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SEPIC converter based Photovoltaic system with Particle swarm Optimization MPPT

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ABSTRACT

This Paper presents Maximum Power Point Tracking (MPPT) of Photovoltaic Array under partial shading condition. The power available at the output of photovoltaic cells keeps changing with solar insolation and ambient temperature because photovoltaic cells exhibit a nonlinear current voltage characteristic. A good number of publications report on different MPPT techniques for PV system most of the existing schemes are unable to extract maximum power from the PV array under these conditions. This paper proposes an algorithm to track the global power peak under partially shaded conditions. The Particle swarm optimization algorithm is based on several critical observations made out of an extensive study of the PV characteristics and the behavior of the global and local peaks under partially shaded conditions. All the observations and conclusions, including results are presented.

Key words : Solar Energy, Maximum power point tracking (MPPT),Photovoltaic Array (PV), Perturb&Observe(P&O) method, Particle Swarm optimization(PSO) method, SEPIC converter.

1. INTRODUCTION

Photovoltaic (PV) is envisaged to be a popular source of renewable energy due to several advantages, mostly low operational cost, almost maintenance free and environmentally friendly.To optimize the utilization of large arrays of PV modules, maximum power point tracker (MPPT) is normally employed in conjunction with the power converter (dc–dc converter).The objective of MPPT is to ensure that the system can always harvest the maximum power generated by the PV arrays. However, due to the varying environmental conditions, that is temperature and solar insolation, the P–V characteristic curve exhibits a maximum power point (MPP) that varies nonlinearly with these conditions thus posing a challenge for the tracking algorithm. To date, various MPP tracking methods have been proposed. These techniques vary in complexity, accuracy, and speed. Each method can be categorized based on the type of the control variable it uses: i) voltage, ii) current, or iii) duty cycle. An ideal is modeled by a current source in parallel with a diode. However no solar cell is ideal and there by shunt and series resistances are added to PV cell diagram the model as shown in the Figure 1. R_S is the intrinsic series resistance whose value is very small. R_P is the equivalent shunt resistance which has a very high value [1].

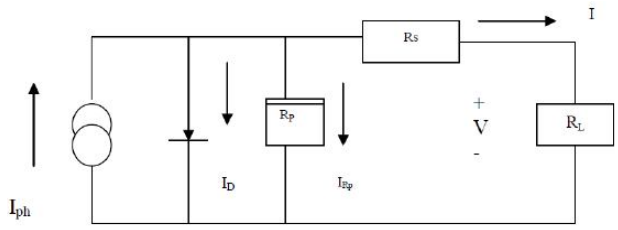

Figure 1: Equivalent circuit of a PV cell

$$I = I_{ph} - I_{R_P} - I_D \tag{1}$$

$$I = I_{ph} - I_O \left[\exp\left(\frac{V + I.R_S}{V_T} \right) - 1 \right] - \left[\frac{V + I.R_S}{R_P} \right] \tag{2}$$

Where, Iph is the Insolation current, I is the Cell current, I_0 is the Reverse saturation current, V is the Cell voltage, R_S is the Series resistance, R_P is the Parallel resistance, V_T is the Thermal voltage (KT/q), K is the Boltzman constant, T is the Temperature in kelvin, q is the charge of an electron with different irradiation level the MPP will change as shown in Figure 2.

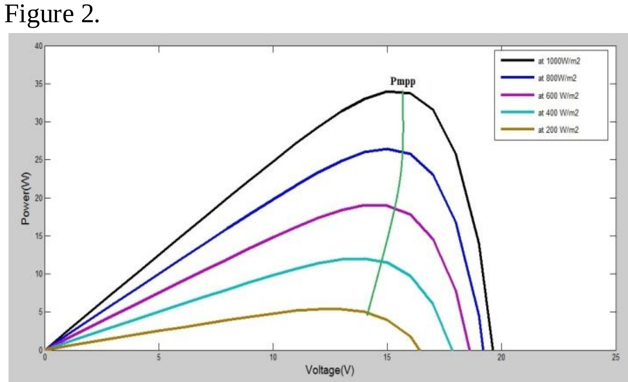

Figure 2: P-V characteristic of a solar array for a fixed temperature but varying irradiance

