Simulation and Control of DC-DC Converters Using Particle Swarm Optimization Technique

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Abstract- In this paper, an on-line Particle Swarm Optimization (PSO) controller for Buck, Boost, and Buck-Boost converters has been developed. To exhibit the effectiveness of proposed algorithm, the performance of the PSO controller has been compared with the classical Proportional Integral Derivative (PID) controller and the necessary results are presented to validate the PSO for control purposes. The comparative study results emphasize that the optimized PSO controller provided better performance and superior to the other control strategies because of fast transient response, minimum steady state error and good disturbance rejection under various variations of the operating conditions and, hence, the most tightly output voltage regulation is achieved. Simulation results show the superior control performance of the PSO controller and that the system is stable, reliable, and easy to control.

Keywords: Particle Swarm Optimization (PSO), PID controller, Optimization, DC-DC converters, Averaged State-Space.

1. Introduction

DC-DC converters are electronic devices used to change DC electrical power efficiently from one voltage level to another. These converters are widely used in switched-mode power supplies, adjustable speed drives, uninterruptible power supplies, telecommunication equipment, spacecraft power system, and many other applications to change the level of an input voltage to fulfil required operating conditions. Each type of the converters is inclined to more suitable for some types of applications than for others. Most converters topologies are based on the buck converter (step-down), boost converter (step-up), buck-boost converter setup or Cuk converter. Among these converters, the buck converter and the boost converter are the basic topologies. Both the buck-boost and Cuk converters are combinations of the two basic topologies. Consequently, they are usually subjected of large load variations when operated in these applications. Therefore, the main objective of a good control strategy to be developed for such converters must achieve an output voltage regulation, under large load variations, as fast as possible without having any stability problem [1]. Usually, the output voltage is regulated by varying the duty cycle of the power MOSFET driving signal. The mode of operation of the converter is simply varied from switch (ON) to (OFF) state and the Kirchhoff's law is applied to obtain the differential equation of each state of the converter [2].

The switching power converters in general are inherently non-linear and time invariant and therefore, the control approach requires effective modelling and analysis of the converters [3]. Controller design for any system needs knowledge about system behaviour. Usually this involves a mathematical description of the relation among inputs to the process, state variables, and output. This description in the form of mathematical equations which describe behaviour of the system (process) is called model of the system.

Conventionally, Proportional-Integral-Derivative (PID) controllers are most popular and widely used controllers in most power electronic closed loop systems [4-5]. In other hand, it is difficult for the PID controller to respond well to changes in operating point, and they exhibit poor performance when the system is subjected of a large load variation [6-7]. As a result, most classical control design techniques are not capable of efficient control design for these systems. In conventional analogue design approaches, control problems are more complex and topology dependent. The major disadvantages include the difficulty in adjusting; system alteration and higher functions are difficult, low reliability and sensitivity to noise [8-9].

In recent years, various researches was performed on applying the non-linear methods to control DC/DC converters; however, the controller design approaches based on the linearized state-space average model, due to the simplicity of implementation and generality [2], [10]. Today, many researchers have adopted the intelligent design techniques which proven success in improving the performance. Among the various techniques of artificial intelligence, the most popular and widely used techniques in control systems are the fuzzy logic, Neural Network (NN) and the Particle Swarm Optimization (PSO). Such an intelligent controller designed may even work well with a system and with an approximate model [11-15].

In this paper, two types of controllers are designed namely the PID controller and online PSO controller. Initially the designs of PID controller parameters for the buck converter were optimized. PSO controllers are adopted for regulating the output voltage of buck converter, boost converter, and buck-boost systems. The PSO is utilized in this work because of its proved performance in different applications and because of its simplicity, since neither expensive computations nor specialized methods are needed. The above simulation results are compared and, however, it is found that PSO outperforms random search through and at the end of the search process, showing better convergence behaviour and over-fitting avoidance. This result gives evidence that online PSO can work as any-time method for controlling the switching operation of the DC-DC converters. Consequently, the simulation results of the adopted converters systems behaviours and the effectiveness of the controller for regulation purposes is an important feature of this paper.

2. Small Signal Analysis of the Ideal Converter

The small signal averaged state-space method is a generalized analysis tool which is readily applicable to either simple circuits or complex structures. The linear averaged time-invariant models achieved by using this method are relatively simple, but a lot of mathematical efforts are needed to derive the final results. To obtain such models, the step-by-step procedure proposed in [2], [16-18] is adopted to our problem.

2.1 Buck Chopper

The buck converter with ideal switching devices will be considered here which is operating with a switching period T and duty cycle D is shown in Figure 1 [2].

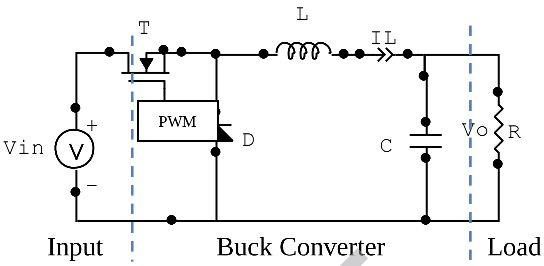
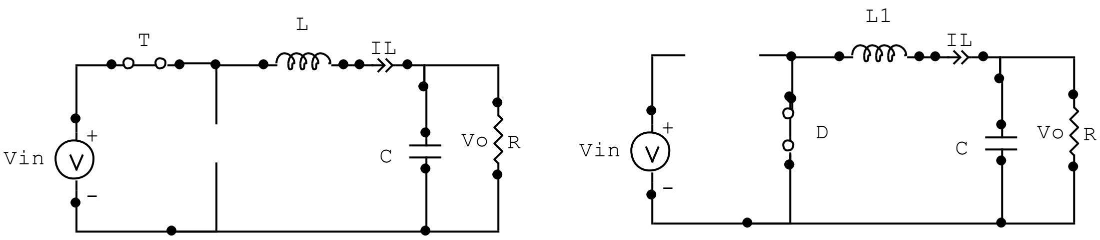


Figure 1: Buck converter circuit

The state equations corresponding to the converter in continuous conduction mode (CCM) can be easily understood by applying Kirchhoff's voltage law on the loop containing the inductor and Kirchhoff's current law on the node with the capacitor branch connected to it. When the ideal switch is ON, and OFF the dynamics of the inductor current and the capacitor voltage are represented in Figure 2.



(a): T state on, D state off (b): T state off, D state on

Figure 2: The buck converter sub-circuits configuration in the ON and OFF states

Consequently, by assuming the continuous conduction mode of operation, the state-space equations when the main switch is ON and OFF are shown by [4]:

$$\begin{cases} \dfrac{dv_c}{dt} = \dfrac{1}{c}(i_L - \dfrac{V_c}{R}) \\ \dfrac{di_L}{dt} = \dfrac{1}{L}(v_{in} - v_c) \end{cases} \quad \text{For } (0 < t < DT) \qquad (1)$$

and when the switch is OFF

$$\begin{cases} \dfrac{dv_c}{dt} = \dfrac{1}{c}(i_L - \dfrac{V_c}{R}) \\ \dfrac{di_L}{dt} = \dfrac{1}{L}(-v_c) \end{cases} \quad \text{For } (DT < t < T) \qquad (2)$$

