

Maximum power point tracking scheme of photo voltaic array using an evolutionary algorithm

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Abstract

Current-voltage, power-voltage characteristics of a substantial photovoltaic (PV) clusters under non-uniform illumination conditions are portrayed by numerous steps and peaks. Tracking the maximum power under fast varying irradiance conditions accurately is a difficult task. Most of the existing schemes fail to extract maximum power from the PV cluster under fast varying irradiance conditions. This project work uses an evolutionary algorithm Artificial Bee colony (ABC) is used to find the maximum power peak in the Uniform irradiation condition. In this paper the characteristics of the photovoltaic arrays in the uniform and non-uniform irradiation conditions are observed. SEPIC (single ended primary inductor converter) is used to boost load voltage. Then ABC algorithm is used to extract the global peak most efficiently by avoiding the disadvantages of other techniques. Maximum power point tracking scheme is employed in MATLAB SIMULINK.

Keywords: *Photo voltaic module modelling, SEPIC converter, Maximum power point tracking, Uniform irradiance.*

1. Introduction

Due to gush in the usage of the renewable energy resources there is a huge rush in the usage of the Photo Voltaic power generation in many applications. The single PV cell alone can't bear the heavy load because the power generated by the one PV cell is very small so PV cells are arranged either in series or parallel to meet the load. The solar cell's power-voltage (P-V) and current-voltage (I-V) characteristics are non-linear. In the non-uniform irradiance case due to the objection of the solar irradiation by the clouds, birds and trees and so on, could result in hot spots on the solar panel. To avoid the hot spots bypass diode is employed to create a replacement path [1]. The output characteristics of

the PV arrays are complicated and to obtain them there is a need for use of efficient models [2]-[5]. For extracting maximum power, the characteristics of the PV modules under uniform and non-uniform condition is carefully studied by using efficient models (for single PV module and also for the combination of more than one PV module) in this work.

To model the PV cell or module a single diode model [6] can be employed. Modelling equations for finding the PV model parameters such as parallel resistance, series resistance is mentioned in [7], [8]. From the past few years researchers are using two diode model [9], [10] for more effective PV modelling. In this paper single diode PV model is employed for modelling. In [11,12] PV modelling is done in MATLAB considering electrical parameters. The simulation outputs state that there is an excellent resemblance with the characteristics of the system. Electrical qualities of the photo voltaic modules when exposed to uniform and non-uniform irradiation conditions were investigated in [2], [13]. Overall in this paper a single diode PV model is used which is built in MATLAB/SIMULINK using S-function builder.

It is known from the characteristics that the P-V and I-V curves of the Photo Voltaic cell are non-linear and to deliver maximum power to the load different MPPT algorithms are proposed [14], [15] of which Perturb and observe method (P&O) and modified P&O are employed in this paper. Their performance is compared with MPPT scheme realised using Artificial Bee Colony algorithm (ABC). For sending power to the load by employing MPPT a SEPIC converter is used in this work

2. Photo Voltaic Cell Modelling

The P-V and I-V curves of the solar PV module is as shown in Figure 1

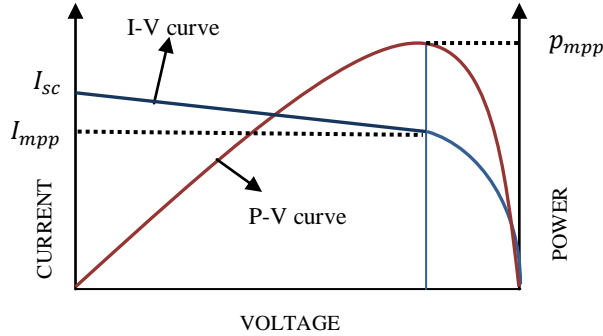


Fig.1. P-V and I-V characteristics of the solar cell

A. Modelling equations of solar PV cell

The basic PV model circuit using single diode model is shown in Figure 2

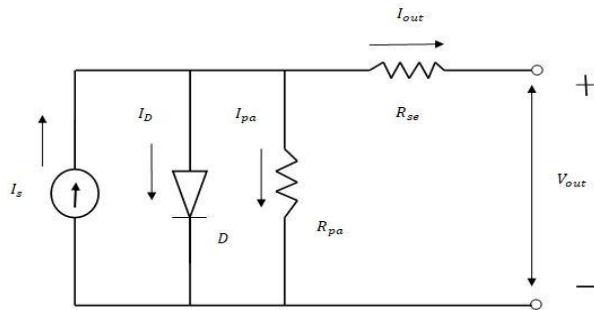


Fig.2. Basic PV cell modelling

The symbols in Figure 2 are described as below

- I_s : Solar PV cell current
- I_{out} : Output current
- I_D : Diode current
- I_{pa} : Shunt resistance current
- D : Diode
- R_{pa} : Parallel resistance
- R_{se} : Series resistance
- V_{out} : Output voltage

