World Applied Sciences Journal 35 (12): 2580-2590, 2017
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2017.2580.2590

Evaluation of GA Tuned PI Controller for Maximum Power Point Tracking for Solar PV System under Partially Shaded Conditions Based on Two Diode Model

[1]S. Karthika, [2]P. Rathika and [3]D. Devaraj

[1]Assistant Professor, ECE Dept., V.V. College of Engineering, Tisaiyanvilai, India
[2]Professor, EEE Dept., V.V. College of Engineering, Tisaiyanvilai, India
[3]Professor, CSE Dept., Kalasalingam University, Krishnankoil, India

Abstract: The electric power supplied by a photovoltaic (PV) power generation system depends on the solar irradiation and temperature. The PV system can supply the maximum power to the load at a particular operating point which is generally called Maximum Power Point (MPP), at which the entire PV system operates with maximum efficiency and produces its maximum power. This paper presents a GA tuned PI controller for the maximum power point tracking for photovoltaic system. The proposed MPP Tracking controller is designed for 10kW solar PV rooftop system. This paper proposes an improved modelling approach for the PV system by two diode model. This two diode model has better accuracy at low irradiance level that allows more accurate prediction of PV system performance during partial shaded conditions. The proposed GA tuned PI controller based MPPT algorithm increases the efficiency of the PV system, by tracking the global Maximum Power Point (MPP) using evolutionary technique. The proposed system is simulated by using MATLAB-SIMULINK. From the simulation results, GA tuned PI controller has shown better performance during partial shaded conditions.

Key words: MPPT · DC-DC Converter · GA · PI controller · Photovoltaic (PV) System · Partial Shading

INTRODUCTION

Solar photovoltaic is a phenomenon where the solar irradiation is converted directly into electricity through solar cell [1-5]. Each photovoltaic cell array has an optimum operating point called the Maximum Power Point (MPP), which varies depending on cell temperature and the present irradiation level.

The two main problems with solar photovoltaic systems are the low conversion efficiency and the variation of power generation with changing weather conditions. A PV generation system should operate at its Maximum Power Point (MPP) to increase system efficiency. Therefore, MPP tracking is very crucial for PV power generation systems. However, the MPP changes with the irradiation level and temperature due to the nonlinear characteristics of PV modules. To overcome this problem, many MPPT algorithms have been developed.

There are several algorithms have been widely developed and implemented to track the MPP. The various MPPT algorithms are Perturb and Observe (P&O) method [6-9], Incremental Conductance (IC) method [6-10], Artificial Neural Network method [11], Fuzzy Logic method [12], Constant Voltage [13], Three Point Weight Comparison [14], [15], Short Current Pulse [16], Open Circuit Voltage [17] and Temperature method [18]. These algorithms differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change and hardware needed for the implementation. A complete review of different MPPT algorithms can be found in [8] the most commonly used methods are Perturb and Observe (P&O), incremental conductance and three-point weight comparison.

Among these, Perturb and Observe (P&O) method is widely used in practical PV systems for the MPPT control due to its simple implementation, high reliability and tracking efficiency [5], [19], [20].Problem that arises in P&O MPPT method is that the operating voltage in PV panel always fluctuates due to the need of continuous tracking for the next perturbation cycle. As a result, under rapidly changing atmospheric conditions, this method

Corresponding Author: S. Karthika, Assistant Professor, ECE Dept., V.V. College of Engineering, Tisaiyanvilai, India.

performs well, but this case will be more complicated if the half or more of the PV array does not receive uniform irradiation, as in partially cloudy conditions due to passing by clouds, towers, trees etc… In normal conditions, the P-V curve has only one maximum point, however, if the PV array is partially shaded, there are multiple maxima in these curves. The Perturb and observe and the Incremental conductance, fail to extract the maximum power of the PV panel if the PV generator is partially shaded. Hence, in this paper a GA tuned PI controller based MPPT technique is proposed in order to predict the global maximum point. This paper also proposes an improved modelling approach of the two diode model to simulate the Photovoltaic system which allows more accurate prediction of PV system performance during partial shaded conditions.

Two-Diode Model of Photovoltaic Module: The general model of solar cell can be derived from physical characteristic of the diode. Among the modeling methods of PV cell, the two diode model is known to be accurate model [21], [22]. The equivalent circuit of two diode solar cell is shown in Fig. 1. The output current of the diode can be described as,

$$I_{d1} = I_{o1}[\exp(\frac{V_D}{nV_T}) - 1] \quad (1)$$

$$I_{d2} = I_{o2}[\exp(\frac{V_D}{nV_T}) - 1] \quad (2)$$

where I_{d1} and I_{d2} are the diode current, I_{o1} and I_{o2} are the reverse bias saturation currents of diode1 (D1) and diode2 (D2) respectively. The term I_{o2} is introduced to compensate the recombination loss in the depletion region as described in [23]. V_D is the voltage across the diode, V_D is the solar ideal factor of the diode and V_T is the thermal voltage.

Thermal voltage V_T however can be defined as:

$$V_T = \frac{KT}{q} \quad (3)$$

where K is Boltzmann constant ($1.3806503 * 10^{-23}$ J/K), T is temperature in degrees Kelvin and q is electron charge ($1.6021764 * 10^{-19}$°C).