In general, a PV array source is operated in conjunction with a dc–dc power converter, whose duty cycle is modulated in order to track the instantaneous MPP of the PV source. Several tracking schemes have been proposed. Among the popular tracking schemes are the perturb and observe (P&O) or hill climbing, incremental conductance, shortcircuit current, and open-circuit voltage modified techniques have also been proposed, with the objective of minimizing the hardware or improving the performance. The tracking schemes mentioned above are effective and time tested under uniform solar insolation, where the P–V curve of a PV module exhibits only one MPP for a given temperature and insolation. Under partially shaded conditions, when the entire array does not receive uniform insolation, the P-V characteristics get more complex, displaying multiple peaks only one of which is the global peak (GP);rest are local peaks as show in Figure 3.It is found that the conventional MPPT can track the maximum power point under normal atmospheric conditions, but the MPPT algorithm has to track the MPPT under partial shading conditions. The presence of multiple peaks reduces the effectiveness of the existing MPP tracking (MPPT) schemes, which assume a single peak power point on the P–V characteristic. The occurrence of partially shaded conditions being quite common (e.g., due to clouds, trees, etc.), there is a need to develop special MPPT schemes that can track the global peak GP under these conditions [2][3].

1.1 Critical observations under Partial shading conditions

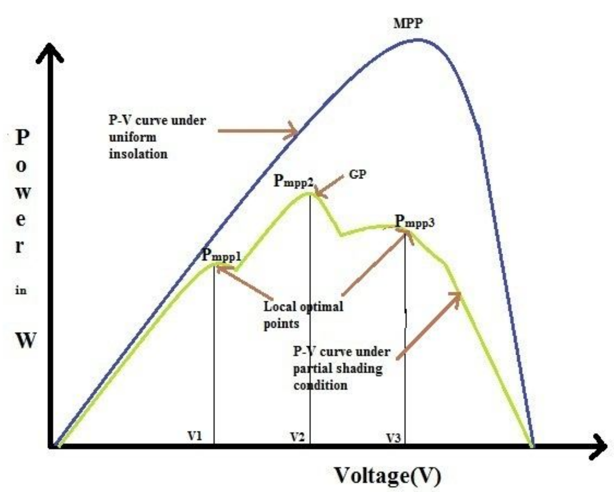

Figure 3: P-V curve of PV array under normal and Partial shading conditions.

i) Under partially shaded conditions have multiple steps, while the P–V curves are characterized by multiple peaks.

ii) In addition to insolation and temperature, the magnitude of GP, and the voltage at which it occurs are also dependent on the shading pattern and array configuration.

iii) Fig.3 shows that the GP may lie on the left side of the load line.

iv) The peaks on the P–V curve occur nearly at multiples of 80% of V_{OC} module (Figure. 3).

v) The minimum displacement between successive peaks is nearly 80% of V_{OC} module (Figure 3).

vi) Extensive study of P–V curves, as well as practical data, have revealed that when the P–V curve is traversed from either side, the magnitude of the peaks increases. After reaching the GP, the magnitude of the subsequent peaks (if they are present) continuously decreases.

2. DC-DC CONVERTERS

The DC-DC converters for PV system are as follows

2.1 Buck converter

The buck converter is a step down DC-DC converter with an output voltage is lower than the input. The operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

2.2 Boost converter

A boost converter (step-up converter) is a power converter with an output dc voltage greater than its input dc voltage.

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is always higher than the input voltage. When the switch is turned-ON, the current flows through the inductor and energy is stored in it. When the switch is turned-OFF, the stored energy in the inductor tends to collapse and its polarity changes such that it adds to the input voltage. Thus, the voltage across the inductor and the input voltage are in series and together charge the output capacitor to a voltage higher than the input voltage.

2.3 Buck-Boost Converter

The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. The output voltage is of the opposite polarity as the input. This is a switched-mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. The Proposed SEPIC converter topology is discussed in the following section.

3. Single-ended primary-inductor converter (SEPIC)

Single-ended primary-inductor converter (SEPIC) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor(or MOSFET). SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output [4].

3.1Circuit operation

The schematic diagram for a basic SEPIC is shown in Figure 4. As with other switched mode power supplies (specifically DC-to-DC converters), the SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S_1, which is typically a transistor such as a MOSFET. MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors (as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs).

