

## Performance enhancement of photovoltaic system using genetic algorithm- based maximum power point tracking

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Received: 21.01.2018

Accepted/Published Online: 29.03.2019

Final Version: 26.07.2019

**Abstract:** In recent years, enormous progress has been made on power generation using photovoltaic (PV) system. Solar power is one of the most promising renewable energy sources that is providing its benefit specifically in rural areas. With the increasing need for solar energy, it becomes necessary to extract maximum power from the PV array. The output power of the solar cells varies directly with the ambient temperature and Irradiation. Therefore, the challenge is to track maximum power from the PV array when environmental factors change. This paper focuses on increasing the efficiency of a PV array by incorporating artificial intelligence techniques. The genetic algorithm-based optimization technique is developed in order to track maximum power at given ambient conditions. The performance of the algorithm was tested under various environmental conditions using MATLAB/Simulink. A comparative study is done on the PV system using the conventional perturb & observe algorithm and genetic algorithm. The results show that the proposed MPPT technique is capable of tracking maximum power from the PV array with reduced oscillation and fast tracking speed.

**Key words:** Irradiation, optimization, genetic algorithm

### 1. Introduction

Electricity generation and its resulting CO<sub>2</sub> emissions are primarily determined by different types of technology used. To meet our present needs of electricity without harming the environment, it becomes necessary to depend on renewable power generation. Renewable energy sources like wind and solar are gaining their share of total power generation because of their sustainability and being harmless to the environment. The economic benefits of a photovoltaic (PV) array can be increased by increasing the conversion efficiency of the PV system. The main problem associated with the solar cell is that the output power from the solar cell depends on the amount of sunlight falling on it. Depending on the levels of irradiance, an appropriate maximum power point tracking (MPPT) technique can be selected. Several emerging technologies exploit intelligent controllers to maximize the output power from a PV array. MPPT is an integral part of the PV system. Conventional MPPT techniques can work effectively only when an accurate modeling of a PV system is presented.

A PV cell is represented by the current source, and a single diode with series and parallel resistance [1, 2]. Parameters estimation was done by using the genetic algorithm approach in order to obtain an accurate modeling of the PV array [3]. Perturbation and observation (P&O) is one of the most commonly used MPPT techniques

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due to its simplicity [4, 5]. This method is not effective during fast changes in irradiation level and at low levels of irradiation. Also, it introduces oscillations at the maximum power point area. For rapidly varying irradiation levels, the incremental conductance (IC) algorithm may be appropriate [6, 7]. The IC algorithm searches for the location at which instantaneous conductance is equal to the incremental conductance. This method gives the best performance with fast-tracking time. The drawback of this method is that it has a complex circuitry and that the iteration size decides the accuracy of the system. With the increase in the iteration size, a fast response can be achieved but an accurate maximum power point cannot be tracked. Conventional controllers lag in their performance due to their poor efficiency under partial shading conditions. For that, Zaki et al. have developed an MPPT technique using the artificial neural network (ANN) back propagation algorithm [8, 9]. ANN-based methods are only suitable for systems that have enough training data. Fuzzy logic-based controllers [10, 11] do not require knowledge and mathematical modeling of the PV array.

This paper presents a genetic algorithm approach for controlling a DC/DC boost converter for enhancing the performance of PV array. The duty cycle of the boost converter is adjusted so that maximum power tracking is achieved. For ease of perception, this paper is divided into the following sections: Section 2 gives the mathematical modeling of a PV array and boost converter. Section 3 introduces MPPT techniques using the Genetic Algorithm approach. Section 4 analyzes the result and compares the result with conventional techniques. Section 5 provides the conclusion and future scope of this work.

## 2. Mathematical modeling of PV array and boost converter

### 2.1. Modeling of the PV array

Among different modules presented in a PV system, the single-diode model discussed in [1, 2] is used here. It consists of a current source, single diode followed by shunt and series resistance. This model provides a compromise between simplicity and effectiveness. In Figure 1, the diode is connected in parallel with the light-generated current source.  $R_{sh}$  and  $R_s$  represent intrinsic shunt and series resistance of the PV cell. Power losses due to manufacturing defects are represented by the shunt resistance. This provides the alternate path for the light-generated current and thereby reduces the amount of current entering the solar cell junction.  $R_s$  represents the series resistance connecting the active portion of the cell so that  $R_s$  varies with the reciprocal of irradiance. PV cells are connected together to form PV modules; the interconnection of PV modules constitute a PV array. The equivalent circuit of a PV array is shown in Figure 2. In this work, 96 PV cells are connected in series forming a PV module; 5 modules are connected in series and 30 modules are connected in parallel forming the PV array.