To model the I-V characteristic of PV array, equation (4) has been derived from the circuit shown in Fig. 1,

$$I = I_{PV} - I_{d1} - I_{d2} - \frac{V + R_S I}{R_{sh}} \quad (4)$$

where I_{PV} is the light generated current, I_{d1} and I_{d2} are the diode current, V is the PV array terminal voltage, R_S is the equivalent series resistance of the array and R_{sh} is the equivalent parallel resistance. The series resistance is the sum of structural resistance of PV panel and it has strong influence when PV panel acts as voltage source. The parallel resistance R_{sh} has more influence when PV panel acts as current source.

The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is influenced by the temperature according to the following equation.

$$I_{pv} = (I_{pv,n} + k_I \Delta_T)\frac{G}{G_n} \quad (5)$$

where $I_{PV,n}$ is the light-generated current at the nominal condition (usually 25°C and 1000W/m^2), Δ_T = T-T$_n$ (being T and T$_n$ the actual and nominal temperatures [K]), G [W/m^2] is the irradiation on the device surface and G$_n$ is the nominal irradiation.

For a single diode model the diode saturation current I_0 and its dependence on the temperature is given by,

$$I_o = \frac{I_{sc,n} + K_I \Delta_T}{\exp(\frac{V_{oc,n} + K_V \Delta_T}{aV_t}) - 1} \quad (6)$$

where *a* is the diode ideality constant, K_V and K_I is the current and voltage coefficients. $I_{sc,n}$ and $V_{oc,n}$ are the nominal short circuit current and nominal open circuit voltage. To simplify the model, in this work, both of the reverse saturation currents, I_{o1} and I_{o2} are set to be equal.

$$I_{o1} = I_{o2} = I_o = \frac{I_{sc,n} + K_I \Delta_T}{\exp(\frac{V_{oc,n} + K_V \Delta_T}{aV_t}) - 1} \quad (7)$$

Thus using these equations the 10kW solar PV system is designed to analyze their performance under standard and partial shaded conditions.

Simulation and Analysis of 10kW Solar PV System: The Proposed MPPT algorithm is designed for 10kW solar PV system. The system contains totally 49 solar modules. They are connected as shown in Fig.2. They are arranged in seven rows. Each row consists of seven modules. Table I shows the specifications of a single PV module. Each module consists of 54 solar cells.

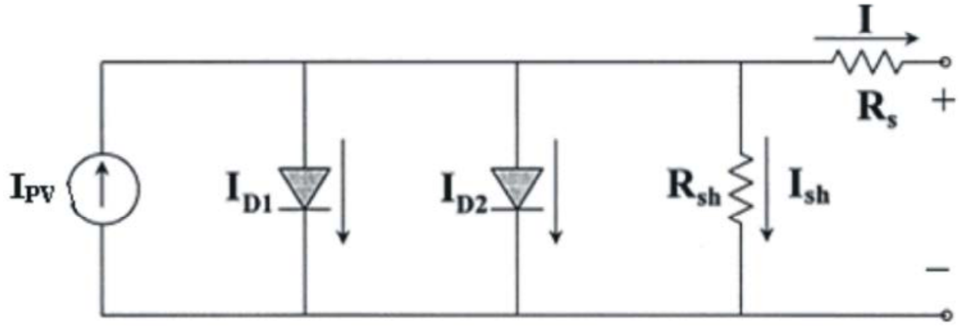


Fig. 1: Equivalent circuit of a two diode solar cell

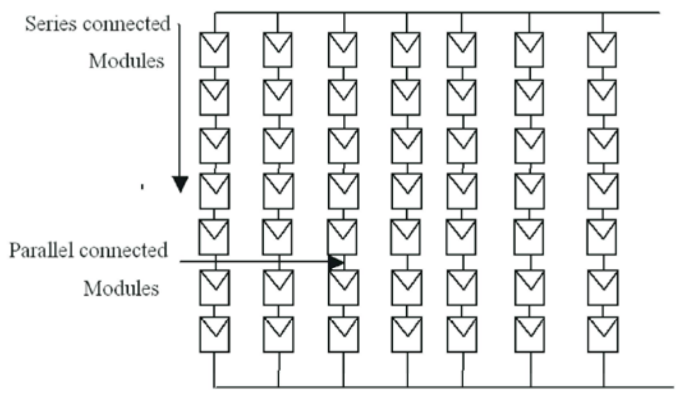


Fig. 2: 10kW solar PV system

Table 1: Parameters of the XL 6P54G200 PV module at 25°C and 1000W/m^2

Peak Power (W), P_{MPP}	200
Peak Power Voltage (V), V_{MPP}	27.16
Peak Power Current (A), I_{MPP}	7.89
Open Circuit Voltage (V), V_{oc}	33.64
Short Circuit Current (A), I_{sc}	8.21
Temperature Coefficient of current (mA/°C) , K_i	0.003
Temperature Coefficient of voltage (mV/°C) , K_v	-0.123
Number of series cells, N_s	54

The performance characteristics of the10kW solar PV system has been studied and analyzed under the following conditions.

Case A: Standard Conditions: The PV system is simulated under standard test condition at the Insolation level of 1000W/m^2 and temperature 25°C.

