Global MPPT Control of Photovoltaic Array Using SEPIC Converter under Partial Shading Condition

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Abstract
The factors affecting the performance characteristics of a photovoltaic (PV) array are temperature, solar insolation, shading and array configuration. The PV system exhibits a non-linear I-V characteristic and its unique maximum power point on the P-V curve varies with insolation and temperature. The passing clouds, neighbouring buildings and trees are shadowing the PV arrays completely or partially as a result, it becomes more complex P-V characteristics with multiple peaks in case of partially shaded conditions. Conventional Maximum Power Point Tracking (MPPT) techniques fail to reach global peak power point and tend to stay in local peak power point which significantly reduces the efficiency of the PV system. This paper mainly focuses on extracting the maximum power from PV array under partially shaded conditions by executing improved hill climbing algorithm to identify the global maximum power point (GMPP) and SEPIC is used as a dc-dc interface. Simulation results have been presented to verify the performance of the proposed GMPPT technique

Keywords: *Maximum power point tracking (MPPT), Hill climbing algorithm, Photovoltaic I-V characteristics, Global Maximum Power Point (GMPP)*

INTRODUCTION

Solar photovoltaic energy has gained recognition as an alternative source of energy. The technique for efficiently extracting the maximum power from a solar panel under varying meteorological conditions is presented in our project [1]. The methodology is based on connecting a pulse width modulated dc/dc SEPIC converter [2]. The operation of the SEPIC converter is controlled so that electrical energy from the PV array to the load is transferred with Maximum power. Various methods have been developed for the MPPT operation under rapidly changing condition [3, 4]. Those methods fail to track the global maximum power point (GMPP) under partially shaded conditions. Therefore, different algorithms have been proposed in the literature [5, 6]. The new algorithm which is based on the hill climbing technique with adaptive step size is implemented to track GMPP. The main difference between the method used in the proposed GMPPT method and other technique used in the past is that PV array output power is used to directly control the dc/dc converter thus reducing the complexity of the system. The resulting system has high efficiency, low cost and easy implementation in a low cost microcontroller [7].

SYSTEM DESCRIPTION

This section describes the details of the PV system and design of the converter with GMPPT.

Description of basic block diagram

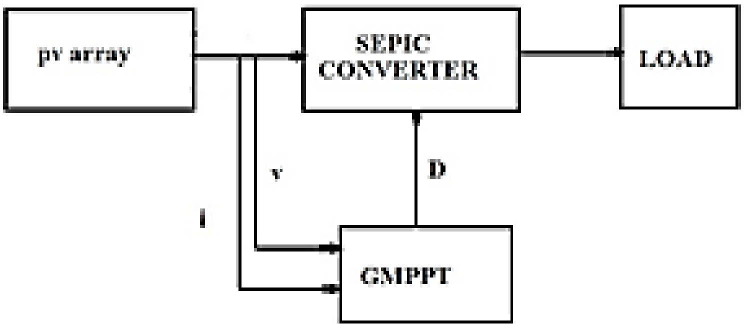

Figure1: *Block Diagram of Proposal System*

Basic block diagram of PV maximum power point tracking system implemented using SEPIC converter is shown Fig.1. The solar system with four PV modules in series connection supplying the system load. SEPIC converter is extracting the maximum power from the PV system which is occurred by controlling the duty cycle D, using an MPPT controller. As in most of the MPPT controllers, PV voltage Vpv and current Ipv are measured to implement the global MPPT algorithm.

Design of SEPIC converter

The SEPIC converter is used as an interface to provide load matching. The buck-boost converter of SEPIC is used due to the advantage of having non-inverted output. Having the low input ripple current for the SEPIC converter make the MPP tracking ease. In addition to that, SEPIC converter is more efficient than buck-boost converter. The circuit diagram of the SEPIC converter is shown below.

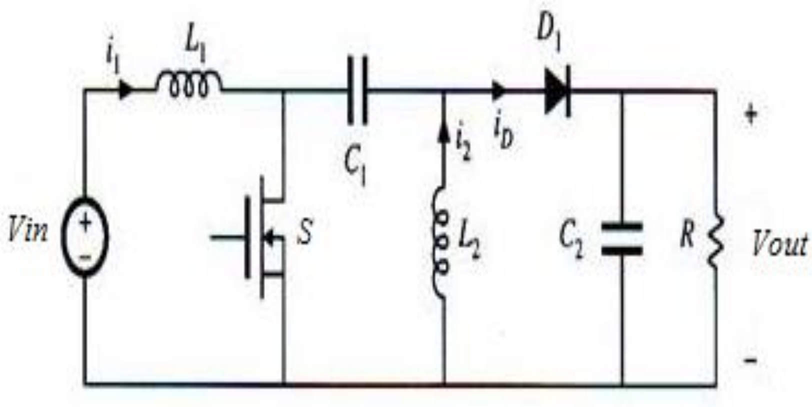

Figure 2: *Circuit diagram of SEPIC converter*

The SEPIC converter can be operated in continuous conduction mode and dis continuous conduction mode. Working in continuous conduction mode (CCM) presents two operating modes.

