MPPT TECHNIQUE USING SEPIC CONVERTER TO TRACK MAXIMUM POWER POINT FOR PV PANEL

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Abstract**—**In this paper, a technique using a SEPIC converter to efficiently track the maximum power point of a solar panel under varying meteorological conditions is presented. Every PV panel has an optimum operating point which varies depending on cell temperature, the isolation level and array voltage. So, in order to maximize the PV output power, a maximum power point tracker should be used in PV system .The SEPIC converter is one of the buck-boost converters which maintain the output voltage as constant irrespective of the solar isolation level. SEPIC has minimal active components, a simple controller, and clamped switching waveforms that provide low noise operation. Incremental conductance control method has been used as MPPT algorithm. The technique is simple and elegant and does not require complicated mathematical computation.

Keywords**—**Maximum power point tracking, PV Module, SEPIC Converter.

I. INTRODUCTION

Solar energy is most sought today in developing countries, the fastest growing segment of the photovoltaics market. People go without electricity as the sun beats down on the land, making solar power the obvious energy choice. "Governments are finding its modular, decentralized character ideal for filling the electric needs of the thousands of remote villages in their countries." It is much more practical than the extension of expensive power lines into remote areas, where people do not have the money to pay for conventional electricity. Solar panel is the fundamental energy conversion component of photovoltaic (PV) systems. Its conversion efficiency depends on many extrinsic factors, such as insolation levels, temperature, and load condition[1].

There are several advantages of photovoltaic solar power that make it "one of the most promising renewable energy sources in the world." It is non-polluting, has no moving parts that could break down, requires little maintenance and no supervision, and has a life of 20-30 years with low running costs. It is especially unique because no large-scale installation is required. Remote areas can easily produce their own supply of electricity by constructing as small or as large of a system as needed. Solar power generators are simply distributed to homes, schools, or businesses, where their assembly requires no extra development or land area and their function is safe and quiet. Power even has advantages over wind power, hydropower, and solar thermal power. The latter three require turbines with moving parts that are noisy and require maintenance. We still use solar power in the same two forms today, thermal and photovoltaic. The first concentrates sunlight, converts it into heat, and applies it to a steam generator or engine to be converted into electricity in order "to warm buildings, heat water, generate electricity, dry crops or destroy dangerous waste." Electricity is generated when the heated fluid drives turbines or other machinery. The second form of solar power produces electricity directly without moving parts. Today's photovoltaic system is composed of cells made of silicon, the second most abundant element in the earth's crust. "Power is produced when sunlight strikes the semiconductor material and creates an electric current." The smallest unit of the system is a cell. Cells wired together form a module, and modules wired together form a panel.

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different levels around the world, mostly depending on distance from the equator. Although solar energy refers primarily to the use of solar radiation for practical ends, all renewable energies, other than geothermal and tidal, derive their energy from the Sun in a direct or indirect way. Active solar techniques use photovoltaics, concentrated solar power, solar thermal collectors, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies. Since solar energy is not available at night, storing its energy is an important issue in order to have continuous energy availability. Both wind power and solar power are intermittent energy sources, meaning that all available output must be taken when it is available, and either stored for *when it can be used later*, or transported over transmission lines to *where it can be used now*. Concentrated solar power plants typically use thermal energy storage to store the solar energy, such as in high-temperature molten salts. These salts are an effective storage medium because they are low-cost, have a high specific heat capacity, and can deliver heat at temperatures compatible with conventional power systems. This method of energy storage is used, for example, by the Solar Two power station, allowing it to store 1.44 TJin its 68 m^3 storage tank, enough to provide full output for close to 39 hours, with an efficiency of about 99%[3].

