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Performance Enhancement of Constant Voltage Based MPPT for Photovoltaic Applications Using Genetic Algorithm

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Abstract

Maximum power point tracking (MPPT) is aimed in all photovoltaic (PV) applications. The Constant Voltage (CV) based MPPT technique is considered one of the most commonly-used techniques in PV systems. This paper is aimed at enhancing the performance of the CV technique using PI controller with gains determined by the genetic algorithm (GA). The proposed method has been evaluated by numerical simulation using MATLAB under different atmospheric conditions. For evaluation and comparison analysis, the CV based MPPT technique with PI gains determined by the trial and error (TAE) have been presented. Performance assessment covers time response and MPPT efficiency. The results show performance improvement by fast time response and high MPPT efficiency as compared to the CV technique with gains determined by the TAE.

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Keywords: Photovoltaic; Maximum Power Point Tracking; Constant Voltage Technique; Genetic Algorithm; Boost Converter.

1. Introduction

NOWADAYES, solar cells are an attractive source of energy. Plentiful and everywhere, this source can be exploited to provide power to a variety of devices - from small mobile computers to large automobiles and power plants. This broad user base requires solutions tuned to financial and efficiency requirements of particular

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applications [1]. The operating point of a PV module is located at the intersection of its I – V curve with the load-line. This operating point may be far from the maximum power point (MPP) with a subsequent loss of a significant part of the available solar power. A MPP tracker is used to achieve optimum matching between the PV module and the load characteristics. The performance of various MPPT techniques was compared before [2]. It is concluded that the CV technique is the simplest MPPT technique as it needs only one sensor to measure the module output voltage [1,3–5]. However, it suffers low accuracy, and it requires more than one sensor to increase its accuracy. Normally, the CV technique uses a dc – dc converter preceded by PI controller with gains K_P and K_i. The PI controller is used to determine the duty ratio d of the dc – dc converter by regulating the error signal ΔV between module output voltage V_{PV} and a reference voltage V_{ref}. The reference voltage is assumed equal to the voltage V_m corresponding to MPP at standard test conditions (STC) as given in the data sheet provide by the manufacturer of the PV module [5]. The suitable gains of the PI controller are usually determined using time-consuming trial and error (TAE) [6–9]. However, systematic determination of the gains of the PI controller were reported in the literature for many research areas except the CV based MPPT technique for PV applications [10–12].

Thus, the purpose of this paper is to determine accurately the PI controller gains by genetic algorithm (GA) based determination method to enhance the accuracy of the CV technique. The performance of the tracker was checked with gains determined by GA against that with gains determined by TAE. Thus, this study is organized as follows; Section 2 presents proposed GA-determination of gains. Next, the tracker system is described in section 3. After that, the results and discussion are presented in section 4. Finally, the conclusions of the study are reported in section 5.

2. Proposed GA-determination of the PI Controller Gains

The GA is based on minimization of the fitness function expressed as:

$$Fitness\ Fun = \int (\Delta V)^2 dt \tag{1}$$

where ΔV is the difference between V_{PV} and V_{ref}. GA operates on a population of the PI controller gains in order to compute the corresponding fitness function value for each pair of K_p and K_i. In order to predict a population for new generation, four processing steps named, scaling, selection, crossover and mutation have to be executed [13]. The procedure of the population generation continues until a termination criterion is satisfied where optimum gains are determined. This procedure is described in flow chart in Fig. 1.

3. Investigated Tracker System

3.1. PV Mathematical Model

The single diode model is the most commonly-used in power electronics studies due to its parameterization depends only on provided information by data sheet [14]. This model consists of a current source, a diode, and series and parallel resistances. The characteristics of a PV module can be gotten from the 2nd Kirchhoff law as in Eq. 2 [15]:

$$I = I_{ph} - I_o \left\{ \exp\left(\frac{V + IR_s}{n_s V_t} \right) - 1 \right\} - \frac{V + IR_s}{R_{sh}} \tag{2}$$

$$I_{ph} = I_{ph-ref} * G / 1000 \tag{3}$$

$$I_{sc} = I_{sc-ref} * G / 1000 \tag{4}$$

$$I_{sc} = I_{sc} * (1 + K_i / 100 * (T - 298)) \tag{5}$$

$$V_{oc} = n_s * V_t * \ln \left\{ \frac{I_{ph} * R_{sh} - V_{oc}}{I_{o-ref} * R_{sh}} \right\} \tag{6}$$

