Design and Implementation of SEPIC converter for Solar Energy Conversion System Using Hill Climbing MPPT Algorithm

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Abstract- **In this paper, the PV systems are designed to meet the load requirement in the best possible manner. In order to maximize the power output the system components of the photovoltaic system should be optimized. For the optimization maximum power point tracking (MPPT) is a promising technique that grid tie inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more solar panels. We propose a system architecture that provides a fast and conditionally stable maximum power Point tracking scheme with high tracking efficiency is proposed for photovoltaic applications. This is achieved through the method of hill climbing MPPT technique used in power converters. We describe the design and implementation of a high-efficiency Single Ended Primary Inductance MPPT converter, along with digital control techniques that ensure both local and global maximum power extraction. The simulation results by MATLAB/SIMULINK investigate in detail the concept of Maximum Power Point Tracking (MPPT) which significantly increases the efficiency of the solar photovoltaic system.**

Keywords: **Photovoltaic Systems, Grid connection, Hill climbing method, Maximum Power Point Tracking (MPPT), Single Ended Primary Inductance Converters (SEPIC).**

I. INTRODUCTION

Renewable energy sources such as solar energy are acquiring more significance, due to shortage and environmental impacts of conventional fuels. The photovoltaic (PV) system for converting solar energy into electricity is in general costly and is a vital way of electricity generation only if it can produce the maximum possible output for all weather conditions. The PV array has a highly non-linear current-voltage characteristic varying with the irradiance and temperature that substantially affects the array power output. The role of this proposed system with high efficiency, called the maximum power point tracking network (MPPT), is to ensure operation of the PV generator (PVG) at its MPP, in the face of changing atmospheric conditions and load variations. Typically, the MPPT power stage is implemented by using a *DC-DC* converter at the front with the pulse width modulated (PWM).

The maximum power point tracking (MPPT) control of the PV system is therefore critical for the success of a PV system. MPPT algorithms, ranging from simple hill-climbing algorithms to fuzzy logic and neural network algorithms, have been considered extensively in the literature. The hill climbing algorithm is widely used in practical PV systems because of its simplicity and because it does not require prior study or modeling of the source characteristics and can account for characteristics' drift resulting from ageing, shadowing, or other operating irreglarities [1], [2]. The basic hill climbing algorithm is the P&O algorithm. Although the P&O algorithm works well when the irriadance changes slowly, it exhibits erratic behavior for rapidly changing irradiance level that causes incorrect or slow powertracking. This led to the development of the Modified Perturb and Observe (MP&O) algorithm [3]. The MP&O algo rithm improves the P&O algorithm at the expense of speed of response to changes of irradiance. A new method, named the Estimate-Perturb-Perturb (EPP) algorithm was previously published by the authors, which was shown to have good performance [4]. The EPP algorithm uses one estimate for every two perturbs those results in a fast response to irradiance changes, leading to significantly higher PV system power output.

In this paper, we chose to implement the DC–DC converter system using SEPIC converters. While the proposed boost topology enables high switching frequency for small size, low cost and high efficiency, it does not contribute any voltage gain, which would reduce the number of panels that must be series connected. In most residential and utility-based installations, however, there are a sufficient number of PV panels to provide for the inherent stacking of voltages without requiring the additional step-up from the power converter.

II. PV ARRAY MODEL

A solar panel cell basically is a p-n semiconductor junction. When exposed to the light, a DC current is generated. The generated current varies linearly with the solar irradiance [4]. The equivalent electrical circuit of an ideal solar cell can be treated as a current source parallel with a diode shown in figure 1.

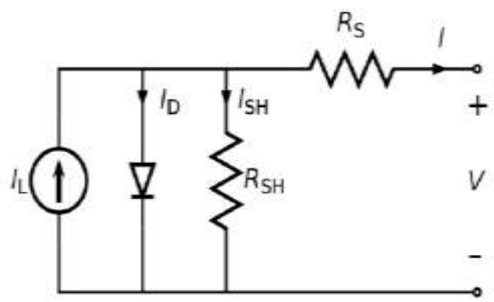

Figure. 1: Equivalent electrical circuit of a solar cell

The I-V characteristics of the equivalent solar cell circuit can be determined by following equations [4].
The current through diode is given by:
ID = I [exp (q(V + I RS)/KT)) – 1] (1)
While, the solar cell output current:
I = IL – ID – Ish (2)
I = IL – I [exp (q(V + I RS)/KT)) – 1] – (V + IRS)/ Rsh (3)
Where:
I : Solar cell current (A)
I: Light generated current (A) [Short circuit value assuming no series/ shunt resistance]
ID: Diode saturation current (A)
q : Electron charge (1.6×10-19 C)
K : Boltzman constant (1.38×10-23 J/K)
T : Cell temperature in Kelvin (K)
V : solar cell output voltage (V)
Rs: Solar cell series resistance (Ω)
Rsh: Solar cell shunt resistance (Ω)