B. Modelling equations of photo voltaic cell:

The basic equation [10] of output current and output voltage from the figure 2

$$I_{out} = I_s - I_o \left\{ e^{\frac{q(V_{out} + R_{se}I_{out})}{AKT}} - 1 \right\} - \frac{V_{out} + R_{se}I_{out}}{R_{pa}} \quad (1)$$

In this one I_o is reverse saturation current of diode, q is charge of the electron ($1.602 \times 10^{-19}C$), A is the diode ideal factor K is Boltzmann constant and its value is ($1.38 \times 10^{-23}J/K$). In the above equation the parallel resistance was considered as infinity and solar PV current as short circuit current. By taking above considerations the equation (1) becomes [10]

$$I_{out} = I_s - I_o \left\{ e^{\frac{q(V_{out} + R_{se}I_{out})}{AKT}} - 1 \right\} \quad (2)$$

N-R method is used to solve (2) to plot P-V and I-V curves for the module by coding in S-function builder of SIMULINK.

C. Electrical characteristics of solar PV cell (EGING-50W)

Maximum power	→ 50 W
Maximum voltage	→ 17.98 V
Maximum current	→ 2.77 A
Short circuit current	→ 3 A
Open circuit voltage	→ 22 V

D. PV model implementation in MATLAB-SIMULINK

The unknown parameters are found considering the electrical parameters, S-function builder was employed in order to design the PV model. The reason behind using the S-function builder is its speed of execution is better compared to the embedded MATLAB function. When it come to the real time operations it was very advantageous due to its MEX set up which makes it easily connects to the d-space controller. There will be no time lag in the system and the sensing of parameters is also faster. The basic sub system of S-function builder developed in the MATLAB-SIMULINK is shown in Figure 3.

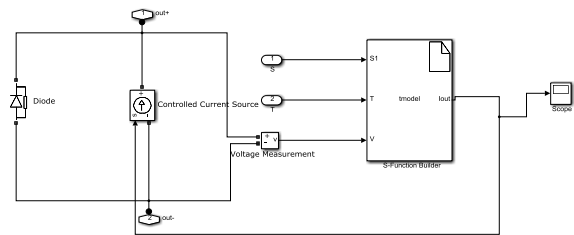


Fig.3. PV module model in MATLAB SIMULINK

The Output curves obtained for the PV model are shown in Figure 4.

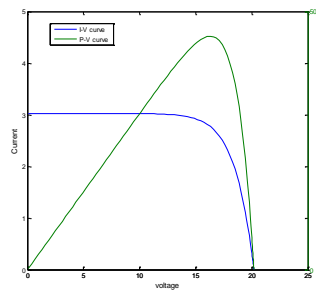


Fig.4. P-V & I-V curves

A single PV module was alone not able to meet the higher loads because the PV output power is very small so the PV modules can be arranged in series and parallel to power the load by boosting the voltage or current. To boost the voltage without changing current three single modules in series can be used as shown in Figure 5.

D.1. Arrangement of the PV modules in 3×1 configuration

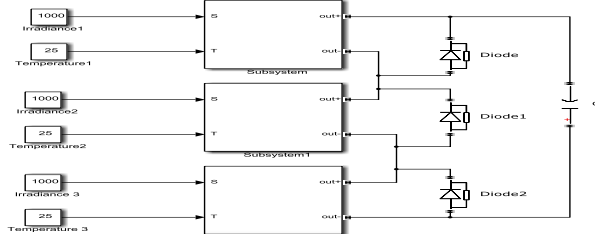


Fig.5. 3×1 configuration (uniform irradiation)

The Output characteristics obtained from the SIMULINK model is shown in Figure 6. The power rating can be increased while the current remains the same.

