

Design and Development of Charge Controller for PV Applications

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Abstract: Solar photovoltaic (PV) technology is becoming more popular because of number of advantages. These advantages include zero greenhouse emission, low maintenance cost, least limitations with regard to site installation. However, the conversion efficiency of PV technology is very low about 15-18%. Also, the power generated from PV system is varying with meteorological parameters like solar irradiance, temperature etc. It is very important to analyse the performance of PV system under different meteorological conditions and also track the maximum power point (MPP) using MPPT technique. By keeping in the aforesaid a performance analysis of perturb and observe (P&O), incremental conductance (INC) has been carried out.

In the present study, the design of standalone PV system with converter and charge controller alongwith different MPPT techniques has been carried out and the results are compared. It has been found that the standalone PV system with charge controller gives more promising results.

Keywords: Solar photovoltaic, Charge Controller, MPPT Technique.

1. Introduction

India is a developing country and densely populated. The factors influencing its status are very common but lack of electricity is also a big issue in the development of this country. Lack of electricity factor can be eliminated by providing sufficient electricity to the increasing load demands. In rural areas where power supply is very unstable due to lack of quantity, there renewable power generation takes place for that small need.

According to Ministry of Power statistics, the inbuilt power generation capacity of India as on September 30, 2017 was 331152.58 MW [1]. Further, the total demand of load for electricity in India is expected to cross 950,000 MW by 2030 and it is beyond doubt that a substantial contribution would be from renewable energy. As on September 30, 2017, the current installed capacity of thermal power is 219449.51 MW which is 66.26 % of total installed capacity. Current installed capacity of coal based thermal power is 193426.50 MW which comes to 58.40 % of total installed base and current installed base of gas based thermal power is 25185.38 MW which is 7.6 % of total installed base, while Sebaseous (oil) based thermal power is 837.63 MW which is 0.25% of total installed base. In addition, 44765.42 MW of power is generated through large hydro and 6780 MW and 60157.66 MW of power is generated from nuclear energy and renewable energy sources respectively. The graphical representation of Indian power sector as on January 31, 2016 is presented in Fig. 1.

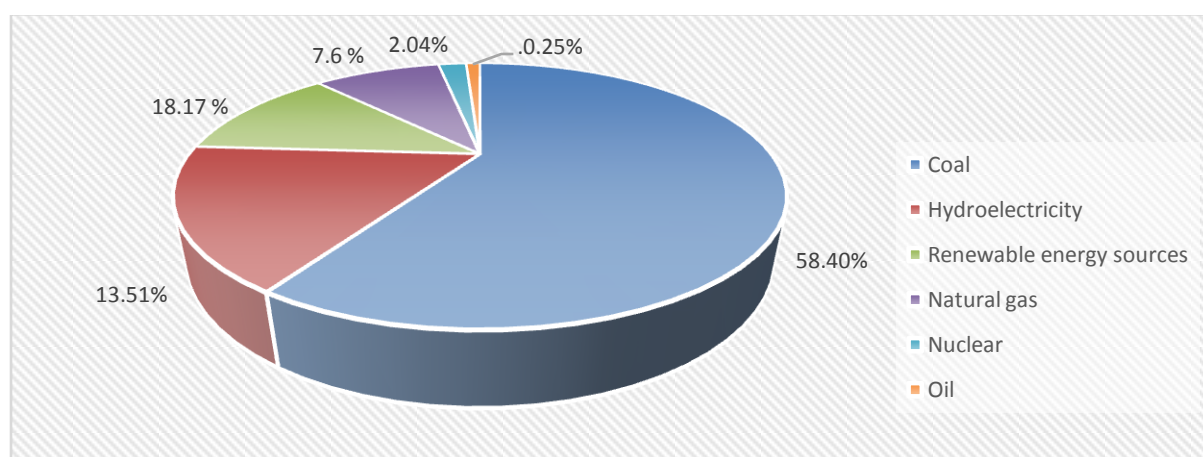


Fig. 1 Indian power sector at glance

In the given survey it is clear that the contribution of renewable sources is very less. But it is increasing continuously as the advantages are more over fossil fuels. In these renewable sources wind power, solar power, small hydro power, biomass power, Bagasse Cogeneration and waste to power are some examples. Further, the contribution of wind turbines is high in electricity generation. Wind power generation is good and efficient for large scale production. In recent years, due to decreasing the cost of solar PV cells,

maintenance free system, attention goes to generate electricity from solar photo voltaic (PV). One more reason is of getting huge power in the form of photons from the sun. That much amount of power is enough to generate continuous electricity for long duration. Therefore, it is continuously growing in electricity production field and new technologies are introducing in this field of generation. Further, a lot of work has been done in this direction [3-32].

The power generated from PV system is varying with meteorological parameters like solar irradiance, temperature etc. Therefore, it is important to analyse the performance of PV system under different meteorological conditions and also track the maximum power point (MPP) using MPPT technique. Also, the PV systems have very low overall efficiency about 13-20% as they suffer from many conversion losses. Hence, this paper is aimed to develop, analyze and study the simulation of the solar PV system with MPPT for improving the efficiency and performance. The main objective of this work is

- To design and develop MATLAB/Simulink model of Solar Photo Voltaic (SPV) system.
- Performance analysis of Maximum Power Point Tracking (MPPT) techniques for PV system with battery storage.
- To develop the simulation charging model for single phase solar PV system with different MPPT technique.

2. Solar Photovoltaic Technology

Solar energy can be utilized with the help of two technologies i.e. solar thermal technology and solar photovoltaic technology. In India, solar thermal technology for power generation is limited. However, there is a drastic advancement in photovoltaic technology. The power generated from PV system can be expressed using the following equation:

$$P = Ax^2 + Bx + C \quad (\text{Watts}) \quad (1)$$

Where, P = power generation (watts),

x = solar radiation

A, B, C are the constants, which may be derived from the measured data.

The photovoltaic (PV) cell is the smallest constituent in a photovoltaic system. Photovoltaic cells are basically made up of a PN junction. In fact, when sunlight hits the cell, the photons are absorbed by the semiconductor atoms, freeing electrons from the negative layer. This free electron finds its path through an external circuit toward the positive layer resulting in an electric current from the positive layer to the negative one. However, the power produced by solar cell is not enough for power generation applications. To obtain the higher power, solar cells are interconnected and hermetically sealed to constitute a photovoltaic module. Further, series – parallel combination of PV modules constitute a PV array. The equivalent circuit of PV module is presented in Fig. 2.