Where

Vin = input voltage for converter

Il1 = current through inductor L1

Il2= current through inductor L2

Vo= output voltage

Mode 1**:** (0<t<DT) Fig. 2 shows at moment t=0, switch S is turned on. The energy from the source Vin is stored in the inductance L1 and the capacitor C1 transfer its energy to the L2(T2). The capacitor C1 voltage is considered

constant and equal to Vin. The currents Il1 and Il2 increases linearly No energy is supplied to the load capacitor during this Time. During this stage diode D1 is kept blocked and the Output capacitor (Co) supplies energy to load.

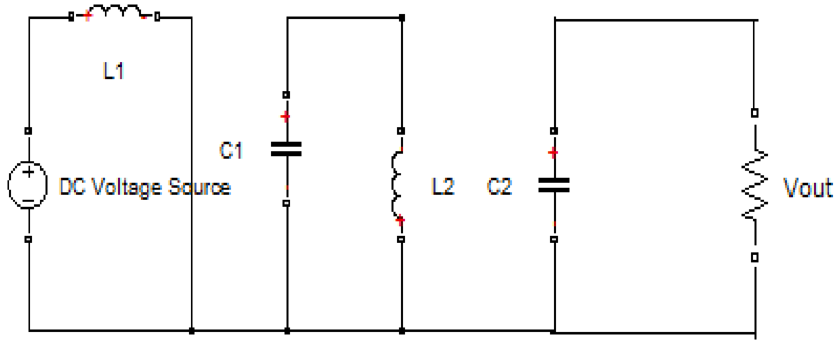

Figure 3: *Switch on Operation*

Mode2: (DT<t<T) fig 7.3 shows at moment t=DT, switch S is turned off and the diode D1 is turned on, transferring the inductor storage energy to the load. The currents Il1 and Il2 decreases linearly. The voltage across switch the switch (Vin+Vo).

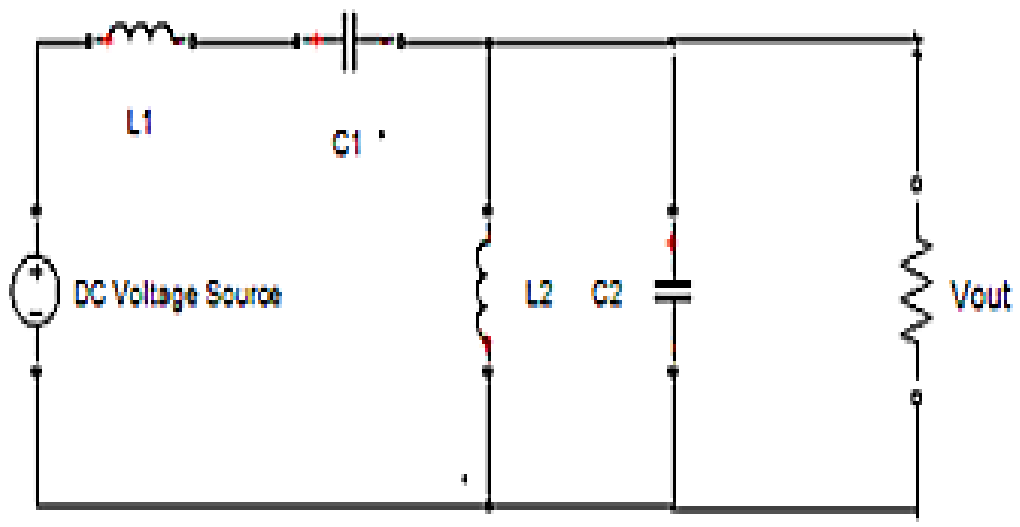

Figure 4: *Switch Off Operation*

The following equations are used to design the SEPIC converter.

Step 1: Resistance Value

$R= (V_0)^2/P$

$R= (45)^2 /90$

R=22.5 ohm

Step 2:Duty Cycle Consideration

$D = \frac{Vo}{(Vin+Vo)}$

D = 45/ (65+45)

D = 0.4090

Step 3: Output Current

Iout =Vo/R

Iout = 45/22.5

Iout = 2 A

Step 4: Inductor Selection

A good rule for determining the inductance is to allow the peak-to-peak ripple current to be approximately 10% of the maximum input current at the minimum input voltage.