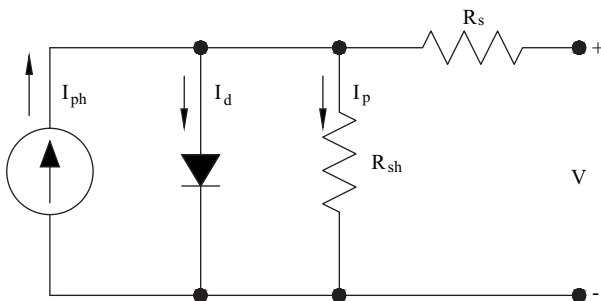


Figure 1. PV cell equivalent circuit.

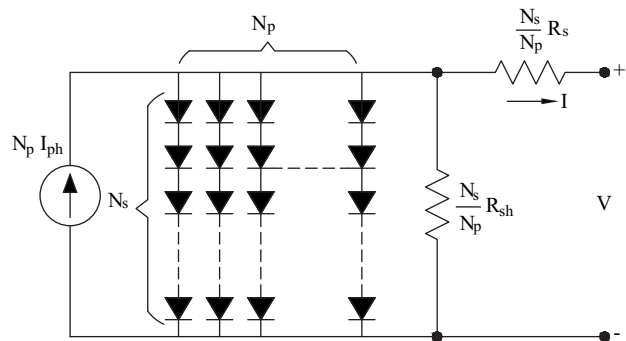


Figure 2. Equivalent circuit of a PV array.

Using Kirchhoff's law, the output current for a single PV cell is given by

$$I = I_{ph} - I_d - I_{sh}, \tag{1}$$

where  $I_{ph}$  - photocurrent at short circuit (A),

$I_d$  - Diode current (A), and

$I_{sh}$  - Current in shunt resistance (A).

If  $N_s$  and  $N_p$  represent the numbers of cells that are connected in series and parallel, then the output current equation changes to

$$I = N_p I_{ph} - N_p I_d - I_{sh} \tag{2}$$

$$I = N_p \times I_{ph} - N_p \times I_o \times \left[ \exp \left( \frac{\frac{V}{N_s} + I \times \frac{R_s}{N_p}}{n \times V_t} \right) - 1 \right] - I_{sh} \tag{3}$$

The module photocurrent in ampere (A) is given as:

$$I_{ph} = [I_{sc} + K_i (T - 298.15)] \times I_r / 1000. \tag{4}$$

The module saturation current  $I_o$  varies with the module temperature, and is given by

$$I_o = I_{rs} \left[ \frac{T}{T_r} \right]^3 \exp \left[ \frac{q \times E_{go}}{nk} \left( \frac{1}{T} - \frac{1}{T_r} \right) \right]. \tag{5}$$

Here,  $E_{go}$  denotes the band-gap energy of the semiconductor = 1.1 eV, and  $n$  is the ideality factor that takes the value between 0 and 1.  $q$  is the electron charge ( $1.602 \times 10^{-19}$  C),  $V_d$  is the voltage across the diode (V),  $k$  is Boltzmann's constant ( $1.381 \times 10^{-23}$  J/K) and  $T$  is the junction temperature in Kelvin (K).  $T_r$  represents the reference temperature (298.15 K)

$I_{rs}$  represent module reverse saturation current which is given by

$$I_{rs} = \frac{I_{sc}}{\left[ \exp \left( \frac{qV_{oc}}{N_s k n T} \right) - 1 \right]}. \tag{6}$$

$V_t$  represents diode thermal voltage, which is given by

$$V_t = \frac{K \times T}{a} \tag{7}$$

and

$$I_{sh} = \frac{V \times \frac{N_p}{N_s} + I \times R_s}{R_{sh}}. \tag{8}$$

Figures 3 and 4 show the V-I and P-I characteristics of the PV system with a constant irradiation level of 1000 W/m<sup>2</sup> at 25 °C. PV Module specifications are given in Table 1.