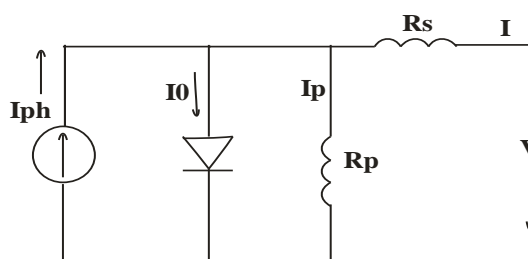


Fig. 2 Equivalent circuit model of solar cell

Further, MATLAB-Simulink Model of standalone PV system of 5000 W has been shown in Fig. 3 and the P-V and I-V characteristics of PV system for different irradianations levels like 1000w/m² at the fixed temperature of 25°C is plotted and shown in Fig. 4- Fig. 5.

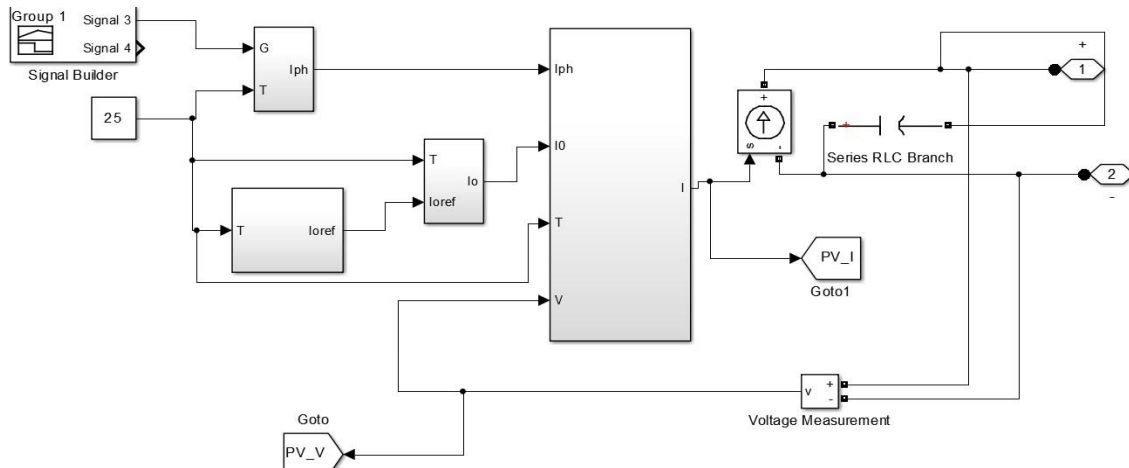


Fig. 3 MATLAB-Simulink Model of Photovoltaic System

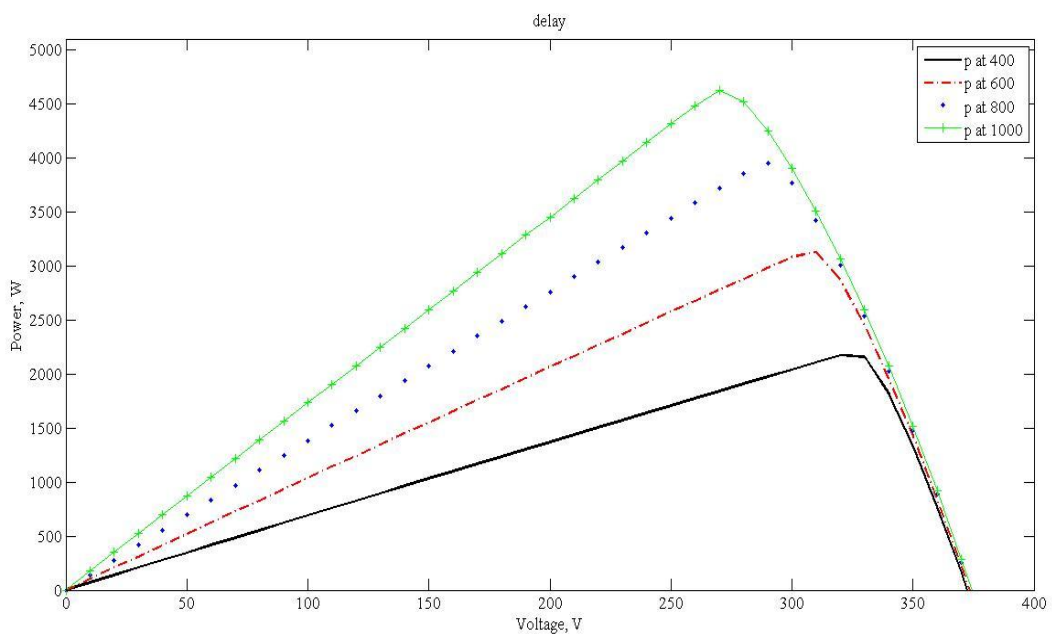


Fig. 4 P-V curve for 5000W system at 1000, 800, 600 and 400 radiation

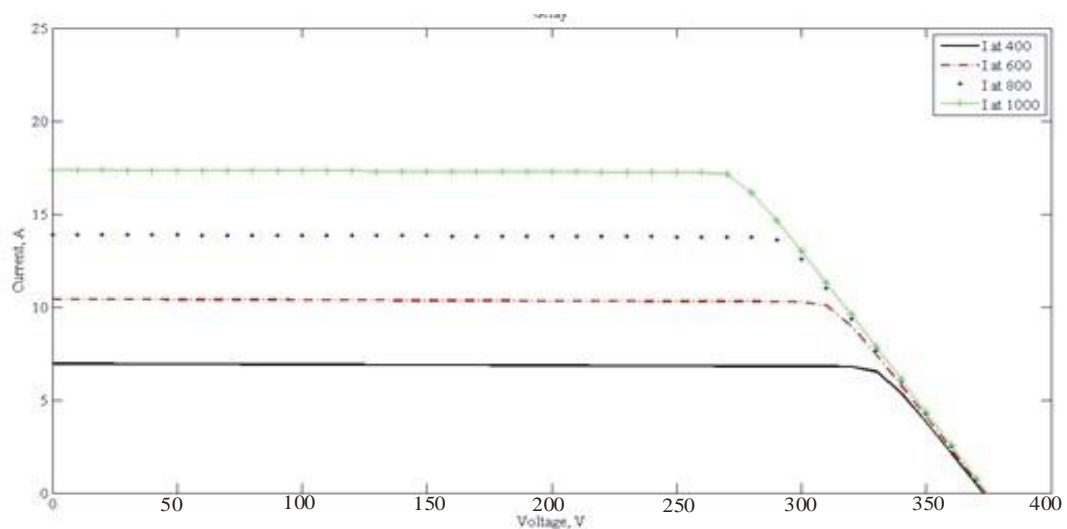


Fig. 5. I-V curve for 5000W system at 1000, 800, 600 and 400 radiation

2.1 DC - DC Boost Converter

DC–DC converter is used to interface the PV array to DC bus to perform three major functions including step up/step down the PV voltage, regulate the varying DC output voltage of PV array and implement the MPPT of solar array to ensure operation at maximum efficiency. However, there are various topologies of DC-DC converter including buck, boost, push pull, half bridge, full bridge, flyback, buck-boost etc. The choice of topology depends on system requirements and its applications. In this paper, DC-DC boost converter is designed to step up the PV voltage.