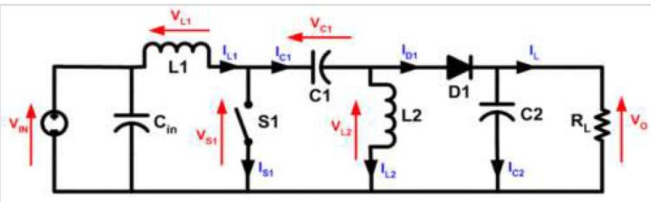

Figure 4: Schematic of SEPIC

3.2 Continuous mode

A SEPIC is said to be in continuous-conduction mode ("continuous mode") if the current through the inductor L_1 never falls to zero. During a SEPIC's steady-state operation, the average voltage across capacitor C_1 (V_{C1}) is equal to the input voltage (V_{in}). Because capacitor C_1 blocks direct current (DC), the average current across it (I_{C1}) is zero, making inductor L_2 the only source of load current. Therefore, the average current through inductor L_2 (I_{L2}) is the same as the average load current and hence independent of the input voltage.

Looking at average voltages, the following can be written:

$$V_{LN} = V_{L1} + V_{C1} + V_{L2} \quad (3)$$

Because the average voltage of V_{C1} is equal to V_{IN}, $V_{L1} = -V_{L2}$. For this reason, the two inductors can be wound on the same core. Since the voltages are the same in magnitude, their effects of the mutual inductance will be zero, assuming the polarity of the windings is correct. Also, since the voltages are the same in magnitude, the ripple currents from the two inductors will be equal in magnitude.

The average currents can be summed as follows:

$$I_{D1} = I_{L1} - I_{L2} \quad (4)$$

When switch S_1 is turned on, current I_{L1} increases and the current I_{L2} increases in the negative direction. (Mathematically, it decreases due to arrow direction.) The energy to increase the current I_{L1} comes from the input source. Since S_1 is a short while closed, and the instantaneous voltage V_{C1} is approximately V_{IN}, the voltage V_{L2} is approximately $-V_{IN}$. Therefore, the capacitor C_1 supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L_2. The easiest way to visualize this is to consider the bias voltages of the circuit in a d.c. state, then close S_1 as shown in Figure 5.

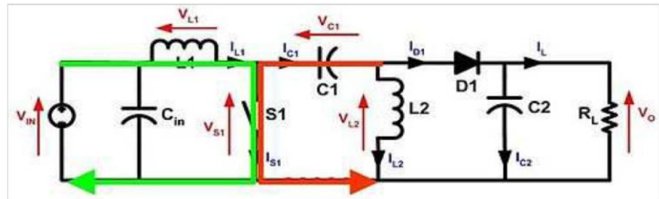

Figure 5: With S_1 closed current increases through L_1 and C_1 discharges increasing current in L_2.

When switch S_1 is turned off shown in Figure 6, the current I_{C1} becomes the same as the current I_{L1}, since inductors do not allow instantaneous changes in current. The current I_{L2} will continue in the negative direction, in fact it never reverses direction. It can be seen from the diagram that a negative I_{L2} will add to the current I_{L1} to increase the current delivered to the load. Using Kirchhoff's Current Law, it can be shown that $I_{D1} = I_{C1} - I_{L2}$.It can then be concluded, that while S_1 is off, power is delivered to the load from both L_2 and L_1. C_1, however is being charged by L_1 during this off cycle, and will in turn recharge L_2 during the on cycle.

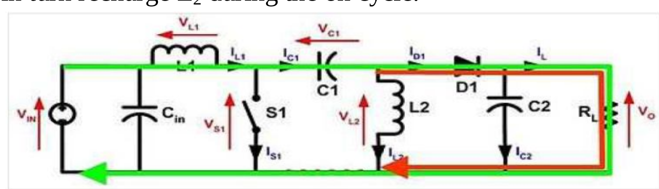

Figure 6: With S1 open current through L_1 and current through L_2 produce current through the load.

Because the potential (voltage) across capacitor C_1 may reverse direction every cycle, a non-polarized capacitor should be used. However, a polarized tantalum or electrolytic capacitor may be used in some cases, because the potential (voltage) across capacitor C_1 will not change unless the switch is closed long enough for a half cycle of resonance with inductor L_2, and by this time the current in inductor L_1 could be quite large.