The maximum power produced varies with both irradiance and temperature. Since the conversion efficiency of PV arrays is very low, it requires maximum power point tracking (MPPT) control techniques. The maximum power point tracking (MPPT) is the automatic control algorithm to adjust the power interfaces and achieve the greatest possible power harvest, during moment to moment variations of light level, shading, temperature, and photovoltaic module characteristics. The purpose of the MPPT is to adjust the solar operating voltage close to the MPP under changing atmospheric conditions. It has become an essential component to evaluate the design performance of PV power systems. This investigation aims to assess different MPPT techniques, provide background knowledge, implementation topology, grid interconnection of PV and solar micro inverter requirements presented in the literature, doing depth comparisons between them with a brief discussion. The MPPT merits, demerits and classification, which can be used as a reference for future research related to optimizing the solar power generation, are also discussed. Conventional methods are easy to implement but they suffer from oscillations at MPP and tracking speed is less due to fixed perturb step. Intelligent methods are efficient; oscillations are lesser at MPP in steady state and tracked quickly in comparison to conventional methods[5].

In recent years there has been a growing attention towards use of solar energy. The main advantages of photovoltaic (PV) systems employed for harnessing solar energy are lack of greenhouse gas emission, low maintenance costs, fewer limitations with regard to site of installation and absence of mechanical noise arising from moving parts. However, PV systems suffer from relatively low conversion efficiency. Therefore, maximum power point tracking (MPPT) for the solar array is essential in a PV system. The nonlinear behavior of PV systems as well as variations of the maximum power point with solar irradiance level and temperature complicates the tracking of the maximum power point. A variety of MPPT methods have been proposed and implemented.

II. PV PANEL MODELLING

A photovoltaic cell is a device which converts light energy to electrical energy. If band gap is less than energy of photon of light, electron is emitted and creates current. Photovoltaic cell is forward biased [3]. A group of photovoltaic cell is called as PV module. PV modules are arranged in series and parallel to get modules different sizes that ranges from 60W to 170W. In this paper the solar panel is designed for 60W. A PV array consists of a number of photovoltaic cells in series and parallel connections. Series connections increases the voltage of the module, and in parallel increases the current in the array [4]. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell which is shown in Figure-1.

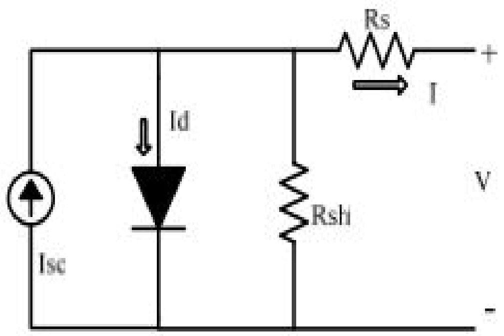

Figure 1: Circuit diagram of PV model

The characteristic equation for a photovoltaic cell is given by equation,

$$I=I_{pv}-I_s\left[\exp\frac{q(V+IR}{N_s K T}-1\right]-\frac{V-R}{R_P} \quad (1)$$

Where
I_{pv} = PV Current (A)
I_s = Saturation Current (A)
Q = Electron Charge (1.60217×10-19 C)
K = Boltzmann constant (1.38065×10-23 J/K)
A = Diode ideality constant
R_s = Series Resistance of cell (Ω)
R_p = Parallel Resistance of cell (Ω)
N_s = No. of Cells in series
T = Temperature (K)

To model the solar panel correctly two diode model is relevant. But here it is limited to single diode model. Figure-2 shows IV curve of solar and also the P-V characteristics, when voltage and current characteristics are multiplied as shown in Figure-3. Panel power output reaches its peak at point mentioned as MPP.

