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MPPT Using P&O and IC Based PI Controller for Solar PV System with Charge Controller

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Abstract

The power output of the solar PV system depends mainly on the two variables such as temperature and irradiance. A technique for the effective use of solar PV is known as the MPPT. This technique extracts the highest available energy from the solar PV panel by enabling it to operate at the maximum effective output. This paper introduces 2 MPPT controllers that are standard Perturb & Observe (P&O) and Proportional Integral (PI). In specific, the performance of the controllers under two conditions is analyzed such as constant irradiation and different temperatures, constant temperature and different irradiations. The simulation work is carried out under MATLAB/SIMULINK, environment.

Keywords

PV System, Perturb & Observe (P & O), Proportional Integral (PI), Maximum Power Point Tracking (MPPT), DC-DC Converters.

Introduction

Present days, growth of natural resources, in particular solar power has received a great deal of global attention owing to its sustainability, maintenance-free and noise-free features, etc. However, the operation of solar PV devices is extremely dependent on external variables, like solar irradiance and temperature, which have enormous consequences for the production of PV devices. Therefore, MPPT controllers are necessary to maintain effective operation of PV modules in the solar PV system [1]. From the literature it is observed that many techniques are available for MPP tracking.

Perturb & Observe technique was more appropriate for other MPPT controllers because it is a standard method [2], it provides better efficiency under altering climate circumstances. The drawbacks of P&O method are more oscillations and extended commutation time. The proposed Incremental Conductance based PI controller is used to solve the above problems. The suggested technique delivers the rapid response under climatic circumstances. The photovoltaic technique comprises of photovoltaic modules and DC-to-DC converters [3]. The PV system's V&I output is given to the MPPT, which generates a duty cycle. Constant voltage and current techniques are used for charging the battery. This will enhance the life cycle of the battery and reduces the losses. The voltage and current of the buck converter are kept constant with the assistance of the PI controller.

Solar PV System

The photovoltaic system converts sunlight energy into electricity. Fig.1 shows the single diode of photo-voltaic module [4].

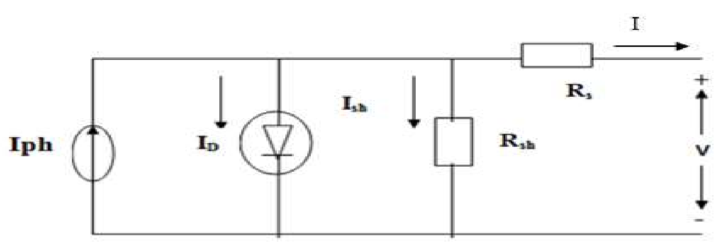

Fig 1: Solar PV Cell

The current (I) of the solar photovoltaic system is calculated on the basis of equation 1.

$$I = I_{ph} - I_D - I_{sh} \quad (1)$$

Based on equation 2, the diode characteristic equation (I_D) is calculated.

$$I_D = I_S\left[\exp\left(\frac{q(V_L + I_L R_S)}{nKT}\right) - 1\right] \quad (2)$$

The leakage shunt current (I_{sh}) is calculated on the basis of equation 3.

$$I_{sh} = \frac{V_L + I_L R_s}{R_{sh}} \quad (3)$$

Here, $R_s$is the series resistance &R_{sh} is the shunt resistances; I_D is the diode current;V_L is the load voltage; n is ideality factor; K is the constant of Boltzmann, q is the electron charge and T is the temperature of the cell. Equation (4) will obtain from equations (2), (3) and (1).

$$I = I_{ph} - I_s\left[\exp\left(\frac{q(V_L+I_L R_S)}{nKT}\right) - 1\right] - \frac{V_L+I_L R_S}{R_{sh}} \quad (4)$$

P & O Based MPPT

The Perturb& Observe MPPT technique is most commonly utilized in photovoltaic system applications, due to its easy execution and simplicity. It's an iterative approach for obtaining the MPP. It measures a photovoltaic module current and voltage, and then perturbs the working point of a solar module to determine the exchange of path. Flow diagram of P &O method is shown in Fig.2 [5].

Step1: Measure current and voltage values for solar PV system.

Step 2: Calculate power P (k) = V (k)*I (k) and change of power $\Delta p = p(k) - p(k-1)$.

Step 3: Check for the condition $\Delta p > 0$.

Step 4: If $\Delta p > 0$ the operating voltage rises,else the operating voltage will reduce.

The power value may reduce or increase, depending on the above circumstances and move nears the maximum power point. During voltage & current fluctuations, the step size is kept higher by using P & O method [6, 10].

