Optimal PI Parameters Tuning for a DC-DC Boost Converter

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ABSTRACT

This paper designs a nonlinear PI-type controller for the robust control of a boost DC-DC converter using a particle swarm optimization (PSO) algorithm for increasing the output voltage of the photovoltaic (PV) system. In addition, the PI controller is used to tracking the maximum power from the PV panel, at different atmospheric condition. For tuning PI controllers is a tedious work and it is difficult to tune the PI gains optimally due to the nonlinearity. This paper presents an approach to use the particle swarm optimization algorithm to design the optimal PI controllers. The Simulations results show that the proposed controller exhibits better behavior in terms of settling time and overshoot and better performance of the converter.

I. Introduction

Today, the use of converters has increased due to the widespread use of renewable energy sources and the cheapening of semiconductor materials. IGBT and MOSFET semiconductor materials are generally used in the control process. DC-DC converter, are available in the literature: buck converter, boost converter, buck-boost converter, CUK, and Fly-Back converters. Output voltage control of these converters is more difficult, especially in boost and buck-boost type converters. The difficulty in controlling this type of converter is because the control input is included in both the voltage and current equations. By controlling the current, the output voltage is also controlled [1]. Linear and unconventional robust control structures must be used to improve the performance of DC-DC converters. In addition to the preference of these control structures, the control parameters should also be determined optimally. The determination process is done by meta-heuristic optimization methods apart from the trial and error method [2]. There are many computational techniques inspired by biological systems for this. Many of these have been developed inspired by natural events. For example, artificial neural networks are a simplified model of the human brain [3]. Genetic algorithms are inspired by the evolutionary process in biology. Here, the subject discussed is social systems, which are different types of biological systems. In particular, the cooperative behaviors of simple individuals interacting with each other and their environment are examined. The most popular among these algorithms is the genetic algorithm inspired by Darwin's theory of evolution. This algorithm follows the steps in the natural evolution process [4]. However, it is not widely used in stable systems because the initial conditions are chosen randomly. The PSO algorithm has been inspired by the social behavior of bird flocks looking for their food [5]. The Artificial Bee Colony (ABC) mimics the hunting behavior of the bee swarm. Ant Colony is another optimization algorithm inspired by the foraging behavior of ant colonies, like the ABC algorithm [6]. The converter can be operated in both open loop and closed loop. Here the proposal deals with the closed loop circuit, where the PI controller is to be tuned with the PSO algorithm. Particle Swarm Optimization is one of the Genetic algorithms, where the best fitness factor is provided for better efficiency [7]. In this paper the PI controller is used for controlling the voltage signal after that it will send to PWM generator then the PWM generator is generate the PWM signals for power module. The PSO based optimization algorithm is used to deal with the different disturbances that can affect the normal operation of the PV panel. The performance of this optimization algorithm is further improved by the introduction of a PI controller that accelerates the rising time and eliminates the steady state error [8].

II. Solar cell characteristics

The solar cells are generally connected in series and in parallel, in parallel with Nph cells to increase the current and in series with Nsh cells to increase the voltage then increase the PV power. PV generator is made up of interconnected modules to form a unit producing high continuous power compatible with conventional electrical equipment. The used model is shown in Figure.1, which consists of four components: a current generator Iph, a diode, a parallel resistance Rsh and a serial resistance Rse [9].

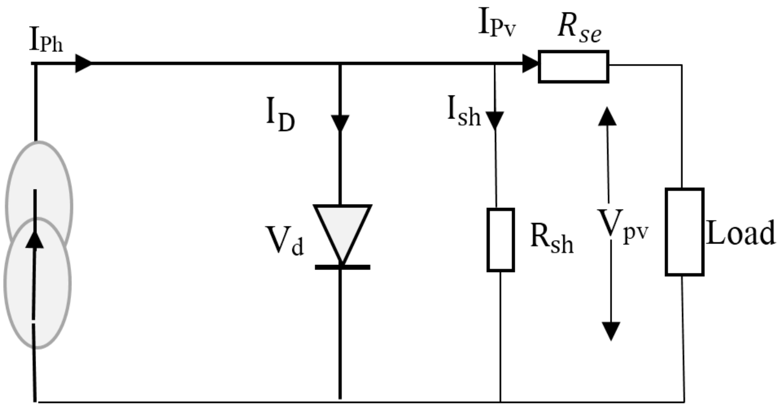


Figure. 1 Equivalent diagram of a photovoltaic cell.