For the purpose to obtain the relation between changes in the converter duty cycle (the switching control signal) and the system states, the following perturbations can be applied:

$$D = D + \hat{d} \text{ for } \frac{\hat{d}}{D} << 1 \text{ , } v_{in} = v_{in} + \hat{v}_{in} \text{ for } \frac{\hat{v}_{in}}{v_{in}} << 1, \ v_c = v_c + \hat{v}_c \text{ for } \frac{\hat{v}_c}{v_c} << 1, \text{ and } i_L = i_L + \hat{i}_L \text{ for } \frac{\hat{i}_L}{i_L} << 1.$$

In order to provide examining the response of the converter to load changes, a current source generator I_o is added in parallel with load resistor; therefore, this leads to following assumption:

$$I_o = I_o + \hat{I}_o \quad \text{for} \quad \frac{\hat{I}_o}{I_o} << 1$$

Based on the equations for each circuit configuration shown in Figure 2, the small signal averaged state-space model is obtained as bellow, in which the variable with a hat are small AC variation about the equilibrium point:

$$\begin{bmatrix} \dfrac{d\hat{i}_L}{dt} \\ \dfrac{d\hat{v}_c}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{-1}{L} \\ \dfrac{1}{C} & \dfrac{-1}{RC} \end{bmatrix} \begin{bmatrix} \hat{i}_L \\ \hat{v}_c \end{bmatrix} + \begin{bmatrix} \dfrac{v_{in}}{L} & \dfrac{D}{L} & 0 \\ 0 & 0 & \dfrac{1}{C} \end{bmatrix} \begin{bmatrix} \hat{d} \\ \hat{v}_{in} \\ \hat{I}_o \end{bmatrix} \qquad (3)$$

2.2 Boost Chopper

The boost converter circuit consists of the same components as the buck converter: a controlled power semiconductor, an uncontrolled diode, an inductor, a capacitor, and a load. The difference is the way the components are configured. The modelling procedure is the same as the steps followed for the Buck chopper. Therefore, as a matter of simplicity, just the final results are reported. The Boost converter is shown in Figure 3 and the small signal averaged state-space model is as follows [2], [16-18]:

$$\begin{bmatrix} \dfrac{d\hat{i}_L}{dt} \\ \dfrac{d\hat{v}_c}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{-D'}{L} \\ \dfrac{D'}{C} & \dfrac{-1}{RC} \end{bmatrix} \begin{bmatrix} \hat{i}_L \\ \hat{v}_c \end{bmatrix} + \begin{bmatrix} \dfrac{v_{in}}{L} & \dfrac{1}{L} & 0 \\ 0 & \dfrac{-i_L}{C} & \dfrac{1}{C} \end{bmatrix} \begin{bmatrix} \hat{d} \\ \hat{v}_{in} \\ \hat{I}_o \end{bmatrix} \qquad (4)$$

where D′ = 1 – D and the boost converter voltage gain is given as $\dfrac{V_o}{V_{in}} = \dfrac{1}{1-D}$.

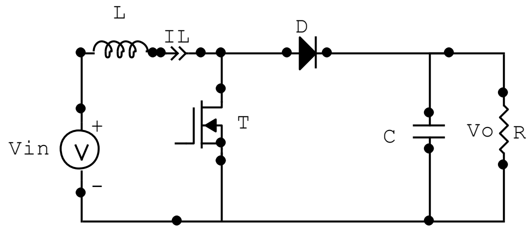


Figure 3: Boost converter circuit

2.3 Buck-Boost Chopper

The buck-boost converter is capable of producing a dc output voltage which is either greater or smaller in magnitude than the DC input voltage where therefore, it is a cascade combination of a buck and a boost converter. The arrangement of the buck-boost converter can be modelled in several ways. The most widely used model of these converters is the state space averaging [2], [16-18]. In these models, the output voltage is controlled by varying the duty cycle of the gate pulse excitation. The circuit of the converter is shown in Figure 4.

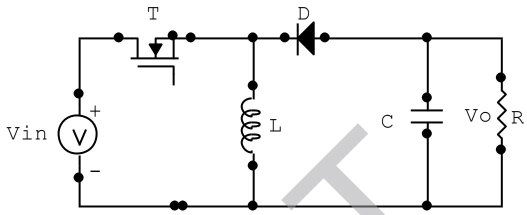


Figure 4: DC-DC Buck-Boost Converter

DC/DC converters are often designed based on mathematical models. For the purposes for achieving a certain performance objective, an accurate model is essential. The average state-space model of the buck–boost converter is obtained as [2]:

$$\begin{bmatrix} \dfrac{d\hat{i}_L}{dt} \\ \dfrac{d\hat{v}_c}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{-D'}{L} \\ \dfrac{D'}{C} & \dfrac{-1}{RC} \end{bmatrix} \begin{bmatrix} \hat{i}_L \\ \hat{v}_c \end{bmatrix} + \begin{bmatrix} \dfrac{v_{in}+v_C}{L} & \dfrac{D}{L} & 0 \\ \dfrac{-i_L}{C} & 0 & \dfrac{1}{C} \end{bmatrix} \begin{bmatrix} \hat{d} \\ \hat{v}_{in} \\ \hat{I}_o \end{bmatrix} \tag{5}$$

where $D' = 1 - D$ and the boost converter voltage gain is given as $\dfrac{V_o}{V_{in}} = \dfrac{D}{1-D}$.

3. PID controller

In order to regulate the output voltage, voltage mode controller is used. The voltage mode control executes the PID control law where it attempts to correct the error between a measured process variable and a desired set point. Due to the various advantages of PID, it is widely used for industrial applications in the area of power electronics. Some of the main causes for the use of this classical controller that it is easy implementation of tuning method like Ziegler-Nichols tuning procedure, simple to implement, easy to understand, and reliable for linear systems. In the other hand, the disadvantages of PID controllers are that it does not reliable and satisfactorily in case of non-linear systems. In addition, it shows longer rise time when overshoot in output voltage decreases and produces overshoot affecting the output voltage regulation of converter [5-6], [19].

In the present work, a PID controller in digital form is utilized for the PID parameters K_p, K_i, K_d with a sampling time of T_s as [5]:

$$u_c(k) = u_c(k-1) + a \ e(k) + b \ e(k-1) + c \ e(k-2) \tag{6}$$

Where $u_c(k)$ is the control signal at iteration (sample) *k*, *e* (*k*) is the error between a reference value and the desired system output voltage at sample *k*, $a = (K_p + K_i \frac{T_s}{2} + \frac{K_d}{T_s}$, $b = (-K_p + K_i \frac{T_s}{2} - \frac{2K_d}{T_s}$, and $c = \frac{K_d}{T_s}$. In this work it is adopted, for the purpose of finding the suitable control law for PID and PSO controllers, the following command duty ratio algorithm for PWM controller as [5]:

$$D = \frac{V_{ref}}{V_{in}} - \frac{LC}{V_{in}} u_c(k) \tag{7}$$

4. PSO algorithm

The PSO algorithm was originally proposed by Kennedy and Eberhart in 1995 [20].The PSO algorithm is an evolutionary computational technique, but it differs from other well-known evolutionary computation algorithms such as the genetic algorithms. Although a population is used for searching the search space, there are no operators applied on the population. Instead, in PSO, the population dynamics simulates a 'bird flock's' behaviour, where social sharing of information takes place and individuals can profit from the discoveries and previous experience of all the other companions during the search for food. Thus, each companion, called particle, in the population, which is called swarm, is assumed to 'fly' over the search space in order to find promising regions of the landscape. Optimization methods based on swarm intelligence are called behaviourally inspired algorithms as opposed to the genetic algorithms, which are called evolution-based procedures.