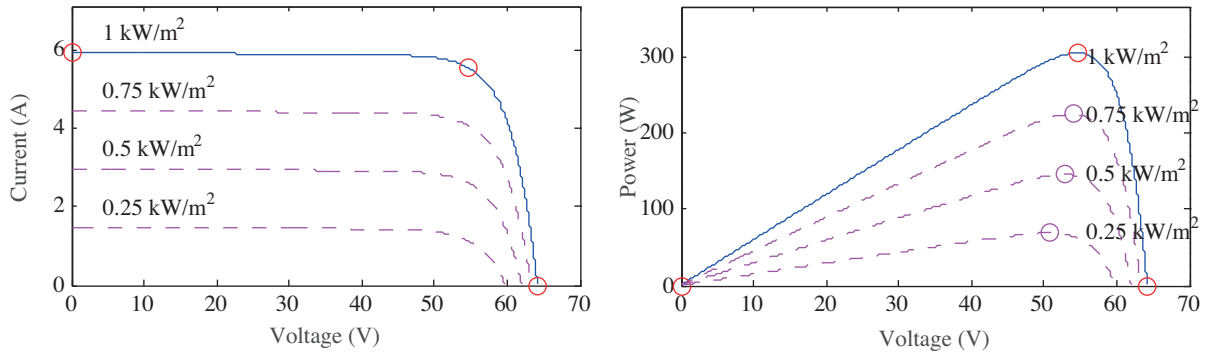


Figure 3. V-I and P-V characteristics of PV module.

Table 1. PV module specifications.

Parameter	Values
Maximum power ( $P_{max}$ )	305 W
Voltage at Pmax ( $V_{mp}$ )	54.7 V
Current at Pmax ( $I_{mp}$ )	5.58 A
$V_{oc}$	64.2 V
$I_{sc}$	5.96 A
$R_p$	993.51 $\Omega$
$R_s$	0.037998 $\Omega$
$N_s$ (Number of modules in series)	5
$N_p$ (Number of strings in parallel)	30
Temperature coefficient for P	-0.38% / $^{\circ}C$
Temperature coefficient for V	-0.177 V / $^{\circ}C$

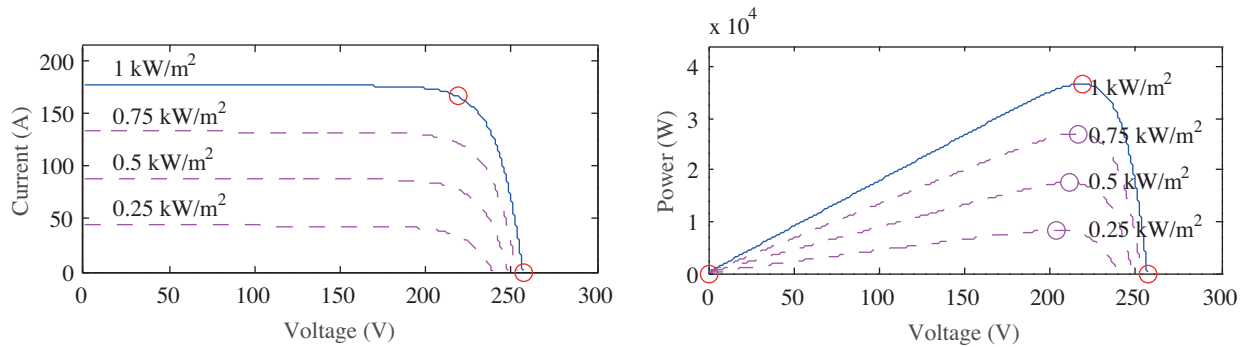


Figure 4. V-I and P-V Characteristics of PV Array

2.2. Modeling of boost converter

A boost converter is used to obtain a high regulated output voltage from the unregulated input voltage. The DC/DC converter circuit [12] consists of an inductor L, a power switch S, a diode D, a filter capacitor C, and a load resistor R, as shown in Figure 5.