The I-V characteristics of 10kW solar PV system are obtained by simulation which is shown in the Fig. 3 (a). The voltage and the current characteristics are multiplied to get the P-V characteristics as shown in Fig. 3(b). The different operating voltage of solar cell will produce different output power under different temperature but has a unique maximum power point as shown in Fig. 3(b). The temperature and the irradiation depend on the atmospheric conditions, which are not constant during the year and not even during a single day; they can vary rapidly due to fast changing conditions. This causes the MPP to move constantly, depending on the irradiation and temperature conditions. If the operating point is not close to the MPP, more power losses occur. Hence it is essential to track the MPP in any conditions to assure that the maximum available power is obtained from the PV panel.

Case B: Partially Shaded Conditions: The performance of the PV array is affected by temperature, solar insolation, shading and array configuration. The PV arrays get shadowed completely or partially by the passing clouds, neighboring buildings, towers and trees. The curves in Fig.4 represent the I-V and P-V characteristics of the solar PV under partially shaded conditions.

The PV system is simulated under partially shaded conditions with bypass and blocking diodes where the temperature is 25°C and the Insolation level is 1000W/m^2 and modules are receiving full insolation is 200W/m^2 on shaded modules. If the bypass diodes are not present, the shaded modules will limit the current output of the unshaded modules of the series assembly. This may not lead to thermal destruction of the PV modules but may

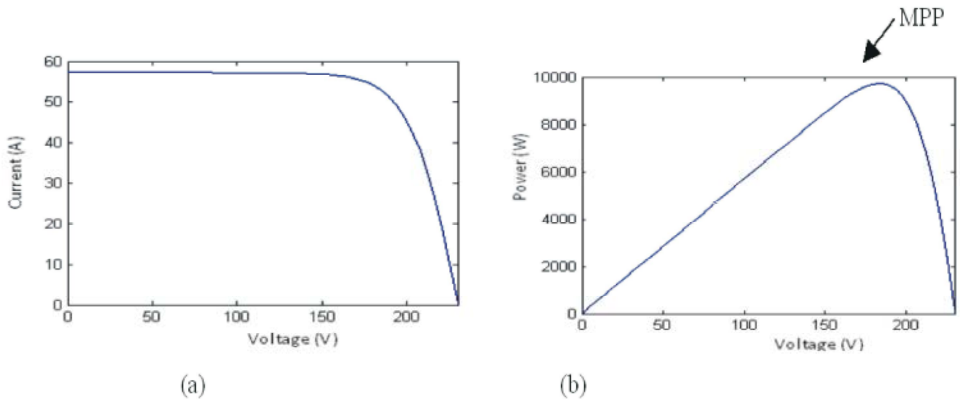


Fig. 3 I-V and P-V Characteristics of solar PV system

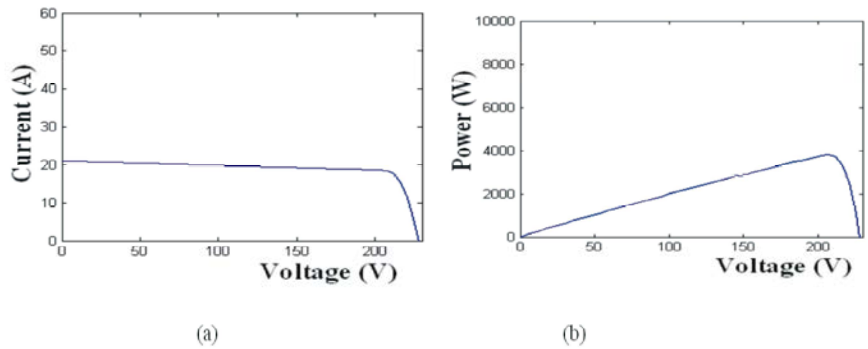


Fig. 4: I-V and P-V Characteristics of Solar PV System under non uniform conditions without bypass and blocking diodes

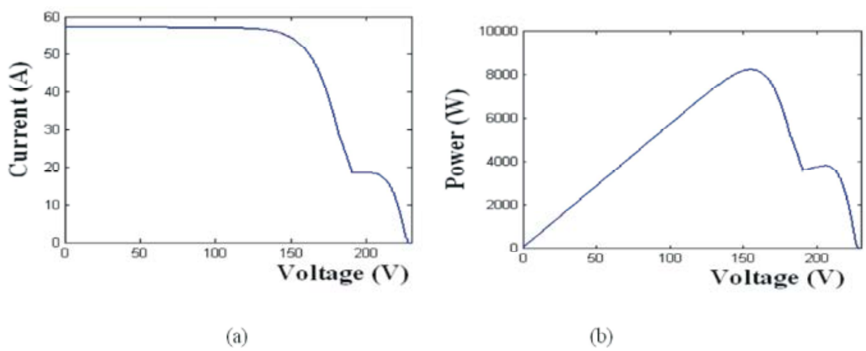


Fig. 5: I-V and P-V Characteristics of Solar PV system with bypass and blocking diodes

also decrease the available output power from the PV array. The blocking diodes will prevent the reverse current through the series assemblies. This reverse current may cause excessive heat generation and thermal breakdown of PV modules.

The curves in Fig. 5 represent the I-V and P-V characteristics of the solar PV under partially shaded condition with bypass and blocking diodes. The 10kW solar PV system with bypass and blocking diode is shown in Fig. 6. The I-V and P-V characteristics under partially shaded condition shows that the presence of bypass diodes will allow the unshaded modules of all the series assemblies to conduct their maximum current at a given insolation and temperature.