$$V_{oc} = V_{oc} + K_v * (T - 298) \tag{7}$$

$$I_o = I_{sc} * \left\{ \frac{V_{oc} - I_{sh} * R_s}{R_{sh}} \right\} * \exp\left(\frac{-V_{oc}}{n_s * V_t} \right) \tag{8}$$

$$I_{ph} = I_o * \exp\left(\frac{V_{oc}}{n_s * V_t} \right) + \frac{V_{oc}}{R_{sh}} \tag{9}$$

where V and I are the voltage and current of the PV module, respectively. n_s is the number of series connected cells in the module. I_{ph} and I_o are the photo-generated current and the dark saturation current. V_t is the junction thermal voltage. R_s and R_{sh} are the series and shunt resistances. The model represented by Eq. 2 has five unknown parameters: I_{ph}, I_o, V_t, R_s and R_{sh}. The objective is to estimate these unknown parameters under STC from the data sheet provided by the manufacturer. PV data-sheet provides only four information about its output electrical characteristics at STC, which are short-circuit current I_{sc}, open circuit voltage V_{oc}, operating voltage and current at MPP (V_m, I_m), and n_s. Three equations are obtained by substituting these information in Eq. 2. The fourth equation is obtained at MPP where dP/dV is equal to zero. Then, the fifth equation is gotten by approximating that R_{sh} equals to inverse of the slope dI/dV at (0, I_{sc}). Solving these five formulated equations determines the unknown parameters of the PV module at STC. After that, the influence of temperature and radiation is expressed by Eqs. (3 – 9) [14,15].

3.2. Boost Mathematical Model

To extract maximum power, a boost converter is connected between the PV module and the load resistor, and duty ratio of this converter is used to modify the equivalent load resistance as seen by the source, so that maximum power is transferred between PV module and load demand. The boost converter contains two electrical storage elements (inductor L and capacitor C). Therefore, two governing equations expressing the inductor current i_l and capacitor voltage v_C are written as [16]:

$$\begin{aligned} \frac{di_l}{dt} &= \left[\frac{-r_l - r_m}{L} * d + \frac{-R(r_c + r_l + r_d) + r_c(r_l + r_d)}{L * (R + r_c)} * (1 - d) \right] * i_l \\ &+ \frac{-R}{L(R + r_c)} * (1 - d) * v_c + \frac{V_i - v_m}{L} * d + \frac{V_i - v_d}{L} * (1 - d) \end{aligned} \tag{10}$$

$$\frac{dv_c}{dt} = \frac{1}{(R + r_c) * C} * \left[-v_c + R * (1 - d) * i_l \right] \tag{11}$$

where v_m and v_d are switch and diode forward voltages. V_i is the adjustable input voltage to the converter.

3.3. PI Controller

The PI controller gains K_p and K_i determine the performance of the controller. K_p decreases rise time of the module output voltage V_{PV}, increases overshoot of V_{PV}, and reduces steady state error ΔV and K_i decreases rise time of V_{PV}, increases overshoot and settling time of V_{PV}, and eliminates steady state error ΔV.

4. Results and Discussion

To verify the performance of the proposed system using resistive load (R = 50 W). The tracker under study includes PV module BP-MSX120, boost converter and PI controller. The module's specifications are tabulated in Table 1 [17]. The parameters of the boost converter are grouped in Table 2. The proposed PV mathematical model is validated by power system simulator (PSIM) based PV model. The max deviation does not exceed ± 0.5%. The electrical characteristics of the PV module are demonstrated by I – V curves in Figs. 2 and 3. The radiation and temperature influence the module I – V characteristics as shown in Figs. 2 and 3, respectively. Fig. 2 shows that both the short circuit current and the open circuit voltage increase with the increase of the radiation level.