A boost converter is designed to step up a fluctuating or variable input voltage to a constant output voltage. To produce a constant output voltage feedback loop is used. The output voltage is compared with a reference voltage and a Pulse Width Modulation (PWM) wave is generated. It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter, followed by buck-boost converter and boost converter. Therefore, boost converter has been used in this work and the circuit diagram is presented in Fig. 6.

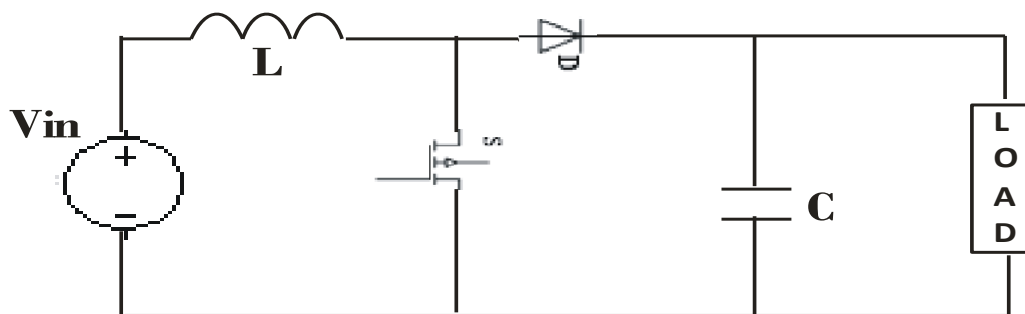


Fig. 6 Boost Converter circuit diagram

Where, V_{in} represents input voltage, L represents inductor, D is duty cycle, C is capacitance. Further, D can be obtained using equation (2)

$$D = 1 - V_{in}/V_{out} \quad (2)$$

Further, MATLAB-Simulink Model of boost converter is depicted in Fig. 7

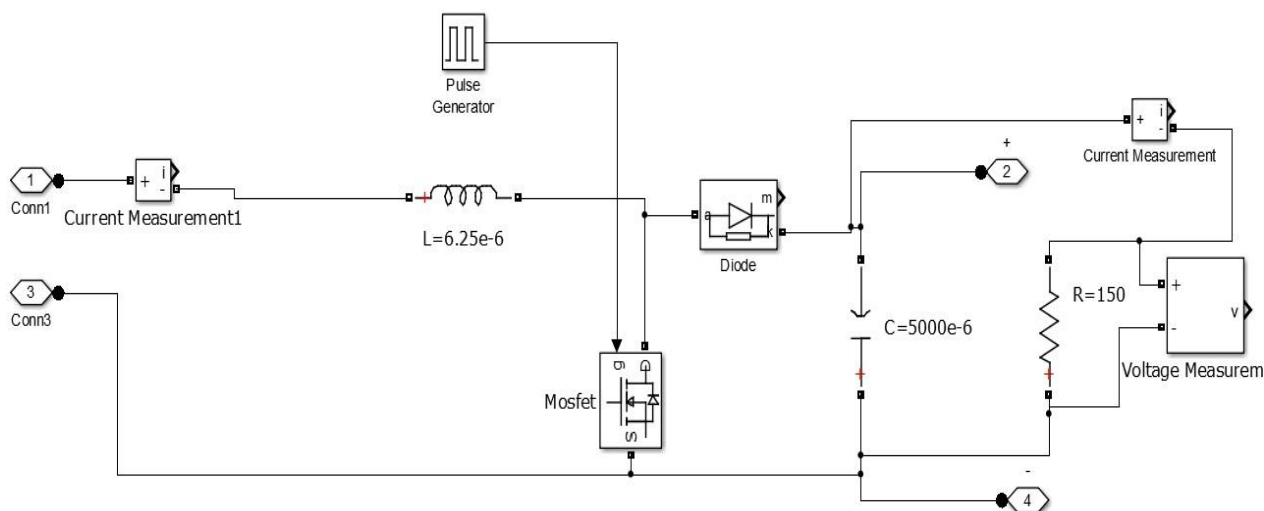


Fig. 7 MATLAB-Simulink Model of boost converter

2.2 Battery Storage System

The primary storage energy source is the battery bank. The battery bank usually consists of a many number of batteries connected in series or parallel. Each battery in the bank is typically 6 or 12V, and multiple batteries are connected in series or parallel to obtain the desired system voltage.

There are many types of commercial batteries available today. Some examples particularly applicable for solar are sealed (maintenance free) lithium-ion, Lead-acid, silver-zinc and zinc-air. Among of them Lead-acid batteries is mainly used because of its relatively cheap cost and ease of availability. One major drawback of it is a relatively large weight/energy density ratio. Each type of batteries have different characteristics (e.g. energy density/kg, charge/discharge rate) and uses however a comprehensive study of batteries is beyond the scope of this thesis.

The power generated from PV system is fluctuating in nature; therefore there is a need of storage systems. In addition, energy storage systems are useful in both utility and small scale applications. The battery storage systems in grid connected systems helps to achieve the objectives like mitigation of the variability and intermittency of PV power by ensuring the maintenance of constant voltage and frequency meeting the peak electricity demand during low power generation from PV system. There are many battery models are available in literature. However, this paper uses the lead acid battery. This model is chosen for its simplicity, low cost and easy availability. Further, the E can be evaluated using equation (3)

$$E = E_0 + A[\exp\{-B|dt\} - 1] - K \frac{Q}{Q-idt} \quad (3)$$

where E_0 is the no load battery voltage (V), K is the polarization voltage (V), Q is the battery capacity (Ah), A is the exponential zone amplitude (V), B is the exponential zone time constant inverse (Ah), and $\int i dt$ is the charge supplied and drawn by the battery (Ah). Further, the battery voltage (V_{Battery}) can be computed by:

$$V_{\text{battery}} = E - R_{\text{in}} I_{\text{battery}} \quad (4)$$

Where, R_{in} is the battery internal resistance (Ω), I_{Battery} is the battery current (A),

Further, the Battery Bank for 5000W PV system is obtained by connecting many battery in series and MATLAB/Simulation of Battery Bank is shown in Fig. 8 and the technical specification of the selected battery is presented in Table 1.