The inductor value is calculated by:

$L1 = (\frac{Vin}{IL \times f}) \times D$
L1 = (65/16614) × 0.4090
L1=1.6mH

Step 5: Coupling Capacitor
As per thumb rule generally 10 µF ceramic capacitor is selected

Step 6:Output capacitor selection
Cout = (Iout × Dmax) / (Vripple × 0.5 ×fsw)
Cout = ((2*0.4090) / (2.25 × 0.5 × 30000))
Cout =24.23µF

Step 7:Current Ripple (ΔI_L)
$Io \times \frac{Vo}{Vin} \times 40\%$
IL = 2*(45/65)*40%
IL=0.5538 A

Table 1: *Parameter Values of SEPIC Converter*

Parameter	**Value**
L1,L2	1.6mH
Cout	24.23 µF
Cp	10 µF
Vs	30 – 120 V
Fsw	30 KHz

IMPORTANCE OFGLOBAL MAXIMUM POWER POINT TRACKING

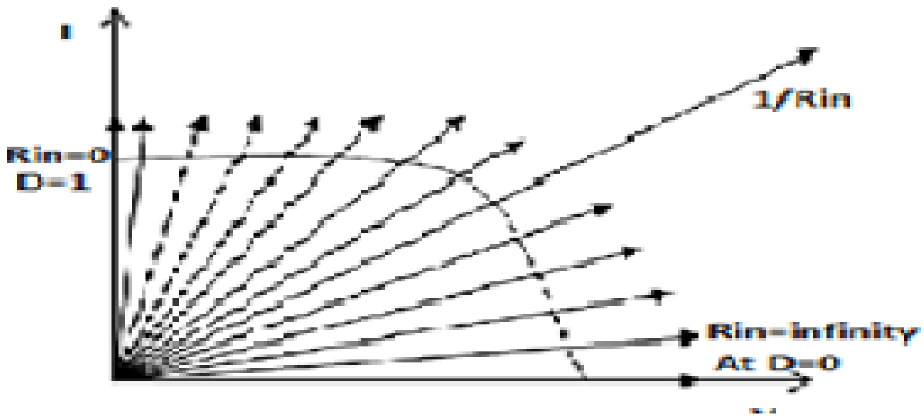

Figure 5: *SEPIC Converter Operating Area*

The penetration of PV systems as distributed power generation systems has been increased dramatically in the last years. In parallel with this Global Maximum Power Point Tracking (GMPPT) 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 Global Maximum Power Point Tracking (GMPPT) technique should be used to track the maximum power point.

It was mentioned earlier that the range of operation of SEPIC converter covers the entire V-I characteristics of the PV cell module as shown in fig.4 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 by

Rin= (1-D)^2/D^2 × R0
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.

EFFECTS OF PARTIAL SHADING CONDITION ON THE PV ARRAY
Characteristics of PV curve under PSC

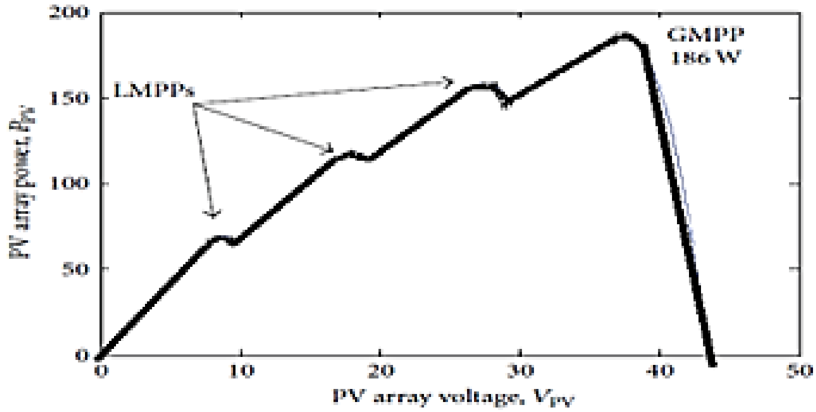

***Figure 6:** PV characteristics of a partially shaded PV array*

A PV array usually consists of several PV modules which are connected in series-parallel to obtain the desired voltage and current. Bypass diodes are used in parallel with each PV module to protect modules from hot-spot problems. When the solar irradiance is uniform, only one MPP exists on the P-V characteristic curve. But under non-uniform irradiation (partial shading) conditions, several local maximum power points evolve on the P-V characteristic curve. Fig.6 shows the P-V characteristic of a partially shaded PV array when they receive the irradiation as 800 W/m2, 200 W/m2, 200 W/m2, and 800W/m2 from top to bottom with respect to Fig.7.