III. SEPIC CONVERTER

The single-ended primary-inductance converter (SEPIC) is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. This type of con-version is handy when the designer uses voltages from an unregulated input power supply such as a low-cost wall wart. Unfortunately, the SEPIC topology is difficult to understand and requires two inductors, making the power-supply footprint quite large. Recently, several inductor manufacturers began selling off-the-shelf coupled inductors in a single package at a cost only slightly higher than that of the comparable single inductor. The coupled inductor not only provides a smaller footprint but also, to get the same inductor ripple current, requires only half the inductance required for a SEPIC with two separate inductors.

Figure 2 shows a simple circuit diagram of a SEPIC converter, consisting of an output capacitor, C; coupled inductors L_1 and L_2; an AC coupling capacitor, C_1;a power FET, S; and a diode,D.

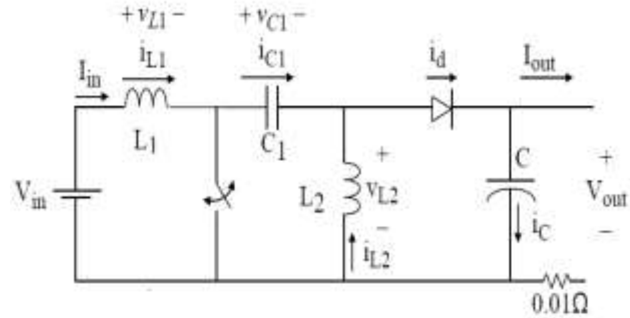

Figure. 2: Simple circuit diagram of SEPIC converter

Under normal operation, the circuit is in "continuous conduction" (i.e., iL1 and iL2 are always greater than zero). The first important relationship comes from the fact that capacitor C1 should be large enough so that voltage *vC*1 has low ripple. Applying average KVL around the loop formed by Vin, L1, C1, and L2 , and recognizing that the average voltages across L1 and L2 are each zero, yields

*vC*1=*Vin* . (4)

The second important relationship comes by applying KCL in the average sense at the node atop L2. Since the average currents in C1 and C are both zero, then

iL2avg =idavg =Iout . (5)

With continuous conduction, the circuit has two states – switch closed, and switch open. These states are shown in Figures 3a and 3b.

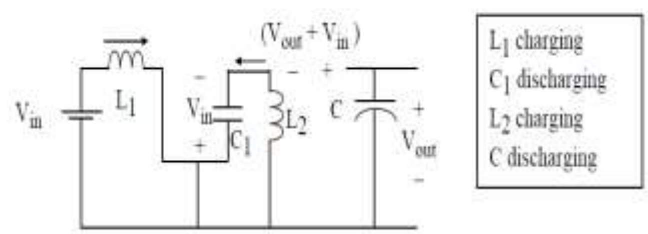

Figure. 3a: Switch Closed for DT Seconds

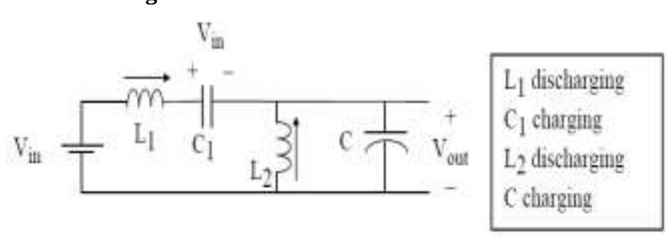

Figure. 3b: Switch Open for (1-D)T Seconds

When the switch is closed (Figure 3a), the diode is reverse biased and open, current *iL*1 increases at the rate of

$$\frac{Dil1}{dt} = \frac{Vin}{L1}, 0 \le t \le DT \qquad (6)$$

So that L1 is "charging." When the switch is open (Figure 2b), the diode is forward biased, and
iL decreases at the rate of

$$\frac{Dil1}{Dt} = -\frac{Vout}{L1}, DT < t < T \qquad (7)$$

So that L1 is "discharging." The voltage across L1 is shown in Figure 4.

