorithm compares the values of the power fed by the *PV* panel before and after perturbation. If the *PV* power is increased after the perturbation, then the voltage is increased otherwise voltage is decreased. The DC-DC converter is used to drive the perturbation of the operating voltage. Flowchart of P&O method is shown in Fig. 7.a. The disadvantage of this method is that, as soon as the MPP is reached, the voltage and duty cycle oscillates around the MPP. The magnitude of oscillations depends on the value of step size included in the system. Increase in step size decreases the settling time and vice versa, so there is a tradeoff between settling time and magnitude of oscillations

4.2. Incremental Conductance Method

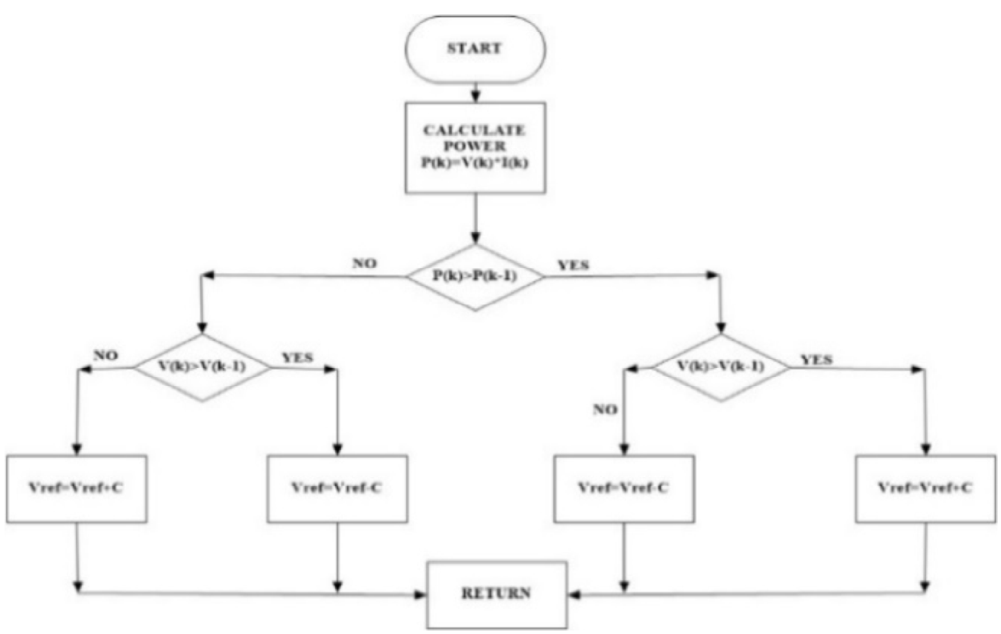
Incremental conductance is another online method to detect maximum power point. In this algorithm the present and previous values of panel voltage and current are sensed and are used to calculate values of dI and dV. The oscillations around MPP can be eliminated by comparing instantaneous conductance (I/V) with incremental conductance (dI/dV). Flowchart of incremental conductance method is shown in Fig. 7.b. If $dP/dV = 0$, then MPP is reached, which is depicted in equation (13). Equations (14) indicate that operating point is on left side while equation (15) indicates that operating point is on right.