In the context of multivariable optimization, the swarm is assumed to be of specified or fixed size with each particle located initially at random locations in the multidimensional design space. Each particle is assumed to have two characteristics: a position and a velocity. In addition, it wanders around in the design space and remembers the best position (in terms of the food source or objective function value) it has discovered. The particles communicate information or good positions to each other and adjust their individual positions and velocities based on the information received on the good positions. Thus the PSO model simulates a random search in the design space for the maximum value of the objective function. As such, gradually over many iterations, the birds go to the target (or maximum/minimum of the objective function).

Let x and v denote a particle position and its corresponding flight velocity in a search space, respectively. Therefore, the i^{th} particle is represented as $x^i = (x^{i1}, x^{i2}, \ldots, x^{id})$ in the d-dimensional search space. The best remembered of the i^{th} particle individual particle position is recorded and represented as $pbest^i = (pbest^{i1}, pbest^{i2}, \ldots, pbest^{id})$. The index of best remembered swarm position among all the particles in the group is represented by the $gbest = (gbest^1, gbest^2, \ldots, gbest^d)$. The flight velocity for particle i is represented as $v^i = (v^{i1}, v^{i2}, \ldots, v^{id})$. The modified velocity and position of each particle can be calculated using the current velocity and the distance from $pbest^i$ to gbest as presented in the following flow chart shown in Figure 5. The modified velocity and position of each particle can be calculated using the current velocity and the distance from $pbest^{id}$ to $gbest^d$ as presented in the following formulas [21-22]:

$$v_{k+1}^{id} = wv_k^{id} + c_1 r_1 (pbest_k^{id} - x_k^{id}) + c_2 r_2 (gbest^d - x_k^{id}), \; i=1,2,\ldots,n \text{ and } d=1,2,\ldots,m \quad (8)$$

$$x_{k+1}^{id} = x_k^{id} + v_{k+1}^{id} \quad (9)$$

where w, $c1$ and $c2 \geq 0$. n is the number of particles in a group; m is the number of members in a particle; w is the inertia weight factor; $c1$ and $c2$ are acceleration constants; $r1$ and $r2$ are two random numbers between 0 and 1; x_k^{id} and v_k^{id} are the velocity and the current of particle i in the d^{th} -dimensional search space at iteration k, respectively.

In general, PSO shares many similarities with evolutionary computation techniques. The main difference between the PSO and other approaches is that PSO does not have operators and the particles update themselves with the internal velocity; they also have a memory that is important to the algorithm. In addition, the PSO is easy to implement and there are few parameters to adjust. Furthermore, PSO is computationally inexpensive since its memory and speed requirements are low [22].

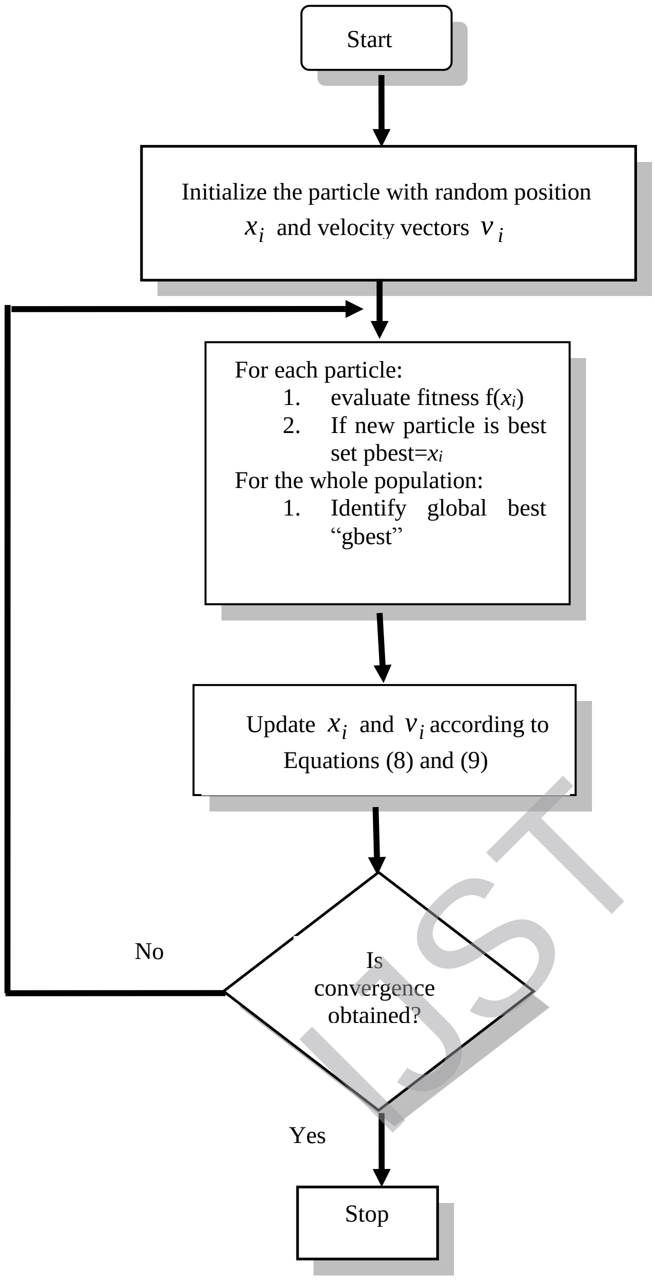


Figure 5: Flow chart of PSO algorithm

5. Simulation results and performance evaluation

Simulation results of buck converter are presented in this section where the buck converter parameters are presented in Appendix A. For simulations purposes, the buck converter system was simulated in C++ environment using numerical technique based on forth order Runge-Kutta method with time step size of 20 µsec. The simulation environment is used to test the transient and steady-state response of the system to various disturbances from the input source and load side.

Initially, the simulation results are used to compare the open-loop response of the system with the compensated closed-loop responses of the system.

5.1 Performance assessment of PI controller based on system response

In this paper, a buck converter controller using PI controller was initially applied. The goal of the controller is to maintain the output voltage constant at 6 V in spite of load changes and variation in input voltage. The design of PI controller is done by adjusting the value of K_p till the desired output is obtained ignoring any offset and then adjust K_i to reduce any offset error. The values of K_p and K_i were found to be equal 489.25 and 0.87 respectively. Here in this work, the integral term in a PI controller causes the steady-state error to reduce to zero, which is not the case for proportional control in general. The lack of derivative action may make the system steadier in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs [21]. The schematic diagram of the above PI controller circuit is shown in Figure 6.