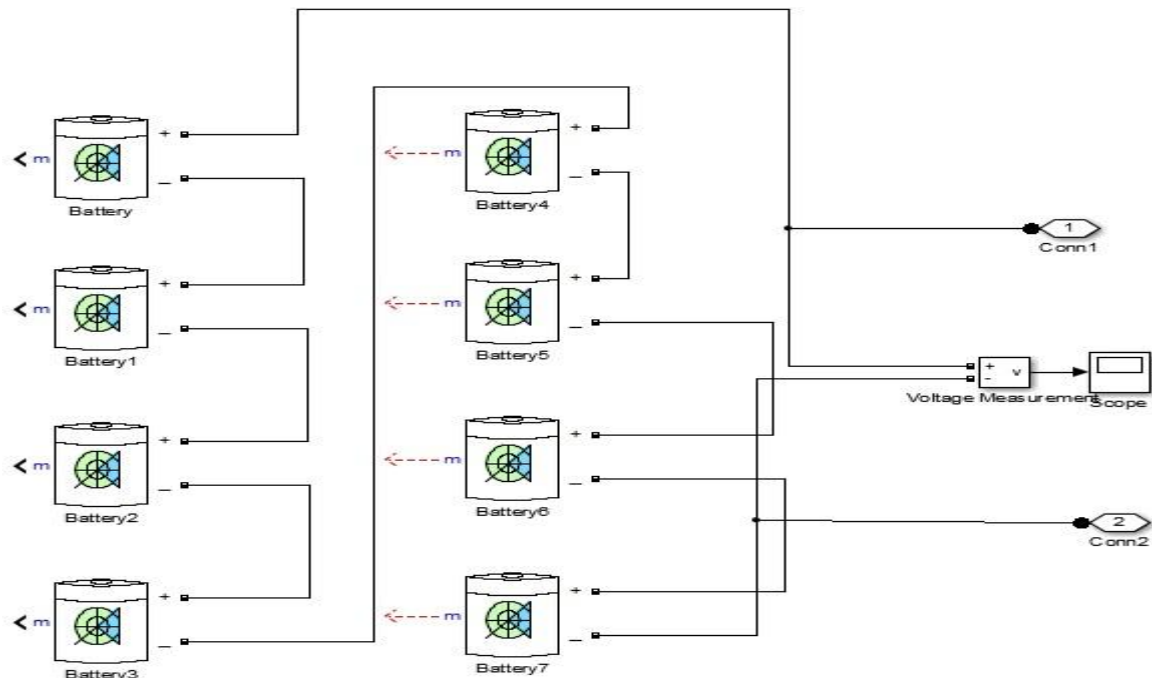


Fig. 8 MATLAB/Simulation of Battery Bank

Table 1. Specification of Battery

Nominal Voltage	30V
Rated Capacity	13Ah
Initial State of Charge	95%
Internal Resistance	0.036923

2.3 Designing of H-Bridge Inverter

The main function of the inverter is to ensure that the PV modules are operated at the maximum power point (MPP) by ably supporting the DC converters. The other is to inject a near sinusoidal current into the load with fewer harmonics. The inverters can be operated in two modes such as

1. Square wave inverters
2. PWM inverters of following types
 - Single pulse width modulation
 - Multiple pulse width modulation
 - Sinusoidal pulse width modulation

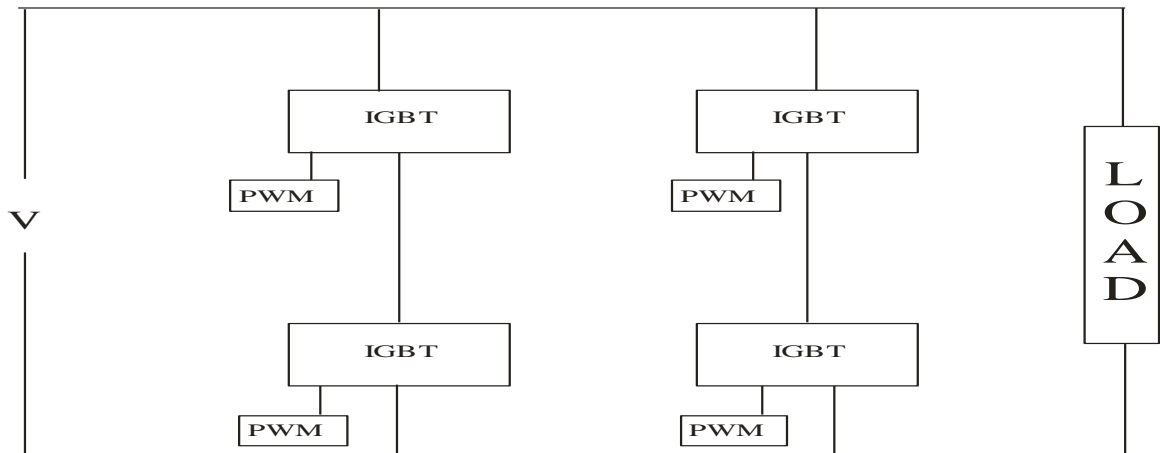


Fig. 9 Single phase H-bridge inverter

Further, the MATLAB/SIMULINK Model of H-Bridge Inverter along with control technique is shown in Fig. 10-Fig,11.