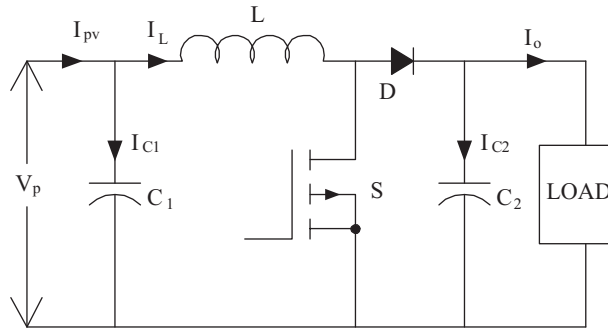


Figure 5. Boost converter circuit.

The duty cycle for the boost converter is chosen based on the equation(9)

$$D = 1 - \left[ \frac{V_{in(min)} \times \eta}{V_{out}} \right], \tag{9}$$

where  $V_{in(min)}$  - minimum input voltage,

$V_{out}$  - Desired output voltage,

$\eta$  - Efficiency of the converter.

The inductor value is one of the crucial parameters that decide the converter efficiency [13]. This value is chosen based on Eq. (10)

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{\Delta I_L \times f_s \times V_{out}}, \tag{10}$$

where  $V_{in}$ = typical input voltage,

$f_s$ = minimum switching frequency of the converter,

$\Delta I_L$ = estimated inductor ripple current.

The inductor current rating should always be higher than the maximum switching current in the system. During the functioning of the boost converter, the switch is closed for the duration  $D \times T$  and the switch is opened for the duration  $(1-D) \times T$ , where  $T$  is the time-period for one complete cycle.

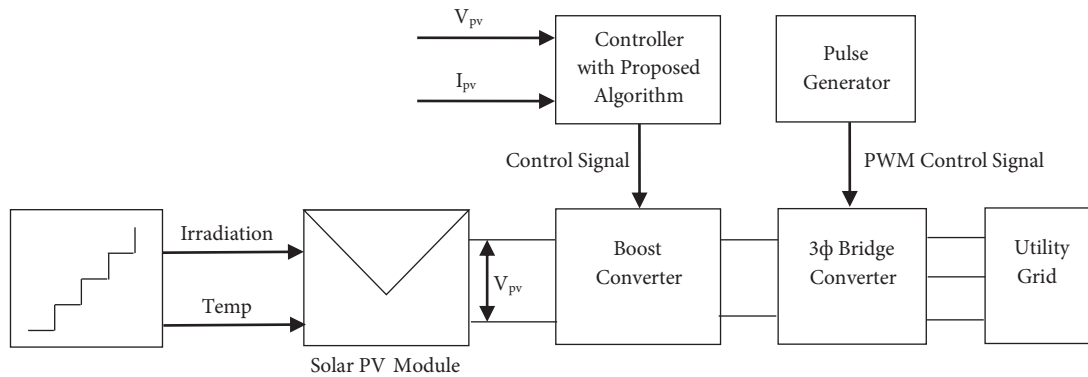
The nonlinear equations that represent the boost converter are as follows:

$$\frac{dV_{pv}}{dt} = \frac{1}{C_1} (i_{pv} - i_L) \tag{11}$$

$$\frac{dV_{out}}{dt} = \frac{1}{C_2} \left( (1 - D) i_L - \frac{V_o}{R_L} \right) \tag{12}$$

$$\frac{di_L}{dt} = \frac{1}{L} (V_{pv} - (1 - D) V_o) \tag{13}$$

The block diagram of the proposed system is shown in Figure 6.