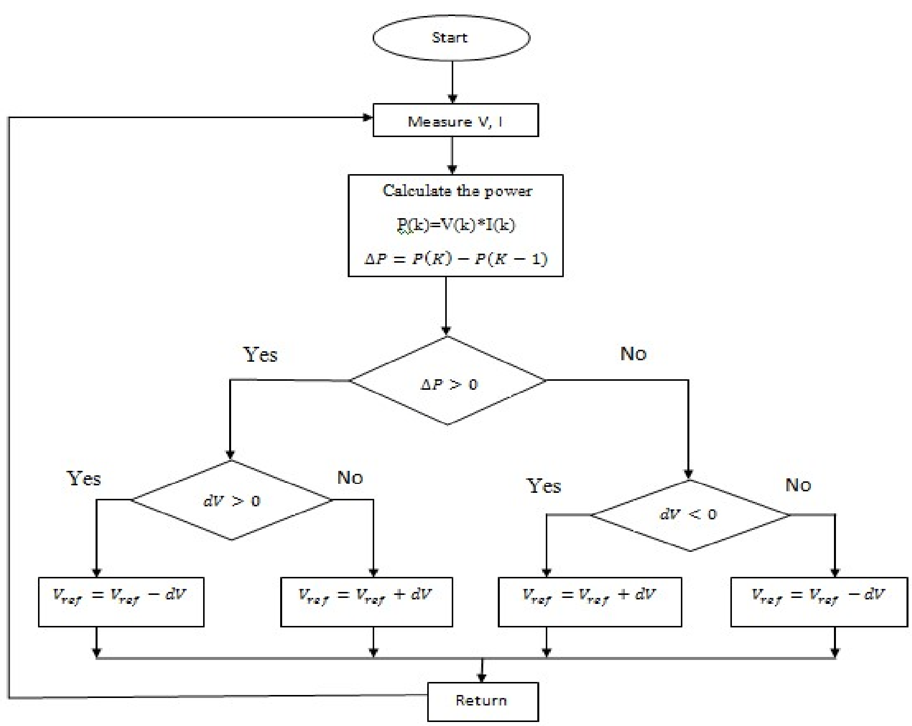

Fig. 2: Flow Chart of P & O Method

Incremental Conductance based PI MPPT

Incremental Conductance (IC) algorithm is used to overcome the drawbacks of P & O method. It is depending on the derivative performance of the solar PV module power is '0' at MPP shown in equation (5), positive values at the left of MPP as in equation (6) and negative values at the right of MPP shown in equation (7). The algorithm is operated based on the connection between instant conductance (I/V) and Incremental Conductance (ΔI/ΔV) [7].

$$\frac{\Delta I}{\Delta V}+\frac{I}{V}=0 \quad \text{at MPP} \tag{5}$$

$$\frac{\Delta I}{\Delta V}+\frac{I}{V}>0 \quad \text{Left of MPP} \tag{6}$$

$$\frac{\Delta I}{\Delta V}+\frac{I}{V}<0 \quad \text{Right of MPP} \tag{7}$$

This algorithm gives inaccurate results for lower irradiations. A new parameterε is implemented as in equation (8) to solve the above problem.

$$\frac{\Delta I}{\Delta V}+\frac{I}{V}\leq \varepsilon \tag{8}$$

Fig.3 shows the flowchart of INC algorithm. Where D is step-size of perturbation and ∂ is duty cycle. The amplitude of the oscillations is regulated by the value of ε around the MPP. It reduces with the rise inε and the operating point moves away from the real MPP for a comparatively higher value of ε. In order to improve the efficiency of the MPPT system, the value of ε should be accurately determined [8].