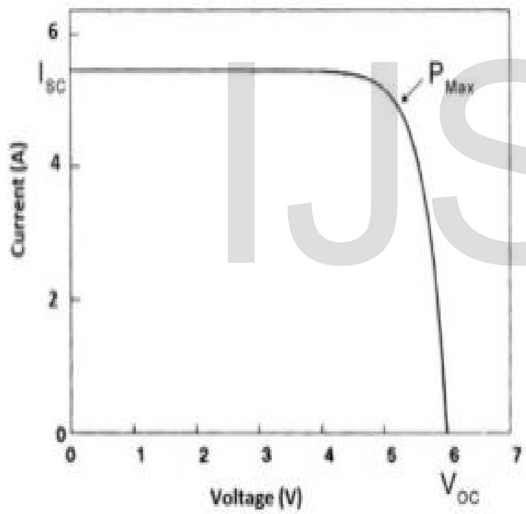

Figure 2: I-V characteristics of a solar panel

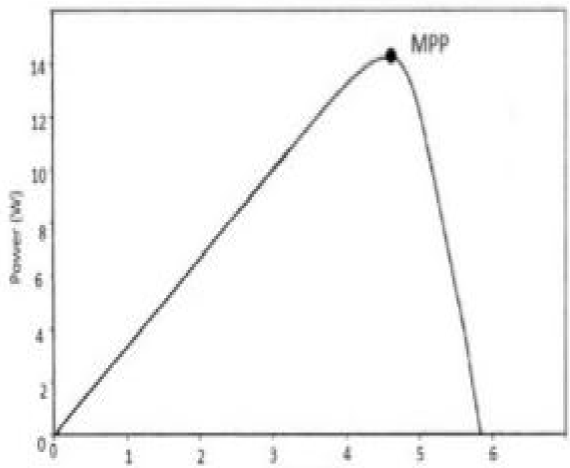

Figure 3 : PV Characteristics of a solar panel

III. MPPT ALGORITHMS

As we know power conversion efficiency of solar module very low. To increase efficiency of solar module proper impedance matching requires to increase efficiency of solar module. MPPT algorithms are vary due to simplicity, efficiency, tracking speed, sensor required and cost. It is seen that the V-I characteristics of the solar module is nonlinear and extremely affected by the solar irradiation and temperature. To maximize the output power of solar module, it has to be operated at fixed value of load resistance. This requires a separate power converter circuit for the MPPT. In our design, a SEPIC type DC-DC converter is used to extract the maximum power from solar module.

For small-scale systems, MPPT is popular for economical reasons. The various methods used for MPPT are as follows:

1. Power matching scheme
2. Curve-fitting technique (hill climbing method)
3. Perturb-and-observe method
4. Incremental conductance technique

A. Curve-Fitting Technique

The curve-fitting technique requires prior examination of the solar panel characteristics, so that an explicit mathematical function for describing the output characteristics is formulated. Although this technique attempts to track the maximum power point without computing the voltage–current product explicitly for the panel power, the curve-fitting technique cannot predict the characteristics including other complex factors, such as aging, temperature, and a possible breakdown of individual cells[5].

B. Perturb-and-Observe (PAO) Method

The P&O algorithms operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage or current and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases ($dP/dV_{PV}>0$), the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way. A common problem in P&O algorithms is that the array terminal voltage is perturbed every MPPT cycle; therefore when the MPP is reached, the output power oscillates around the maximum, resulting in power loss in the PV system. This is especially true in constant or slowly-varying atmospheric conditions. Furthermore, P&O methods can fail under rapidly changing atmospheric condition, which is shown in figure 4. Starting from an operating point A, if atmospheric conditions stay approximately constant, a perturbation ΔV the voltage V will bring the operating point to B and the perturbation will be reversed due to a decrease in power. However, if the irradiance increases and shifts the power curve from P1 to P2 within one sampling period, the operating point will move from A to C. This represents an increase in power and the perturbation is kept the same. Consequently, the operating point diverges from the MPP and will keep diverging if the irradiance steadily increases[4].