Fig. 5 reveals that the array having bypass and blocking diodes introduces multiple steps in the I-V characteristics and multiple peaks in the P-V characteristics, under the partially shaded conditions. Under partially shaded conditions, the PV characteristics get more complex with multiple peaks. It is observed that, the PV system voltage and current are measured at 135V and 57A respectively, corresponding to the maximum power point.

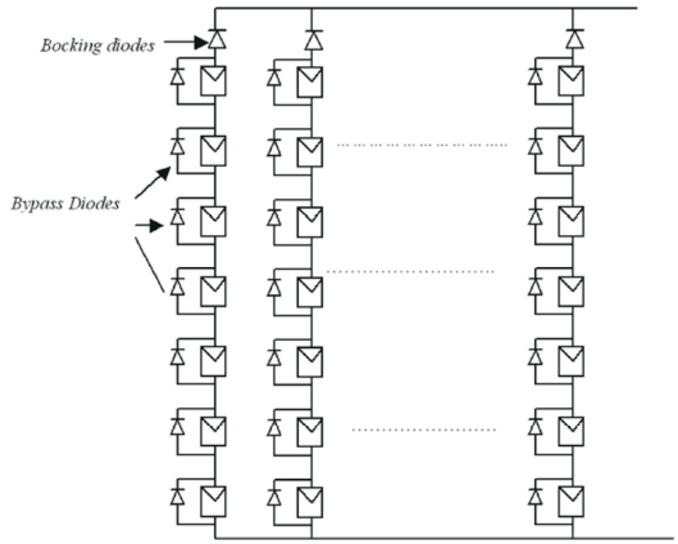


Fig. 6: 10kW solar PV system with bypass and blocking diodes

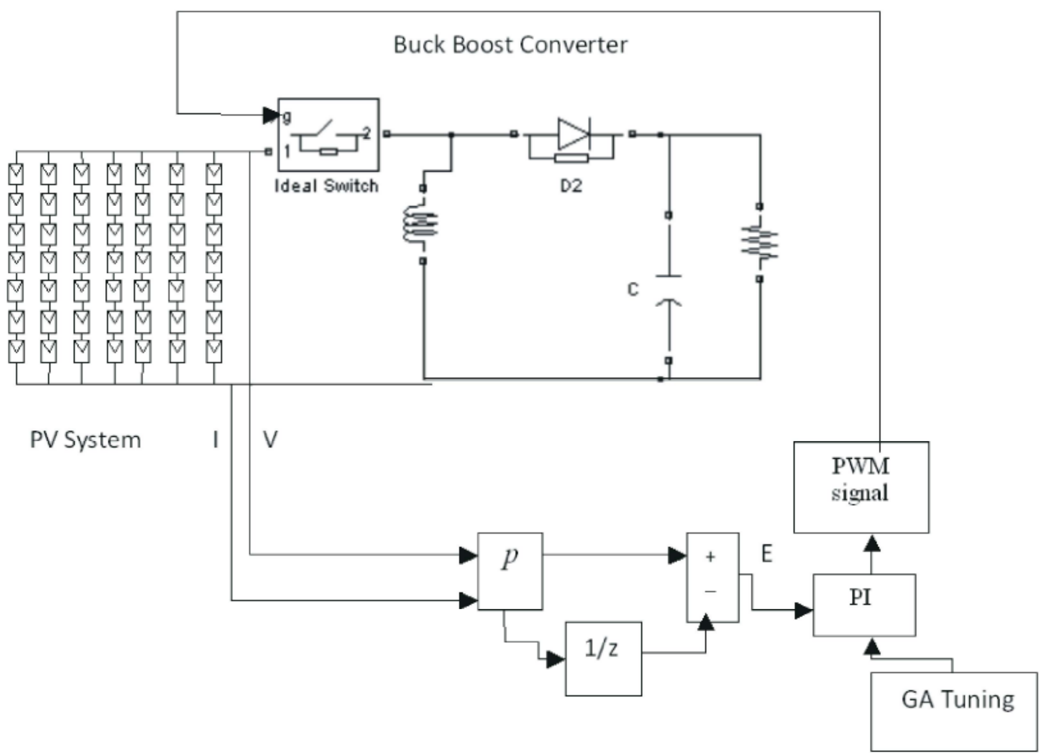


Fig. 7: GA tuned PI Controller based MPPT solar PV panel

Conventional Maximum Power Point Tracking techniques can trap at local maxima under partial shading [24-27]. This significantly reduces the energy yield of the PV systems. In order to solve this problem, a maximum power point tracking algorithm based on GA tuned PI controller that is capable of tracking global MPP under partial shaded conditions is proposed.

Proposed System: The block diagram of proposed solar PV system is shown in Fig. 7. It mainly consists of a PV array, a buck boost dc-dc converter, GA tuned PI controller and load. A pure resistive load is connected to the PV module through the buck boost dc-dc converter.

The Photovoltaic array generates the DC voltage which does not have constant values, but fluctuates depending on the intensity of solar irradiation and temperature. Hence, a DC to DC boost converter is used to regulate the output voltage of the PV module and to keep the system to operate at its maximum power point in order to draw maximum possible power from solar panels at all times, regardless of the load. The proposed controller is used to generate the optimal voltage from the photovoltaic system by modulating the duty cycle applied to the buck boost dc-dc converter using GA algorithm. The GA based Maximum Power Point is used to minimize the voltage fluctuation and to trap the maximum power under partial and rapidly fluctuating shadow conditions. The output of the GA tuned PI controller is used to generate the voltage reference of the PWM (Pulse Width Modulation) signal. And this pulse is given to the buck boost converter circuit to change the output of the photovoltaic system. The GA tuned PI controllers can track the maximum power point under partially shaded conditions.