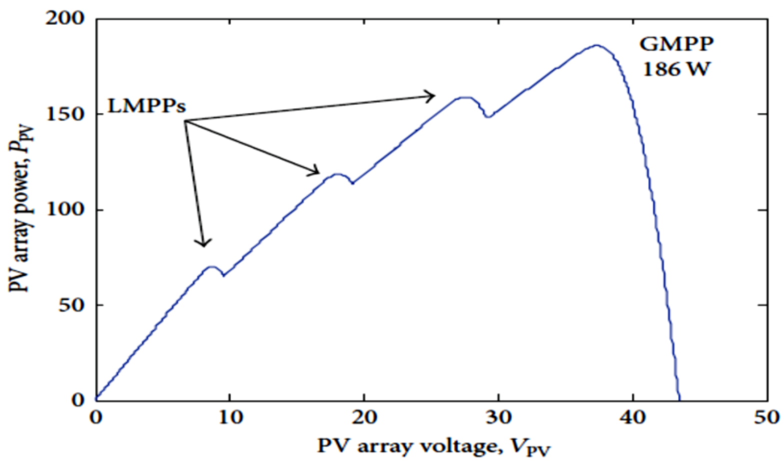

***Figure 7:** Peak exists of PV curve*

Fig.6, fig.7 and fig.8 show that there are several peaks that exist on the P-V curve. In fig.6, the global MPP occurs at a voltage quite close to that one at which the unique MPP normally occurs in the uniform irradiation case. In fig.7, global MPP occurs at a low voltage level and the local MPP occurs at a voltage quite close to that one at which the unique MPP normally occurs. In fig.8, global MPP occurs at middle voltage level. This global MPP happens to be in between two local MPPs. Therefore, partial shading has a strong impact on the P-V characteristic curve of the PV system.

Failure of conventional MPPT

The uniform irradiation conditions serve very well at mostly used MPPT techniques like P & O method, Incremental Conductance method, RCC method etc. They track the maximum power point efficiently because there exist only one MPP on the P-V characteristic curve. But under partial shaded conditions, there exists several MPPs on the P-V curve as explained in the previous section.

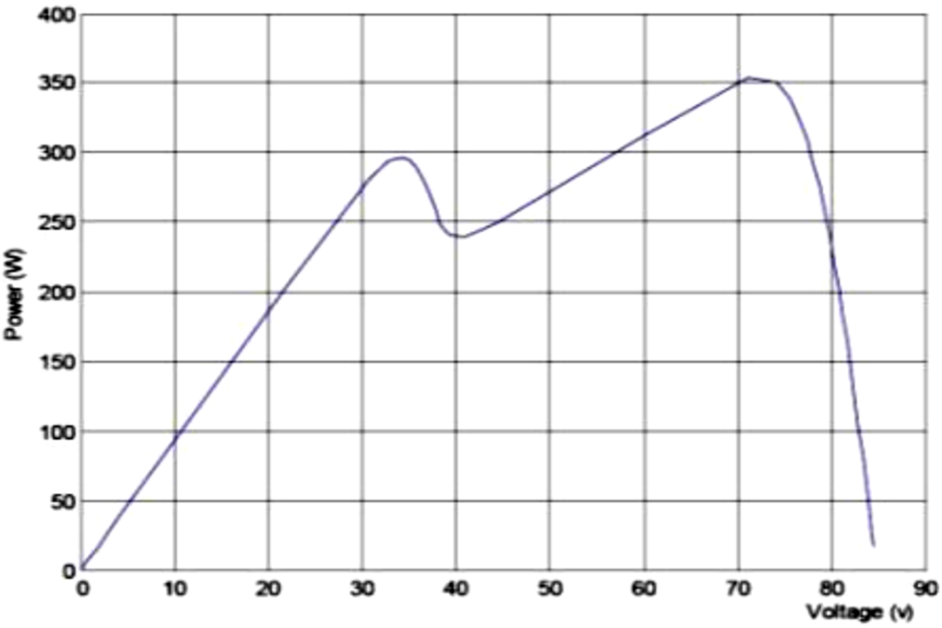

Figure 8: *Peak exists of PV curve*

In the case of uniform irradiation happens, conventional MPPT methods fail to track the global MPP and stay at a local MPP which occurs at a voltage pretty close.