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV} \tag{12}$$

$$-\frac{I}{V} = \frac{dI}{dV} \tag{13}$$

$$\frac{dI}{dV} > -\frac{I}{V} \tag{14}$$

$$\frac{dI}{dV} < -\frac{I}{V} \tag{15}$$



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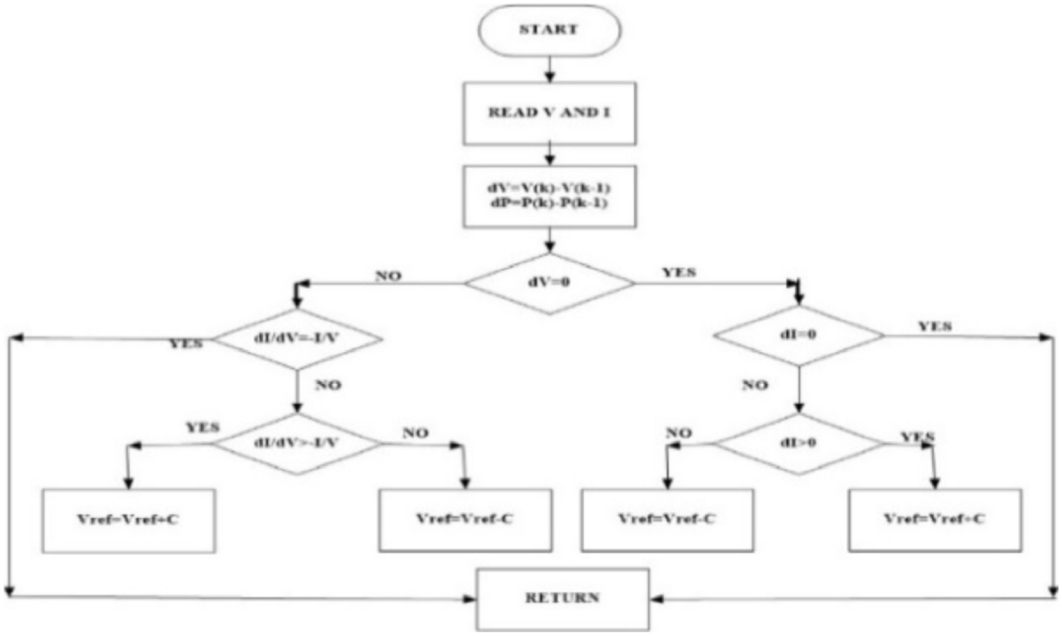
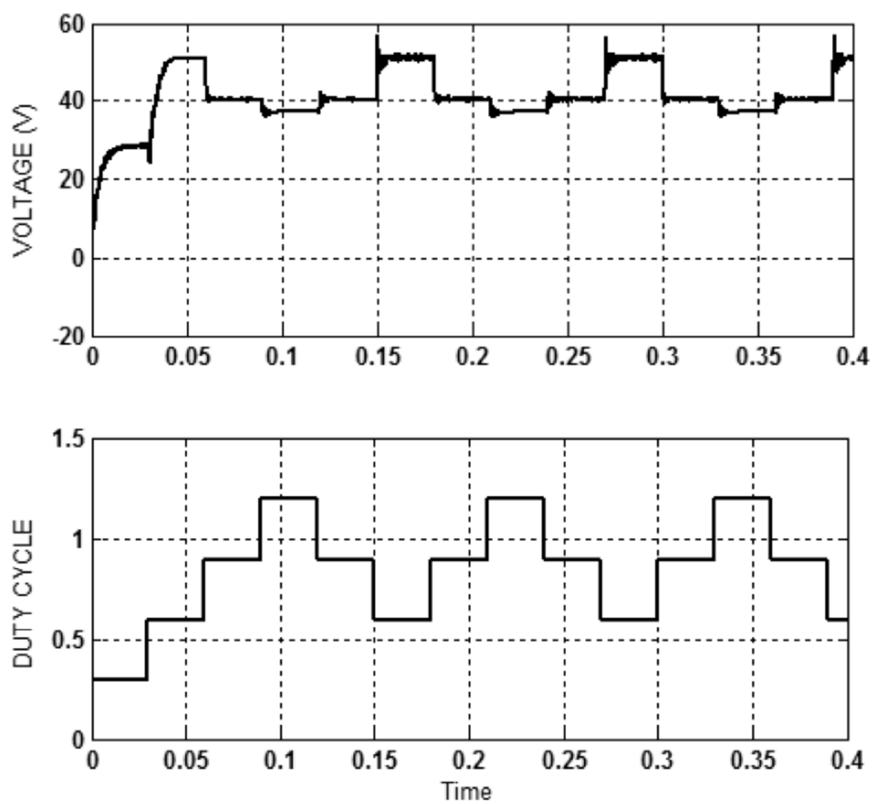


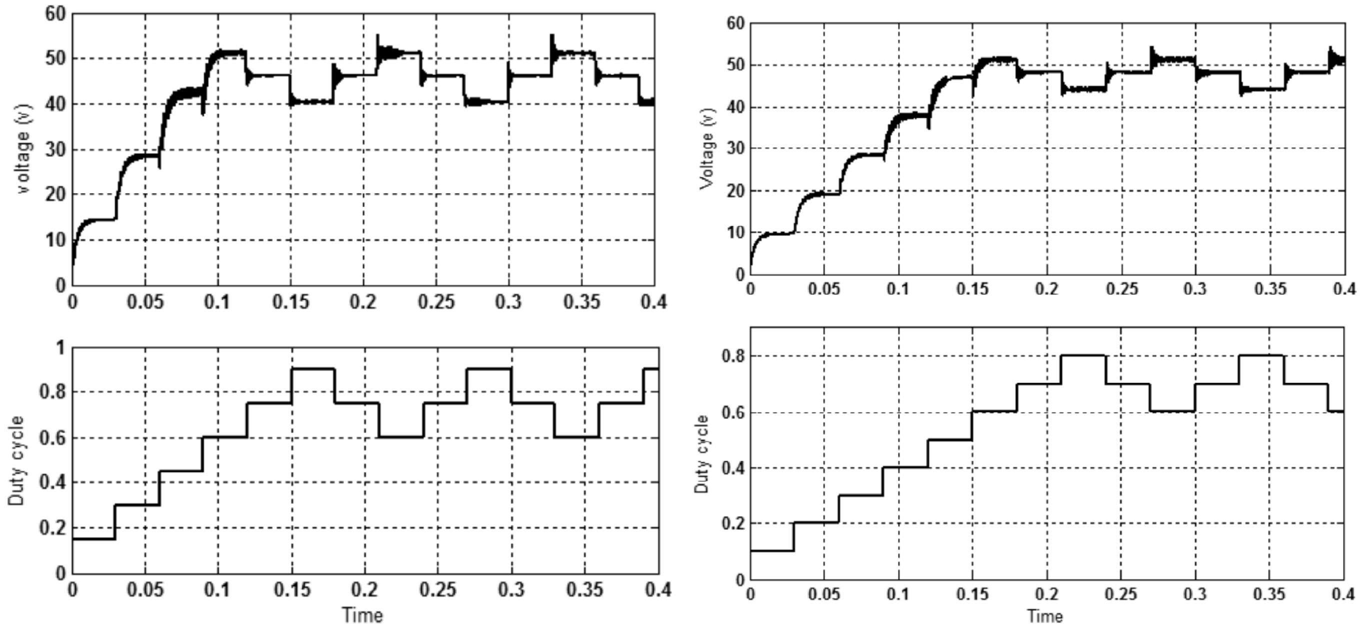
(b)