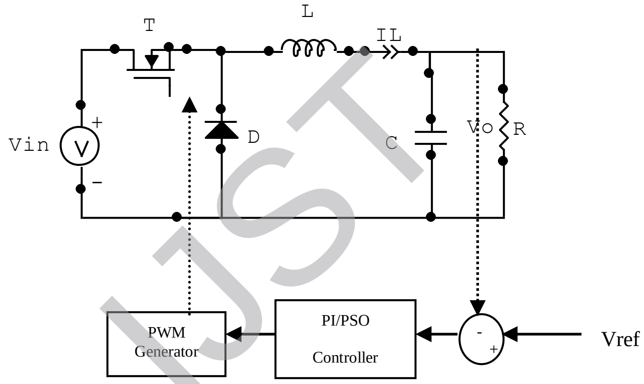
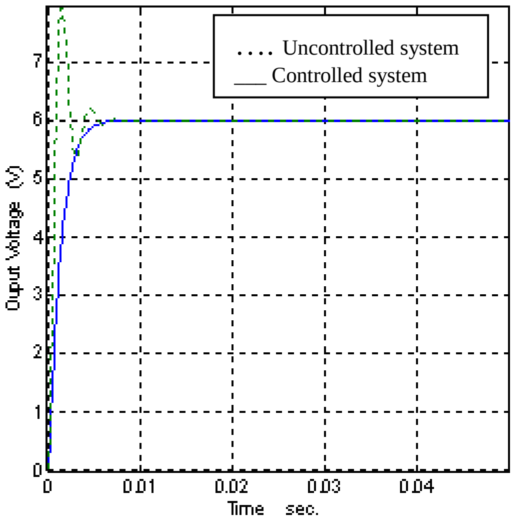
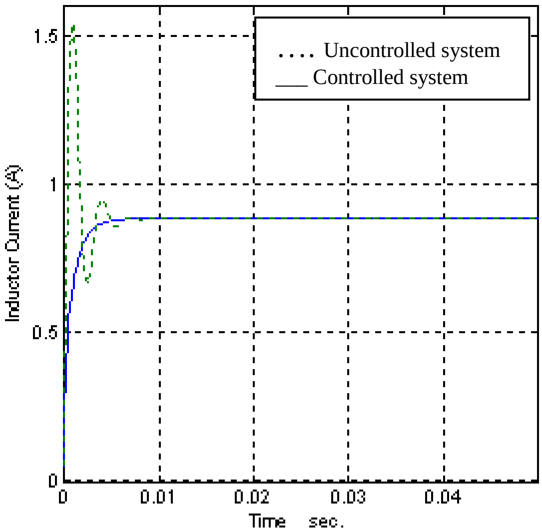


Figure 6: Schematic diagram of the proposed control system.

The output voltage and load current for open-loop system and the compensated one by a PI controller for a 12 V DC power source and 0.5 duty cycle are illustrated in Figure 7. Here in this work, the ultimate aim is to achieve a robust controller in spite of uncertainty and load changes. The converter specifications under consideration are rise time, settling time, maximum overshoot and steady state errors which are shown in Table (1) for the undisturbed case where no overshoots or undershoots are evident. Both responses have zero steady-state error and the open-loop response has a percentage maximum overshoot of 32.48%. The controlled response has a zero overshoot, while it's settling time as compared to the open loop is increased by 0.78%. However, the rise time has been increased from 0.64 *msec* for the open loop case to 2.8 *msec* for the PI compensated system.



(a): Controlled and uncontrolled system output voltage



(b): Controlled and uncontrolled system inductor current

Figure 7: Time Response of Open-loop and Closed-loop System to 12 V DC Power Source

Table 1: The undisturbed system transient specifications with open loop and PI controller

Method	Rise Time (*msec*)	Settling Time (*msec*)	Maximum Overshoot %	Steady State Error (V)
Open loop	0.64	5.06	32.48	0
PI Controller	2.8	5.1	0	0

5.2 Response to step changes in the reference voltage

The simulation is also carried out by varying the system reference voltage where the results for the output voltage and load current are shown in Figure 8. The reference voltage is changed from 6 V to 8 V at moment t= 0.025 sec where it can be seen that the corresponding output voltage has been changed to 8V from the time 0.025 sec. to 0.05 sec. Here, the controller adopts the change in reference value, vary the duty cycle of the converter accordingly and produce the reference as the output voltage as shown. Consequently, the controller approximately does not take any time to vary the output voltage from 6V to 8V as illustrated in Figure 8.

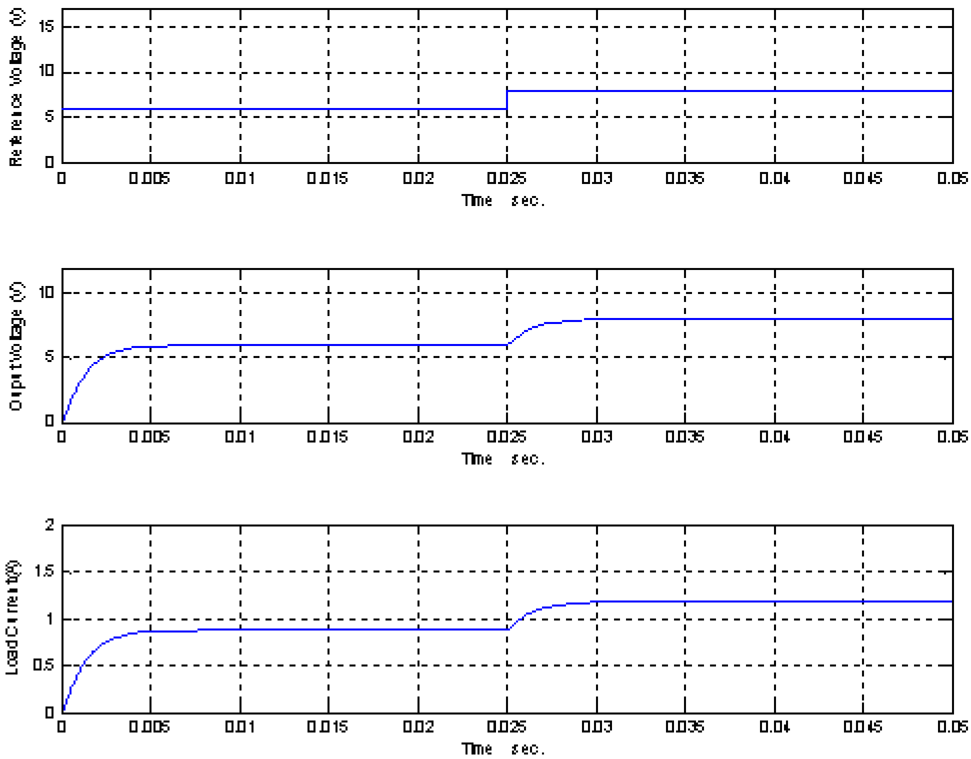


Figure 8: System responses of PI controlled buck converter with the reference voltage is changed from 6V to 8V.

5.3 Response to step changes in the input voltage

In the present case, the input voltage step is varied from 12 to 8V at 0.01 sec and from 8V to 16V at 0.03 sec. The time response of the output voltage and load current in a closed-loop system compensated by a PI controller is illustrated in Figure 9. The changes in the input voltage do not make any variations in the output voltage and load current since the controller adopt the variations in the parameters and continuously track the reference voltage and therefore, the duty cycle of the MOSFET is changed so that to maintain the output voltage at the same designed value within a fraction of millisecond as shown. This proves the effectiveness and the robustness of the controller as well as that the controller responds very well under this change.