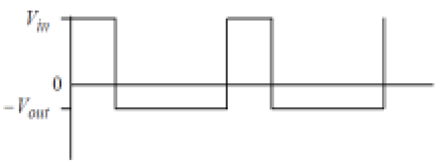

Figure. 4: Inductor L1 Voltage in Continuous Conduction

Because of the steady-state inductor principle, the average voltage across L1 is zero. Since $vL1$
has two states, both having constant voltage, the average value of $vL1$ is

$$\frac{(Vin)DT+(-Vout)(1-D)T}{T} = 0 \qquad (8)$$

So that

$$VinD - Vout + VoutD = 0 . \qquad (9)$$

Simplifying the above yields the final input-output voltage expression

$$Vout = \frac{DVin}{1-D}. \qquad (10)$$

Thus, the converter is in "buck" mode for D < 0.5, and in "boost" mode for D > 0.5.
The assumption of a lossless circuit requires input power to equal output power, so

$$Iout = \frac{(1-D)Iin}{D} \qquad (11)$$

IV. MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking (MPPT) technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. There are different techniques used to track maximum power point. Few of the most popular techniques are: perturb and observe, incremental conductance, fractional short circuit current, fractional open circuit voltage, neural Networks and fuzzy logic. The choice of the algorithm depends on the complexity and time the algorithm takes to track the MPP and implementation cost. In this paper hill climbing method has been used.

The basic operating theory of the hill climbing method [10], [11] is similar to that of the P&O method. Both method use the condition that $P(n)$ is greater than $P(n - 1)$ or not to make the judgment. As described in previous Section, the P&O method uses the condition dP/dV to determine whether the maximum power point has been found or not. However, the hill climbing method uses the condition dP/dD to judge. In most applications, DC-DC converters and DC-AC inverters are usually used as the power interface devices between PV modules and loads. The hill climbing method uses the duty cycle (D) of these switching mode power interface devices as the judging parameter when the task of the maximum power point tracking is implemented. When the condition $dP/dD = 0$ is accomplished, it represents that the maximum power point has been tracked. The flow diagram of the hill climbing algorithm is shown in Fig. 5.

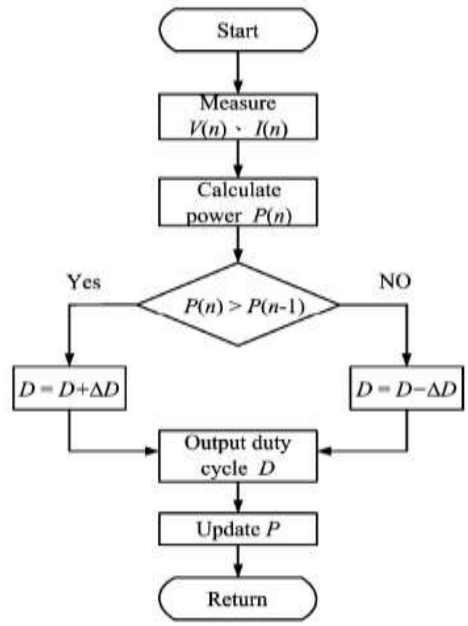

Figure. 5: The flow diagram of the hill climbing method

The duty cycle in every sampling period is determined by the comparison of the power at present time and previous time. If the incremental power $dP > 0$, the duty cycle should be increased in order to make $dD > 0$. If $dP < 0$, the duty cycle is then reduced to make $dD < 0$. The advantages of the hill climbing method are similar to those of the P&O method which are simple structure and less required parameters. Shortcomings of the hill climbing method are described below. Fig. 8 is the P-D curve diagram of PV modules when the power interface device is DC-DC buck converter. If the initial operating point of the PV system is located on the left side of the maximum power point, the duty cycle has to be continuously increased on the basis of the judgment procedure of the hill climbing method in order to track the maximum power point. When the operating point of the PV system is located on the right side of the maximum power point, the duty cycle should be continuously reduced to return back to the maximum power point. However, if the operating point wants to move toward the maximum power point ($dP > 0$) the incremental duty cycle should be greater than zero ($dD > 0$) according to the judgment procedure of the hill climbing method shown in Fig. 7. This will cause the operating point to move farther away from the maximum power point. Therefore, a misjudgment of tracking direction may happen under this kind of situation. For the hill climbing method, this misjudgment is a fatal weak point [5].