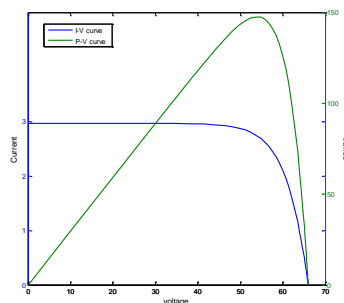


Fig.6. P-V & I-V curves

D.2. Arrangement of the PV modules in 1×4 configuration

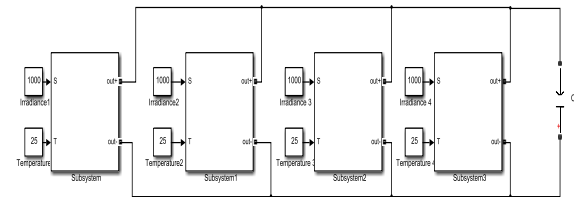


Fig.7. 1×4 configuration

The Output characteristics obtained for the 1×4 configuration is shown in Figure 8 below.

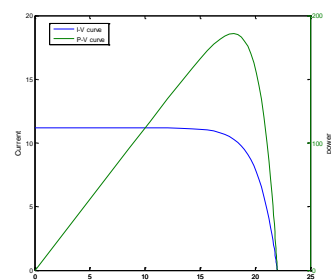


Fig.8. P-V & I-V curves

The power rating can be increased by boosting the current while the voltage remains constant.

The above cases are simulated for uniform irradiation condition so that there is the similarity in the characteristics with the only variation in the levels of outputs. But under non-uniform irradiation condition there will be multiple peaks in the output characteristics. Here three panels in series configuration was used to serve the purpose, all the irradiance levels are different

D.3. Arrangement of the PV modules in 3×1 configuration (non uniform case)

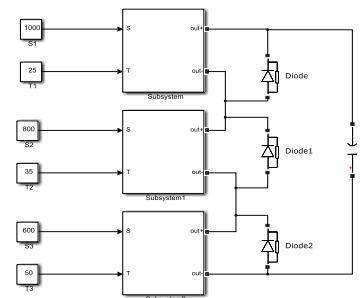


Fig. 9. 3×1 configuration (Non uniform irradiation)

The Output characteristics for the above arrangement is shown in Figure 10 below.

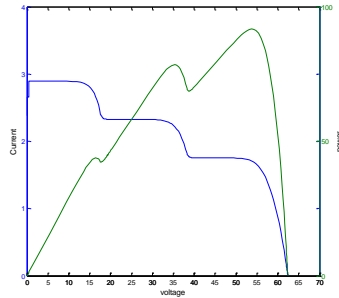


Fig.10. P-V & I-V curves

In figure 10 multiple peaks can be observed in the P-V and I-V curves.

3. Sepic converter

SEPIC (single ended primary inductor converter) is the DC-DC converter was employed in this paper to power the load. The only difference between the simple boost converter and this SEPIC is addition of the extra inductor and capacitor [16] which is shown in figure 11.

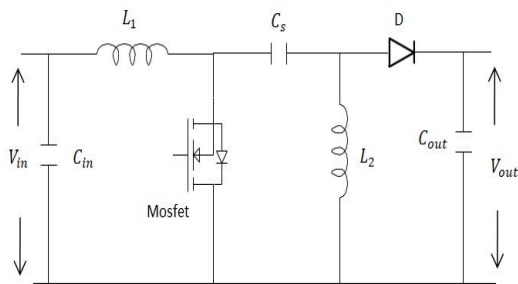


Fig.11. Basic design of SEPIC converter

The SEPIC converter has the advantages such as

1. It is able to meet the both increased and the decreased load.
2. The output voltage was non-inverted.
3. The extra addition of the inductor and capacitor added in the circuit also act as filters and reduce the oscillations in the output.

The SEPIC converter has the disadvantages of the increase in cost due to the extra addition of the inductor and capacitor. In this paper the frequency of system considered is 25 KHz and a MOSFET is employed as a switch..

The mathematical equations for solving unknown parameters are [16]

Duty cycle:

$$D = \frac{V_{out}}{V_{out} + V_{in}} \quad (3)$$

Inductances:

$$L_1 \approx L_2 \approx \frac{V_{IN}}{\Delta I_L} * \frac{D_{max}}{f_{sw}} \quad (4)$$

$$\Delta I_L = \left[I_{out} * \frac{V_{out} * 40\%}{V_{in}} \right] \quad (5)$$

Coupling capacitance:

$$C_s = \frac{I_{OUT} * D_{max}}{\Delta V_{cs} * f_{sw}} \quad (6)$$

Input capacitor:

Any value greater than the 10 μ f is sufficient for the efficient working of the converter.