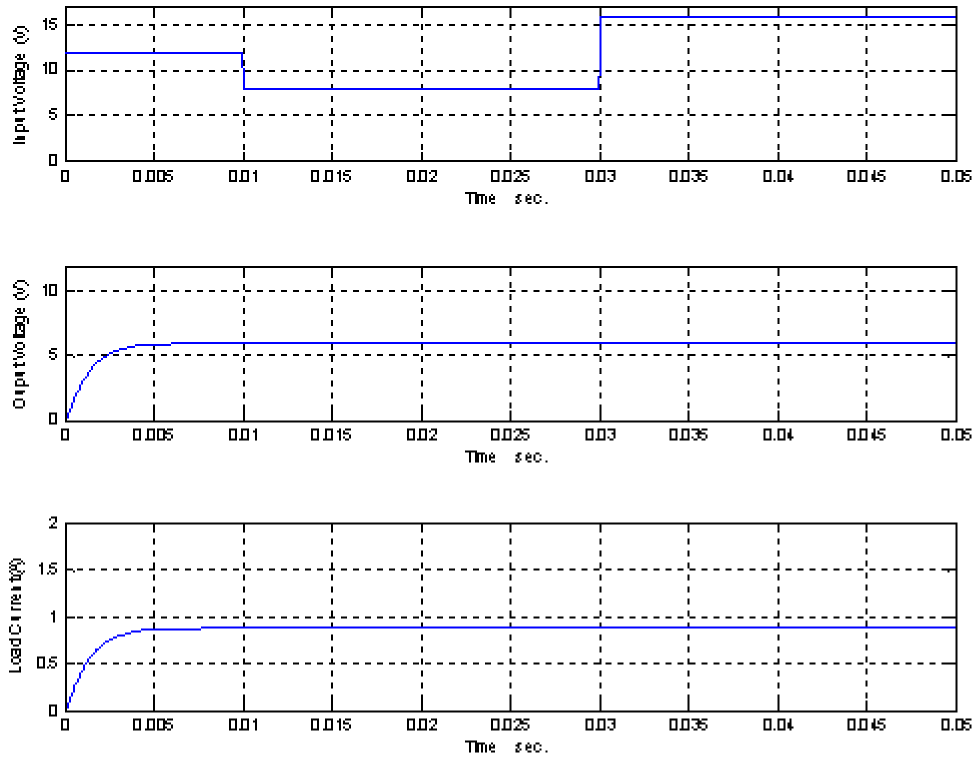


Figure 9: Output responses of the controlled buck converter

when the input voltage is changed.

5.4 Response to step changes in load current

Fig. 10 shows the simulation results when the proposed PI controller is applied to the converter under load variation. The load resistor (R) is suddenly changed from 6.8 Ω (nominal value) to 3.4Ω and again to 10.2Ω. It can be noticed from Figure 10 that under test condition R=6.8Ω, the output voltage response attends steady state value of 6 V which is an expected output for this application. By changing the value of resistance load, it has been seen that as load resistance increase, the output overshoot is being large and the settling time increases. As a result, it can be shown that the variation in the load resistance significantly affects the output voltage and load current transient responses.

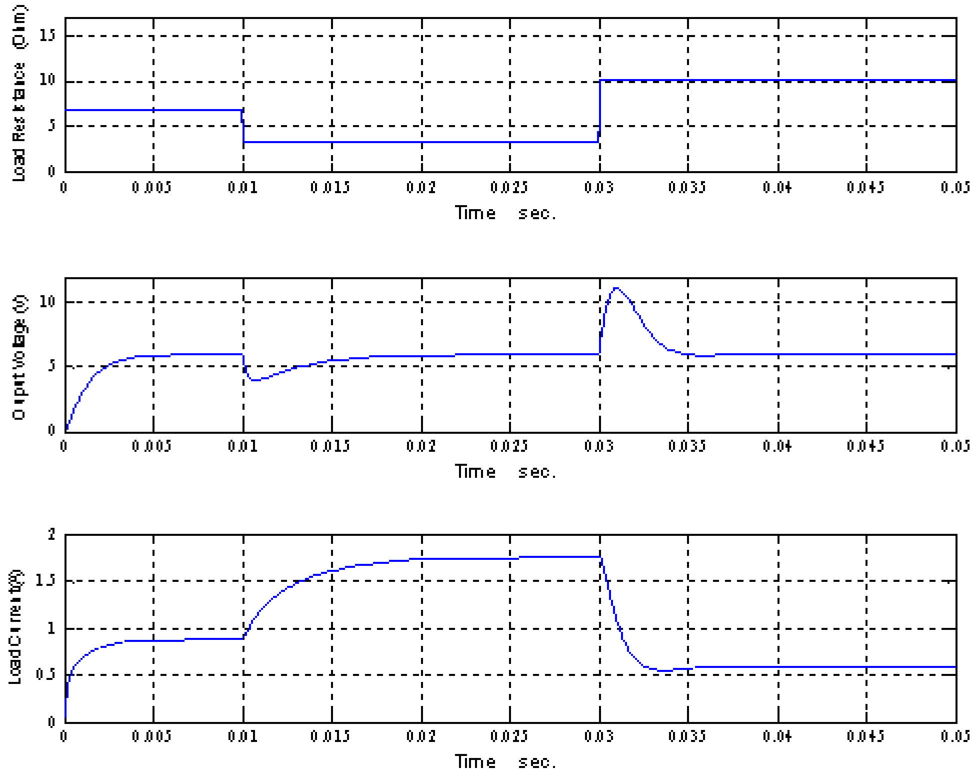


Figure 10: System responses for change in load resistance form 6.8Ω to 3.4Ω and then to 10.2Ω

6.0 Simulation of closed-coop of DC-DC buck converter Using PSO algorithm

In this work, PSO is used to find the optimal values of the duty cycle parameters to improve the behaviour of a Buck converter. The objective of the optimal controller design is to maintain constant output voltage and reduce the maximum.

To investigate the effectiveness of the PSO-based controller on the performance of the Buck converter, the evolution procedure of PSO Algorithms which was shown in Fig. 5 has been considered. The structure of the controller based-PSO algorithms is shown in Figure 6. Moreover, the time responses are chosen as the performance indices to be obtained. Since computational time is one of the important factors to be considered in an optimization process, investigations on the number of individuals/particles were carried out by varying those numbers from 50 to 700. Fewer individuals/particles resulted in high values of errors but faster computational time, while a high number of individuals/particles resulted in smaller values of the mean error with very slow execution time. In order to get compromise values between the mean error and computational time, the best number of individuals/particles was found to be 500 for all algorithms The other parameters considered for PSO algorithm are c1 = 2, and c2 = 2. Moreover, the number of dimensions (*Nod*) is=5 and the maximum iteration number (*Noi*) equal 20 and are used for checking termination criterion in this algorithm. Consequently, the inertia weight factor (*w*) is selected according to the following equation:

$$w = 0.9 - 0.7 * (i / Noi) \text{ where } i \text{ is the } i^{th} \text{ iteration.} \quad (10)$$

The decreasing of w through the search process, called adaptive inertia weight is a process similar to that of simulated annealing in which temperature is decreased exponentially, allowing global and local search [20-22]. As in most search algorithms, in PSO a cost function is needed to evaluate the aptitude of candidate solutions. Generally, the definition of a cost function depends on the problem at hand, but in general should reflect the proximity of the solutions to the optima. The cost function that is adopted in this work is selected to be based on the mean squared error between the system output voltage that measured at the load and a reference value. In the following, the application of PSO for the optimization of the value of the duty cycle is presented.

The simulated results of the undisturbed system that are obtained by deploying a PSO controller are shown in Figure 11. The performance of the control scheme is assessed in terms of time domain specifications associated with output voltage and inductor current responses as compared to the open loop system behaviour. In addition, the performance and transient specification of the undisturbed system, which include rise time, settling time, maximum overshoot, and steady state error are obtained and presented in Table (2).

From Table 2 it can be inferred that, the value of rise time is less in the controlled response, setting time is comparatively highly less using PSO controller, peak overshoot value is very small as compared to PI controller and the steady state error is zero for both cases. Thus, it can be concluded that the PSO controller is best suited for feedback controller design in all aspects.