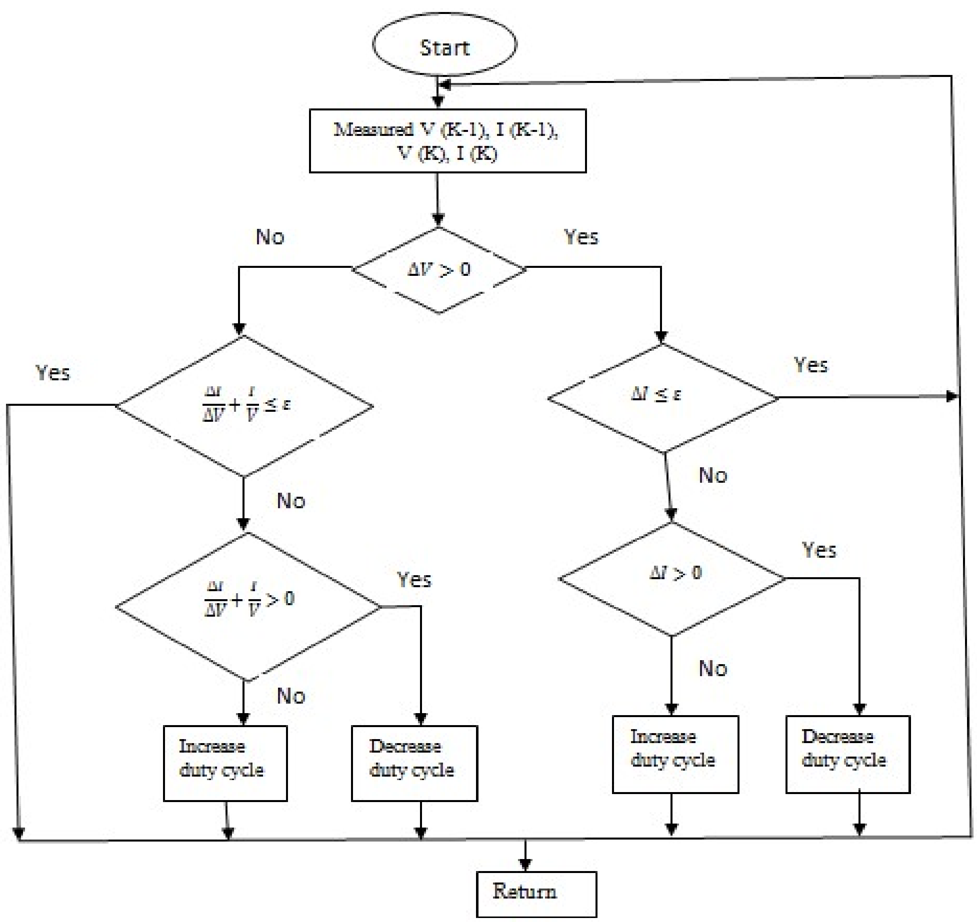

Fig. 3: Flow Chart of INC Method

PI Controller

Fig.4 shows the PI controller block diagram. PI controller is a feedback control loop that calculates error signal by taking a system output difference. Proportional integral control is employed to manage the end voltage & also the power of step-down converter. Ziegler – Nichols methodology is employed to select the Kp and Ki. Kp is effectual to decrease the boost up time and it is inexact solution to reduce the error. The Ki is helpful to reduce the steady state error. Proportional integral control is connected to buck device to maintain the constant voltage [4].

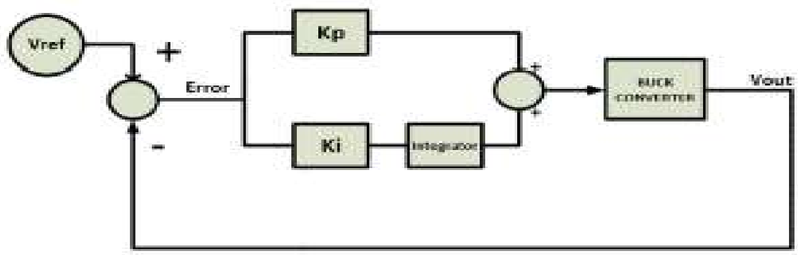

Fig. 4: Block Diagram of PI Controller

DC – DC Converters

Step-up Converter

Step-up converter is also called as step-up chopper. MOSFET is used as a switch in this chopper. MOSFET is in ON state during 0 < t <DT & diode is reversed, the voltage across inductor $V_L = V_{in}$. Switch is in OFF state during DT < t <T and diode is forwarded [9],the inductor voltage is $V_L = V_{in} - Vout$. During steady state situation transform of inductor current must be 0 at the time of switching [11].

Equation (9) represents the duty cycle of step-up converter. Duty cycle is calculated based on input and output voltage. Inductance and capacitance values are calculated by using equation (10) and (11) respectively.

Duty cycle $$D = 1 - \frac{V_S}{V_O} \quad (9)$$

Inductance $$L = \frac{V_S.(V_O - V_S)}{\Delta I_L f_S V_O} \quad (10)$$

Capacitance $$C = \frac{I_O.D}{f_S \Delta V_O} \quad (11)$$

Where Vs = input voltage, Vo = Output voltage, fs = Switching frequency

Step-down Converter

Step-down converter is also called as step-down chopper. The switch is in ON state during 0 < t < DT, diode becomes reverse. The voltage across inductor is $V_L = V_{in} - V_{out}$. Whereas the switch is OFF state during DT < t < T, diode conducts and the inductor voltage is $V_L = -V_{out}$. During steady state process, transform of current is zero [9].

Equation (12) represents the duty cycle of step-down converter. Duty cycle is calculated based on input and output voltages. Inductance and capacitance values are calculated by using equations (13) and (14) respectively.

Duty cycle $$D = \frac{V_O}{V_S} \quad (12)$$

Inductance $$L = \frac{V_O.(V_O - V_S)}{f_S.\Delta I_L.V_S} \quad (13)$$

Capacitance $$C = \frac{\Delta.I_L}{8.f_S.\Delta V_{rpl}} \quad (14)$$

Where V_s = Input voltage, V_0 = Output voltage, f_s = Switching frequency

Simulation Results and Discussion

Different MPPT techniques are used to simulate the MPP monitoring for solar PV system. The mathematical modeling of a one diode model is developed and designed using MATLAB simulation. The performance is evaluated by multiple curves based on temperature and irradiation conditions.