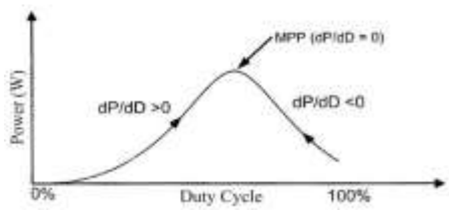

Figure. 6: The *P-D* curve diagram of PV modules

V. PREVIOUS RESEARCH

Sweeka Meshram *et al* [7], presented simulation modeling of the grid connected DC linked PV/Hydro hybrid system. The DC bus of the PV and hydro system has been common linked to reduce the cost and complexity of the hybrid system. The hybrid system acts as a dominant system and power grid will be acting as a standby to compensate the deficit in the hybrid system. On rainy days/night, the solar energy will be unavailable, hence the power requirement will fulfilled by hydro system and power grid. In summer, the hydro power will be less; in that case the power requirement will be fulfilled by the PV system and power grid. In other days, the power will be fed by the PV/Hydro hybrid system. Thus, the power requirement throughout the year can be satisfied by the proposed system.

E. M. Natsheh, *et al* [8], Implemented the model of smart grid-connected PV/Wind hybrid system was developed. It comprises photovoltaic array, wind turbine, asynchronous (induction) generator, controller and converters. The model was implemented using MATLAB/SIMULINK software package. The MPPT algorithm was used for maximizing the generated power implementation. The dynamic behavior of the proposed model was examined under different operating conditions. Solar irradiance, temperature and wind speed data is gathered from a grid connected, 28.8kW solar power system in central Manchester. Real-time measured parameters are used as inputs to the development system. The proposed model and its control strategy offer a proper tool for smart grid performance optimization.

The main disadvantages of the above references are that the complexity in the design and cost. To overcome the drawbacks we propose a new model, control and simulation of a smart grid-connected PV power generation system is proposed. Modeling and simulation are implemented using MATLAB/SIMULINK and Sim Power Systems software packages to verify the effectiveness of the proposed system.

VI. PROPOSED APPROACH

The simulation circuit of proposed system implementation is shown in Fig.7. The system comprises of a PV model with boost converter power stage controlled by a Switch to achieve highly efficient output using MPPT Hill climbing Algorithm. The proposed Hill climbing MPPT presents two major advantages: first, by a proper choice of the switching surface based on duty ratio, the response to variations in solar radiation is accelerated by an order of magnitude. In addition, the proposed system facilitates operation as either a voltage source or a current source, thus, it guarantees stability all across the photovoltaic panel. The proposed system architecture provides a fast and maximum power point tracking scheme with high tracking efficiency under temperature and shading conditions with reduced cost.

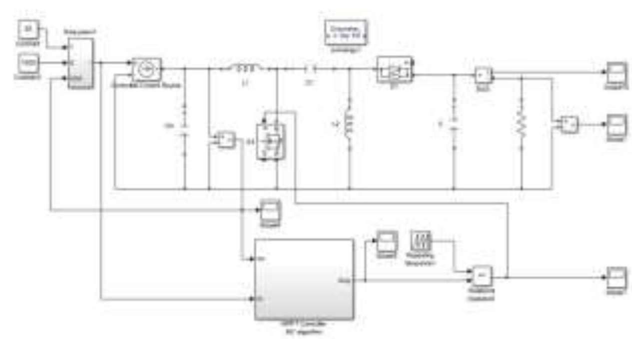

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Figure.7: Simulation circuit diagram of proposed system.

The new design PV module is shown in the Figure 8. The PV module is a designed as a function of the voltage, current, solar radiation, PV cell temperature, Shading parameters, Duty ratio and load condition. The embedding Matlab function for Hill climbing MPPT algorithm is designed with the inputs of Vnew, Vold, Inew, Iold and Duty ratio.