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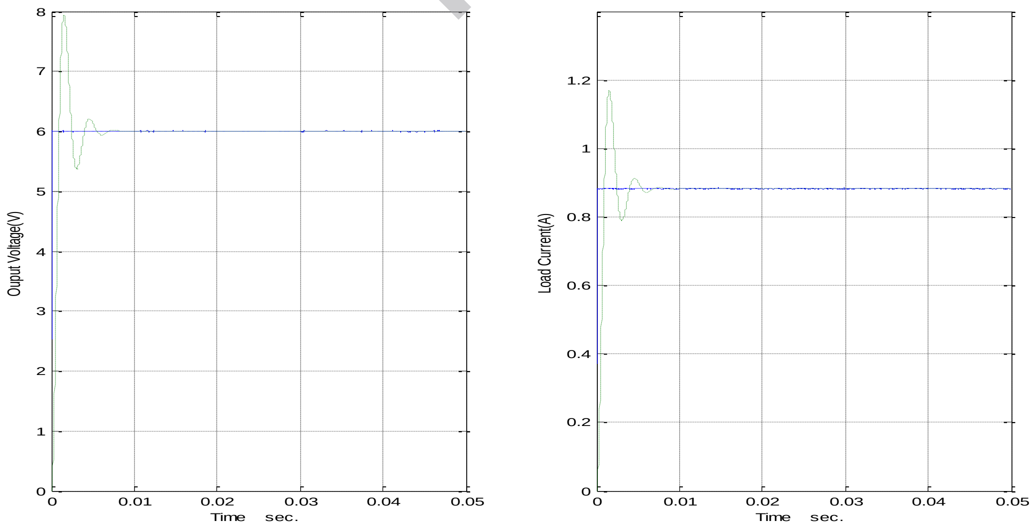


Figure 11: System responses of the controlled buck converter using PSO controller

Table 2: Transient response without any disturbances with open loop and PSO controller

Method	Rise Time (*msec*)	Settling Time (*msec*)	Maximum Overshoot %	Steady State Error (V)
Open Loop	0.64	5.06	32.48	0
PSO Controller	0.02	0.022	0.0024	0

In the following, performance of proposed PSO controller in three different conditions, including of change in the reference voltage, input voltage, and output load are studied. In this case, the simulations have been carried out using the same values and circumstances as that presented in Section 5. Output voltage and current of converter in each of these conditions are shown in Figures 12-14.