Solar PV System without Controller

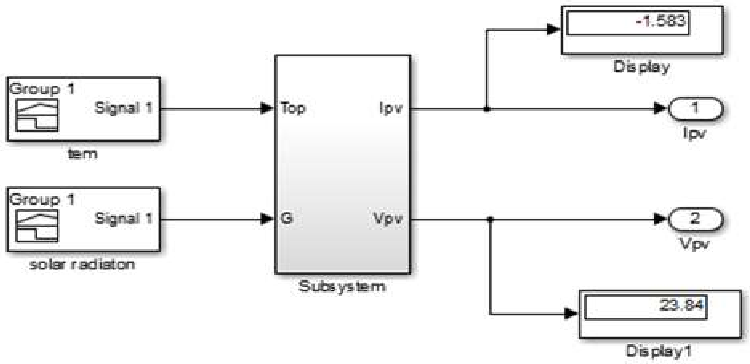

Fig. 5: Simulation Diagram of PV System

Table 1: Specifications of Solar PV System

Open circuit voltage (Voc)	24V
Short circuit current (Isc)	5.1A
Voltage at MPP (Vmpp)	22V
Current at MPP (Impp)	4.8A
Power of MPP (Pmpp)	105.6w
Temperature co-efficient of open circuit voltage (%deg C)	-0.36099
Temperature coefficient of Isc (%deg C)	0.102

Fig.5 shows the simulation diagram of solar photovoltaic system. PV system inputs are temperature and irradiance and outputs are current and voltage. Table.1 shows the specifications of solar PV system.

Case-I: Constant temperature and Variable irradiances

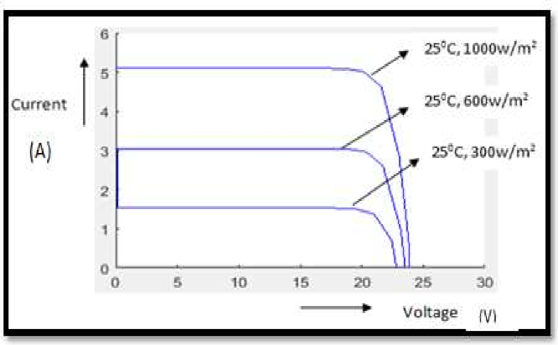

Fig. 6: Effect of Irradiance Variation on I-V Curves

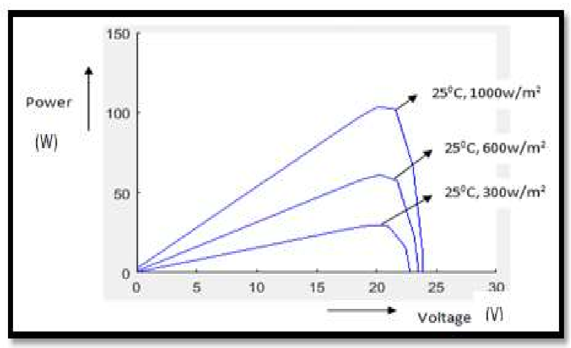

Fig. 7: Effect of Irradiance Variation on P-V Curves

Case-II: Different temperatures and Constant irradiance

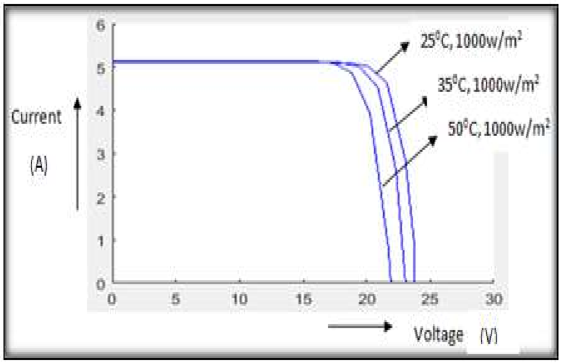

Fig. 8: Effect of Temperature Variation on I-V Curves

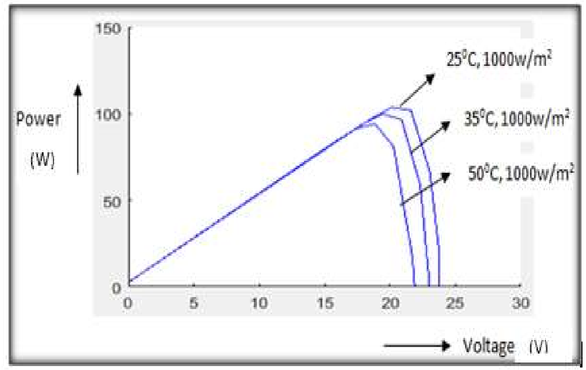

Fig. 9: Effect of Temperature Variation on P-V Curves

Fig.6, Fig.7 and Fig.8, Fig.9 shows the I-V and P-V curves. By observing the above graphs I, V and power values are changed.