The output current is given by the following equation:

$$I_{PV} = N_{sh}I_{ph} - N_{sh}I_0 \left\{ \exp\left[\frac{q\left(V_{pv} + \frac{N_s}{N_{sh}} I_{pv} R_{se}\right)}{akTn_s} \right] - 1 \right\} - \frac{V_{pv} + \frac{N_s}{N_{sh}} I_{pv} R_{se}}{\frac{N_s}{N_{sh}} R_{sh}} \tag{1}$$

Where, the cell reverse saturation current is related to the temperature (T) as follows

$$I_0 = I_{0r}\left(\frac{T}{T_r}\right)^3 \exp\left\{\frac{qE_G}{ka}\left[\frac{1}{298} - \frac{1}{T}\right]\right\} \tag{2}$$

Similarly, the photocurrent Iph depends on the solar radiation (G) and the cell temperature (T):

$$I_{ph} = I_{cc}\left(\frac{G}{G_r}\right) \tag{3}$$

III. Boost converter model

The DC – DC boost converter is used which consists of boost inductor, diode, MOSFET used as a switch, output filter capacitance and resistive load. When supply voltage is given, inductor current increases when the switch is closed. When the switch is opened, both inductor voltage and supply voltage gets discharged through the load. A boost converter is an electrical circuit that allows obtaining an output voltage higher than the input voltage of the circuit [10]. The circuit diagram of traditional boost converter is shown in Figure 2. It consists of constant input voltage (Vs). Boost converter is connected between the supply and the load. To maintain constant output voltage a capacitor is connected to the load (Vo). The feedback is provided by the controller connected to the output of the boost converter.

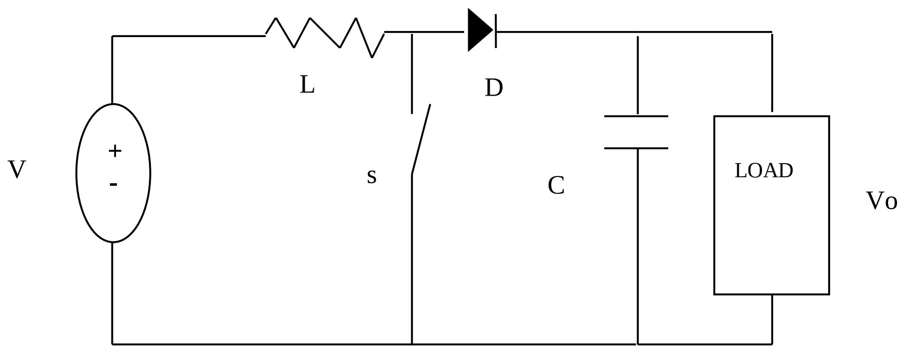


Figure 2. Boost converter.

Boost converter is used to convert DC to DC source basically the solar panel is converting light energy into DC voltage. The output voltage is constant by PI controller; it is used to controlling the output voltage. The error signal is getting from comparator. Again the output voltage is continuously getting as a constant output voltage [11]. This paper provides as the main contribution a procedure, based on PSO, to obtain fixed gains of PI controllers applied for voltage regulation of boost converter with parameters not precisely known, but being on uncertain intervals.

IV. PSO algorithm

The PSO is based on the swarm behavior that many animal species have for the search, exploration, and exploitation of resources. Each particle represents a search agent, which has a position, velocity, and acceleration. Each position of each particle represents coordinates in the search space of the global solution, with each agent having a certain value of the fitness function evaluated in its position. The particle with the best fitness function value for total iterations of the algorithm is called best global g_{best} . Each particle is capable of keep track of its best value for the fitness function during iterations, that value is called best personal p_{best} . The position and velocity for each particle are given randomly at the beginning of the algorithm. As the number of iterations progresses, the particle speed will be accelerated in the direction of the best global and its best personal according to Equation 4.

$$v_i^{k+1} = wv_i^k + c_1 rand_{1i}\left(p_{best_i} - s_i^k\right) + c_2 rand_{2i}\left(g_{best} - s_i^k\right) \qquad (4)$$

Where Vn is the particle speed updating, w is the inertia factor that decreases linearly from 0.9 to 0.4 over iterations, $c1$and $c2$ are the acceleration constants towards the global best and best personal respectively [12].