Figure 7: a Flowchart for P&O method b Flowchart for incremental conductance method

5. SIMULATION RESULTS AND DISCUSSION

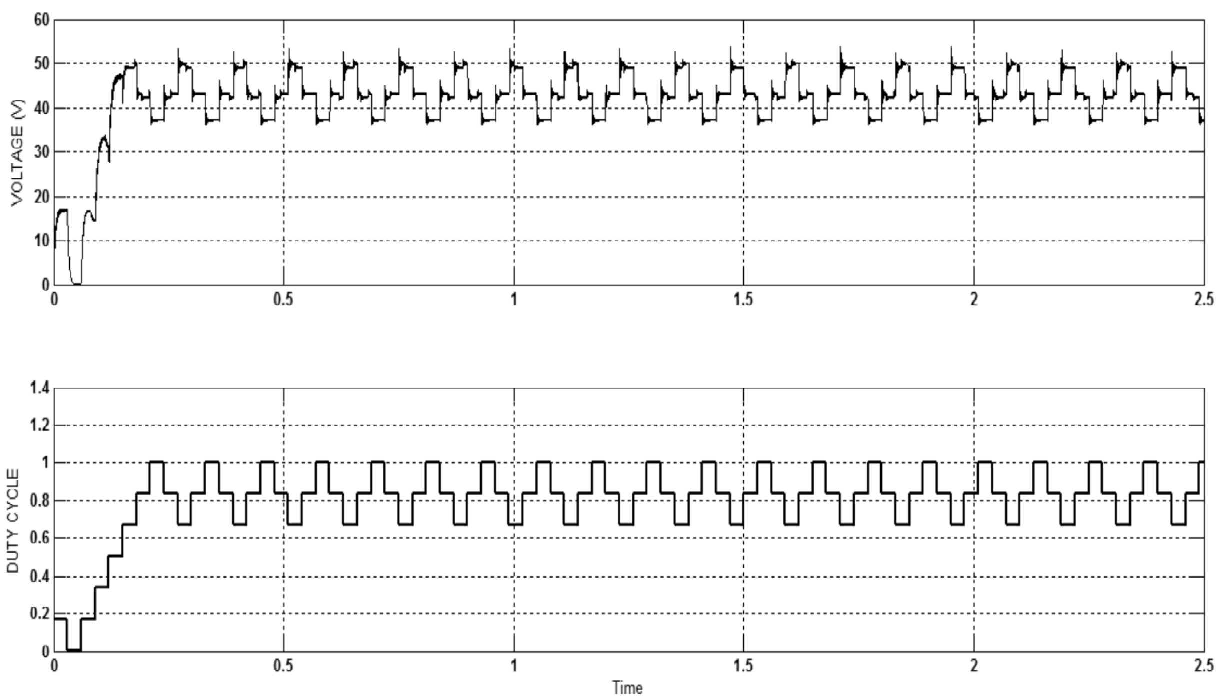
MPPT algorithm has been simulated with boost converter and solar panel along with resistive load in MATLAB/ SIMULINK. P&O and incremental conductance algorithms are analyzed and compared for various step size and sampling time. Sampling time is chosen to be greater than settling time of boost converter to reach the steady state. Settling time of boost converter obtained in this design is 10ms. Three different values for sampling time are chosen