Boost Converter

Fig.10 shows the simulation diagram of boost converter. It is also called as step-up chopper or DC - DC converter. Output waveform of step-up chopper is shown in Fig .11. Initially voltage is suddenly increases & oscillates and settles at particular point.

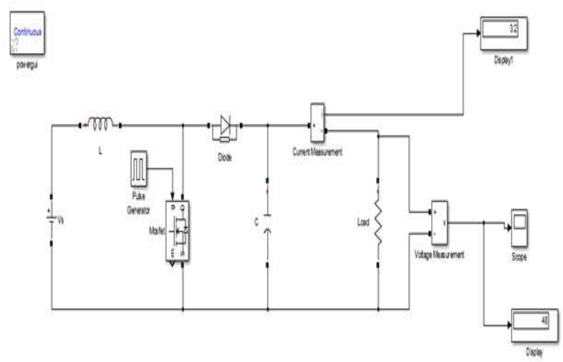

Fig. 10: Simulation Diagram of Step-up Converter

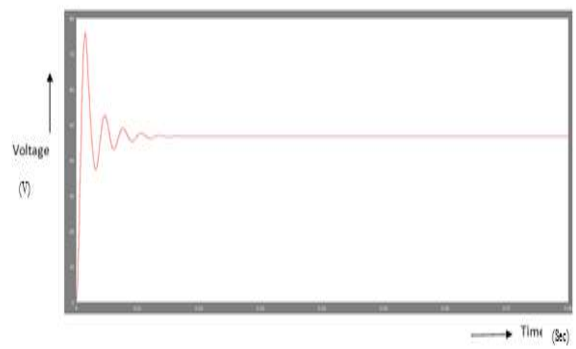

Fig. 11: Output Voltage Waveform of Step-up Converter

Solar PV System with Boost Converter, P & O MPPT and INC based PI MPPT

Fig.12 shows the solar PV system with step-up converter and P & O and INC based PI MPPT. Solar photovoltaic system inputs are temperature and irradiance and outputs are current and voltage. The electrical PV system and step-up device are connected with the assist of controlled voltage source. The step-up chopper is connected to the controlled voltage source. Voltage and currents are measured by measurement blocks. The outputs of measurement blocks are connected to the MPPT blocks.

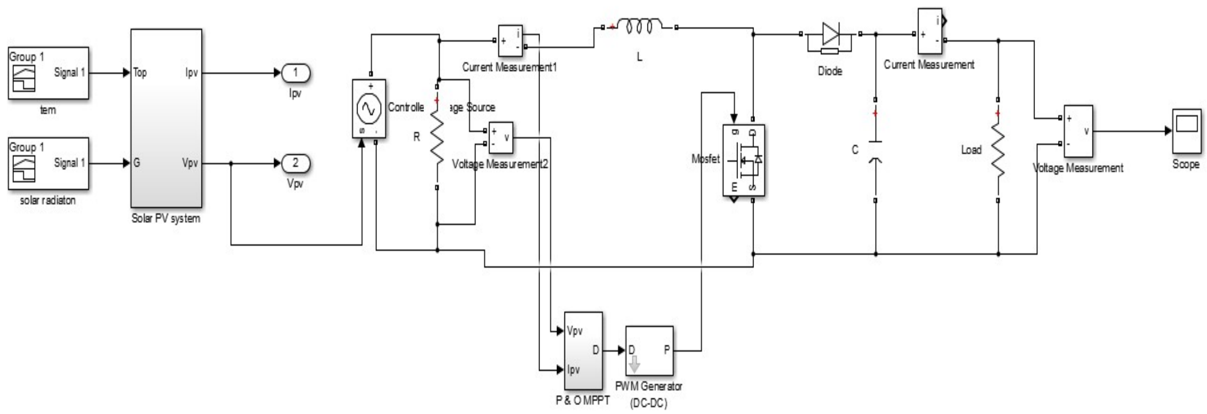

Fig. 12: Simulation Diagram of Solar System with Step-up Chopper and P & O and INC PI based MPPT

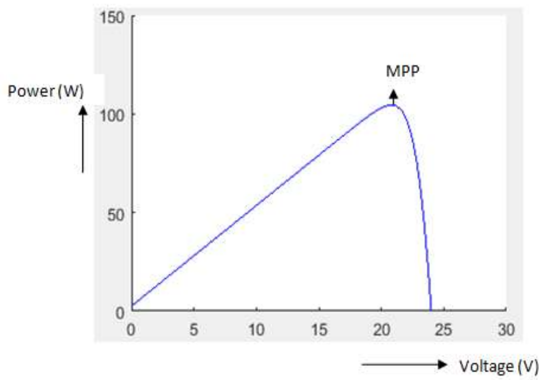

Fig. 13: P-V Curve of P&O and INC PI MPPT(Case-1)