The hill climbing based techniques is so named because of the shape of the Characteristic curve. This technique is sub-categorized in two types:

- Perturb & Observe Algorithm (P&O)
- Incremental Conductance Algorithm (INC)

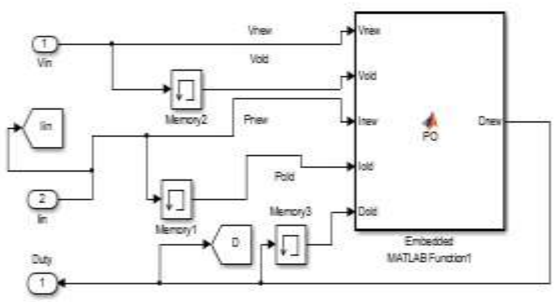

Figure. 8: Embedded Matlab function for Hill climbing Algorithm.

The proposed hill climbing based algorithm consists of the hybrid algorithm using a different algorithm technique along with the hill climbing method for faster and accurate tracking of MPP. The voltage and current controlled algorithms are more accurate and effective than most commonly used hill-climbing algorithms at low solar radiation. Therefore, these algorithms are combined with P&O and Incremental conductance algorithms to increase their effectiveness. The hill climbing based algorithms used to track the maximum power point in slow varying atmospheric conditions. Therefore, to decrease losses due to oscillations, the hill climbing based algorithms is suitable in only rapidly changing atmospheric conditions and the constant voltage method is fast and sufficient for constant conditions.

Mathematical Model

The hill climbing Algorithm of MPPT technique is used as a derivative of conductance to determine the maximum power point (MPP). The MPP is determined by comparing instant conductance I/V to the incremental conductance $\Delta I/\Delta V$. This algorithm performs better than the P&O algorithm in rapidly varying environment Conditions.

The Duty cycle response of the proposed Hill climb algorithm will be derived as follows,

$$Dnew = PO(Vnew, Vold, Inew, Iold, Dold) \quad (12)$$

Where the PO represents the Perturb and Observe method based voltage and current values.

Then the proposed maximum power is calculated as

$$Pold = Vold \times Vnew \quad (13)$$

$$Pnew = Vnew \times Vold \quad (14)$$

The smallest changes that depend on the environment variation in voltage, Current and power will be treated as the derivative function.i.e),

$$di = Iold - Inew$$

$$dv = Vold - Vnew$$

$$dp = Pold - Pnew \quad (15)$$

The conductance value and the power with respect to smallest change Δ will be calculated as

$$dvdi = di/dv \quad (16)$$

$$iv = Inew/Vnew$$

Δ=.0001; Δ2=.0002; dele=.1;

The duty ratio response will be calculated From the equation (4),

Case 1: (dp>dele)-> (Vnew-Vold)=0, (Inew-Iold)=0 then Dnew=Dold; or(Inew-Iold)>0 then Dnew=Dold+Δ1 or Dnew=Dold-Δ1;

Case 2:(dvdi=-iv) , Dnew=Dold ,(dvdi>(-iv)) then Dnew=Dold-Δ1 or Dnew=Dold+Δ1;

From the equation (4) Dnew=Dold ,

Case 3:((Inew-Iold)>0) , Dnew=Dold+Δ2 & Dnew=Dold-Δ2 or Dnew=Dold+Δ2;

Case 4: (Dnew>=99), Dnew=99; & (Dnew<=2) , Dnew=2;

From the above equations the duty ratio responses under various conditions are declared using hill climbing algorithm.

VII. SIMULATION RESULTS AND DISCUSSIONS

The major inputs for the proposed PV model were solar irradiation, PV panel temperature and voltage and current information's. The I-V and P-V output characteristics of the PV model are shown in following simulation results. The output power and current of PV module depend on the solar irradiance and temperature, and cell's terminal operating voltage as well.

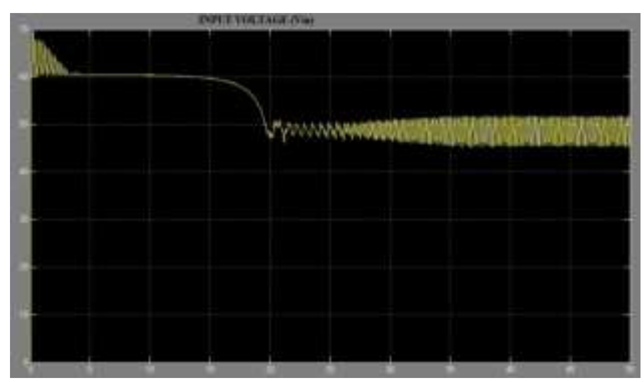

Figure. 9: Simulation result for Panel Input Voltage (Vin) with respect to Time.