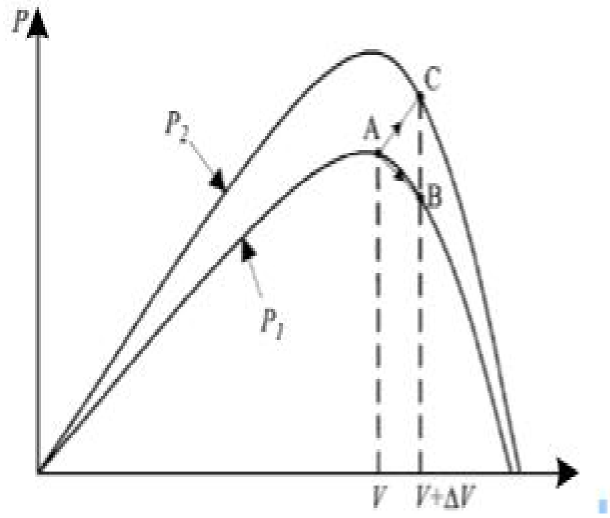

Figure 4 : Divergence of P&O from MPP

C. Incremental Conductance Technique (ICT)

The disadvantage of the PAO method can be improved by comparing the instantaneous panel conductance with the incremental panel conductance. This incremental conductance technique is the most accurate one among the other methods. In this technique, the controller measures incremental change in module voltage and current to observe the effect of a power change. This method requires more calculation but can track fast than perturb and observe algorithm (P&O). Under abruptly change in irradiation level as maximum power point changes continuously, P&O receipts it as a change in MPP due to perturb rather than that of isolation and sometimes end up in calculating incorrect MPP. However this problem get avoided by incremental conductance (INC)[2].

In this method algorithm takes two sample of voltage and current to maximize power from solar module. However due to effectiveness and complexity of incremental conductance algorithm very high compare to perturb and observe. Like the P&O algorithm, it can produce oscillations in power output. This study on realizing MPPT by improved incremental conductance method with variable step-size. So these are two advantage of incremental conductance method. So in our implementation to achieve high efficiency this method utilize incremental conductance (dI/dV) of the photovoltaic array to calculate the sign of the change in power with respect to voltage (dP/dV). The controller maintains this voltage till the isolation changes and the process is repeated. Flow chart of incremental conductance is shown in Figure 5.

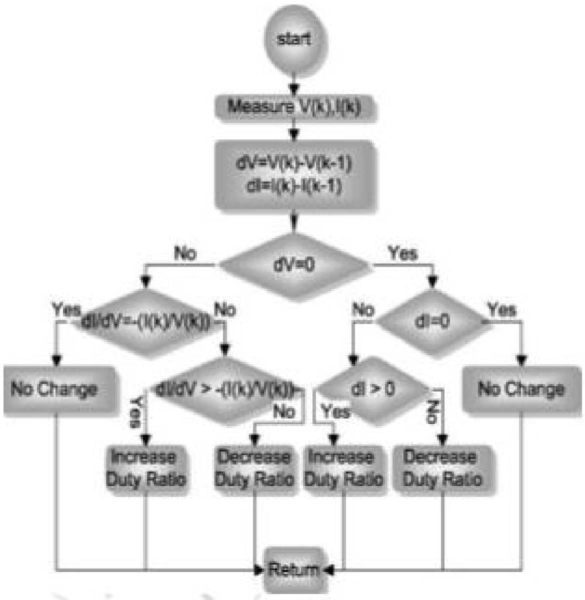

Figure 5: Flow chart of Incremental Conductance (INC) algorithm

IV. COMPARISON OF METHODS

Both perturb and observe, and incremental conductance, are examples of "Hill Climbing Methods "that can find the local maximum of the power curve for the operating condition of the PV array, and so provide a true maximum power point.

The perturb and observe methods can produce oscillations of power output around the maximum power point even under the steady state irradiance. The incremental conductance method has the advantage over the perturb and observe (P&O) method that it can determine the maximum power without oscillatingaround this value. It can perform power point tracking under rapidly varying irradiation conditions with higher accuracy than the perturb and observe method. However, the incremental conductance method can produce oscillations and can perform erratically under rapidly changing atmospheric conditions. The computational time is increased due to the slowing down of the sampling frequency resulting from the higher complexity of the algorithm compared to the P&O method.