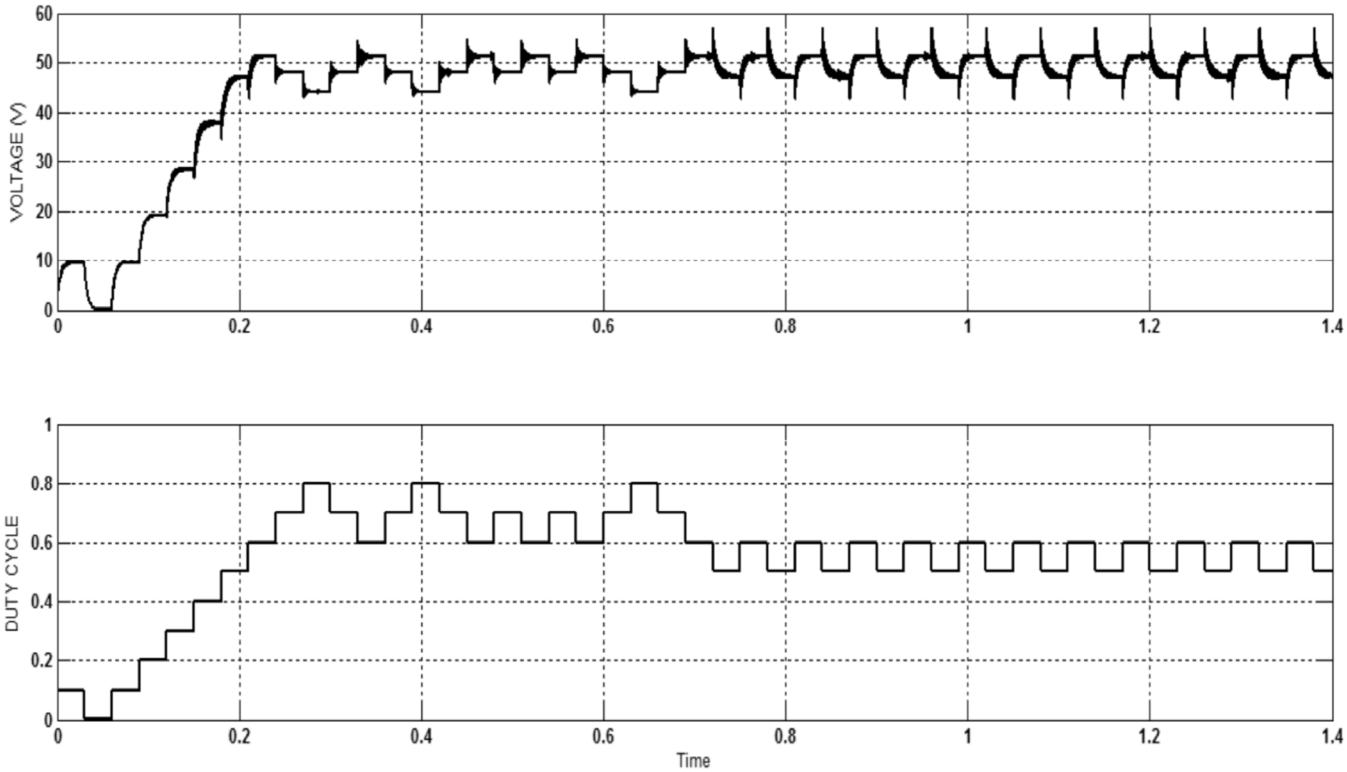
(b) (c)

Figure 8: Output voltage and duty cycle of P&O variable step size with 30ms sampling time a. 0.1 step size, b.0.5 step size c.0.01 step size



(a)

as 15ms, 30ms and 40ms. The step size is chosen randomly as 0.5, 0.1 and 0.01. The algorithms are analyzed in two cases. In case I sampling time is kept constant at 30ms for various step sizes. In case II step size is kept constant at 0.1 for various sampling time. Fig. 8 and 9 shows the output voltage and duty cycle of P&O method for different step sizes and sampling time respectively. Fig. 10 and 11 shows the output response of incremental conductance method for various step size and sampling time. Table 3 shows the comparison of various parameters in P&O and incremental conductance methods. It is observed that in P&O method, magnitude of oscillations increases with increase in step size and settling time varies inversely proportional with step size. There is a decrease