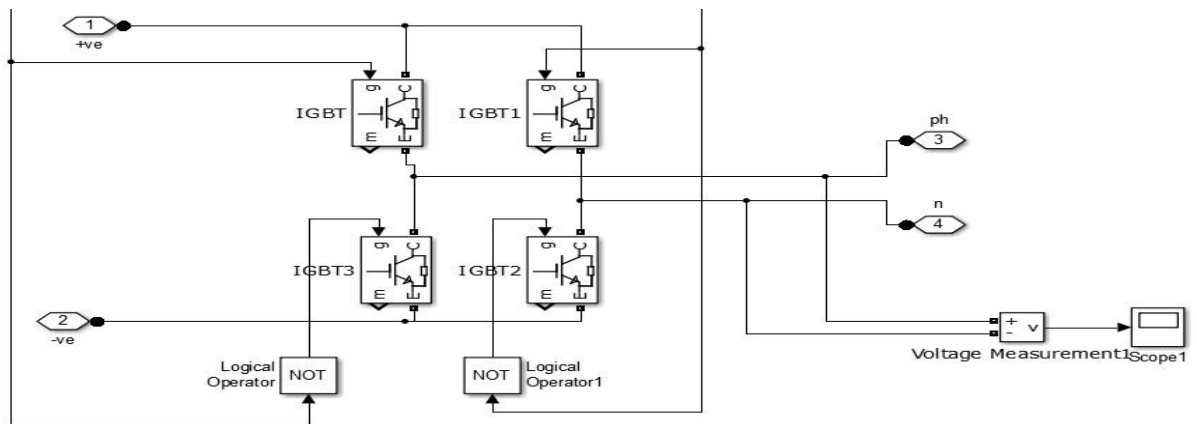


Fig. 10. Simulink model of Single phase H-bridge inverter

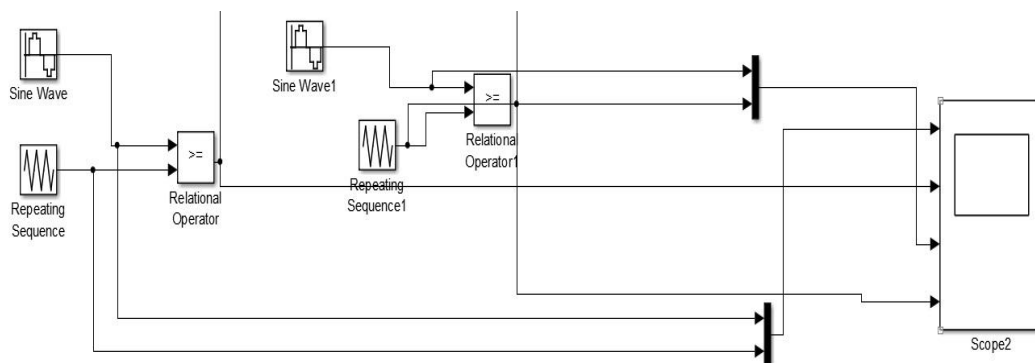


Fig. 11. Control Technique for Single phase H-bridge inverter

2.4 Maximum Power Point Schemes

Solar system utilizes the sun energy for power generation. Solar PV system has nonlinear characteristics so it requires maximum power point tracking (MPPT) to maximize the available energy. Significant parameters are temperature, irradianations, shading and humidity. Point of maximize power always vary so we have to adopt Peak power point to attain maximum power from the system. There are several MPPT techniques out of which perturb-and-observe (P&O) and the incremental conductance (INC) are most frequently used. These methods are based on the fact that, on the PV characteristic, the variation of the power w.r.t. voltage is positive ($dP/dV > 0$) on the left-hand side of the maximum power point (MPP), while it is negative ($dP/dV < 0$) on the right-hand side of the MPP. The main advantages of these methods are that they are generic, e.g., suitable for any PV array, they require no information about the PV array, they work reasonably well under most conditions, and they are simple to implement on a digital controller. Further, the detailed description of these two methods is given in subsequent sections

2.4.1 Conventional Perturb and Observe

The Perturb and Observe (P&O) algorithm is considered to be the most commonly used MPPT algorithm of all the techniques because of its simple structure and ease of implementation. This method is also known as 'hill climbing method'. It is based on the concept that on the PV curve dP/dV goes to zero at the top of the curve. The P&O operates by periodically perturbing (incrementing or decrementing) the PV array terminal voltage or current and comparing the corresponding output power of PV array $P(n+1)$ with that at the previous perturbation $P(n)$. If the perturbation in terminal voltage leads to an increase in power ($dP/dV > 0$), the perturbation should be kept in the same direction otherwise the perturbation is moved to the opposite direction. The perturbation cycle is repeated until the maximum power is reached at the $dP/dV = 0$ point. Further, the Perturbation for P&O technique is given in Table 2.

Table 2. Perturbation for P&O technique

	Perturbation	Change in power	Next perturbation
w	Positive	Positive	Positive
	Positive	Negative	Negative
	Negative	Positive	Negative
	Negative	Negative	Positive

With reference to the above Table, perturbation varies according to the variation in power; when change in power is positive then next perturbation depend upon the previous duty cycle, if previous duty cycle is positive then change in perturbation is also positive otherwise perturbation change is negative. When change in power is negative then next perturbation is negative for the previous positive perturbation and next is positive for the negative previous perturbation. A flowchart illustrating this method is shown in Fig.12.

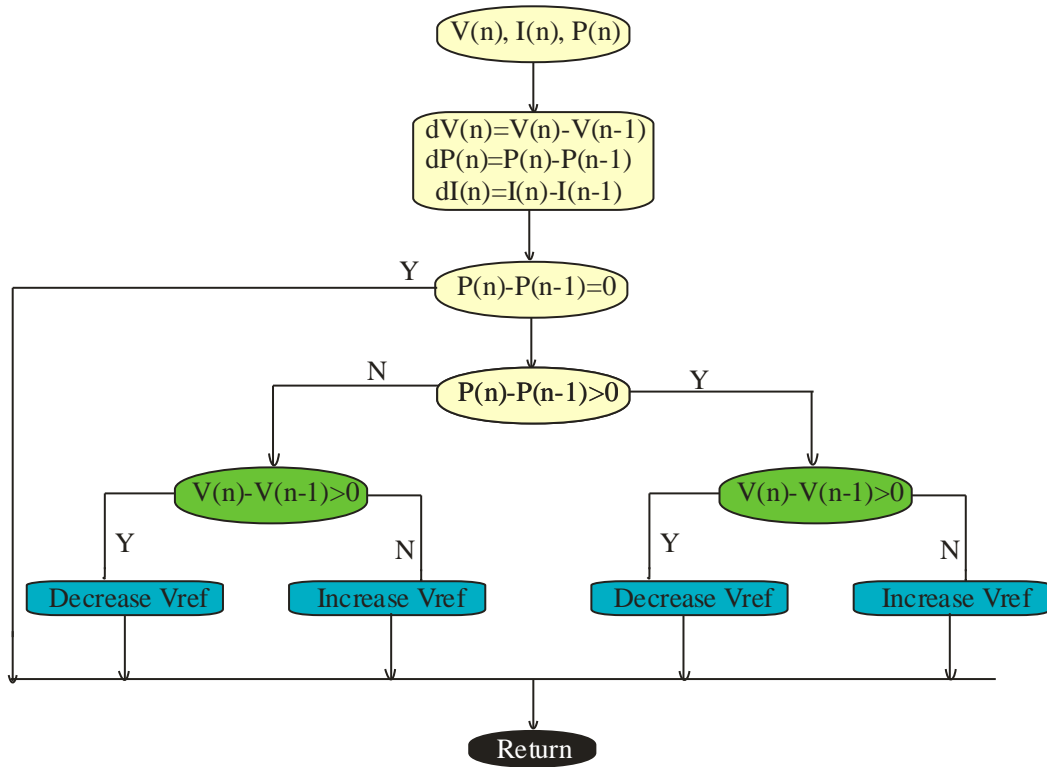


Fig. 12. Algorithm Technique of P&O Technique

Further, the MATLAB/ Simulink modeling of P&O MPPT method is shown in Fig. 13.