The capacitor C_{IN} is required to reduce the effects of the parasitic inductance and internal resistance of the power supply. The boost/buck capabilities of the SEPIC are possible because of capacitor C_1 and inductor L_2. Inductor L_1 and switch S_1 create a standard boost converter, which generate a voltage (V_{S1}) that is higher than V_{IN}, whose magnitude is determined by the duty cycle of the switch S_1. Since the average voltage across C_1 is V_{IN}, the output voltage (V_O) is V_{S1} - V_{IN}. If V_{S1} is less than double V_{IN}, then the output voltage will be less than the input voltage. If V_{S1} is greater than double V_{IN}, then the output voltage will be greater than the input voltage.

The evolution of switched-power supplies can be seen by coupling the two inductors in a SEPIC converter together, which begins to resemble a Fly back converter, the most basic of the transformer-isolated SMPS topologies.

3.3 Discontinuous mode

A SEPIC is said to be in discontinuous-conduction mode (or, discontinuous mode) if the current through the inductor L_1 is allowed to fall to zero.

4. MPPT ALGORITHMS

There are many MPPT techniques are available in the literature some of are the perturb and observe (P&O) or hill climbing, incremental conductance, shortcircuit current[5]-[7], open-circuit voltage,Fuzzy logic[8]-[9] and Neural network[10]-[11].

4.1 Perturb and Observe method

Perturb & Observe (P&O) is the simplest method.This is the most widely used MPPT scheme.The method involves moving operating voltage by one step and then examining the change in generated power. If the power increases, the operating point moves in the same direction. This process goes on until reach MPP[12]-[15].

A detailed MPPT control technique based on the Particle swarm optimization (PSO) is discussed in the following section.

4.2 Particle swarm optimization

The PSO method is a simple and effective metaheuristic approach that can be applied to a multivariable function optimization having many local optimal points. Several cooperative agents are used, and each agent shares or exchanges information obtained in its respective search process. In this method, each agent moves with a velocity V^k in the search space, and this movement depends on two factors: 1) its own previous best position and 2) the previous best position attained among all the agents. These points are expressed mathematically in two equations which specify the velocity and position update of the agent [16]-[18].

$$V_i^{k+1} = wV_i^k + C_1 r_1 P_{best_i} + C_2 r_2 \mathrm{g}_{\mathrm{best_i}} \qquad (5)$$

$$\mathrm{S}_\mathrm{i}^{\mathrm{k+1}} = \mathrm{S}_\mathrm{i}^\mathrm{k} + \mathrm{V}_\mathrm{i}^{\mathrm{k+1}} \qquad (6)$$

Where w is the learning factor; C_1 and C_2 are positive constraints; r_1 and r_2 are normalized random numbers and their ranges are (0-1).The variable P_{best_i} is used to store the best position that i^{th} ant has found so far, and its position (7), is updated if condition (8) is satisfied.

$$P_{best_i} = S_i^k \qquad (7)$$

$$\mathrm{f}(S_i^k) = \mathrm{f}(P_{best_i}) \qquad (8)$$

Here f is the objective function that is maximized in each iteration cycle. The variable $\mathrm{g}_{\mathrm{best_i}}$ is used to store the best position obtained among the agents. During this optimization process, the agents movement is spread over the search space in different directions and for illustration; the trajectories various quantities for one iteration cycle shown in Figure 7.

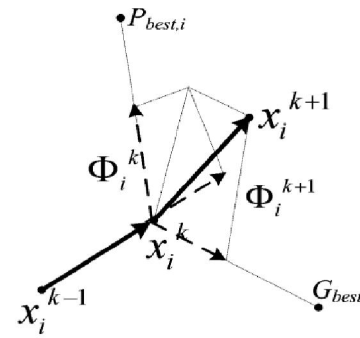

Figure 7: Movement of Particles in Optimization Process

The P-V characteristic exhibits multiple local MPP. When two PV modules are connected in Parallel and one of them is partially shaded, the shaded module's terminal voltage is different from that of the un shaded module. Under this condition, their terminal voltages are V_1, V_2; total power is P; and their variation, it is clear that tracking to a global maximum is nothing but a multidimensional MPPT control problem, wherein both V_1 and V_2 must be controlled simultaneously. In general, if the PV array contains N number of modules, then each individual module voltage $(V_1, V_2, \ldots, V_N)$ must be controlled. Here, the terminal voltages of the individual PV modules are grouped together and represented in the form of an N-dimensional row vector as