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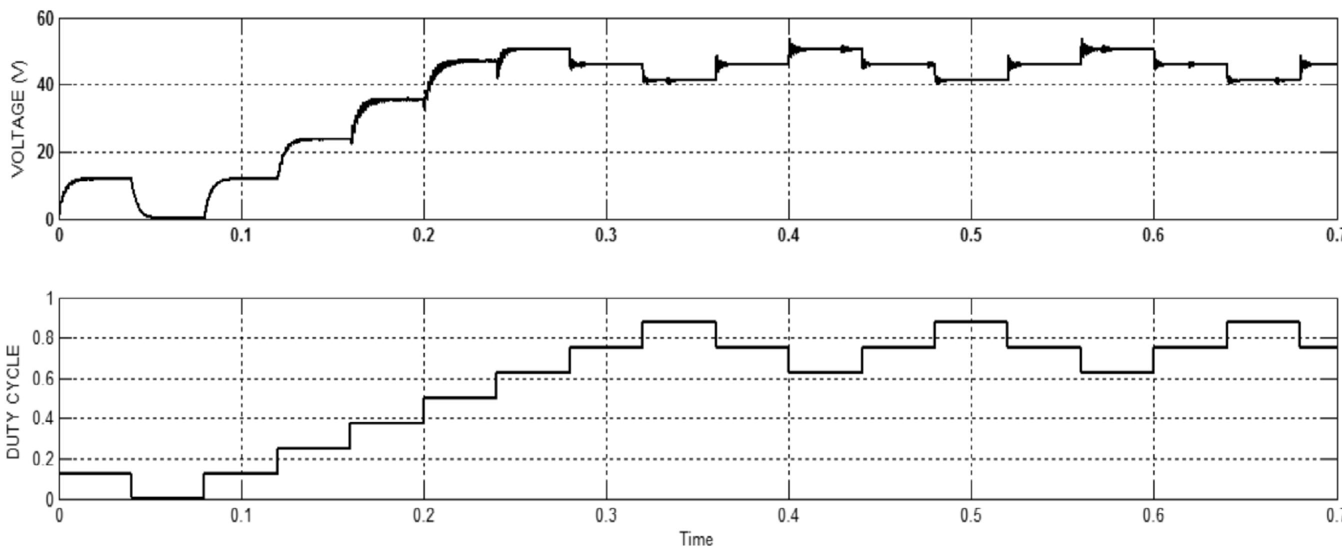
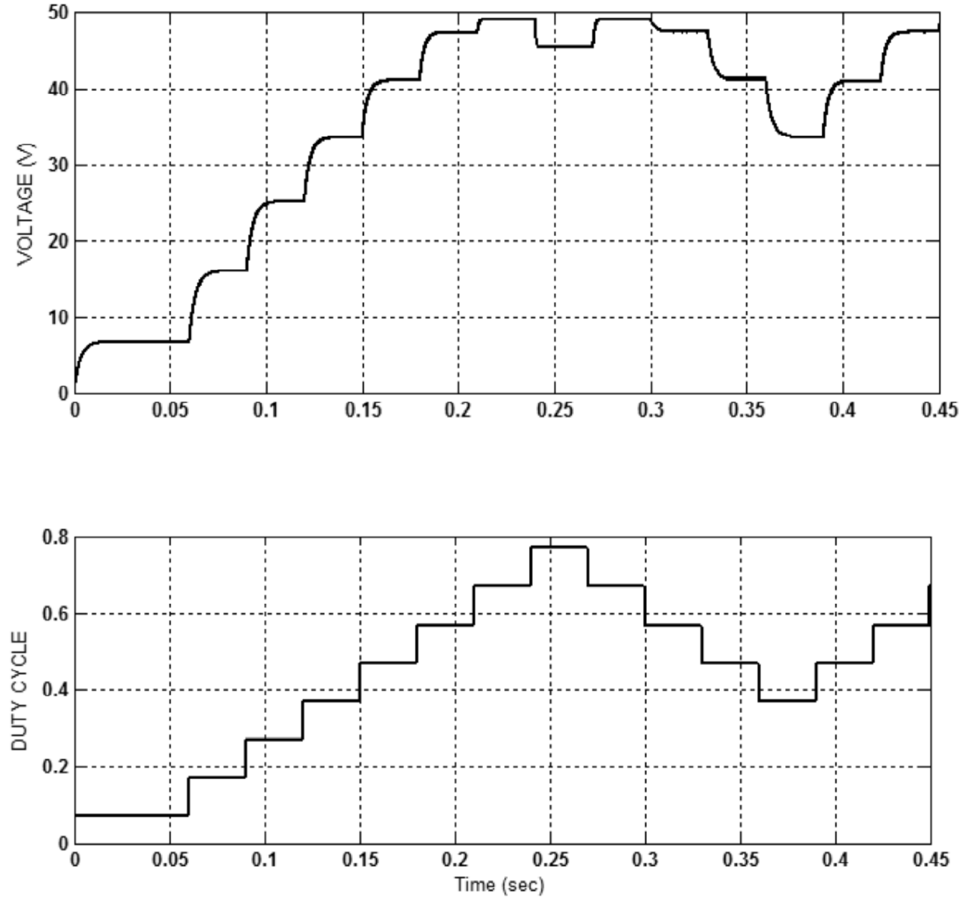


(c)

Figure 9: Output voltage and duty cycle of P&O variable sampling time and 0.1 step size a.0.030 sampling time b.0.040 sampling time c. 0.015 sampling time

in output voltage when sampling time is 40ms. Hence optimal value of step size and sampling time is chosen as 0.1 and 30ms respectively.