Table 1: Key specification of BP-MSX120 module

Parameter	Variable	Value
Maximum power	P_m	120 W
Voltage at Pm	V_m	33.7 V
Current at Pm	I_m	3.56 A
Short circuit current	I_{sc}	3.87 A
Open circuit voltage	V_{oc}	42.1 V
Temperature coefficient of I_{sc}	k_i	0.065
Temperature coefficient of V_{oc}	k_v	- 0.16
No. of cells in series	n_s	72
Series resistances	R_s	0.4471 ohm
Shunt resistances	R_{sh}	1750 ohm
Junction thermal voltage	V_t	0.0366 V

Table 2: Key specification of Boost Converter.

Parameter	Variable	Value
Input Voltage	V_i	adjustable
duty ratio	d	controllable
Inductor Inductance	L	0.05 H
Inductor Resistance	r_l	0.2 Ω
Capacitor Capacitance	C	33 µF
Capacitor Resistance	r_c	0.1 Ω
Switch Forward Voltage	v_m	0.7 V
Switch Resistance	r_m	0.01 Ω
Diode Forward Voltage	v_d	0.71 V
Diode Resistance	r_d	0.01 Ω

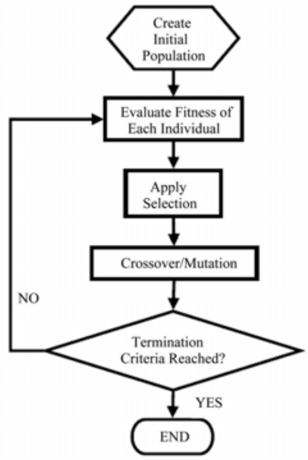

Figure 1: GA steps flow chart

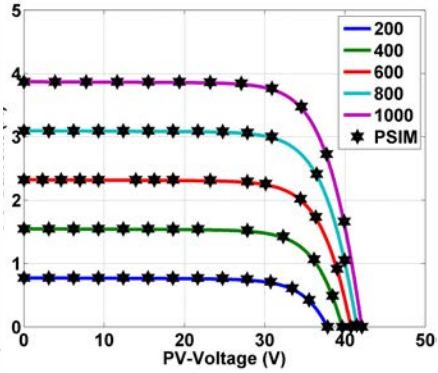

Figure 2: I – V Curves, Radiation Effect (W/m^2).

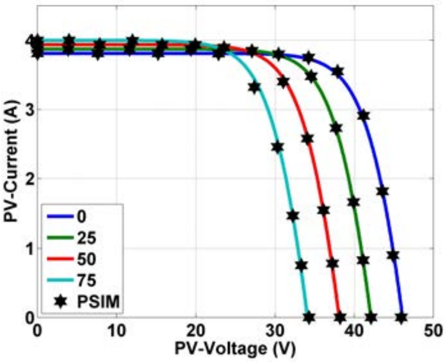

Figure 3: I – V Curves, Temperature Effect (°c)

Fig. 3 shows that the open circuit voltage decreases and the short circuit current increases marginally with the increase of the operating temperature.

For the GA, the initial population of gains and number of generations were selected 20 and 200, respectively. The termination criterion was selected to terminate the new generation process at 200 generations. The scaling function was selected rank, selection function was stochastic uniform, mutation function was uniform with rate 0.01 and crossover function was scattered. The determination of the gains of the PI controller by the TAE provides Kp and Ki values of 1.5 and 13 against 42.19 and 500 obtained by the GA.

Figure 4 shows the temporal variation of P_{PV}, where the temperature at STC and radiation increases from 400 to 1000 W/m^2 with rate 100 W/m^2 per second. The TAE is a solution-oriented as it is generally an attempt to find a solution, not all solutions, and not the best solution. Therefore, it provides inaccurate gains that results large settling time 300 ms against 5 ms on using GA, Fig. 4, and consumes more human effort in determination process of the gains. Fig. 5 shows that the output power of the module P_{PV} assumes higher values on using GA in comparison with those obtained using TAE. This reflects itself on the increase of the MPPT efficiency η_{MPPT}.

$$\eta_{MPPT} = \frac{\int P_{PV}\,(MPPT\ \ Technique\ \ )\,dt}{\int P_{PV\ \max}\,(data\ \ sheet\ )\,dt} \tag{12}$$