**Figure 6.** MPPT control of PV array using proposed algorithm

### 3. MPPT using genetic algorithm approach

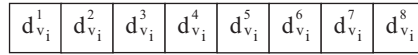
MPPT is the process of finding the point at which power transfer occurs with maximum efficiency. In this paper, the MPPT controller is integrated with a DC/DC converter that adjusts its duty cycle according to its requirement. Genetic algorithm (GA) is an evolutionary approach which got more attention in recent years because of its ability to solve nonlinear optimization problems [14]. GA mimics some of the processes observed in natural evolution. The optimization process starts with the population of randomly generated individuals. Each individual in the population represents one point in the search space, and is coded as a string of binary. The fitness of each individual in the population is evaluated using the fitness function. The fitness value reflects the suitability of each individual to produce a new offspring. To create the next generation of the population, GA operators such as selection, mutation, and crossover are used. Each generation will produce the population that is better than the previous one; over successive generations, each population moves towards an optimal solution. The selection of GA parameters for optimization is shown in Table 2. In this paper, the aim of the GA approach is to extract maximum power from a PV cell under various ambient conditions [15]. The following steps are involved in the GA implementation:

**Table 2.** GA parameters for optimization.

Parameter	Values
Number of design variable	1 (Voltage)
Number of population	40
Maximum number of generation	100
Selection type	Uniform
Ps (Selection probability)	0.5
Pc (Crossover probability)	0.5
Pm (Mutation probability)	0.1

Step1: The main step in evolutionary algorithm is generation of initial population. Good initialization of population leads to better possibility of finding MPP. While using more number of individuals, MPP is reached after few generations, but it needs more execution time. The binary encoding system was used to represent the chromosome. Chromosomes are made up of genes, which represents PV voltage. Figure 7 represents binary

encoding of PV voltage.



**Figure 7.** Binary encoding of PV voltage.

$d_{v_i}^1$  represents the first bit of  $i_{th}$  chromosome in a population. The random initialization of the population is done using Eq. (14) and the generated populations are uniformly distributed in the range  $[d_{v(min)}, d_{v(max)}]$ .

$$d_v = d_{v(min)} + rand(n_p, n_b) \times (d_{v(max)} - d_{v(min)}). \tag{14}$$

$n_p$  and  $n_b$  represent the number of individual in a population and the number of bits in each individual. There are 40 numbers of individuals in a population and 8 bits in each individual. Using brute-force technique it is observed that the initial population of voltage [0-200V] gives the optimal output power at standard test condition (STC).

Step2: In this paper, the fitness function to be maximized is output power from PV array which can be formulated by the following equation

$$P_{pv} = V_{pv} \times I_{pv} \tag{15}$$

Subject to the constrain based on all possible irradiances and temperatures:  $200 V \leq V_{pv} \leq 600 V$ .

Step3: Genetic operators perform various operations on chromosomes, thereby leading them to the solution of maximum power point (MPP).

Selection: The next step is to decide which chromosomes are enough fit to survive. For that, chromosomes are sorted based on their fitness value from highest power to lowest power. For this MPP problem, among the 40 chromosomes, only 50% of the chromosomes are kept for mating, the remaining are discarded to make room for new off-springs.

Mutation: In order to avoid fast convergence towards local maxima, mutations are done. In this paper, mutations are done with rate of 10% in design variable.

Crossover: This operation is performed on two parents with the highest fitness values to produce off-springs. The genetic materials of the parents are exchanged with the hope of better solution. In this work, single point crossover is performed and the crossover point is selected randomly. After selecting crossover point, swapping takes place. Crossover is performed with the rate of 50%.

Step 4: The newly generated population is used to run the algorithm again.

Step 5: There are two scenarios which can terminate the algorithm: The algorithm stops, when maximum number of iterations is reached. It is predefined by the user. In this work, maximum number of iterations is taken as 100. The algorithm stops, when convergence is reached. Convergence represents that repetitive optimal value for successive maximum number of generations. If the termination conditions occur, the algorithm stops or continues with step 2.

Figure 8 shows the optimized voltage evolution with generation and the algorithm terminates due to convergence of optimized voltage.

**4. Results and discussion**

Both conventional and proposed algorithms are tested using SunPower SPR-305 WHT. In order to validate the effectiveness of the proposed controller, simulation is carried out for two cases. One is under standard test

conditions and the other is performed under different environmental conditions. In Figures 9–11, standard test conditions of  $1000 \text{ W/m}^2$  irradiation and  $25^\circ\text{C}$  temperature are considered. The experimental result has four waveforms that include PV system voltage, current, boost converter input and output voltage, and inverter output voltage.