By controlling the duty cycle of SEPIC converter maximum power can be transferred to the load. In order to control the duty cycle input to the SEPIC the PV current and voltage sensed and given as input to the MPPT algorithm whose output is duty cycle

Maximum Power Point Tracking

Maximum power point tracking (MPPT) is a scheme to send the maximum power to load by regulating the duty cycle to the DC-DC converter switch so that the resistance of the load is equals to the resistance of the total source resistance so that the maximum power is transferred. Maximum power point tracking is employed to transfer maximum power from the power output of the PV panel. In this work it was discussed about the two conventional MPPT algorithms and one evolutionary algorithm as below

Conventional algorithms:

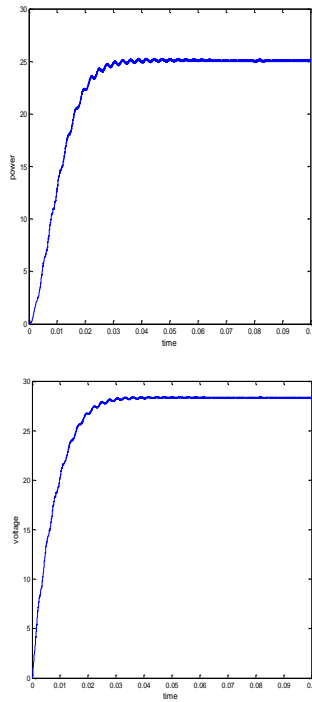


Fig.15. Output power and voltage characteristics of P&O

4.2 Modified perturb and observe method:

The modified P&O method has the comparison of the current which is the only difference when compared to convention P&O algorithm. Comparison of the current helps it in the case of sudden change in the irradiation levels [14]. More over with P&O there is huge fluctuation in the duty cycle when irradiation changes. In case of the modified P&O the fluctuation in the voltage is low, hence the cost required for the protection of equipment will be ultimately reduced so this modified one is more advantageous [14]. Simulation outputs at different S&T combinations using modified P&O are shown in Figures 16-18.

$$2.1 \text{ } s = 1000 \text{ } \frac{\text{W}}{\text{m}^2}, T = 25^\circ \text{C}$$

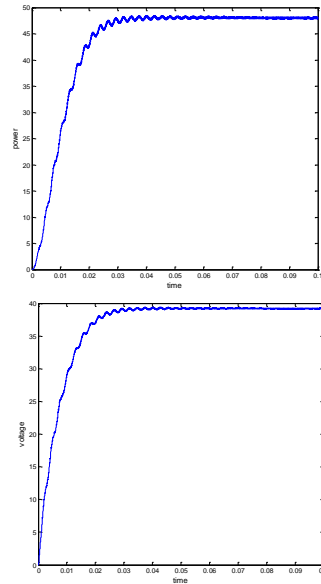


Fig.16. Output power and voltage characteristics of modified P&O

$$2.2. \text{ } s = 800 \text{ } \frac{\text{W}}{\text{m}^2}, T = 35^\circ \text{C}$$

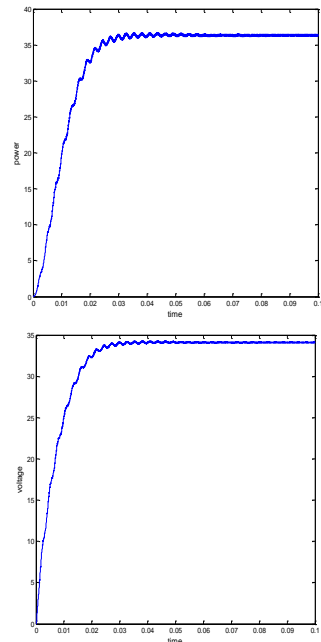


Fig.17. Output power and voltage characteristics of modified P&O

$$2.3. \text{ } s = 600 \text{ } \frac{\text{W}}{\text{m}^2}, T = 50^\circ \text{C}$$

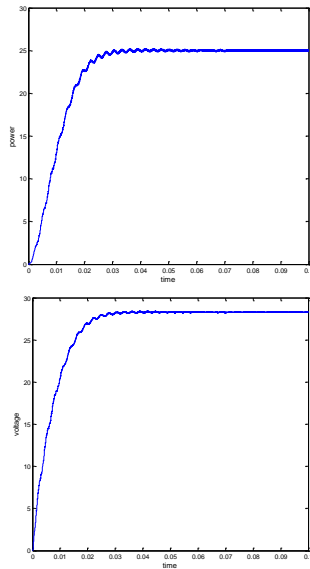


Fig.18. Output power and voltage characteristics of modified P&O

4.3 Artificial bee colony (ABC):

For MPPT, a SEPIC-type dc–dc converter is placed between the PV module and the power consuming load. ABC algorithm is used to track maximum power point.