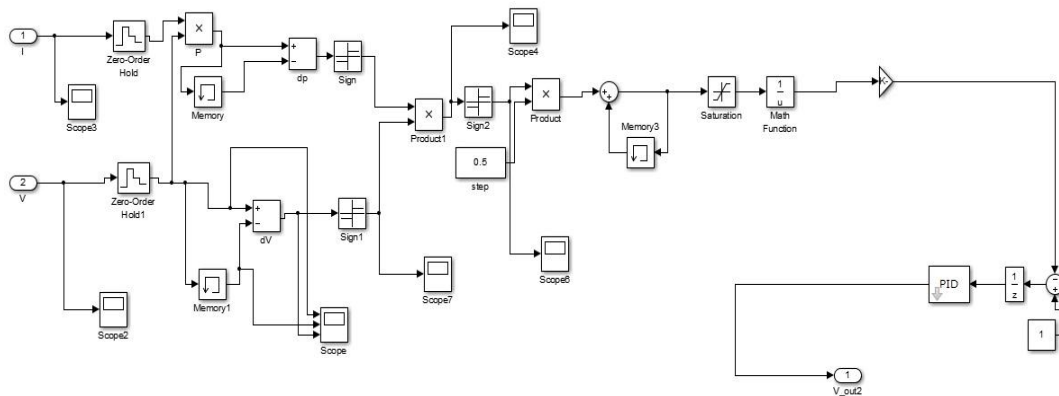


Fig. 13. MATLAB-Simulation of P&O technique

2.4.2 Conventional Incremental and Conductance

Incremental and Conductance (INC) method is based on the fact that the slope of the PV array power and voltage curve is zero at Maximum Power point and it is negative on the right side and positive on the left side of the curve. Incremental conductance (IC) locates the maximum power point when

$$dP/dV = I + V(dI/dV) = 0 \quad (5)$$

this leads to

$$dI/dV = \Delta I/\Delta V = - I_{mpp}/V_{mpp} \quad (6)$$

$$dP/dV = 0 \text{ at MPP}$$

$$dP/dV > 0 \text{ Left of MPP}$$

$$dP/dV < 0 \text{ right of MPP}$$

Maximum point is tracked by comparing instantaneous conductance to the incremental conductance. When the MPP is reached, unless the change in the dI is occurs P_v array is maintained at the maximum point. Speed of the Mpp is determines by the incremental size. When incremental size is wide then fast tracking of Mpp will occur but system might not operate exactly. The ineffective way of performing the INC technique is to use the incremental conductance and the instantaneous conductance to get the error signal. Error signal is zero at the Maximum power point. Further, a flowchart demonstrate this method is depicted in Fig.14.

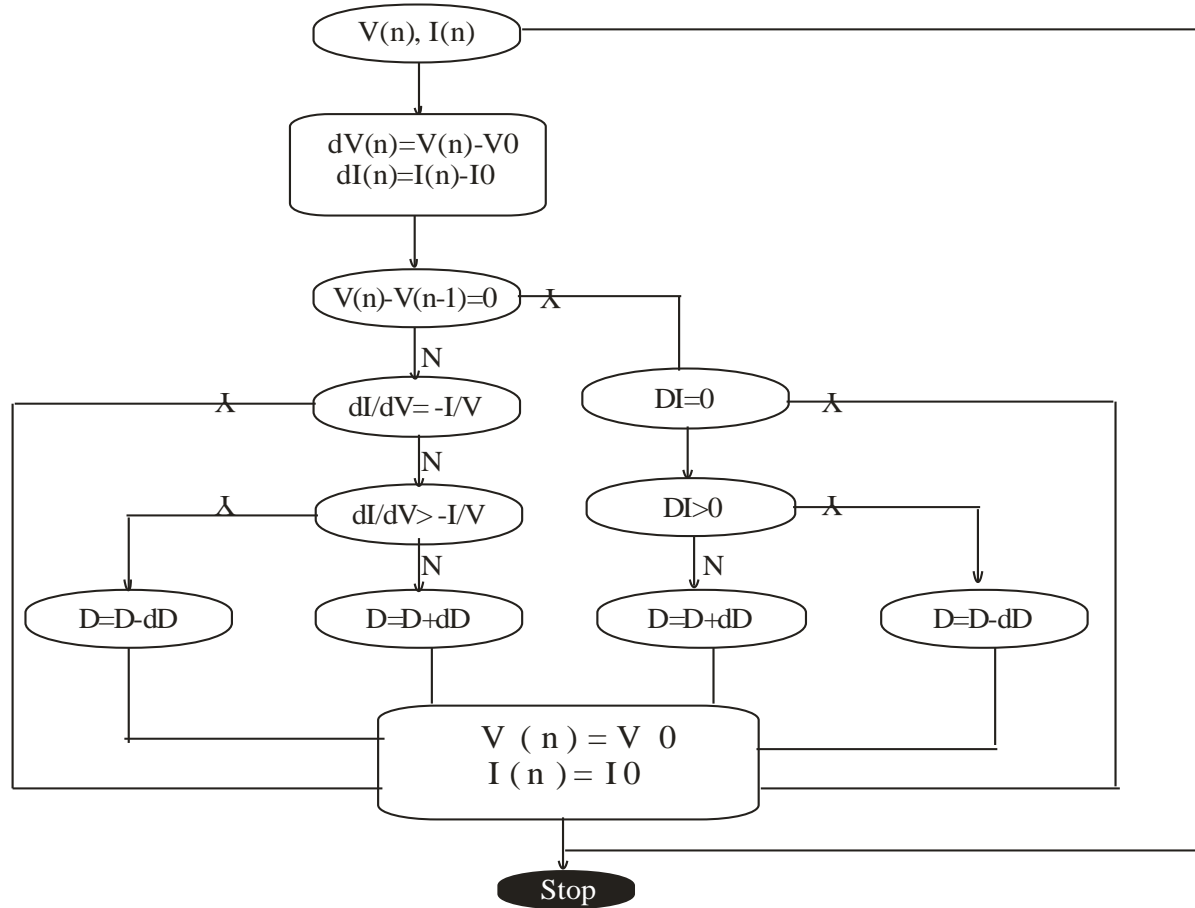


Fig. 14. Flowchart of INC technique

The algorithm starts its cycle by obtaining the present values of I_0 and V_0 , then using the corresponding values stored at the end of the preceding cycle, I_0 and V_0 , the incremental changes are approximated as: $dI=I(n)-I_0$ and $dV=V(n)-V_0$.

The main check is carried out by comparing dI/dV against I/V , and according to the result of this check, the duty cycle D will be adjusted in order to move the array terminal voltage towards the MPP voltage. At the MPP $dI/dV = I/V$, no control action is needed, therefore the adjustment stage will be bypassed and the algorithm will update the stored parameters at the end of the cycle as usual.

Two other checks are included in the algorithm to detect whether a control action is required when the array was operating at the MPP in the preceding cycle ($dV=0$); in this case the change in the atmospheric conditions is detected using ($dI \neq 0$). Now the control signal D , adjustment will depend on whether dI is positive or negative, as shown in the flow chart. When the above IncCond MPT algorithm was tested we noted that the condition $dP/dV = 0$ (or $dI/dV = -I/V$) seldom occurred because of the approximation made in the calculation of dI and dV . However, this condition can be detected by allowing a small marginal error (E) in the above comparisons, i.e. $dP/dV = *E$ and the value of E depends on the required sensitivity of MPT. Further, the MATLAB/Simulated modelling of INC is demonstrated in Fig. 15.