V. Designing of PI controller using PSO

The control process has great importance in closed-loop and automatic control systems. The PI controller is at the forefront of the control systems. This method is widely used in industrial control systems. PI control is a linear control method and its mathematical model is given in Eq.5. Here, Kp and Ki represent the proportional gain and integral gain, respectively, e(t) represents the error. The aim is to obtain the optimal values of these three gains [13].

$$F(t) = K_p.e(t) + K_i.\int e(t).d(t) \quad (5)$$

The PSO based approach to find the global maximum value of objective function as shown in Figure.3.

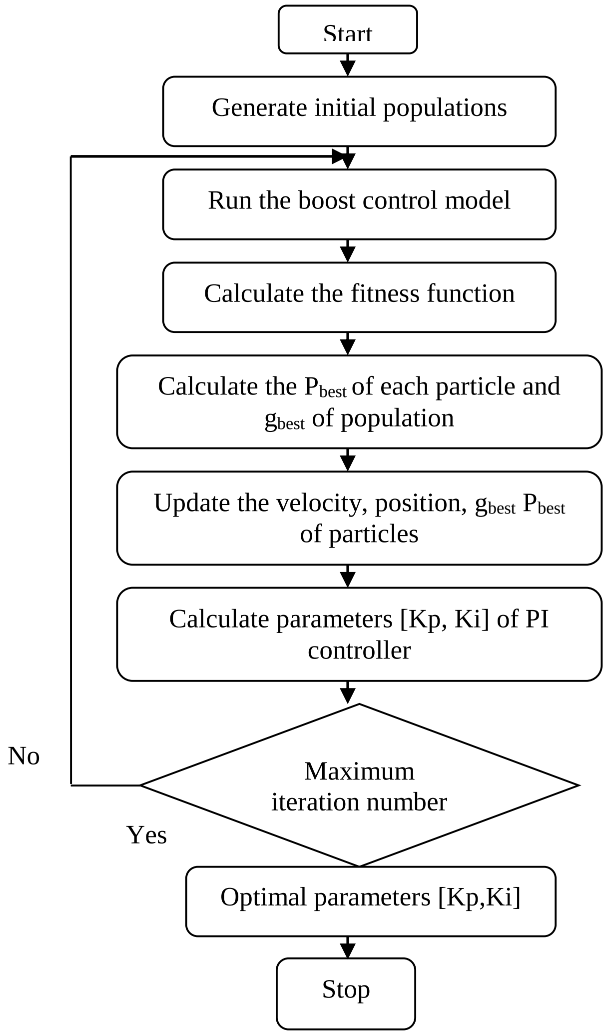


Figure 3. The flowchart of the PSO–PI control system

The PI control compares the input signal V_{ref} (V) with the feedback from the output Vo (V) and creates an error e (t) from the difference. The method of tuning the parameters of PI controller by the Particle Swarm Optimization (PSO) is briefly reviewed.

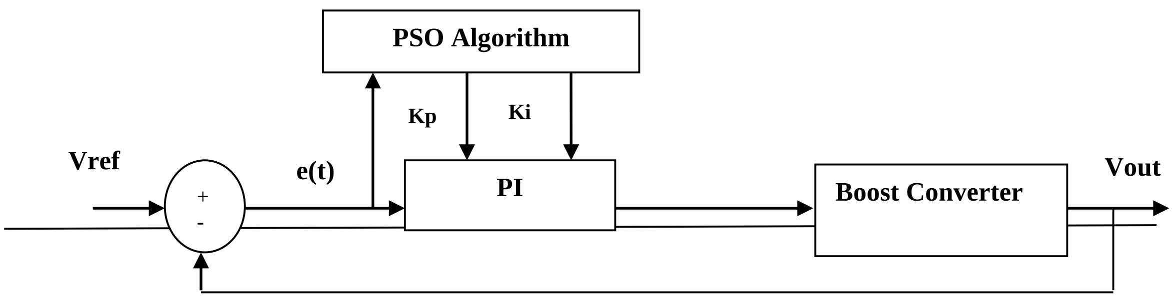


Figure 4. Block diagram of the proposed system.