In this one the original ABC [15] algorithm was modified by the removing scout bee, which ultimately decreases the overall time approach so that it was more accurate to real time purpose.

A. Initialization

In this one the bees are placed at different nectar positions by using the following equation [15]

$$x_k = d_{\min} + \frac{(k-1)(d_{\max} - d_{\min})}{N-1} \quad (7)$$

B. Calculating the Nectar quantity

From the initialized duty cycles the respective power should be evaluated by using the mathematical modelling equations.

C. Detecting the new food source

The overall bees are divided into the employed bees and onlooker bees

C.1. Employed bees

Employed bees compare the quantity of Nectar with neighbourhood bees and swipes with each other based on the quantity of Nectar amount.

C. 2. Onlooker bees

In the dancing area the onlooker bees waits to find the employed bee where there is high nectar quantity and moves towards that position. This movement is defined as below equation [15]

$$x_k(i+1) = x_H(i) + \frac{rand * (d_{\max} - d_{\min})}{\frac{N}{2} - 1} \quad (8)$$

C. 3. Termination

The employed bee and onlooker bee position swapping stops when the following conditions should be reached [15].

$$\left| \frac{P_{pv}^i - P_{pv}^{i-1}}{P_{pv}^i} \right| \geq 0.1 * A_x \quad (9)$$