Review of Genetic Algorithm: GA is stochastic search method where an initial set of possible solutions (called as population) is modified in successive steps using the Darwinian principle of natural selection, recombination (crossover), mutation to yield an optimal solution.

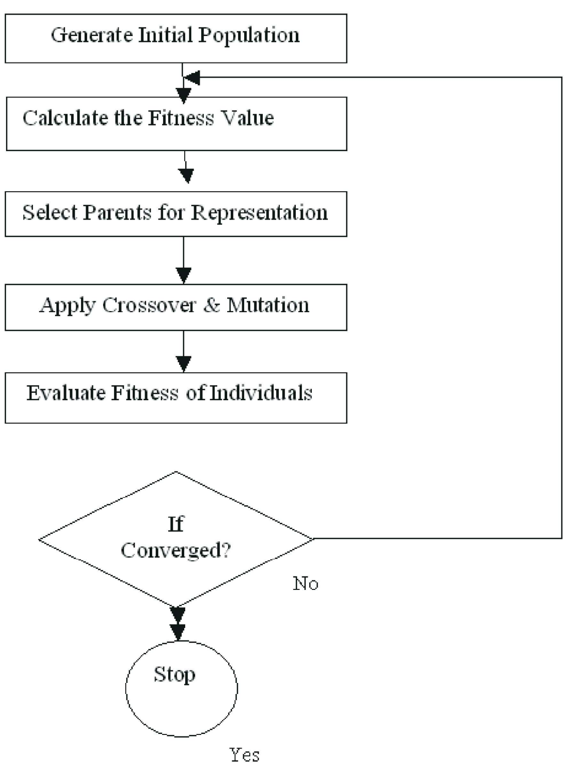


Fig. 8: Flow Chart of Genetic Algorithm

Each individual in the population is called a chromosome and represents a possible solution. GAs use three fundamental operators: selection, crossover and mutation. Selection operator is used to select the best individuals (solutions) in a population. The crossover operator creates new individuals by mixing couples of selected individuals in a population and the mutation operator creates a new individual by randomly mutating a selected part of a selected chromosome. Better convergence of the GA is achieved by both exploiting the search space by selection and crossover operators and exploring the search space for new information by mutation operator.

Fig. 8 shows the various steps in applying GA for any optimization problem. GA maintains a population of individuals that represent solutions to the problem. Each individual in the population is evaluated to give some measure of its fitness to the problem using the objective function (i.e. PI parameters k_p and k_i in this case).

In each generation, a new population is formed by selecting the more fit individuals based on a particular selection strategy. Some members of the new population undergo genetic operations to form new solutions. The two commonly used genetic operations are crossover and mutation. Crossover is a mixing operator that combines genetic material from selected parents. Mutation acts as a background operator and is used to search the unexplored search space by randomly changing the values at one or more positions of the selected chromosome. The above steps are repeated until the convergence criterion is satisfied.

GA Tuned PI Controller: When designing a PI controller using GA, the first important consideration is to create a random population with ‘n’ binary individuals, with a choice of length. A population is a binary matrix where the number of lines represents the number of individuals and column number represents their length. In this case, the individual is just the gain parameters of the PI controller.

The selection of individuals to produce successive generations plays an important role in GA. Tournament selection is used in this work. In tournament selection, ‘T’ individuals are selected randomly from the population and the best of the ‘T’ is inserted into the new population for further genetic processing. Tournaments are often held between pairs of individuals, although larger tournaments can be used. This procedure is repeated until the mating pool is filled.

Fig. 9: (a) Original Strings (b) Children after crossover operation

Fig. 10: 10kW Solar PV System

As the proposed GA uses a two point crossover the proposed two point crossover randomly selects two individuals from the population. Next, one gene from each individuals is selected randomly and their values are swapped. In Fig. 9 (a), the highlighted strings are the selected genes for two point crossover. The children after the crossover operation are shown in Fig. 9(b).

A mutation operator introduces new population into the old population and thereby allows faster convergence and prevents tracking to a local optimal value. For this case, bit-wise mutation is applied which switches a few randomly chosen bits from 1 to 0 or from 0 to 1 with a small mutation probability. Next, the new population is integrated into the old population. Generation by generation the program creates new best individuals corresponding to the maximum fitness value.

The best individuals i.e., the gain parameters (kp, ki) have been given to the PI controller. The output of the PI controller is used to generate the voltage reference of the PWM (Pulse Width Modulation) signal which is given to the buck boost converter circuit to change the output of the photovoltaic system.

Simulation Results: The 10kW solar PV system considered for the experimental setup is shown in Fig. 10. It comprises seven parallel assemblies each with seven series connected PV modules, each having a rating of $P_{MPP} = 200W$, $V_{MPP} = 27.16V$, $VOC = 33.64V$ and $I_{OC} = 7.89A$ at an insolation level of 1000W/m^2 and 25°C temperature. The simulation model for the system is designed by using MATLAB. The performance of the proposed system has been simulated under the following conditions.