$$S^k = [V_1^k, V_2^k \ldots \ldots . V_N^k] \qquad (9)$$

Where N is the size of the row vector and it indicates the number of PV modules in the system. The velocity vector v can be written as

$$v_1^k = [V_1^k - V_1^{k-1}, V_2^k - V_2^{k-1} \ldots \ldots \ldots . . V_N^k - V_N^{k-1}] \qquad (10)$$

Here, the objective function f is the generated power P, which is the summation of power generated by each module. Assuming that there are M number of agents involved in the search process, the terminal voltage vector S_k changes in the following order and also computes the power $P(S_k)$ at each stage.

$$S_1^k \rightarrow S_2^k \rightarrow \cdots \rightarrow S_M^k$$
$$S_1^{k+1} \rightarrow S_2^{k+1} \rightarrow \cdots \rightarrow S_M^{k+1} \quad (11)$$

This process is continued until the global optimum is reached, and in each iteration the velocities and position are updated as per the relationships defined by (5) and (6).

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$$\left| v_{i+1} \right| < -\Delta V \quad (12)$$

$$\frac{\left| P(S_{i+1}) - P(S_i) \right|}{P(S_i)} > \Delta P \quad (13)$$

Equations (12) and (13) basis for convergence detection of the agents and sudden changes in insolation, respectively. The Flow chart of PSO MPPT algorithm as shown in Figure 8.

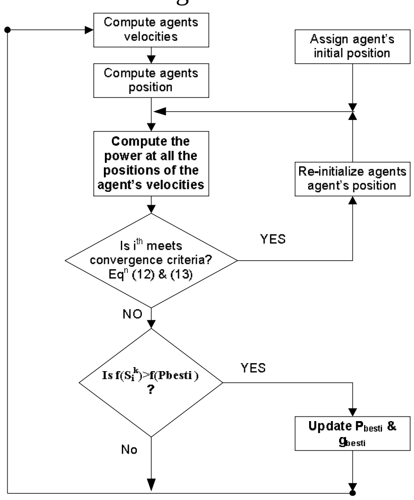

Figure 8:.Flow chart of PSO

5. SIMULATION OF THE PSO AND P&O BASED MPPT

The MATLAB–Simulink simulation model of the PV system with SEPIC converter used in this study as shown in Figure 9. The SEPIC dc/dc converter is utilized due to several reasons, namely 1) it exhibits superior characteristics with respect to the performance of PV array's MPP; and 2) it follows the MPP at all times, regardless of the solar insolation, the array temperature, and the connected load. The converter is designed for following specifications: C_{IN}= C_{OUT} =330 μF,L_a = L_b= 128.825 μH, and 40-kHz switching frequency.

To evaluate the performance of the PSO method, comparison is made with the P&O. Three challenging scenarios are imposed to the system: 1) large step change in (uniform) solar insolation; 2) step change in load; and 3) partial shading conditions. These are discussed in subsequent sections

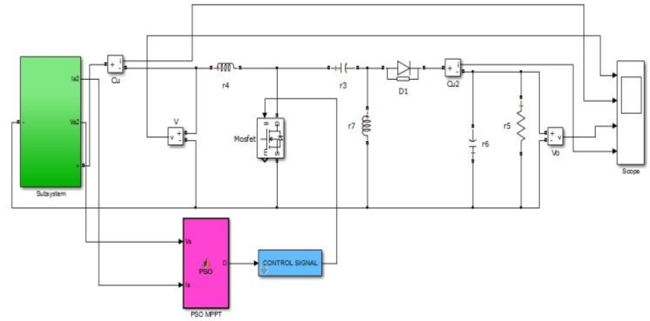

Figure 9: Simulink model of SEPIC converter based MPPT

The simulation of both P&O and PSO MPPT techniques are tested under different insolation(1000 W/m^2 ,800 W/m^2 and %00 W/m^2) conditions. The PV array contains two panels connected in parallel. The partial shading tested by making one panel fully insolated(1000 W/m^2) and other panel partially shaded (800 W/m^2 and 500 W/m^2), the results are tabulated in Table 1.The simulated results are shown in Figures 10-11. In Figuer 10 shows the tracking performance of PSO MPPT algorithm, its track the global peak power and reduce the ripples in the output of SEPIC converter. In Figure 11 shows the P&O MPPT tracking performance, the Output having some ripples due to Non stability under shading conditions.The Performance of both P&O and PSO MPPT algorithms are shown in Table 1.