In the constant voltage ration (or "open voltage")method, the current from the photovoltaic must be set to zero momentarily to measure the open circuit voltage and then afterwards set to a predetermined percentage of the measured voltage, usually around 76%.energy may be wasted during the time the current is set to zero. The approximation of 76% as the MPP/Voc ratio is not necessarily accurate though. Although simple and low cost to implement, the interruption reduce array efficiency and do not ensure finding the actual maximum power point. However, efficiencies of some systems may reach above 95%[4].

V. PROPOSED SYSTEM

A. DESCRIPTION OF BLOCK DIAGRAM

The solar power which can be obtained from solar cell cannot be utilized directly. It is usually stored in the battery and inverter circuit and further it can be used as AC. But the output voltage as well as power from the solar cell depends upon the illumination and intensity of the light. If the light intensity is very low it may produce very low output voltage. The lower output voltage from the solar cell may not charge the battery and the power is wasted. Here an intermediate stage of converter called SEPIC is used to boost the lower output voltage from the solar cell and also buck the voltage if the light intensity is high.

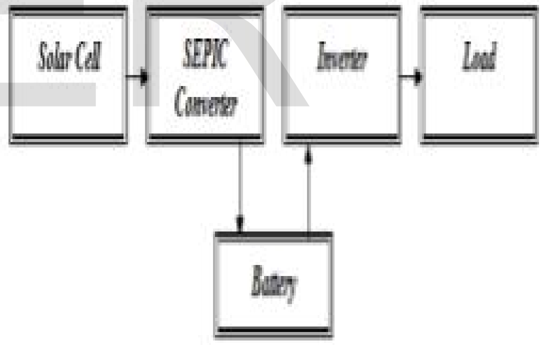

Figure 6: Block Diagram of proposed system

In this SEPIC converter, MPP tracking is much easier because the amount of input current ripple present is non-pulsating. Since the switch present in SEPIC converter is directly connected to ground only low side driving is required which is easier than high side driving used in buck-boost converter. Additionally, the SEPIC converter is highly efficient compared to buck-boost converter.

The voltage gain of a SEPIC converter is given by,

$$V_o = D/1\text{-}D * V_{pv} \quad (2)$$

Where $D = T_{on} / T_s$ is the duty ratio of the converter switch, V_o is the output voltage of the converter and V_{pv} is the input voltage which is fed from the solar array. The control signal of PWM1 is produced by comparing the panel current I_{pv} with a control signal, which is a saw tooth wave derived from the basic equations of SEPIC converter. The SEPIC converter acts in buck mode for reducing the panel voltage to constant value. But for grid interface, the SEPIC converter has to work in the boost mode. The input power of the converter can be controlled by varying the amplitude of the control signal and it is called constant input power mode operation.

B . ANALYSIS OF SEPIC CONVERTER

The SEPIC converter is used as an interface between the PV array and the load to provide load impedance matching with the PV source. SEPIC is essentially a boost converter followed by buck-boost converter. Therefore SEPIC is similar to buck-boost converter but it has the advantage of having non-inverted output. Also the coupling capacitor offers isolation between output side and input side which is unique to SEPIC converter only. In SEPIC converter, MPP tracking can be done with ease because of low input ripple current. In addition to that, SEPIC converter is more efficient than buck-boost converte[6]r. The circuit diagram of the SEPIC converter is figure 7.