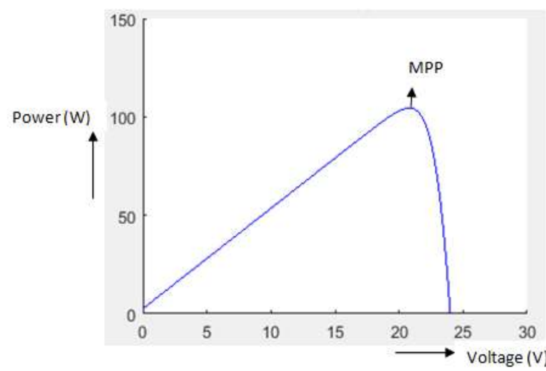

Fig. 14: P-V Curve of P&O and INC PI MPPT (Case-2)

Fig.13 and Fig.14 shows the power-voltage curves for P &O and INC based PI MPPT. From the graphs it is observed that, the power is increased simultaneously. It has improve steady state value but low dynamic performance and more oscillations at the time of MPP tracking. Depending upon load, power-voltage curve also changes.

Buck Converter with PI Controller and Battery

Fig .15demonstrates the buck converter simulation diagram with PI and battery. Step-down chopper output voltage is stored in battery and maintains constant voltage by using PI controller. Here, we are using two batteries, each battery consists of 12V. Battery is used to maintain constant voltage. Table 2 shows the battery specifications.

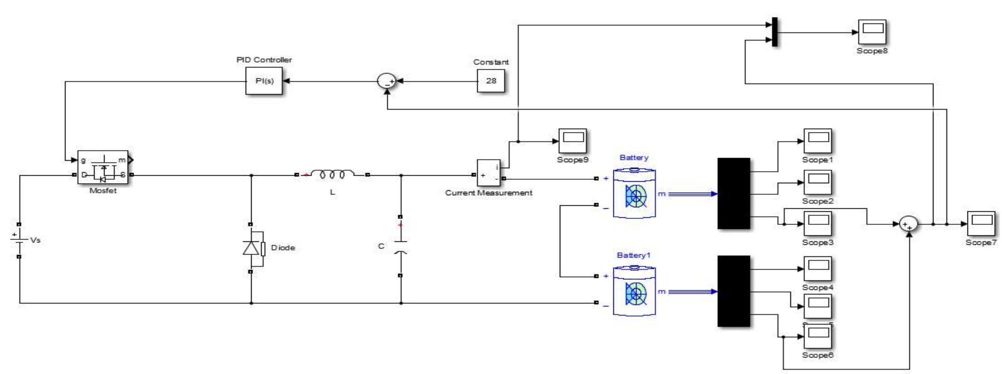

Fig. 15: Simulation Diagram of Step-down Chopper with PI Controller and Battery

Table 2: Specifications of battery [12]

Type	Battery
Nominal voltage	12 V
Rated capacity	100 AH
Design life time	>15 years
Approximate weight (kg)	35 kg
Approx dimensions (mm) (L*W*H)	441(mm)*167(mm)*216(mm)
Applicable temperature	$25^0C - 50^0C$
Self-discharge	Self discharge rate < 0.4% per day (27^0C)
Reference Installation Dimension	According to Client Requirements

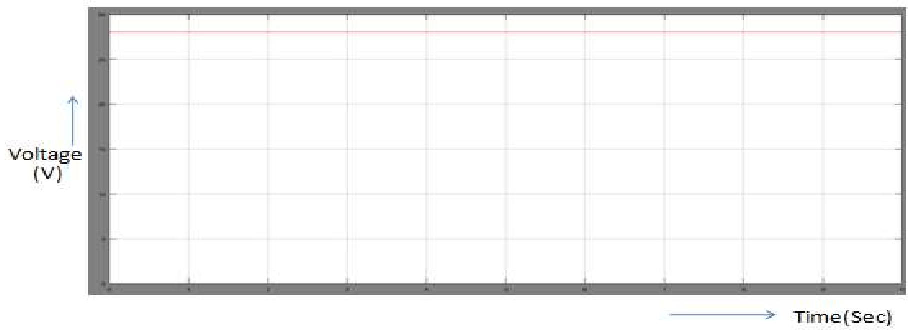

Fig. 16: Output Waveform of Step-down Chopper with PI and Battery

Fig.16 shows the output waveform of step-down device with proportional integral controller and battery. The output response of step-down device with battery has some ripples at the time of starting. Whenever PI controller was applied to the system ripples are reduced and the output voltage will be settled at particular point.