Table 1: Performence of the MPPT algorithms

Irradiation Level	Perturb&observe method			Particle swarm optimization(PSO)		
	V_{mpp}	P_{mpp}	%η	V_{mpp}	P_{mpp}	%η
1000W/m^2	16.33	39.68	99.2	17.3	39.79	99.47
800W/m^2	14.56	28.7	71.75	17.39	32.3	80.75
500W/m^2	9.17	11.5	28.75	13.64	17	42.5
1000W/m^2 and 800W/m^2	15.05	33.4	83.5	16.23	35.5	88.75
1000W/m^2 and 500W/m^2	13.02	24.3	60.75	15.44	28.4	71

6. CONCLUSIONS

There are many MPPT techniques taken in the literature are discussed and analyzed. The Particle swarm optimization (PSO) and Perturb & Observe (P&O) algorithms are simulated and tested under normal and partial shading conditions. Under normal illumination level, PSO based MPPT algorithm tracking MPP without any problem, but the P&O based MPPT, the operating point oscillates around MPP after reached the MPP. In the case of partial shading condition, due to multiple maximum power points (MPP), the PSO based algorithm tracking the global maximum power point (Gmpp) where the P&O based algorithm stops the tracking when local maximum power point (Lmpp) reached. The proposed coupled inductor SEPIC converter is capable of reducing the ripple in the array current and improving the converter efficiency .The implementation of PSO algorithm is complicated as compare to P&O based MPPT algorithm.

Simulation Results

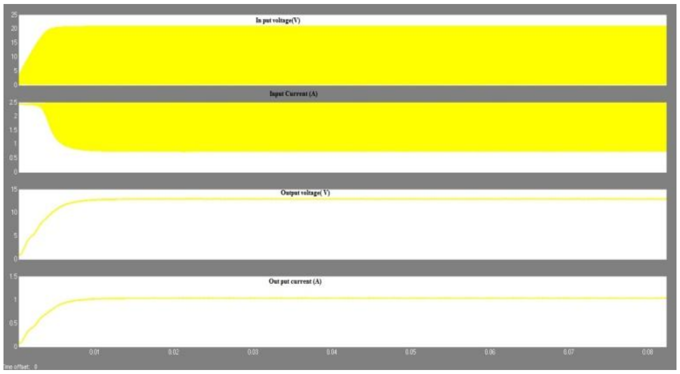

Figure 10: Tracking performance of PSO MPPT algorithm with SEPIC converter.

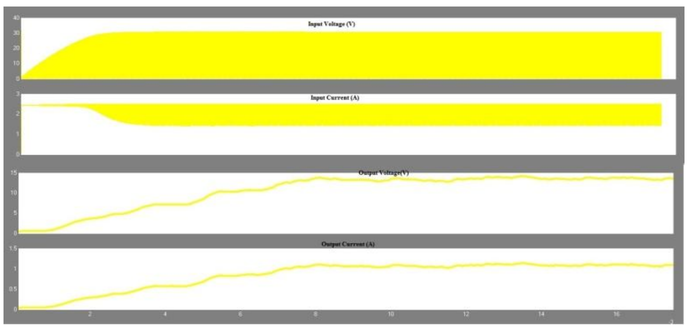

Figure 11: Tracking performance of P&O with SEPIC converter

REFERENCES

[1] Roger Gules, Juliano De Pellegrin Pacheco, Hélio Leaes Hey, "**A Maximum Power Point Tracking System With Parallel Connection for PV Stand-Alone Applications**" *IEEE Transactions on Industrial Electronics*, vol. 55, no. 7, July 2008.