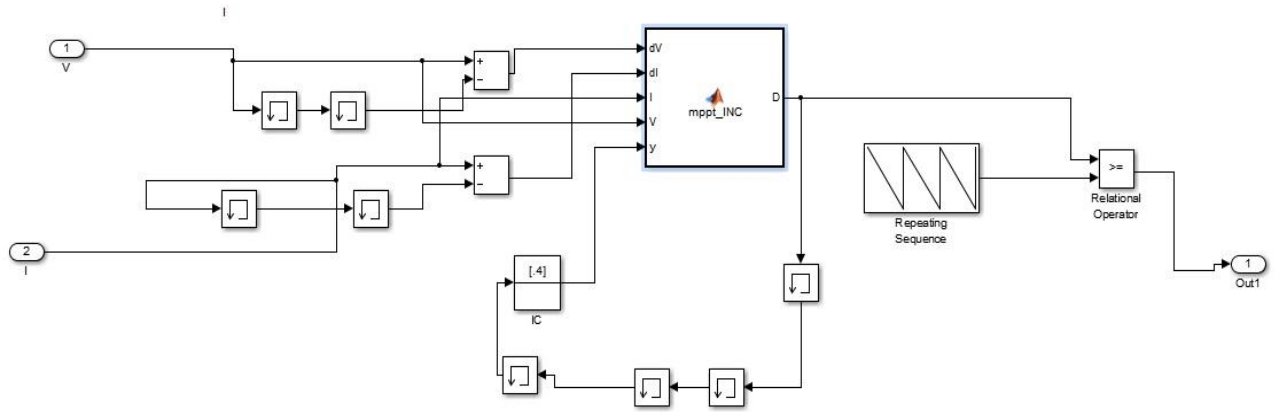


Fig. 15. MATLAB/Simulated modelling of I&C

3. Standalone PV system with converter

In this standalone system we get the current and voltage from the PV array system, these parameter are given to the control algorithm of the duty cycle of the converter for getting the maximum power from the Photovoltaic system, Different MPPT techniques (Perturb and Observe or Incremental and conductance) generates duty cycles for the converter, to getting the maximum power to battery bank for charging. Battery is connected in between the converter and the inverter that supply the power to the dc and ac load. **The** block diagram of Standalone system with converter is depicted in Fig. 16.

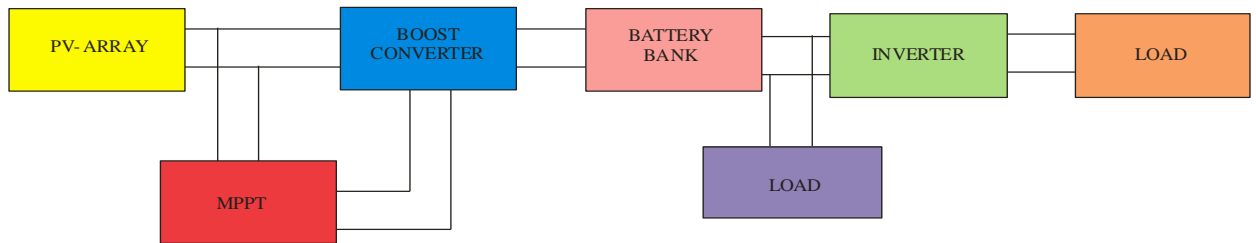


Fig. 16. Block Diagram of Standalone system with converter

Further, the results of boost converter at the converter terminal with P & O and INC MPPT method is shown in Fig. 17- Fig.18 and obtained results has been compared and presented in Table.

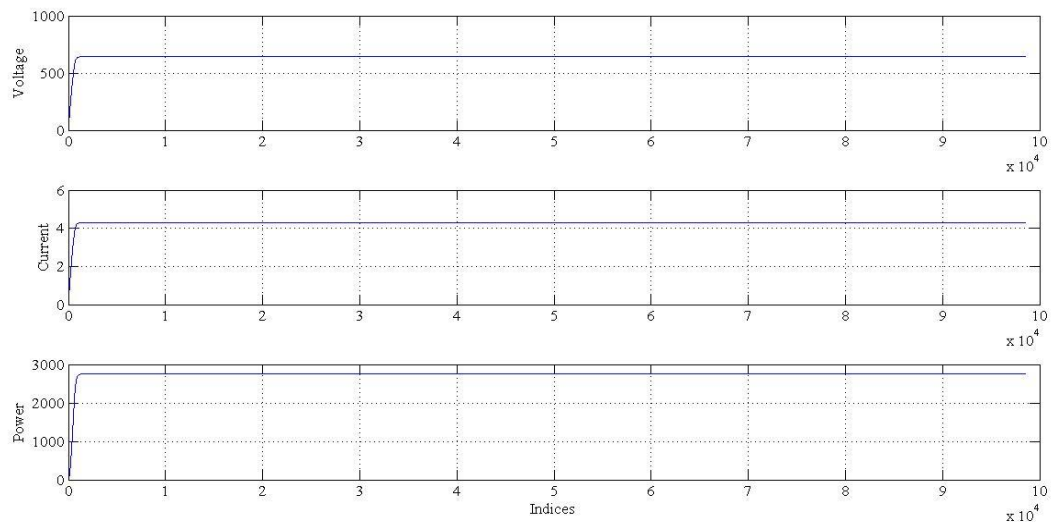


Fig. 17 Boost Converter terminal 1. Voltage 2. Current 3. Power with P & O

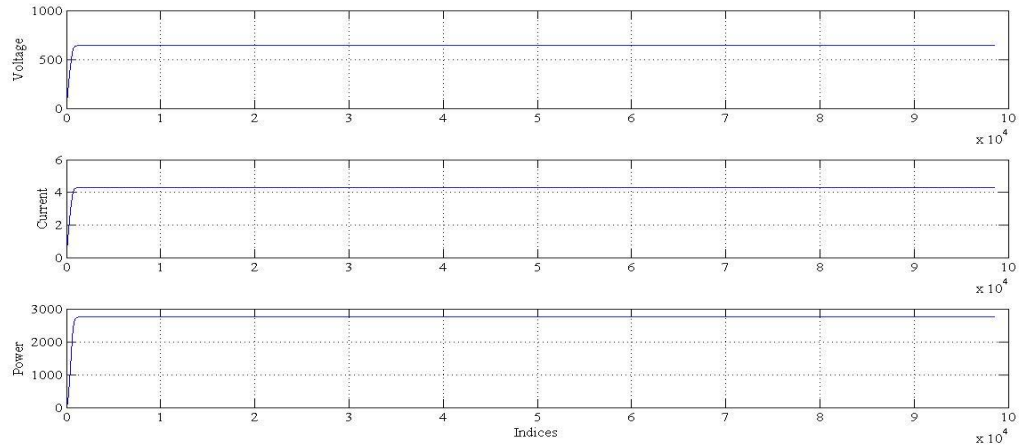


Fig. 18. Boost Converter terminal 1. Voltage 2. Current 3. Power with I&C

Table 3. Parameter competition at converter terminal with MPPT

S.N.	Technique	Power(W)	Current(A)	Voltage(V)	Load
1	P&O	2750	4.28	642.2	R=150
2	I&C	2790	4.31	646.2	R=150

4. Standalone PV System with Charge Controller

Standalone system with charge controller technique we implement the Perturb and observe for getting the maximum power from Photovoltaic system. It will charge the battery upto a certain limit after that it will stop the charging of battery. Block Diagram of Stand alone system with charge controller is shown in Fig. 19. Further, Simulation Model of Stand alone system with charge controller alongwith charging circuit of battery is depicted in Fig. 20- Fig.21.