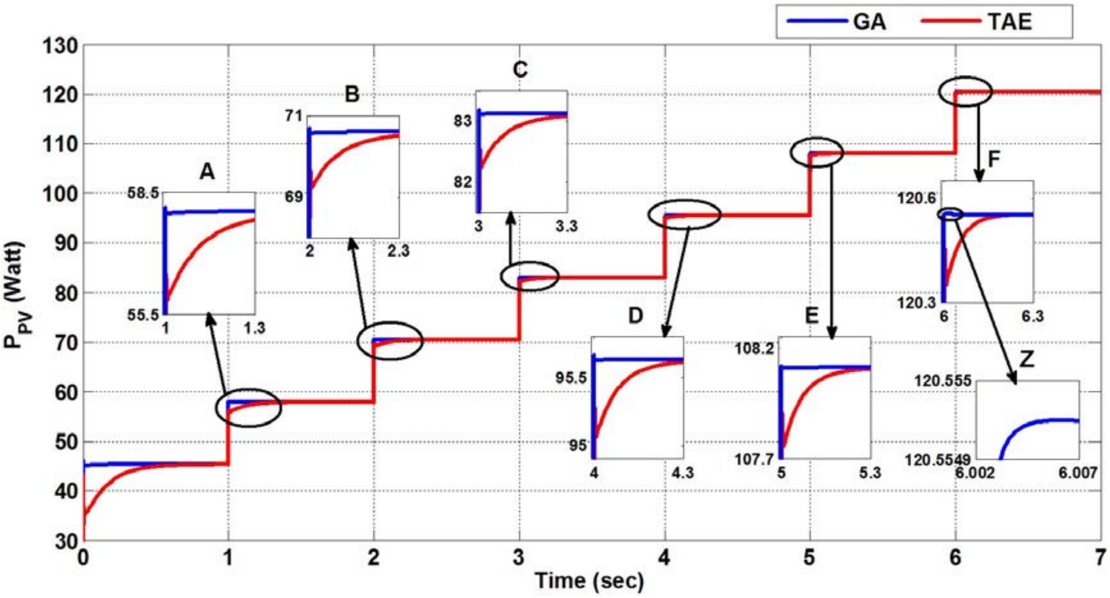

Figure 4: Temporal Variation of P_{PV} at T = 25 ^{o}c and G = 400:1000 W/m^2 with rate 100 W/m^2 per second.

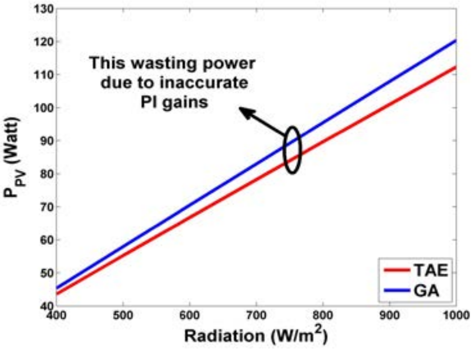

Figure 5: Steady State P_{PV} vs Radiation for both TAE and GA.

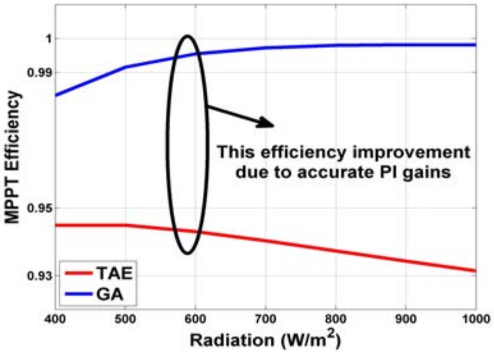

Figure 6: η_{MPPT} vs Radiation for both TAE and GA.

The later was expressed before [18] as in Eq. 12. The numerator is the computed output power based on the CV technique. The denominator is the maximum output power computed using the module data-sheet after being corrected according to the solar radiation and temperature. Fig. 6 shows enhancement of η_{MPPT} on using GA compared with TAE.

5. Conclusions

1- This study proposed a performance enhancement of the CV technique by introducing GA as a determination method for the PI controller gains.
2- The proposed GA based determination method showed an increase of the output power and a decrease of the settling time when compared with those obtained by the use of TAE.
3- The proposed GA based determination method showed an increase of the MPPT efficiency when compared with the use of TAE.

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