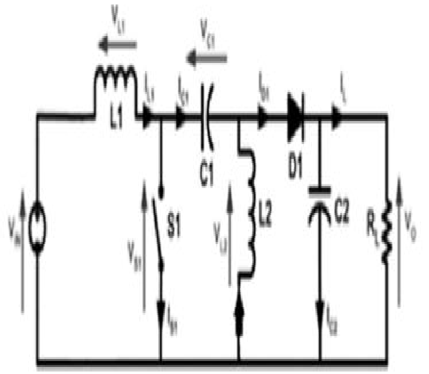

Figure 7: Circuit diagram of SEPIC converter

The design of SEPIC converter has been explained and the designed values of the different parameters of the SEPIC converter is listed in the table 1. The SEPIC converter is designed for 920 W load since four panels are connected in series as each panel is rated for 230 W peak power. Unlike uniform irradiation condition where unique MPP occurs at a voltage close to 0.75Voc, peak power points occur at lower, middle and higher voltage levels of the PV array. Single-ended primary inductor converter (SEPIC) is a type of DC-DC converter, that allows the voltage at its output to be more than, less than, or equal to that at its input. The output voltage of the SEPIC is controlled by the duty cycle of the MOSFET. A SEPIC is similar to a traditional buck-boost converter, but has advantages of having non-inverted output, by means of coupling energy from the input to the output is via a series capacitor. When the switch is turned off output voltage drops to 0 V. SEPIC is useful in applications like battery charging where voltage can be above and below that of the regulator output.

Table : 1 Parameter values of SEPIC converter

PARAMETER	VALUE	UNIT
L1, L2	0.73702	Milli Henry
Cout	1.422	Milli Farad
Cp	10	Micro Farad
Vs	30 to 120	V
f_s	10	kHz

DC-DC converter used in maximum power point tracking system to interface load and PV system SEPIC (Single Ended Primary Inductance Converter) is modelled, output voltage of SEPIC converter can be step-up or step-down then input voltage. In MPPT SEPIC converter work in continuous conduction mode. PWM controlled with switching frequency of 50KHz. Power flow of circuit controlled by using ON/OFF duty ratio threw switching MOSFET[6].

Maximum power point tracking by incremental conductance method + Integral regulator. Maximum power point is obtained when dP/dV=0

Where P= V*Id(V*I)/dV = I + V*dI/dV = 0
dI/dV = -I/V

The integral regulator minimizes the error (dI/dV + I/V) Regulator output = Duty cycle correction, Maximum power point is obtained using incremental conductance method. So in our implementation to achieve high efficiency this method utilize incremental conductance (dI/dV) of the photovoltaic array to calculate the sign of the change in power with respect to voltage (dP/dV). The controller maintains this voltage till the isolation changes and the process is repeated.

The penetration of PV systems as distributed power generation systems has been increased dramatically in the last years. In parallel with this, Maximum Power Point Tracking (MPPT) is becoming more and more important as the amount of energy produced by PV systems is increasing. Since the MPP depends on solar irradiation and cell temperature, it is never constant over time and hence Maximum Power Point Tracking (MPPT) technique should be used to track the maximum power point.

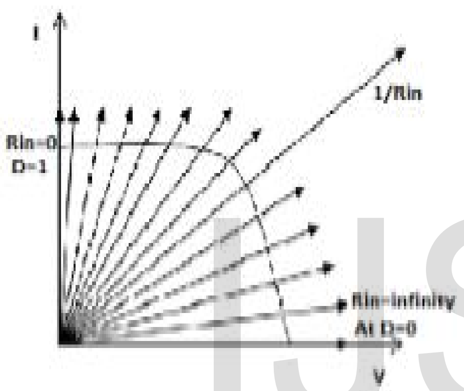

Figure 8 : SEPIC Converter operating area

The range of operation of SEPIC converter covers the entire V-I characteristics of the PV cell/module as shown in fig. 8 and hence it is a suitable converter to be picked for MPPT under normal as well as partially shaded conditions. In general, maximum power is transferred to the load from the source only when the impedances of the load and source are matched. If the load is connected directly to the PV system, the impedance matching may not occur at all operating conditions. Therefore, SEPIC converter is used as an interface to provide the impedance matching. The equation which relates the load resistance and input resistance of the converter in terms of duty cycle D is given in equation,

$$R_{in}= (1-D)^2/D^2 \times R_0 \quad (3)$$

By varying duty cycle, entire P-V curve can be swept using SEPIC converter which is very much essential for tracking global maximum power point under partial shading conditions.