Incremental conductance method contains fewer oscillations in output voltage than P&O method. Settling time decreases with increase in step size and varies inversely with sampling time. Hence optimal value of step size and sampling time is chosen as 0.1 and 30ms respectively



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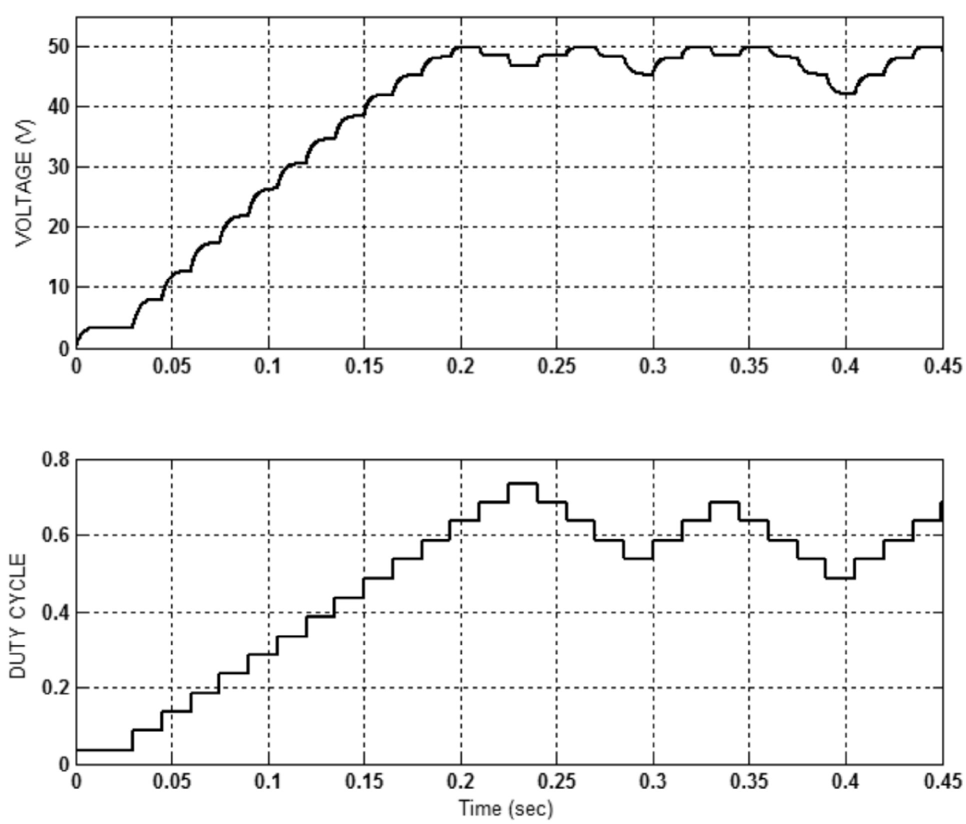

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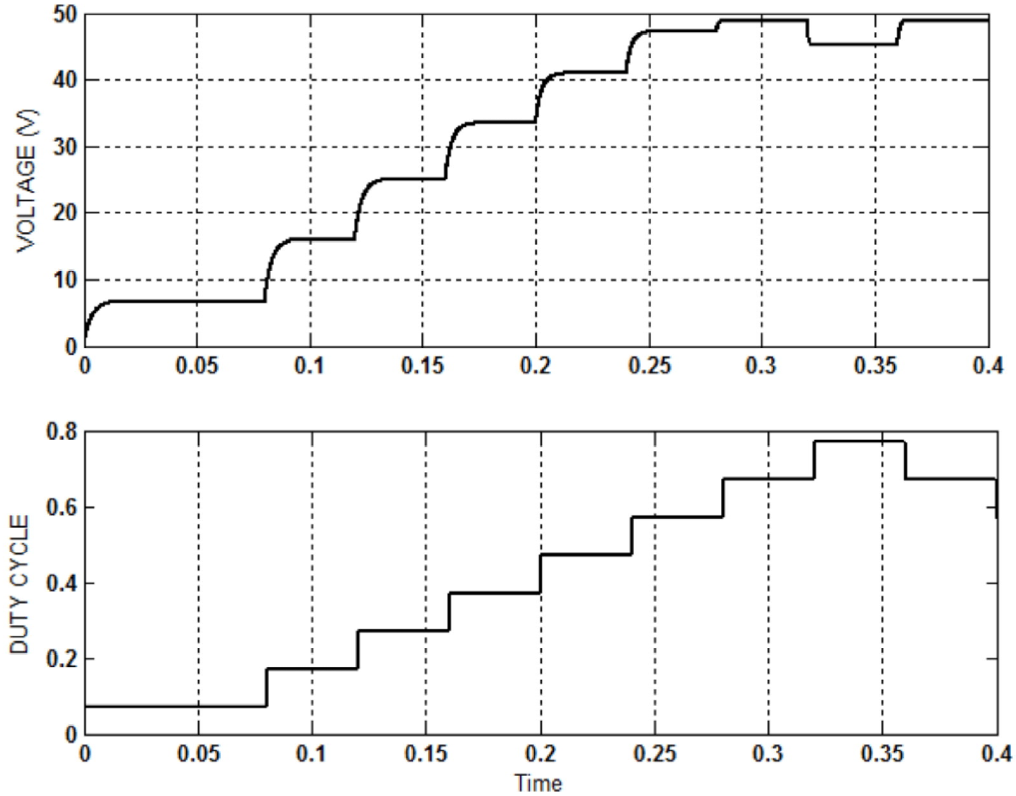