In Figure 9, PV array voltage = Module voltage  $\times N_s = 54.7 \times 5 = 273.5 \text{ V}$

In Figure 10, PV array current = Module current  $\times N_p = 5.58 \times 30 = 167.4 \text{ A}$

The input voltage to the boost converter is from the PV array, which is  $273.5 \text{ V}$ , and after being boosted up, it is  $500 \text{ V}$  which are shown in Figure 11. The boost converter controls the output voltage by varying its duty cycle ( $k$ ), which is calculated using the Eq. (16). In this case, the duty cycle with the value of  $0.453$  is obtained.

$$V_o = V_s / (1 - k) \tag{16}$$

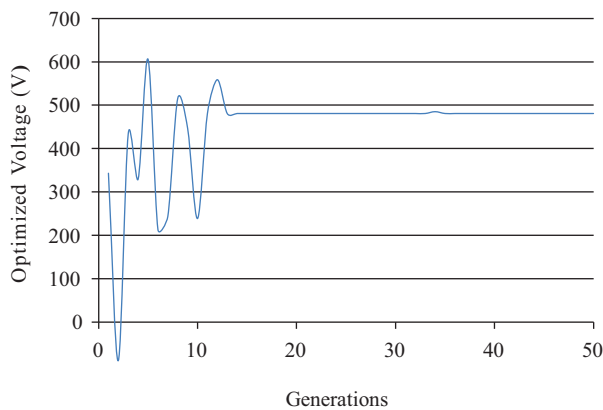


Figure 8. Optimized voltage evolution.

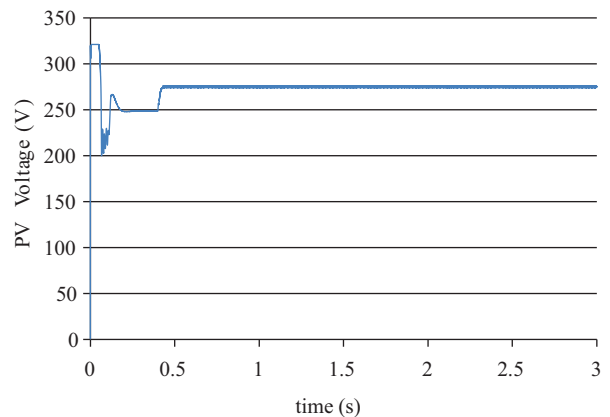


Figure 9. PV array voltage under standard test conditions ( $1000 \text{ W/m}^2$  and  $25^\circ\text{C}$ ).

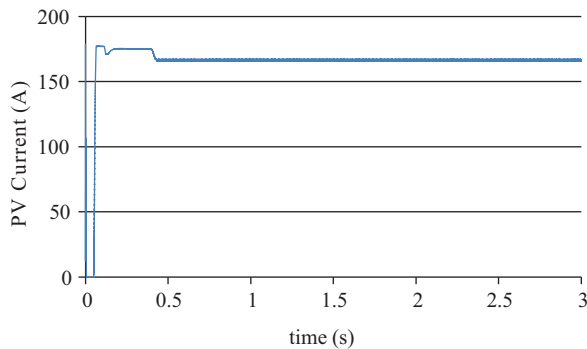


Figure 10. PV array current under standard test conditions ( $1000 \text{ W/m}^2$  and  $25^\circ\text{C}$ ).

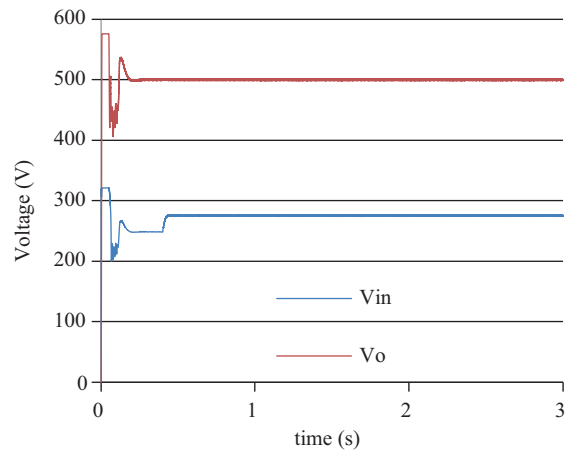


Figure 11. Input and output voltage of boost converter.