The equations below of Integral Square Error (ISE) and Integral Time Square Error (ITSE) performance indices are used as fitness by the PSO. In this paper we will compare between using a PI controller which is tuned by PSO technique and manually.

$$ISE = \int_0^\infty e(t)^2\,dt \qquad (6)$$

$$ITSE = \int_0^\infty t e(t)^2\,dt \qquad (7)$$

VI.Simulation results

The simulation results are presented to demonstrate the effectiveness of the proposed controller, which are implemented using MATLAB Simulink. For the same boost converter configuration, with the aim of finding the optimal values of the PI controller gains. Table 1 summarizes the boost converter configuration.

Table 1. Boost converter configuration.

Description	**Value**	**Unit**
Inductor	10	µH
Capacitor	100	µF
Load	100	**Ω**
Input voltage	10	V
Reference voltage	25	V

Optimization algorithm requires initial values for some parameters. Table 2 summarizes these initial values for simulations performed with PSO.

Table 2. PSO parameters.

Parameters	**Value**
Population size	20
Number of maximum iterations	10
c1	1.5
c2	2

The variation of optimal Ki and Kp gain during the simulation are presented in Figure 5.

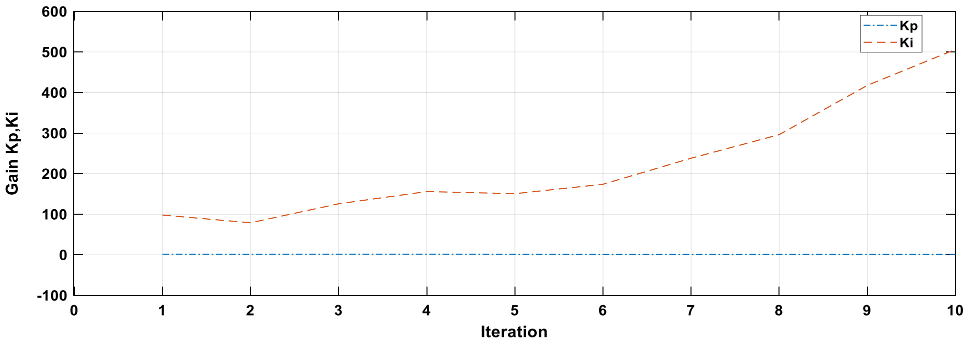
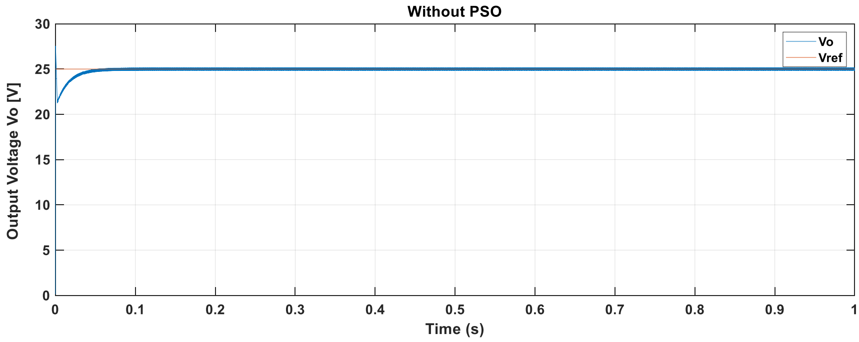
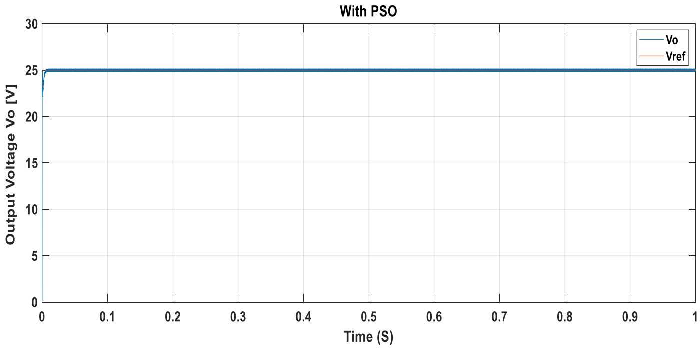


Figure 5. The variation of optimal Kp and Ki gain during the simulation.

A comparison is done here with the results obtained from conventional PI controller, The results of the comparison are that the output voltage Vo ripple is reduced considerably with the help of PSO as shown in figure.6. In our case swarm size = 20 is a good selection, the number of maximum iteration = 10; is satisfying for obtaining a good result. Kp = 1.1187 and Ki = 825.6561, which are shown clearly in figure 5.