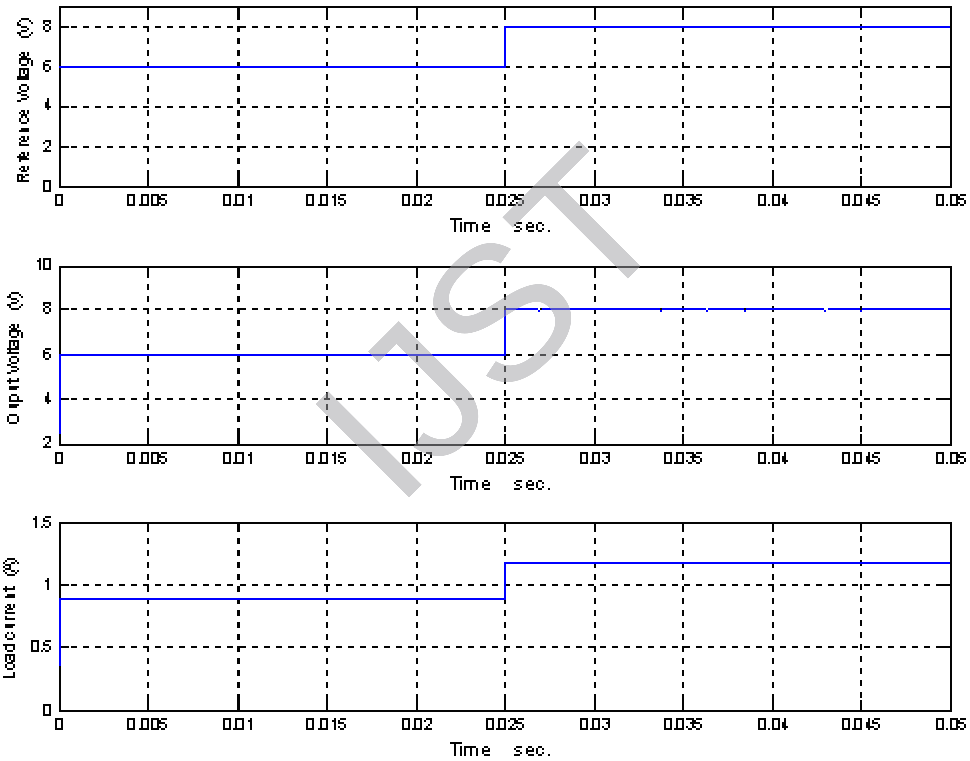


Figure 12: System responses for change in the reference voltage

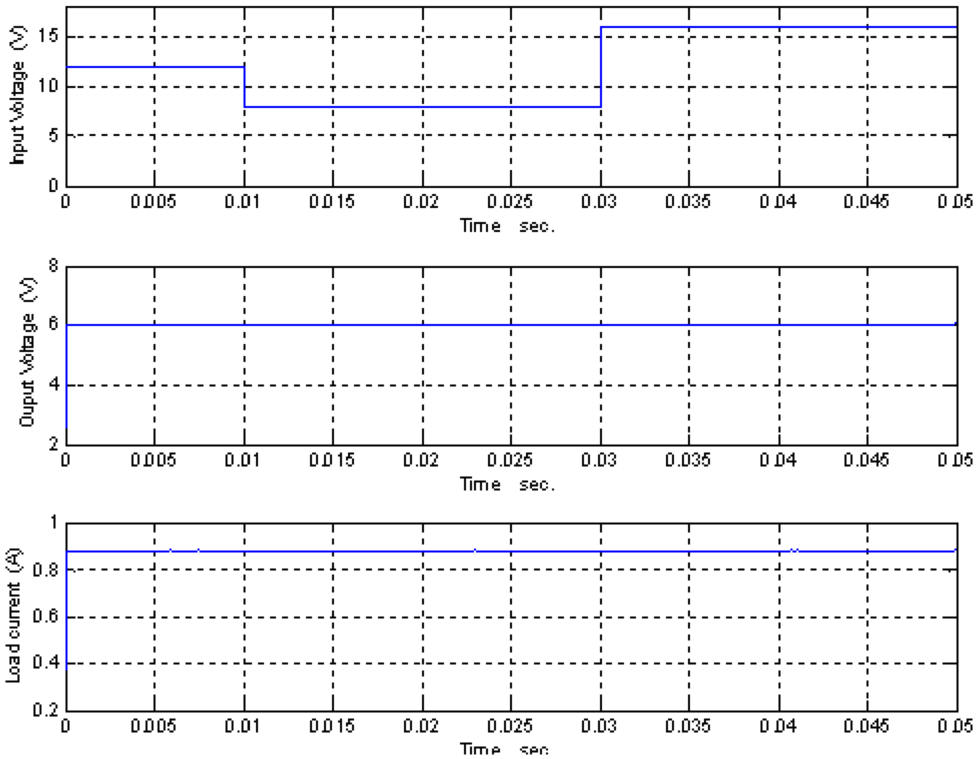


Figure 13: System responses for change in the input voltage

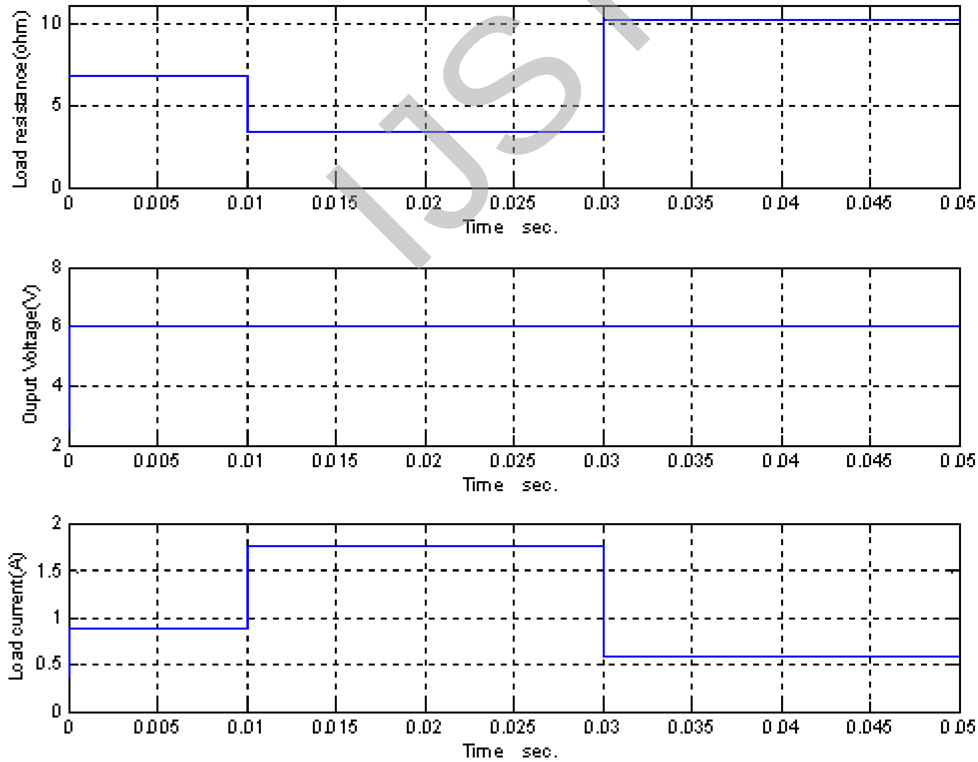


Figure 14: System responses for change in the load resistance

It can be noticed from the simulations shown in Figures 12-14 of closed loop buck converter system using PSO control scheme that the system is very much dynamic in tracking the reference voltage in spite of the variations in its values. As per Figure 13, for a step changes at the input voltage, a satisfactory performance is obtained in the output voltage which it is quickly and immediately dropped to its set value (6V). In addition, the output voltage resumes its reference value (of 6V) immediately after the transient variation caused by the step variation of load. Simulation results verify that the control scheme in this section gives stable operation of the power supply. The output voltage and load current can return to the steady state even when it is affected by line and load variation.

6.1 Comparison of the PSO-based controller with PI control method

In the following, performance of proposed controllers in three different conditions, including of change in reference voltage, the output load and the input voltage are compared. Output voltage and currents of buck converter in each of these conditions were presented previously for both controllers in sections 5 and 6. In addition, the response performance parameters of the output voltage results after simulation for the undisturbed buck converter are given in Table (3). The performance and specification comparison of the designed controllers for DC-DC buck converter are assessed for time domain specifications in terms of peak overshot, rise time, settling time and steady state error that associated with output voltage response without any variations to the load/input of the system. The steady state error, peak overshoots and output voltage ripples are not evident in both the methods.

By comparing the results in Table 3, it can be seen that using PSO method in comparison with PI controller, the response overshoot is approximately equals zero and dropped more than 32% from uncontrolled case. In addition, settling-time and rise-time are both decreased about 98.9% with the using of PSO controller. Therefore, the performance specifications with PSO method shows improved results than that with the PI controller. It is obvious that, PSO has considerable improvement and better performance and is a good alternative way to control power converters than the classical controllers where it has lower raising and setting time.

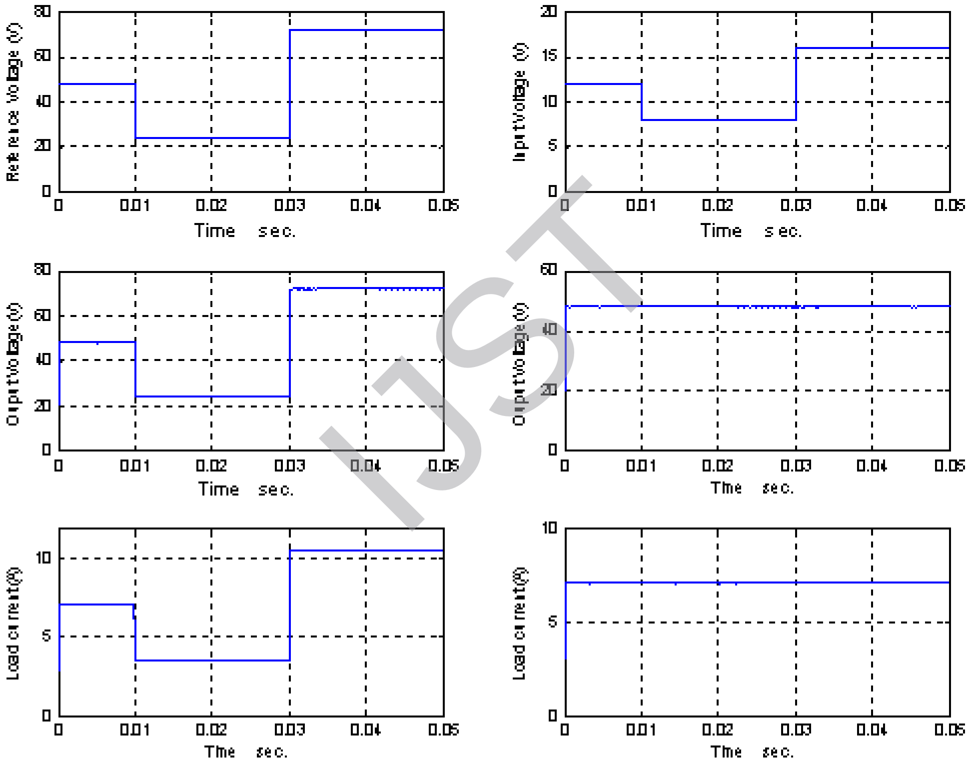
Table 3: Step response specification of the undisturbed system with different controllers

Method	Rise Time (*msec*)	Settling Time (*msec*)	Maximum Overshoot %	Steady State Error (V)
Open Loop	0.64	5.06	32.48	0
PI Controller	2.8	5.1	0	0
PSO Controller	0.02	0.022	0.0024	0