The following simulation result shows that the output characteristic of voltage and current. Fig.5 shows the simulated result for proposed MPPT DC voltage output waveform and it maintains the constant voltage of 330V and 1.1 amps for different irradiation levels.

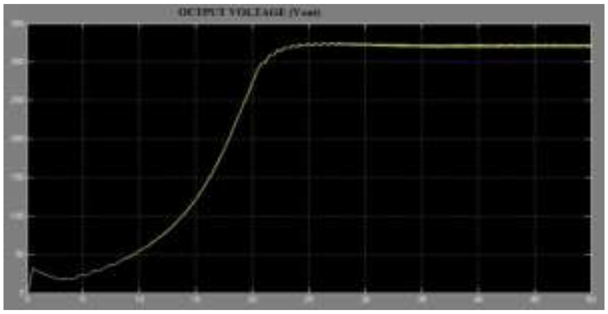

Figure. 10: Simulation result for for proposed MPPT output voltage (Vout) with respect to Time.

Figure. 11: Simulation result for proposed MPPT Output current (Iout) with respect to time.

From the above Simulation result performances, the output voltage and output current of the proposed MPPT algorithm are evaluated at different simulation period. According to the simulation period variations, the output power of the photovoltaic system is varied. Also, the output power of the proposed MPPT system is evaluated. The evaluated values are tabulated as following them (Table I). Similarly, the output current, voltage and power of the proposed system are evaluated using the model which represented from the above Figures.

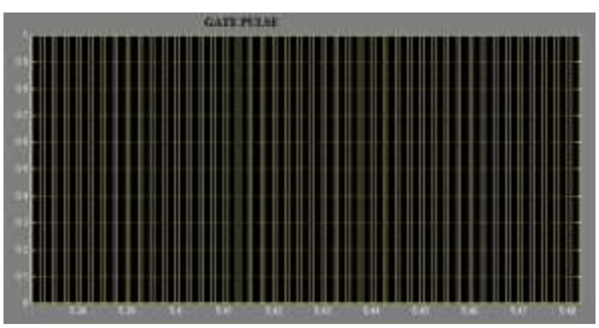

Figure. 12: Simulation result for Switching Gate Pulses

From Figure 10&11 shows that the result of the boost converter for photovoltaic generation the output is 330 volts. The simulation result shows that the output voltage of boost converter is fluctuated before it is regulated at 100 volts. The duration of the time of operation to regulate is about 22 millisecond. Figure 12 shows that the duty ratio response of the proposed MPPT system with the corresponding switching gate pulses.

Table 1: Comparison of parameter values

Parameters	Existing method	Proposed method
Maximum Power	125W	300W
Voltage level	100 V	330 V
Radiation Level	1000W/m2	1000W/m2
Input voltage	(5-10) V	(1-17)V
Topology	Buck	Boost
Tracking Efficiency	95%	99.7%

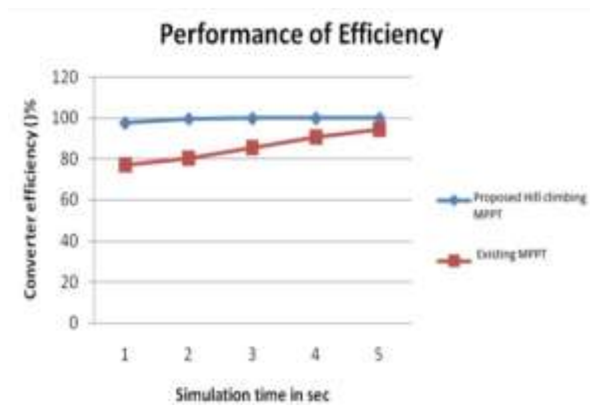

Figure. 13: Performance of efficiency.

From the comparative analysis, it is revealed that the proposed Hill climbing MPPT algorithm is better when compared to the Existing algorithm. The proposed converter efficiency is deviated more than the Existing system. Hence, the proposed Hill climbing MPPT is better than other methods that produces maximum output power is produced at high efficiency for the photovoltaic application.

VIII. CONCLUSION

In the present study, a review of Hill Climbing maximum power point tracking techniques with Simulation results have been described to provide the High power output. From the study, it can be concluded that High efficient output power for a fast and linearly increasing power. The Hill climbing method is implemented and verified simulation results to track Maximum power point.

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