Solar PV System with Boost, Buck and MPPT Techniques

Fig.17 shows the simulation diagram of solar system with step-up, buck and MPPT techniques. Solar photovoltaic system inputs are temperature and irradiance and outputs are current and voltage. PV system and step-up device is attached with the controlled voltage source. Controlled voltage source is attached to the step-up and step-down converter. Voltage and currents are measured with measurement blocks. The outputs of measurement blocks are connected to the MPPT technique like P & O and INC based PI. Output waveform of these MPPT techniques is maintained constant as shown in Fig.18.

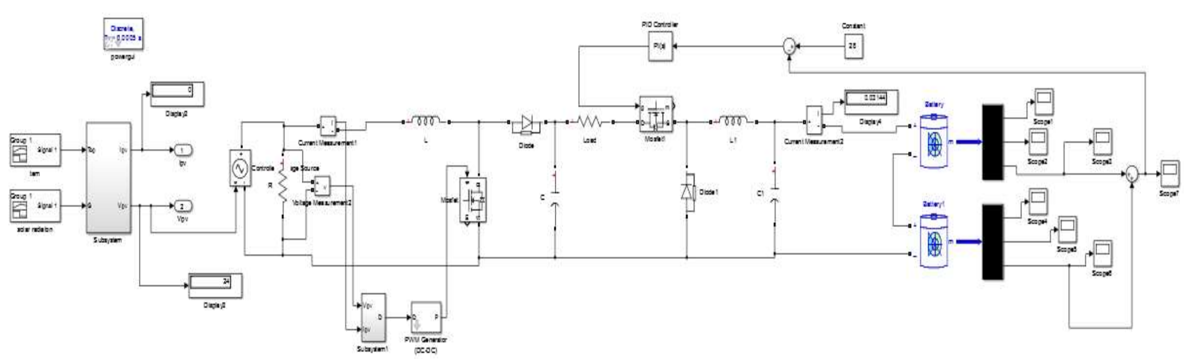

Fig. 17: Simulation Diagram of Solar System with Step-up, Buck and MPPT

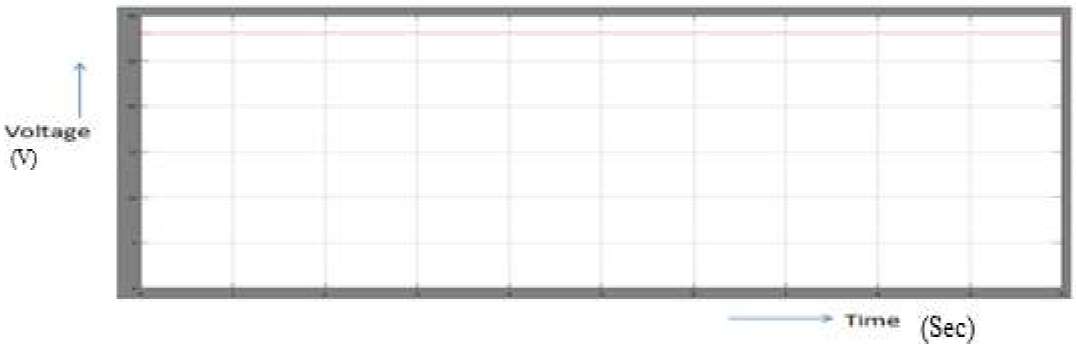

Fig. 18: Output Waveform of Solar PV System with Step-up, Buck and MPPT

Table 3: MPPT Power at Constant Temperature and Different Irradiance

S.No	Constant temperature (^{0}C)	Different irradiance (w/m^2)	Power at without MPP (W)	Power at P & O based MPPT (W)	Power at INC based PI MPPT (W)
1	25	300	29	29.8	30
2	25	600	60	61.3	61.49
3	25	1000	103.5	104.34	104.54

Table 3 shows the MPPT power at constant temperature and different irradiance. Temperature is 25^{0}C and different irradiances are 1000, 600, 300w/m^2. Without controller MPP power at 25^{0}C, 1000w/m^2 is 103.5W. When MPPT techniques like P & O, INC based PI are applied to the system, it increases the power to 104.34W, 104.5W respectively. While reduceing irradiance value power values are also reduceing. By comparing these two MPPT techniques the incremental conductance based PI controller has maximum power and gives accurate results and also it improves the efficiency. Fig.19 shows the graphical representation of results at constant temperature and differnent irradiance.