[2] Hiren Patel and Vivek Agarwal, "**Maximum Power Point Tracking Scheme for PV Systems Operating Under Partially Shaded Conditions**" *IEEE Transactions on Industrial Electronics*, vol. 55, no. 4, April 2008

[3] Hiren Patel and Vivek Agarwal, "**MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics**" *IEEE Transactions on Energy Conversion*, vol. 23, no. 1, March 2008

[4] MUMMADI VEERACHARY "**Power Tracking for Nonlinear PV Sources with Coupled Inductor SEPIC Converter**" *IEEE Transactions On Aerospace And Electronic Systems* Vol. 41, No. 3 July 2005.

[5] Azadeh Safari and Saad Mekhilef, "**Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter**" *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, April 2011.

[6] Fangrui Liu, Shanxu Duan, Fei Liu, Bangyin Liu, and Yong Kang ,"**A Variable Step Size INC MPPT Method for PV Systems**" *IEEE Transactions on Industrial Electronics*, vol. 55, no. 7, July 2008

[7] Mohammad A. S. Masoum, Hooman Dehbonei, and Ewald F. Fuchs, "**Theoretical and Experimental Analyses of Photovoltaic Systems With Voltage- and Current-Based Maximum Power-Point Tracking**" *IEEE Transactions on Energy Conversion*, vol. 17, no. 4, December 2002.

[8] Ahmad Al Nabulsi and Rached Dhaouadi,"**Efficiency Optimization of a DSP-Based Standalone PV System Using Fuzzy Logic and Dual-MPPT Control**" *IEEE Transactions on Industrial Informatics*, vol. 8, no. 3, August 2012

[9] Chian-Song Chiu and Ya-Lun Ouyang,"**Robust Maximum Power Tracking Control of Uncertain Photovoltaic Systems: A Unified T-S Fuzzy Model-Based Approach**" *IEEE Transactions on Control Systems Technology*, vol. 19, no. 6, November 2011

[10] Whei-Min Lin, Chih-Ming Hong, and Chiung-Hsing Chen, "**Neural-Network-Based MPPT Control of a Stand-Alone Hybrid Power Generation System**" *IEEE Transactions on Power Electronics*, vol. 26, no. 12, December 2011.

[11] Whei-Min Lin, Chih-Ming Hong, and Chiung-Hsing Chen,"**Neural-Network-Based MPPT Control of a Stand-Alone Hybrid Power Generation System**" *IEEE Transactions on Power Electronics*, vol. 26, no. 12, December 2011

[12] Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo, "**Optimization of Perturb and Observe Maximum Power Point Tracking Method**" *IEEE Transactions on Power Electronics*, vol. 20, no. 4, July 2005.

[13] Chihchiang Hua, Jongrong Lin, and Chihming Shen,"**Implementation of a DSP-Controlled Photovoltaic System with Peak Power Tracking**" *IEEE Transactions on Industrial Electronics*, vol. 45, no. 1, February 1998.

[14] Eftichios Koutroulis, Kostas Kalaitzakis, and Nicholas C. Voulgaris ,"**Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System**" *IEEE Transactions on Power Electronics*, vol. 16, no. 1, January 2001.

[15] Roger Gules, Juliano De Pellegrin Pacheco, Hélio Leães Hey and Johninson Imhoff ,"**A Maximum Power Point Tracking System With Parallel Connection for PV Stand-Alone Applications**" *IEEE Transactions on Industrial Electronics*, vol. 55, no. 7, July 2008.

[16] Masafumi Miyatake, Mummadi Veerachary, Fuhito Toriumi Nobuhiko Fujii And Hideyoshi Ko, "**Maximum Power Point Tracking of Multiple Photovoltaic Arrays: A PSO Approach**" *IEEE Transactions on Aerospace And Electronic Systems* vol. 47, no. 1 January 2011.

[17] Kashif Ishaque, Zainal Salam, Muhammad Amjad and Saad Mekhilef ,"**An Improved Particle Swarm Optimization (PSO)–Based MPPT for PV With Reduced Steady-State Oscillation**" *IEEE Transactions on Power Electronics*, vol. 27, no. 8, August 2012

[18] Kashif Ishaque,Zainal salam,Hamed Teheri and Amir Shamsudin "**Maximum Power Point Tracking for PV system under Partial Shading Condition via Particle Swarm Optimization**"2011 *IEEE Applied Power*