RESULTS AND DISCUSSION

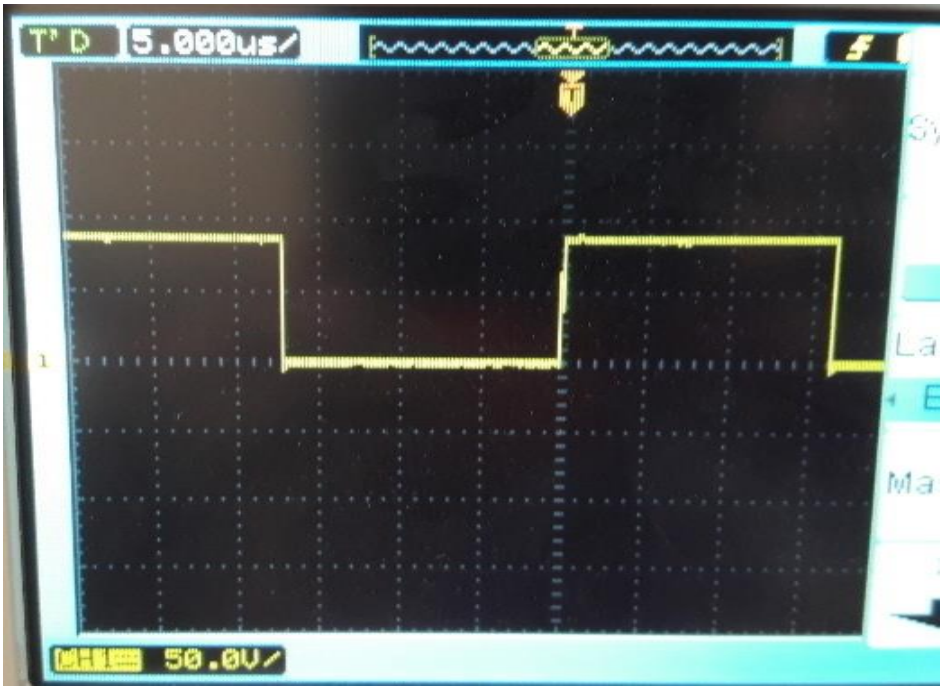

Figure 9: *Pulse to drive power MOSFET*

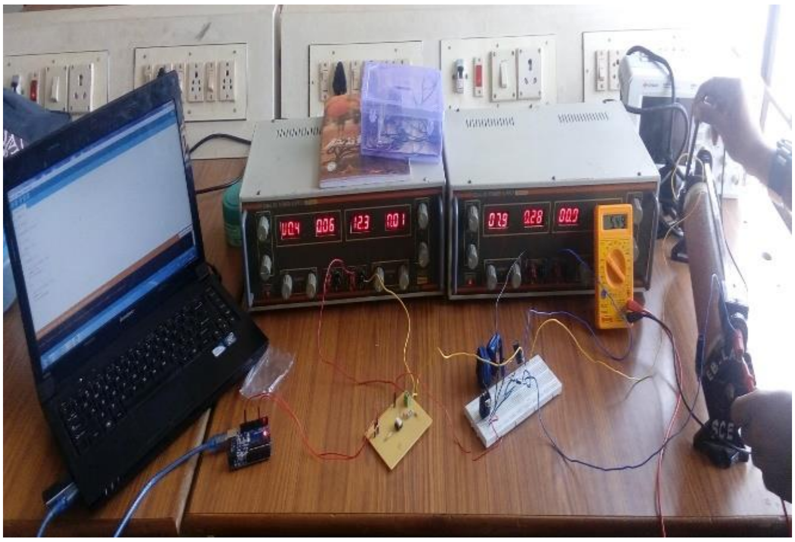

Figure 10: *Hardware Model*

1. The DC-DC boost converter acts as an interface between the PV module and the load.
2. The voltage and current output are sensed.
3. This signal is then compared with a high-frequency triangular wave of 30 kHz. The pulse generated given is to the gate of the power semiconductor device (MOSFET), thereby changing the duty cycle of the converter.
4. This generated pulse must be able to trigger the power circuit of the MOSFET.
5. Thus the source impedance is matched with the load impedance and Maximum power is transferred.

CONCLUSION

Thus the hill climbing algorithm identifies the global maximum power point within reasonable time without missing any local maximum power points through global search as the step size for duty cycle is large enough. Then local search exactly reaches the global maximum power point with minimum oscillations as the step size is very small. Therefore search time as well as magnitude of oscillations around global MPP is reduced significantly thus improving the tracking efficiency and overall system efficiency. The algorithm is carried out with the help of ATMEGA328 microcontroller. This project work clearly demonstrates the need for the alternate energy resources and how economy is achieved with the help of implementing a GMPPT algorithm.

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