The voltage source converter (VSC) converts  $500 \text{ V}$  DC voltage to AC voltage which is shown in Figure 12. Pulse generator of boost converter and VSC uses the sampling time of  $0.001 \text{ s}$  in order to get the better resolution of waveforms. The grid output voltage is shown in Figure 13.



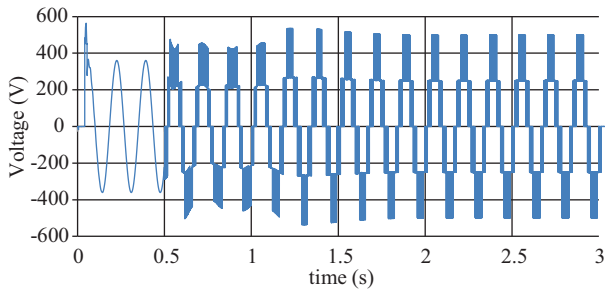


Figure 12. Inverter output voltage.

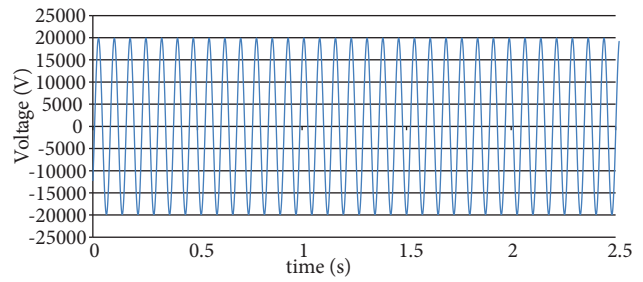


Figure 13. Grid output voltage.

With the change in irradiation, the PV output voltage and current are shown in Figures 14 and 15. In this case, the temperature is maintained constant; the irradiation decreases from  $1000 \text{ W/m}^2$  to  $600 \text{ W/m}^2$  during the period 1.5 s to 3 s. Because the open-circuit voltage changes logarithmically with solar irradiance, there is a slight change in the PV voltage during that period. However, the short circuit current varies directly with the solar irradiance because of the effect of the shunt resistance so that when solar irradiation on the PV cell decreases, the PV current also decreases. Figure 14 shows that the optimal voltage strongly depends on cell temperature.

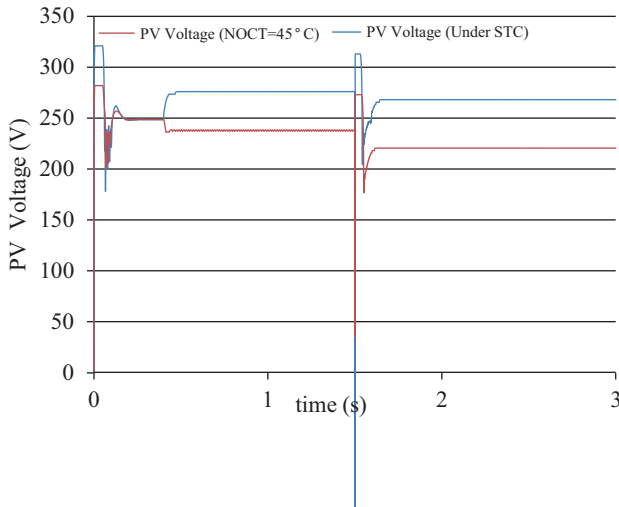


Figure 14. PV voltage with change in irradiation from  $1000 \text{ W/m}^2$  to  $600 \text{ W/m}^2$ .