$$A_x = \text{insolation factor}$$

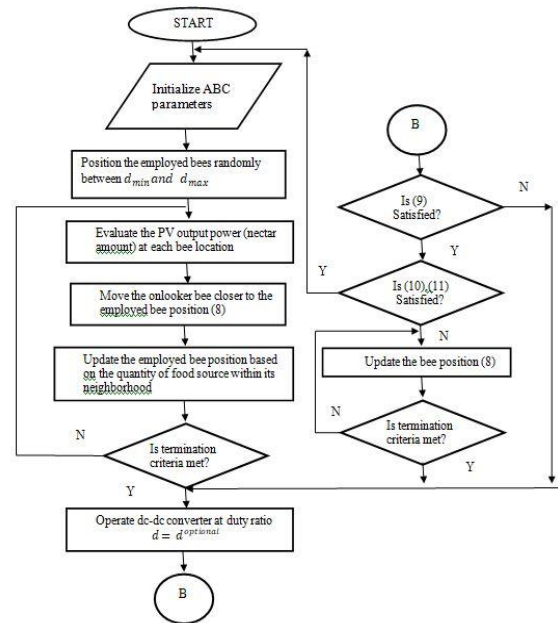


Fig.19. Artificial bee colony algorithm

$$3.1 \text{ s} = 1000 \frac{\text{W}}{\text{m}^2}, T = 25^\circ \text{C}$$

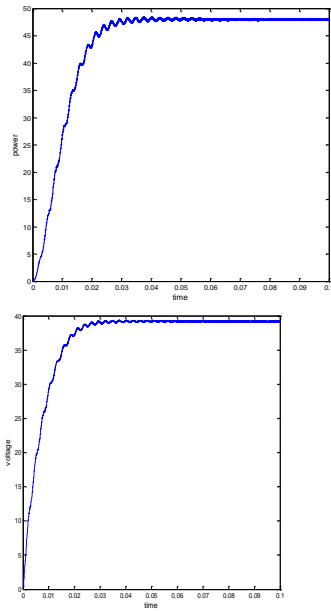


Fig.20. Output power and voltage characteristics of ABC

$$3.2. s = 800 \frac{W}{m^2}, T = 35^\circ C$$

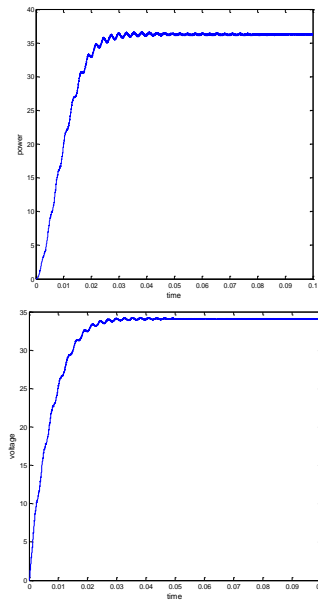


Fig.21. Output power and voltage characteristics of ABC

$$3.3. s = 600 \frac{W}{m^2}, T = 50^\circ C$$

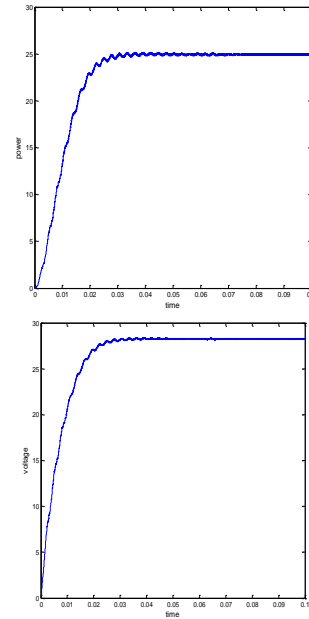


Fig.22. Output power and voltage characteristics of ABC

4.4 Comparison of the algorithms

The comparisons of algorithms were done as the as shown in table 1. From that we can clearly state that the ABC tracks the maximum power more efficiently compared to other two algorithms.

Uniform irradiance varies with time:

In all the above cases the irradiation was constant for the whole time. Now a special case was chosen in which the irradiation level varies with the time. It means uniform irradiance case varies with time for a single module. The output waveforms for three algorithms are shown in Figures 24, 25 and 26. The variation is considered in three levels.

Table.1. comparison of various MPPT algorithms

ALGORITHMS	STC		Irradiance= 800 W/m^2 Temp=35		Irradiance=600 W/m^2 Temp=50	
	D	P	D	P	D	P
P&O	0.697	47.5	0.66	35.899	0.65	24.92
MODIFIED P&O	0.69	47.315	0.669	36.312	0.645	24.67
ABC	0.692	48.325	0.671	36.925	0.647	25

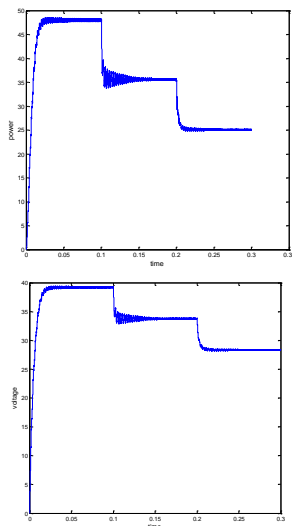


Fig.24. Output power and voltage characteristics using P&O

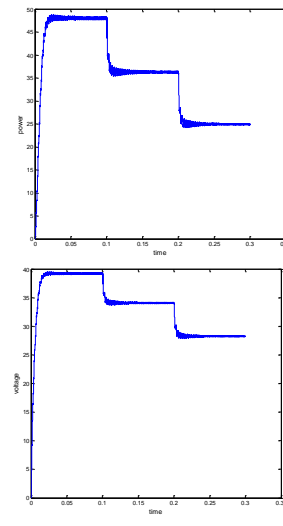


Fig.26. Output power and voltage characteristics using ABC

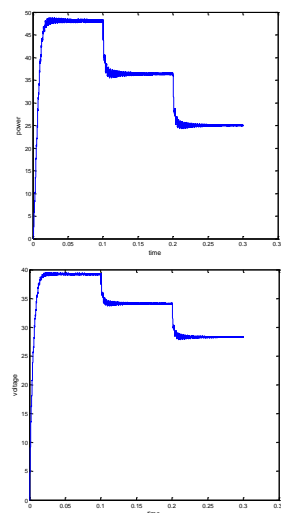


Fig.25. Output power and voltage characteristics using modified P&O

5. Conclusion

PV module modelling is done for both uniform and non-uniform irradiance conditions in this work. P-V and I-V curves are plotted for both series and parallel configurations. A SEPIC converter is designed to power the load for different configurations. P&O, Modified P&O and ABC algorithms are employed for MPPT tracking under varying irradiance condition. The disadvantage of the higher fluctuations in the system P&O algorithms can be overcome by using modified P&O method. Results show that ABC is more accurate in tracking MPPT when compared to other algorithms.

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