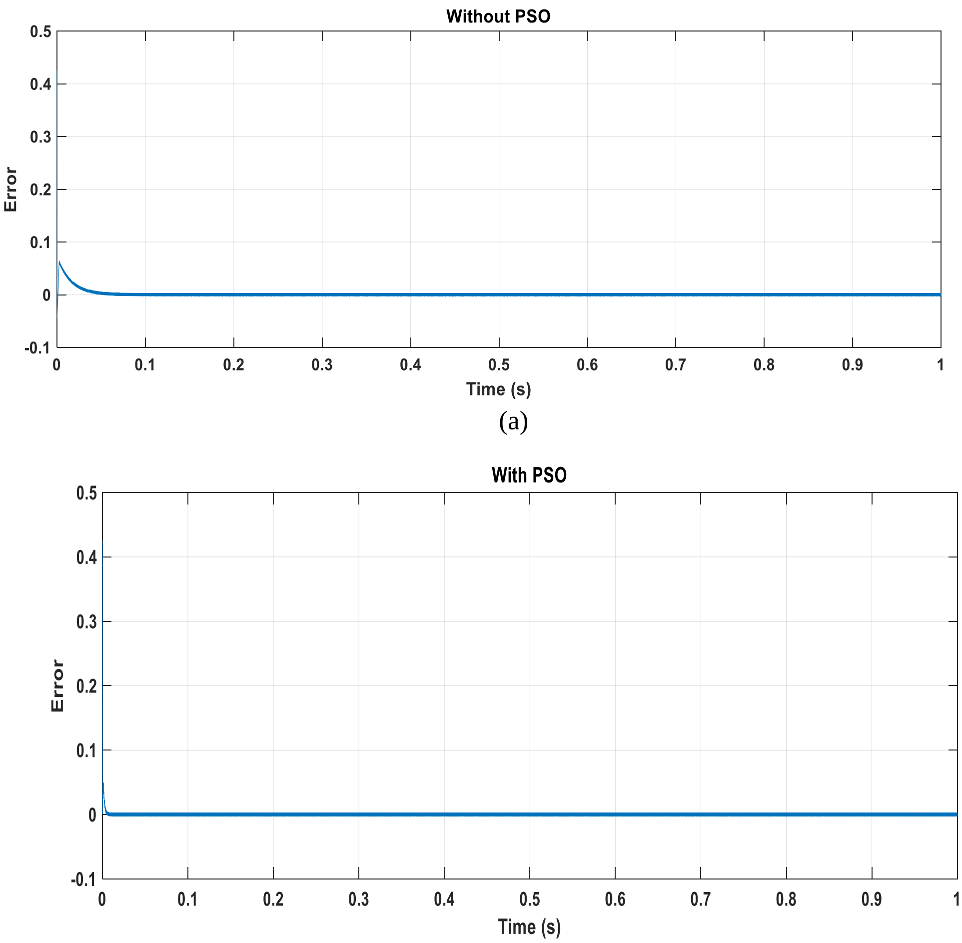


(a)



(b)

Figure 6. Output voltage for boost converter: (a) without PSO,(b)with PSO.



(a)

(b)

Figure 7. Error e(t): (a) without PSO,(b)with PSO.

Table 3. Comparison between PI tuned manually and PI tuned by PSO

Parameters	PI tuned manually	PI tuned by PSO
Kp	1.1	1.1187
Ki	100	825.6561
ISE	4.513e-05	1.41e-05
ITSE	1.048e-06	7.513e-07

From these values obtained it is clearly visible that the error magnitude obtained in different criteria for conventional method is big as compared to the proposed tuning method based on PSO algorithm.

VII. Conclusion

This paper presents PI controller with particle swarm optimization are used to obtain the optimal gain of PI controller. The PI controller is used to achieve less response time and eliminate the steady state error. The boost converter boosts the output voltage from the solar panel to the maximum power point voltage thus improving the efficiency of the panel. The proposed nonlinear PI controller was designed by using the common control engineering knowledge that the transient control performance can be improved if the Kp and Ki gains increase as the error grows. We gave a PSO-based design procedure to optimize and auto tune the nonlinear Kp and Ki gains. Finally, the obtained results show that the optimized regulator using PSO is more efficient than the conventional PI controller and generates fast and stable responses.

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