Case A: Under Uniform Conditions: The performance of the proposed technique has been examined for fixed solar Irradiation level at 1000W/m^2 and at cell temperature 25°C. The maximum voltage that is obtained corresponding to the PV array is 159V, without any maximum power point tracking techniques. Then, GA tuned PI controller MPPT technique is applied to the controller of buck boost dc-dc converter. In this case, the maximum voltage obtained is 205V. For comparison, the PV system is simulated using conventional PI based MPPT techniques and the result is shown in Fig. 11 and 12.

From the Figure 12, it is observed that the GA tuned PI controller can track the maximum power point at .001s and also it generates constant voltage without any deviations. Hence the proposed controller can track the maximum power point faster than the conventional PI tracking controller. Therefore the GA tuned PI controller has better performance compared to the conventional PI based MPPT techniques.

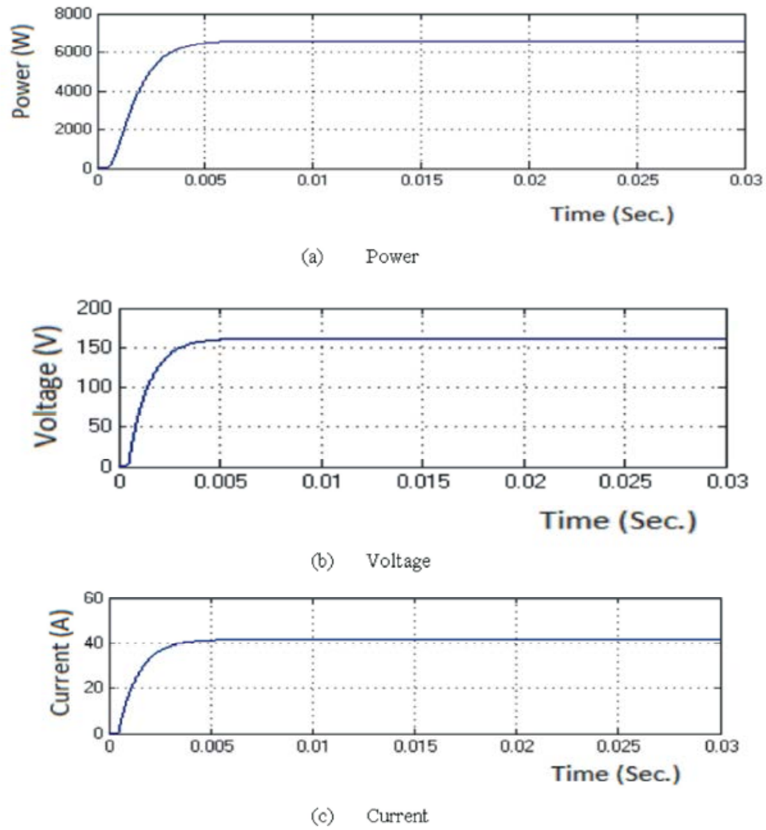


Fig. 11: PI controller responses: For uniform conditions of temperature 25°C and Irradiation 1000 W/m^2.

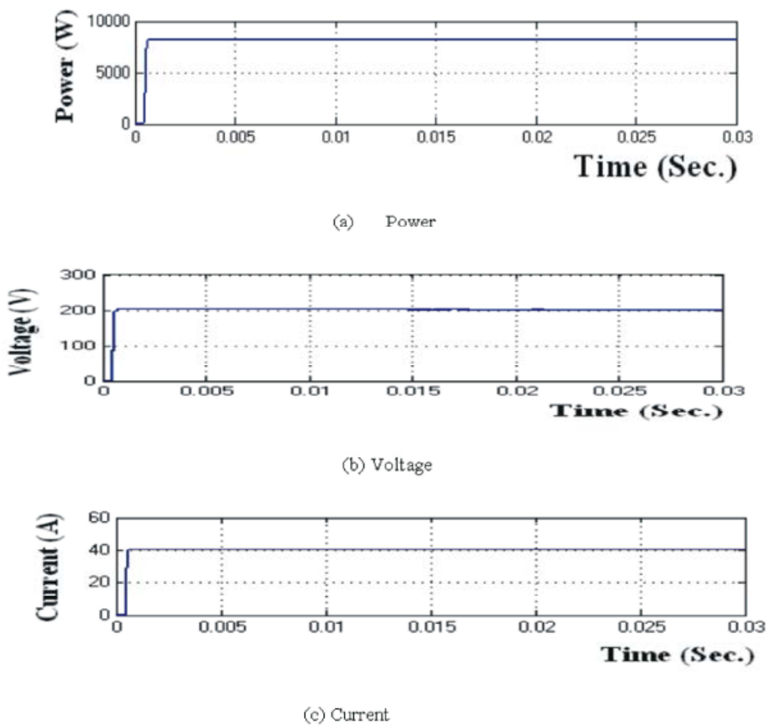
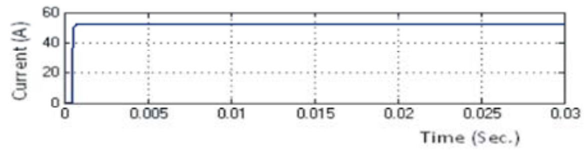
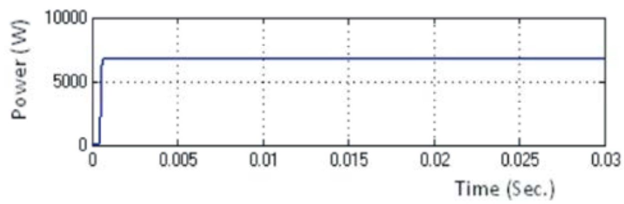


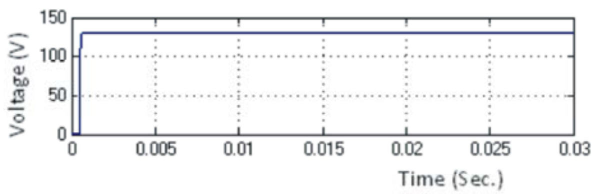
Fig. 12: GA tuned PI controller responses: For uniform conditions of temperature 25°C and Irradiation 1000 W/m^2.