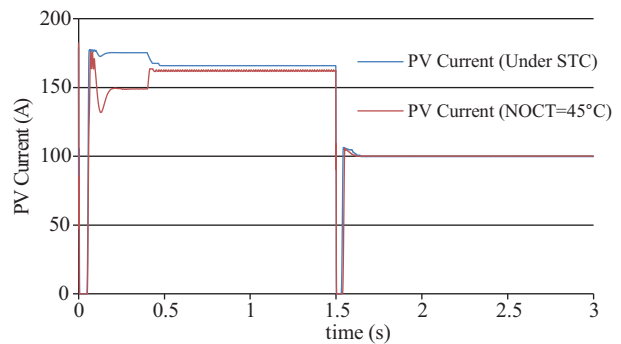
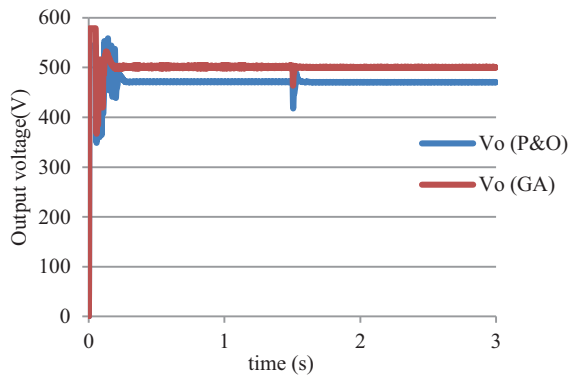


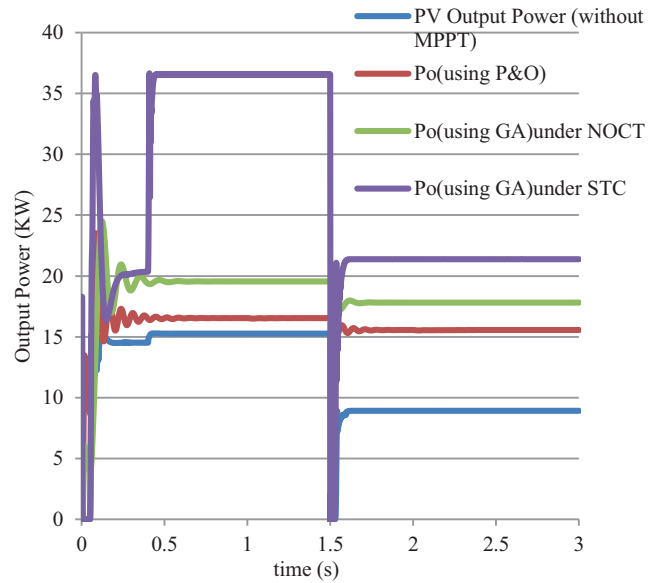
Figure 15. PV current with change in irradiation from  $1000 \text{ W/m}^2$  to  $600 \text{ W/m}^2$ .

In the P&O algorithm, the decision on step size determines the movement of the operating point towards MPP. If the step size is too large, it leads to oscillations about the maximum power point; if it is too small, it results in a slower response. Effective tracking of the PV power by changing the PV voltage is less sensitive to irradiation variation. In this case, a step size of 0.05 is considered. The proposed method is compared with conventional P&O, which is shown in Figure 16. In the conventional method, the time taken to reach MPP is high. It is evident from the experiment result that the tracking speed is increased and power oscillation is reduced in the proposed method.

Figure 17 shows the comparison of PV power with the output power of conventional and proposed method. The main drawback in conventional method is that it fails to track MPP point in case of rapid change in environmental conditions. It is proven that with the help of a GA-based controller, the power on the PV cell improved to the level of maximum power point with less oscillation.



**Figure 16.** Output voltage of boost converter using P&O and GA approach.



**Figure 17.** Output power comparison with change in irradiation.

Time domain specification of conventional and proposed systems are compared in Table 3. From the response, it is inferred that the proposed algorithm tracks MPP with significant reduction in peak time and settling time. This result proves that the proposed controller is efficient in the way of reduced oscillations with better time domain specifications.

**Table 3.** Output Power time domain specifications

Specifications	Using P&O	Using GA
Rise time	0.103 s	0.124 s
Peak time	0.217 s	0.163 s
Settling time	0.598 s	0.432 s

## 5. Conclusion

Since India has an enormous scope of generating solar energy, remarkable work has been done on PV systems to increase the conversion efficiency. This paper presents mathematical modeling of a PV system with a boost converter, and analyzes the performance of the controller under different ambient conditions. Results show that the GA-based MPPT controller can track maximum power with reduced oscillation. Based on the observations in the result, it has been decided that the proposed technology is able to harvest maximum available power with significantly higher efficiency. Future studies may focus on the ability of the controller to track maximum power during a high dimensional change in local and global optima.

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