VI SIMULATION RESULTS

MATLAB is an interactive, matrix-based package scientific and engineering graphical user interface, signal processing, fuzzy logic, and many others. The number optimization, statistics, neural networks, of different toolboxes increases with each newer version of MATLAB numeric computation and visualization. It can solve complex numerical problems in a fraction of the time required.

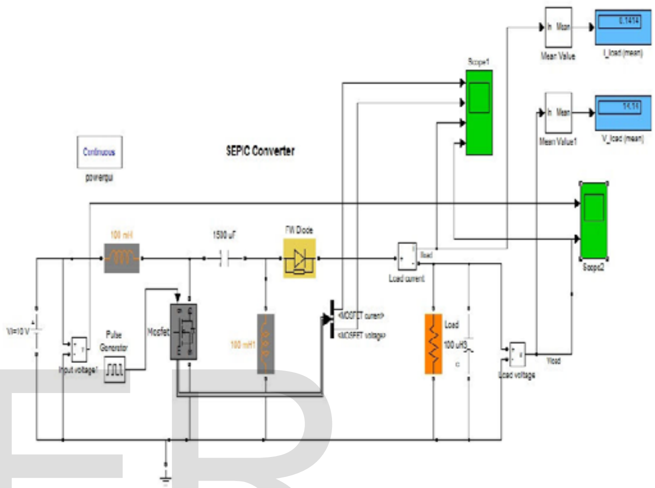

Figure 9 : Simulation of SEPIC Converter

The final simulation model of SEPIC converter is shown in Fig.9. Simulations have been performed to confirm the above analysis. Figs. 9 and 10 show the Simulation of open loop SEPIC Converter and simulation result of SEPIC Converter. Table II shows the simulation input and output parameters.

Table 2 : Simulation parameters

DC Input voltage	L1	L2	C1	C2	Duty cycle	Output Voltage
10V	200e-3H	500e-6H	37e-6F	1000e-6F	54%	15V

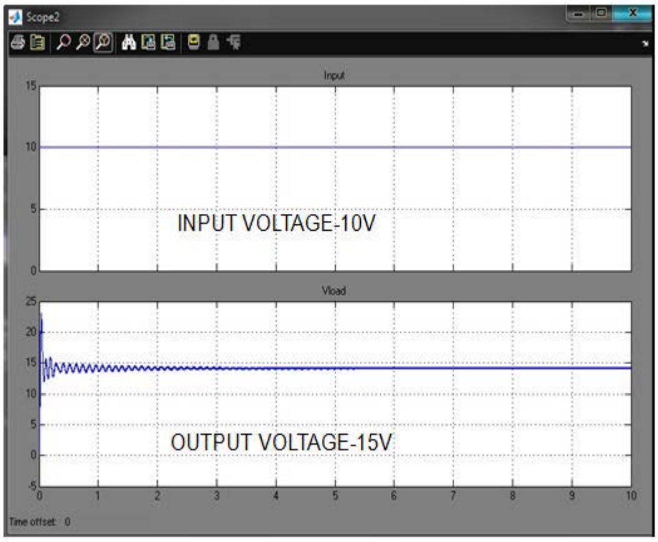

Figure : 10 Simulation Result of SEPIC Converter

VII CONCLUSION

In this paper, the proposed incremental conductance algorithm was used to track the MPP for PV module under a fast - changing solar irradiation level. SEPIC type converter is used in this study as DC/DC converter of the MPPT system. A comparison of incremental conductance method and perturb and observe method has been done in this paper. SEPIC is similar to buck-boost converter which maintain the output voltage as constant irrespective of the solar isolation level, but it has the advantage of having non-inverted output. By adjusting the switching frequency of the converter the maximum power point has been achieved. SEPIC also has minimal active components, a simple controller, and clamped switching waveforms that provide low noise operation. The technique is simple and elegant and does not require complicated mathematical computation.

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