(a) Current

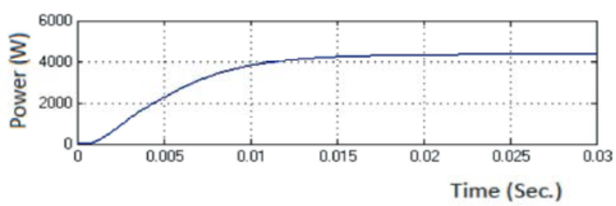


(b) Power

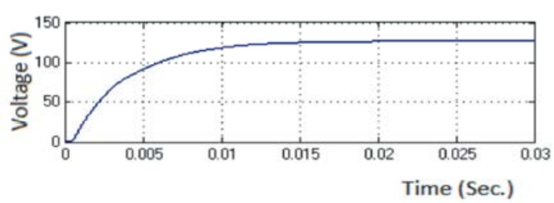


(c) Voltage

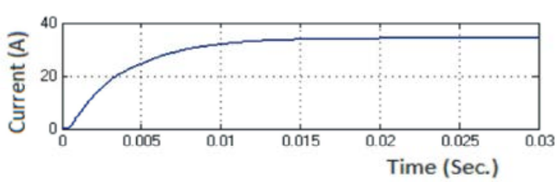
Fig. 13: GA tuned PI controller responses: For partially shaded conditions of temperature 25°C and Irradiation 1000 W/m^2 and 200W/m^2



(a) Power



(b) Voltage



(c) Current

Fig. 14: PI controller responses: For partially shaded conditions of temperature 25°C and Irradiation 1000 W/m^2 and 200W/m^2

Table 1: Power generated as a function of MPPT technique

Conditions	MPPT Methods	Power (W)	Voltage (V)	Current (A)
Under Standard Conditions	GA tuned PI	8610	205	42
	PI	6519	159	41
Under Partially Shaded Conditions	GA tuned PI	7020	135	52
	PI	4480	128	35

Case B: Under Partially Shaded Condition: The performance of the proposed technique has been examined under partially shaded condition (irradiation = 200 and irradiation=1000W/m^2). It is assumed that the array initially receives uniform irradiation of 1000W/m^2. A step change in irradiation level i.e. 200W/m^2 is considered and that causes partial shading of the array.

The simulation result for this condition is shown in Fig. 13 and Fig. 14.

It is observed that, the PV system voltage and current are maintained at 135V and 52A respectively, corresponding to the maximum power point. For comparison, the PV system is simulated using conventional PI controller under partially shaded condition and the result is shown in Fig. 14. From the figure, it is observed that the GA tuned PI controller can track the MPPT at 0.001s and also it generates constant power without any deviation. Hence the proposed controller can track the MPP faster than the conventional tracking controller.

From the data given in Table 1, it is observed that the GA tuned PI controller can track the maximum power compared to the conventional PI based MPPT techniques under partially shaded conditions.

CONCLUSION

This paper has presented an intelligent MPPT control strategy for the PV system using GA. The maximum power point tracking technique was simulated using MATLAB/Simulink. The proposed controller can track the global maximum power point, faster compared to conventional PI based MPPT technique. It has the capability of reducing the voltage fluctuation after MPP has been recognized under partial and rapidly fluctuating shadow conditions. The simulation results show the efficiency of the GA tuned PI controller in maintaining the stable maximum power point under change in irradiation and temperature conditions.

REFERENCES

1. Bidyadhar Subudhi, Raseswari Pradhan, 2013. A Comparitive Study on Maximum Power Point Tracking Techniques for Photovoltaic Power systems, IEEE Trans. On Sustainable Energy, 4(1): 89-98.
2. Kawamura, T., K. Hrada, Y. Ishihara, T. Todaka, T. Oshiro, H. Nakamura and M. Imataki, 1997. Analysis of MPPT Characteristics in Photovoltaic Power System, Solar Energy Materials & Solar Cells, 47: 155-165.
3. Mekhilef, S., R. Saidur and A. Safari, 2011. A Review of Solar Energy use in Industries, Renewable and Sustainable Energy Reviews, 15: 1777-1790.
4. Solangi, K.H., M.R. Islam, R. Saidur, N.A. Rahim and H. Fayaz, 2011. A Review on global Solar Energy Policy, 15: 2149-2163.
5. Salas, V., E. Olyas, A. Barrado and A. Lazaro, 2006. Review of The Maximum Power Point Tracking Algorithms for Stand-Alone Photovoltaic Systems, Solar Energy Materials & Solar Cells, 90: 1555-1578.
6. Abd Kadir Mahammad, Sharifah Saon and Wong Swee Chee, 2013. Development of Optimum Controller on MPPT for Photovoltaic System during Shading Condition, Procedia Engineering, 53: 337-346.
7. Ahmad Al-Nabulsi and Rached Dhaouadi, 2012. Efficiency Optimization of a DSP-Based Standalone PV System Using Fuzzy Logic and Dual-MPPT Control, IEEE Trans. On Industrial Informatics, 8: 573-584.
8. MoacyrAureliano Gomes De Brito, Luigi Galotto, Jr., Leonardo Poltronieri Sampaio, Guilherme de Azevedo e Melo and Carlos Alberto Canesin, 2013. Evaluation of the Main MPPT Techniques for Photovoltaic Applications, IEEE Trans. On Industrial Electronics, 60(3): 1156-1167.
9. Hohm, D.P. and M.E. Ropp, 2000. Comparative study of maximum power point tracking algorithms using an ex-perimental, programmable, maximum power point tracking test bed in Proc. Photovoltaic Specialist Conference, pp: 1699-1702.