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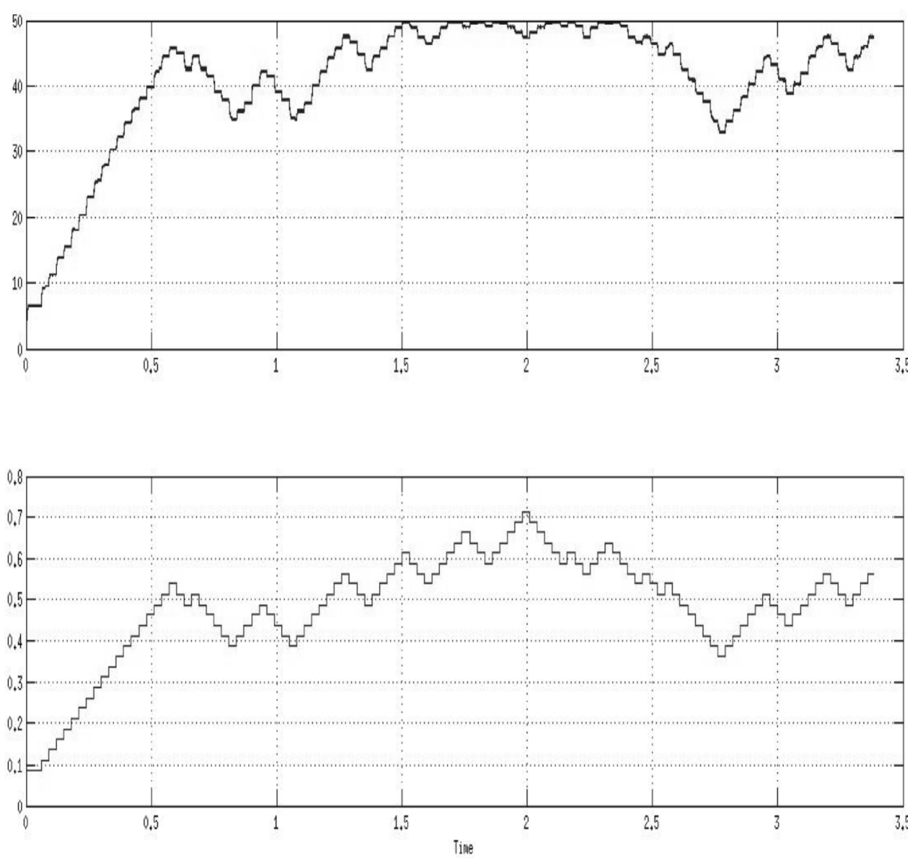
Figure 10: Output Voltage in incremental condutcance with variable sampling time and constant step size a.0.030, b.0.040 c.0.015 sampling time



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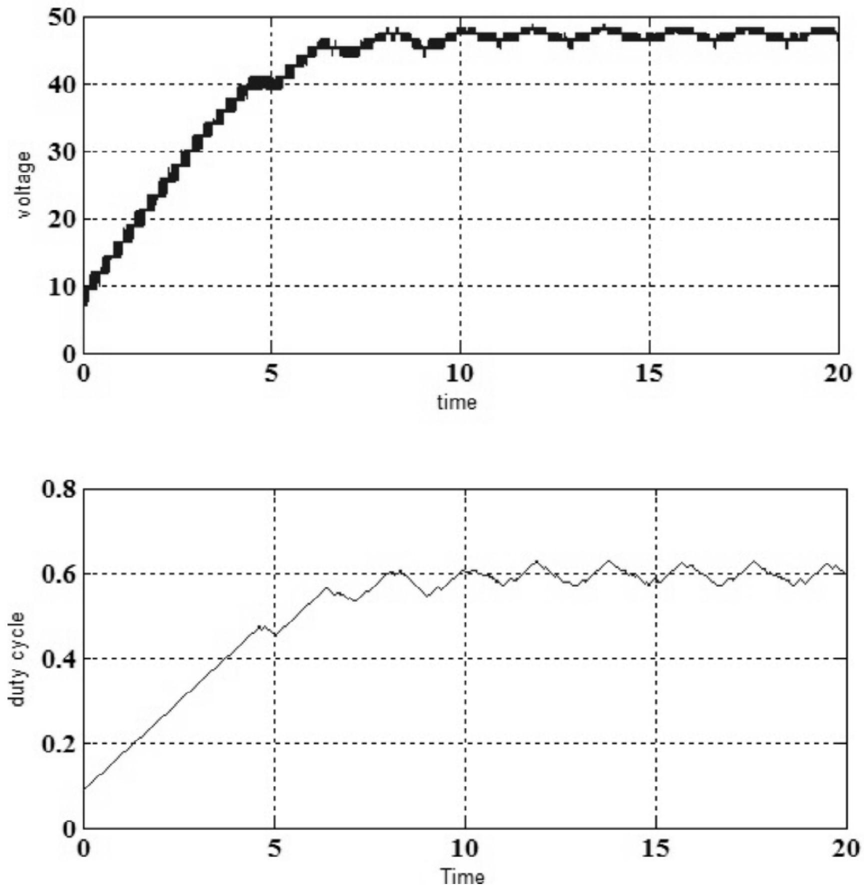