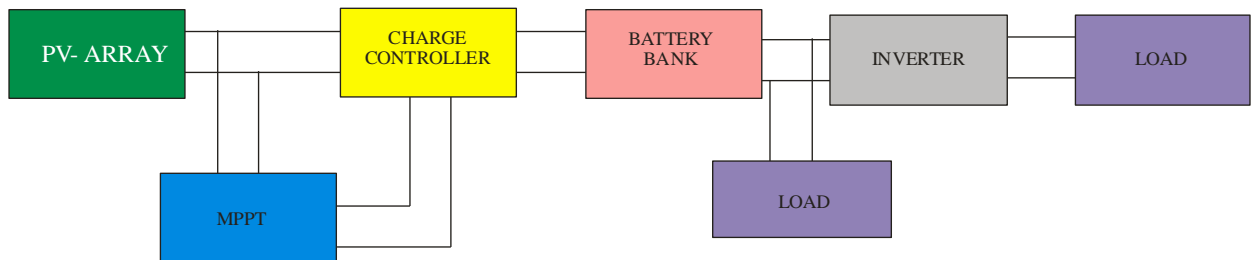


Fig. 19. Block Diagram of Stand alone system with charge controller

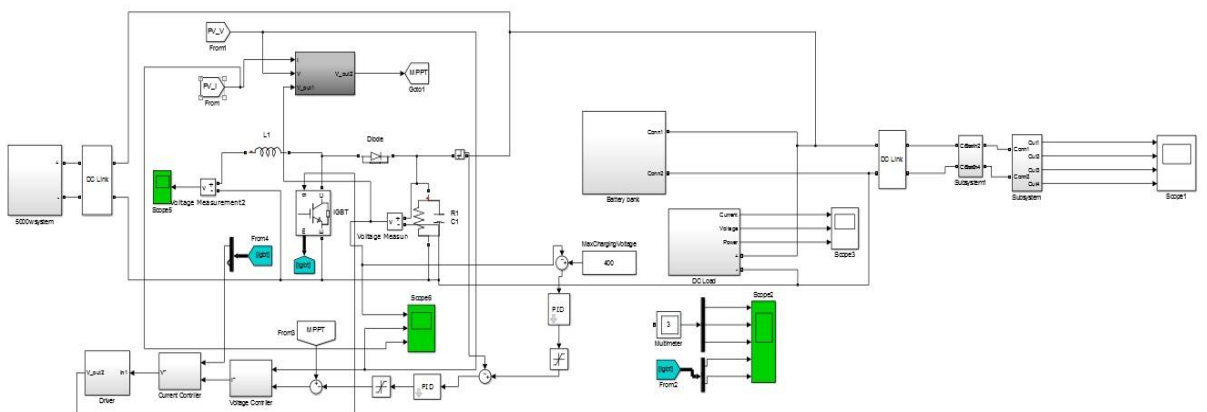


Fig. 20. Simulation Model of Stand alone system with charge controller

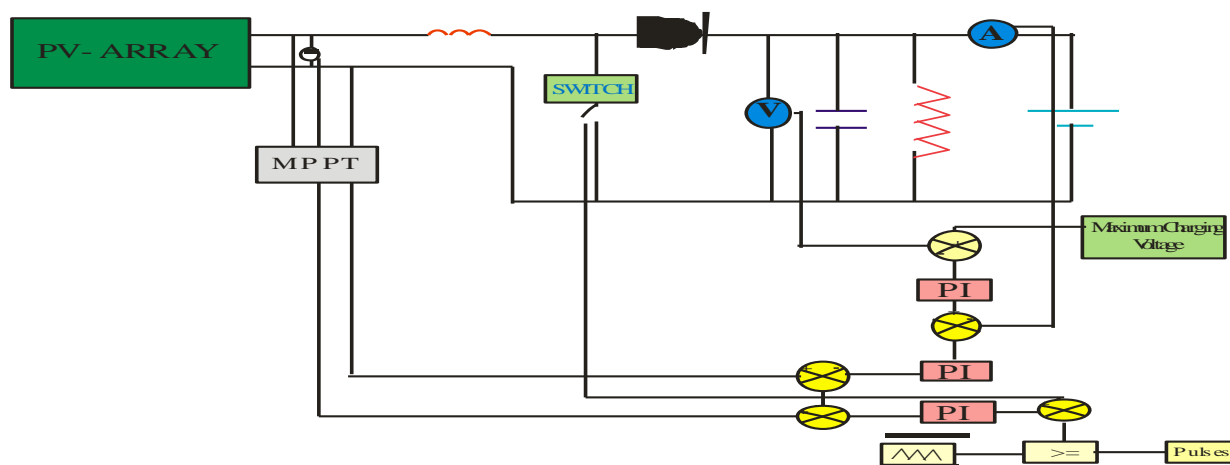


Fig. 21. Charging circuit block diagram for battery

In charge controller, the Maximum power point technique has been used for charging and discharging of the battery. MPP power point at the PV curve is used get the maximum power output to charge the battery. In this circuit diagram Parallel RC network is connected in parallel to the battery for charging and discharging time constant, from the battery terminal the voltage is obtained, this battery terminal voltage is compare with the maximum charging voltage then the error signal is generate which will given into the PI controller. Further, the results obtained with AC and DC load by implementing different MPPT techniques with charge controller is compared and presented in Table 4.

Table 4. Comparison of various parameter with different MPPT

S.No.	Parametre	Average Power (W)		Voltage (V)		Current (A)	
		AC	DC	AC	DC	AC	DC
1	P&O	1575	180	330 (p-p)	424	9.2 (p-p)	0.423
2	INC	1591	183.5	338 (p-p)	427.5	8.81 (p-p)	0.427
3	Charge Controller	1591	179	335 (p-p)	423	8.7 (p-p)	0.423

From Table 4, it is observed that the standalone system with chargecontroller gives more promising results.

5. Conclusion

This paper presents PV/Battery energy system for the standalone system using Matlab/Simulink. The comparison of two different Maximum power point techniques with two different charge and discharge controller technique of the battery is carried out. The control algorithm execute P&O and INC method allow module to operate at maximum power point according to solar irradiation, and match load with the source impedance to provide maximum power. This MPPT model is more suitable because of less cost, easier circuit design.

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