10. Kun Ding, Xin Gao Bian, Hai Hao Liu and Tao Peng, 1995. A MATLAB- Simulink-Based PV Module Model and Its Application Under Conditions of Nonuniform Irradiance, IEEE Trans. On Energy Conversion, 27(4): 864-872, 1995, December 2012.
11. Sun, X., W. Wu, X. Li and Q. Zhao, 2002. A research on photovoltaic energy controlling system with maximum power point tracking, in Power Conversion Conference, pp: 822-826.
12. Kottas, T.L., Y.S. Boutalis and A.D. Karlis, 2006. New maximum power point tracker for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive net-work, IEEE Trans. Energy Conv., 21: 793-803.
13. Hsiao, Y.T. and C.H. Chen, 2002. Maximum power tracking for photovoltaic power system, in Proc. Industry Application Conference, pp: 1035-1040.
14. Yu, G.J., Y.S. Jung, J.Y. Choi, I. Choy, J.H. Song and G.S. Kim, 2002. A novel two-mode MPPT control algorithm based on comparative study of existing algorithms, in Proc. Photovoltaic Specialists Conference, pp: 1531-1534.
15. Noguchi, T., S. Togashi and R. Nakamoto, 2002. Short-current pulse-based maximum-power-point tracking method for multiple photovoltaic-and-converter module system, IEEE Trans. Ind. Electron., 49: 217-223.
16. Park, M. and I.K. Yu, 2004. A study on optimal voltage for MPPT obtained by surface temperature of solar cell, in Proc. IECON, pp: 2040-2045.
17. Takashima, T., T. Tanaka, M. Amano and Y. Ando, 2000. Maximum output control of photovoltaic (PV) array, in Proc. 35th Intersociety Energy Convers. Eng. Conf. Ex-hib., pp: 380-383.
18. De Carvalho, P.C.M., R.S.T. Pontes, D.S. Oliveira, D.B. Riffel, R.G.V. De Oliveira and S.B. Mesquita, 2004. "Control method of a photovoltaic powered reverse osmosis plant without batteries based on maximum power point track-ing," in Proc. IEEE/PES Transmiss. Distrib. Conf. Expo.: Latin America, pp: 137-142.
19. Roberto Farada and Sonia Leve, 2008. Energy Comparison of MPPT techniques for PV Systems, WSEA Trans. On Power Systems, pp: 446-455.
20. Trishan Esram and Patrick L. Chapman, 2007. Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, IEEE Trans. On Energy Conversion, 22(2): 439-449.
21. Salam, Z., K. Ishaque and H. Taheri, 2016. An improved two-diode photovoltaic Model For PV system, IEEE Power Electronics, Drives and Energy Systems, pp: 1-5.
22. Chan, D.S.H. and J.C.H. Phang, 1987. Analytical Methods for the Extraction of Solar-Cell Single- and Double-Diode Model Parameters from *I- V* Characteristics, IEEE Trans., Electron Devices VOL. ED-34, NO.2, pp: 286-293 February 1987.
23. Bader N. Alajmi, Khaled H. Ahmed, Stephen J. Finney and Barry W. Williams, 2013. A Maximum Power Point Tracking Technique for Partially Shaded Photovoltiac systems in Microgrids IEEE Trans. On Industrial Electronics, 60(4): 1596-1606.
24. Hiren Patel and Vivek Agarwal, 2008. MATLAB-Based Modeling to Study the Effectsof Partial Shading on PV Array Characteristics, IEEE Trans. On Energy Conversion, 23(1): 302-310.
25. Zainal Salam, Jubaer Ahmed, Benny S. Merugu, 2015. The Application of Soft Computing Methods for MPPT of PV System: A Technological and Status Review, Applied Energy, 107: 135-148.
26. Issam Houssamo, Fabrice Locment, Manuela Sechilariu, 2013. Experimental Analysis of Impact of MPPT Methods on Energy Efficiency for Photovoltaic Power Systems, Electrical Power and Energy Systems, 46: 98-107.
27. Roopa, P., S. Edward Rajan and R. Pon Vengatesh, 2011. Performance Analysis of PV Module Connected in Various Configurations under Uniform and Non-uniform solar Radiation Conditions IEEE, Int. Conf. on Recent Advancements in Electrical, Electronics and Control Engineering, pp: 142-149.