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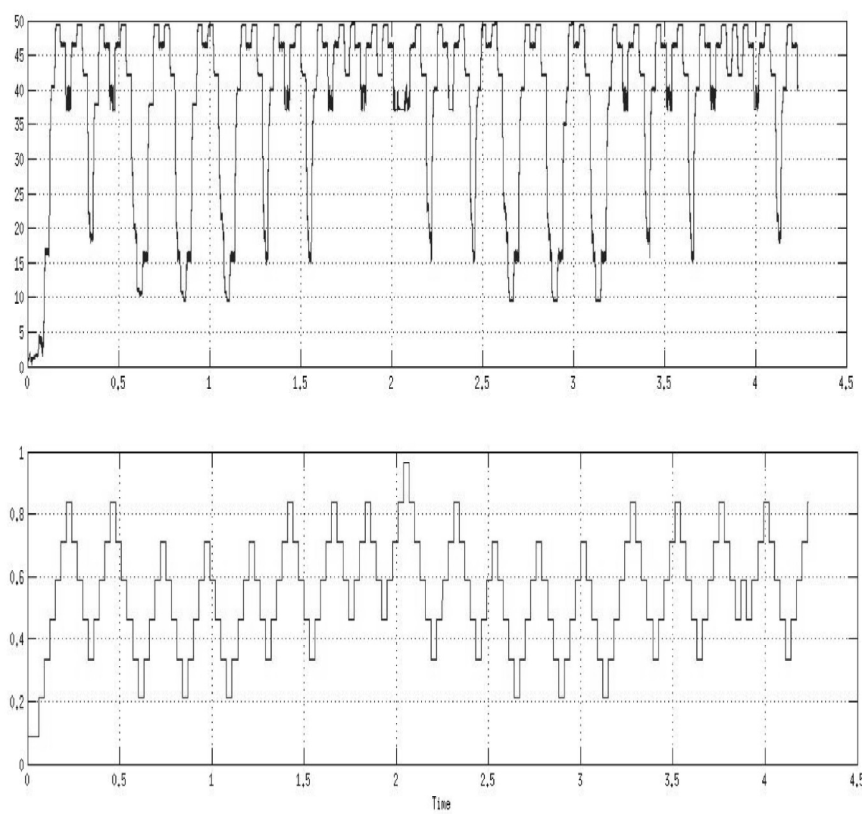

(c)

Figure 11: Output Voltage in incremental condutcance with constant sampling time and variable step size a.0.5, b.0.010 c.0.1 step size

Table 3
Comparison of P&O and Incremental conductance methods

	Parameters		P&O			Incremental Conductance		
			settling time of output voltage (sec)	Magnitude of Oscillation of Duty cycle	Output voltage (V)	settling time of output voltage (sec)	Magnitude of Oscillation of Duty Cycle	Output Voltage (V)
Case I	Step Size	0.5	0.1	0.5	46	0.006	0.5	47
	(sampling time-30ms)	0.1	0.15	0.1	46	0.015	0.01	47
		0.01	0.2	0.01	45	0.050	0.01	47
Case II	Sampling Time	0.015	0.3	0.1	46.65	0.3	0.05	46
	(step size-0.1)	0.030	0.25	0.1	46	0.25	0.05	46
		0.040	0.2	0.1	40	0.2	0.05	38

5. CONCLUSION

The P&O and incremental conductance methods are compared and analyzed using MATLAB/SIMULINK environment. It is observed that optimal selection of step size and sampling time reduces the settling time and magnitude of oscillations considerably. The magnitude of oscillations in incremental conductance method sustains fewer oscillations around MPP than P&O method. Hence it is observed that incremental conductance method yields better results than P&O method for standalone PV system's MPPT algorithm.

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