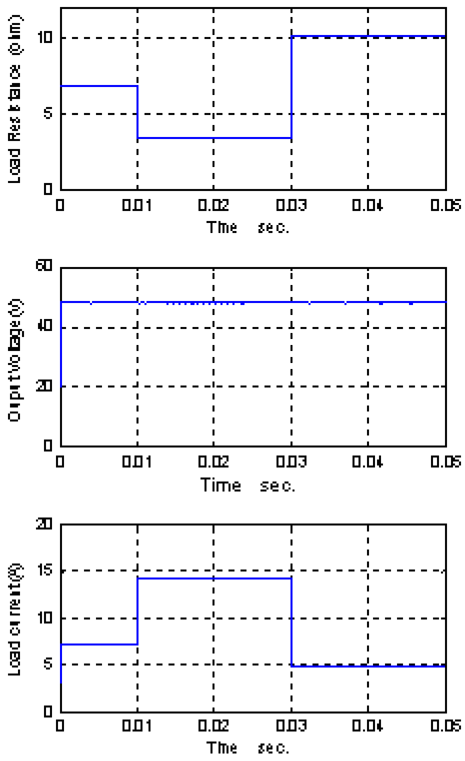
7. Simulation Closed-Loop of boost and buck-boost DC-DC Converters

In the current work, it is noticeable that the PSO controller demonstrates much better performance than the PI controller. Therefore, it is adopted to expand the work to deal with other types of DC-DC coveters. This section clearly discusses the simulation results obtained for a boost and buck-boost using PSO method. Simulation model for PSO control of DC-DC switching converters was build previously and simulated using C++ programming environment with the converter parameters given in Appendix A. The results of output voltage and current for closed loop simulation of converters are shown in Figures 15 and 16.

The results of closed loop using a PSO control scheme for a boost converter is shown in Figure 15. Here the output voltage completely regulated to fixed value of voltage (reference value) at 48 V for the step variations at load resistance of about $\pm 50\%$ of its nominal value. The output voltage resumes its reference value within a very short period after the transient variation of load. Consequently, for a step change at the input voltage of about $\pm 33\%$ of the nominal input value at 0.02 sec. instant, a satisfactory performance is obtained in the output voltage which it is quickly regulated to its set value 48 V. Simulation results verify that the control scheme in this section gives stable operation of the power supply. The output voltage and load current can return to the steady state even when it is affected by input voltage and load variation.



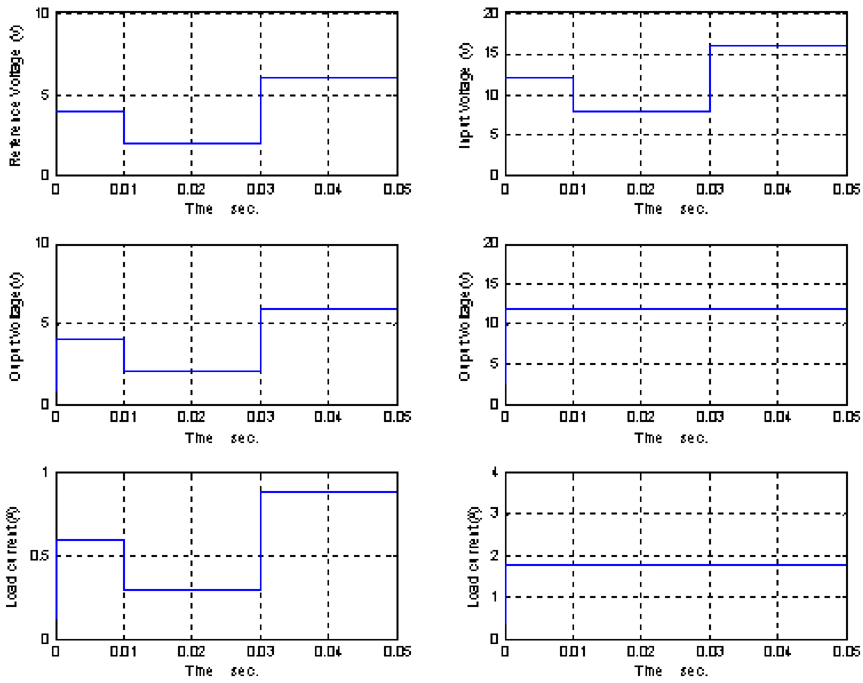
(a) Reference voltage variation (b) Input voltage variation



(c): Reference voltage variation

Figure 15: Output voltage and load current closed-loop for boost converters

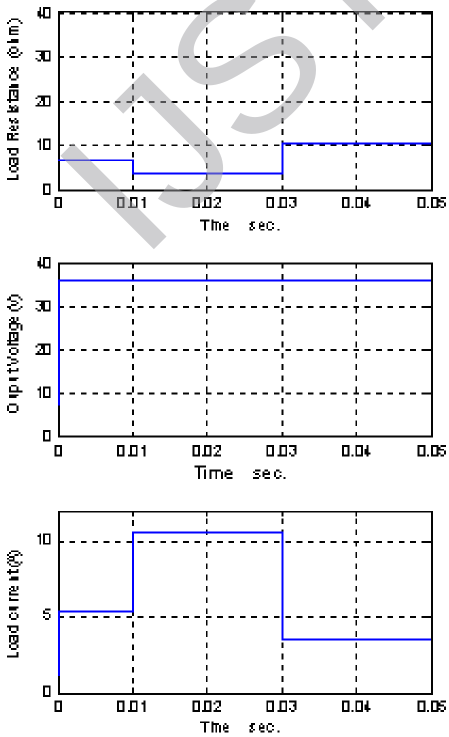
For the case of buck-boost converter system, the system settles down very fast in all of the three situations when the PSO optimal regulator method is employed. The simulations were carried out by varying the reference voltage, input voltage and the load resistance where the corresponding output voltage, and load currents are also presented for the considered method. In spite of such variations, the controller is robust and efficient enough to track the reference voltage. The overshoots and undershoots are seen which is very minimum of the order of less that 0.002% as well as the current shows very much reduced ripples. In order that the dynamic performance has to be ensured the control strategy shows tight output regulation with much lesser settling time, no steady state error and without any undershoots or overshoots which is evident from Figure 16.



(a) (b)

(a) Reference voltage variation with 0.25 duty cycle (buck converter mode)

(b) Input voltage variation with 0.5 duty cycle



(c): Load resistance variation at 0.75 duty cycle (boost converter mode).

Figure 16: Output voltage and load current closed-loop for Buck-Boost converter

As shown in Figures 15 and 16, it is clear that the realization of voltage regulation by the PSO controller of converters is precise and the required load voltage regulation and the desired load current are satisfied.

8. Conclusions

In this paper, on-line PSO controller, which is one of the advanced control scheme that can be implemented with DC-DC converters, was designed to improve the system response such as settling time, overshoot and ripple of the output voltage. PSO is a nonlinear control scheme which was used to control the duty cycle of the system where the controlling of the duty cycle, in turn, controls the output voltage of the system. The advantages of PSO method are: exact mathematical models are not required for the design of such controller, complexities associated with nonlinear mathematical analysis are relatively low, and it is able to adapt to changes in operating points. Comparative studies were made with the two proposed controllers for a sudden change in input voltage magnitude and/or load change. The PSO controller gives the better performance and was more robust for model inaccuracies and disturbances in comparison with the PI controller. Simulated results obtained validate the effectiveness of the proposed PSO control strategy and the controlled converters systems work fine and behave very well with very less overshoot and settling time. This leads to that the overall speed of the system is also increased, as seen by the decrease of the settling time when the converter is connected to the power source.

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Appendix A

Table 1 Buck converter parameters for D=0.5.

Buck, Boost, and Buck-Boost Converters Parameters					
V_{in}	L	C	R	f	V_o
12,12,12 respectively	2.1×10^{-3} H	100×10^{-6} F	6.8 Ω	100 KHz	6, 24, 12 respectively