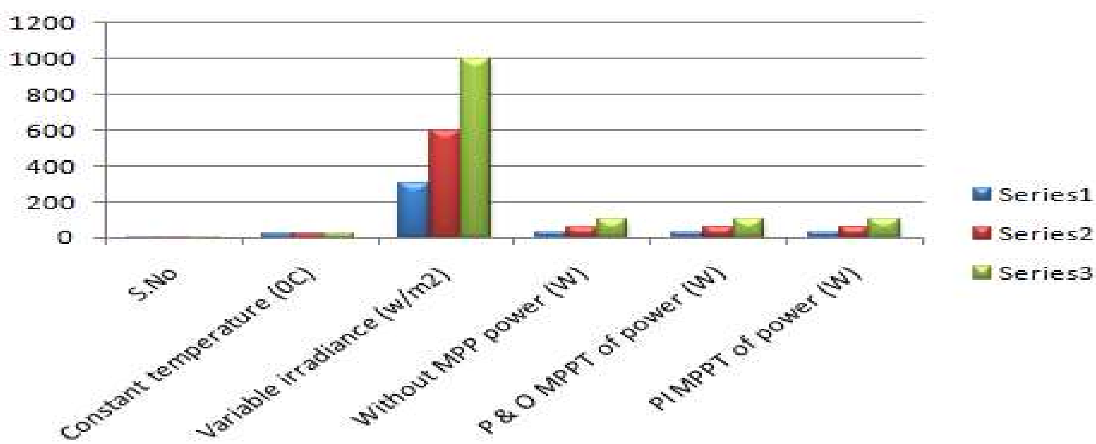

Fig. 19: Graphical Representation of Results at Constant Temperature and Variable Irradiance.

Table 4: MPPT Power at Constant Irradiance and Variable Temperature

S. No	Variable irradiance (w/m^2)	Constant temperature (^{0}C)	Power at without MPP (W)	Power at P & O based MPPT (W)	Power at INC based PI MPPT
1	1000	25	103.5	104.3	104.5
2	1000	35	97.76	99.7	100
3	1000	50	90.67	93.8	94

Table 4 shows the MPPT power at constant irradiance and variable temperature. Variable temperatures are 25^0C, 35^0C, 50^0C and constant irradiance is 1000w/m^2. Without controller MPP power at 25^0C, 1000w/m^2 is 103.5W. When MPPT techniques like P & O and INC based PI are applied to the system, it increases the power to 104.3W and 104.5Wrespectively. While increasing temperature value power values are reduceing. By comparing these two MPPT techniques the incremental conductance based PI has maximum power and gives more accurate and it also improves the efficiency. Fig.20 shows the graphical representation of results at constant temperature and different irradiance.

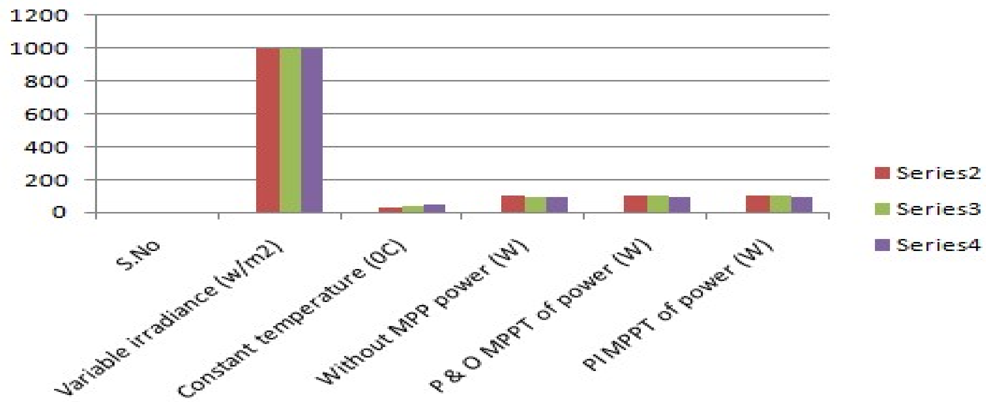

Fig. 20: Graphical Representation of Results at Constant Temperature and Variable Irradiance.

Table 5: Comparison Table of Different MPPT Techniques

Type	P & O	INC PI
Tracking speed	Medium	High
Tracking accuracy	Medium	Accurate
Implementation complexity	Easy	Medium
Dynamic response	Low	Medium
Periodic tuning	Not required	Required
Power oscillations	More	Medium

Table 5 shows the comparison of P&O and INC based PI. By observing these two techniques proposed Incremental conductance based PI technique has higher tracking speed, more tracking accuracy, higher dynamic response and lower periodic oscillations.

Conclusions

The proposed technique is tested at two different climatic conditions such as constant irradiation and different temperatures, constant temperature and different irradiations. The solar PV system output is contrasted with two MPPT controllers such as P&O and IC based PI controller. In this two controllers incremental conductance based PI controller obtaining best performance as comparing to the P&O. INC based PI controller solar PV system operates effectively in terms of MPP and also maintains the constant voltage & appropriate current for the battery. This will reduce the system loses and improves the battery life cycle.

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