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Design of PID Controller for Boost Converter Using Particle Swarm Optimization Algorithm

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Abstract -- DC-DC converters are broadly used in computer peripherals and industrial applications. Boost converter is a specific type of DC-DC converters. Boost converter will step up the input dc voltage to higher regulated dc voltage. In this paper, a model of switched mode DC-DC converter incorporated with the PID controller has designed. The PID controller will control the output voltage of the converter. The PID controller is tuned by Particle Swarm optimization (PSO) Algorithm to get the highest quality of output voltage. This system is implementing in MATLAB Simulink software. The results of simulation showed that the PSO-PID controller will better the performance of the Boost converter than the conventional PID controller.

Index Terms: PID controller, Particle Swarm optimization Algorithm, Boost Converter.

I. INTRODUCTION

DC-DC converters are the devices widely used to change the DC electrical power efficiently from one voltage level to another. DC-DC converters are widely used in computer hardware, power supplies, servo-motor drives and medical equipment's and so that these converters have found significant attention in the recent decades. The main objective of a DC-DC converter is to supply a regulated DC output voltage to a variable-load resistance from an unstable DC input voltage. The problem of regulating the output voltage of these converters have been a subject of great interest for many years, because of the switching property included in their structure DC-DC converters have a non-linear behavior and consequently their controlling design is accompanied by complexities. In addition, due to non-minimum phase nature of the Boost converter, much effort has been directed at the control of this configuration. Transfer function of the DC-DC Boot converter is obtained from the state space averaging method for determining switching converter transfer function at steady state condition.

In modeling area of DC-DC converters, a variety of models are presented, which comprise desirable responses by the implementation of control methods. Most of the previous research concentrated on design of PI and PID controllers for the converter. The objective of this paper is to use PSO algorithm in order to obtain the optimal PID controller gains for the performance of Boost convert. The performance indices used in this paper is Integral Squared Error (ISE) and Integral Absolute Error (IAE).

II. BOOST CONVERTER

A Boost converter circuit shown in Figure 1 can perform step up DC-DC conversion. When the switch is turned ON, the current flows through the inductor and energy is stored in it. When the switch is turned-OFF, the stored energy in the inductor tends to collapse and its polarity changes such that it adds to the input voltage. Thus, the voltage across the inductor and the input voltage are in series and together charge the output capacitor to a voltage higher than the input voltage.

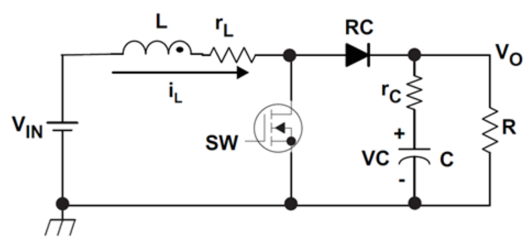

Figure1: Circuit diagram of Boost converter

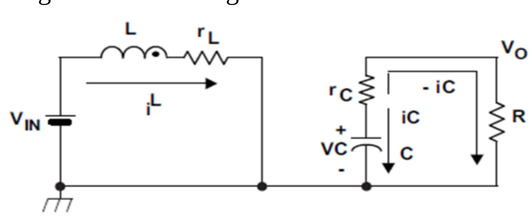

Fig. 2 Boost converter on mode

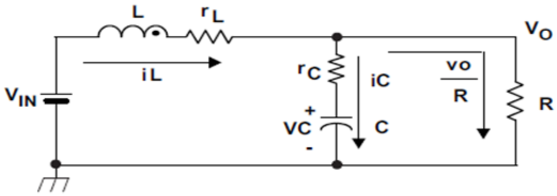

Fig.3 Boost converter Off mode

The circuits (Fig.2 and Fig.3) for the switch-on and switch-off modes of the preferred converter are developed using a state-space approach. The state variables are:

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du \qquad (1)$$

where,

x = State variable;

u = Input voltage(Vin);

y = Output voltage(Vo).

After model, the two modes are averaged over a single switching period T.

III. PID CONTROLLER

The PID controller shown in figure 4 is used to develop the dynamics response and to reduce the steady state error. The derivative controller improves the transient response and the integral controller will reduce steady state error of the system.

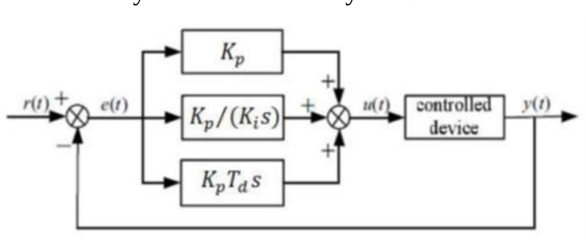

Fig4: Schematic diagram of PID controller

The transfer function of the PID controller is given as follows,

$$k_p + \frac{k_i}{s} + k_d s = \frac{k_d s^2 + k_p s + k_i}{s} \quad k \; (2)$$

The PID controller works in a closed-loop system. The signal u(t) output of the controller is equal to the Kp times of the magnitude of the error plus Ki times integral of the error plus Kd times the derivative of the error as,

$$k_p e + k_i \int e dt + k_d \frac{de}{dt} \qquad (3)$$

This control signal will be then sent to the plant, and the new output y(t) will be obtained. This new output will be then sent back to the sensor again to find the new error signal e(t). The controller takes this new error as input signal and computes the gain values (Kp, Ki, Kd).

IV. PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization algorithm is based on simplified social behavior of animal swarms like birds and fishes. The way of attitude that group of animals used in order to find their supplies is the main concern of the methodology. The basic PSO is developed from research on swarm such as fish schooling and bird flocking. After it was firstly introduced in 1995, a modified PSO was then introduced in 1998 to improve the performance of the original PSO. A new parameter called inertia weight is added. This is a commonly used PSO where inertia weight is linearly decreasing during iteration in addition to another common type of PSO which is reported by Clerc. The latter is the one used in this paper. In PSO, instead of using genetic operators, individuals called as particles are “evolved” by cooperation and competition among themselves through generations.

A particle represents a potential solution to a problem. Each particle adjusts its flying according to its own flying experience and its companion flying experience. Each particle is treated as a point in a D-dimensional space. The ith particle is represented as XI=(xi1,xi2,…,xiD). The best previous position (giving the minimum fitness value) of any particle is recorded and represented as PI=(pi1,pi2,…,piD), this is called pbest. The index of the best particle among all particles in the population is represented by the symbol g, called as gbest. The velocity for the particle i is represented as VI=(vi1,vi2,…,viD). The particles are updated according to the following equations:

$$V_{id}^{n+1}=W.V_{id}^{n}+C1.rand().(P_{id}^{n}-X_{id}^{n})+C2.rand().(p_{d}^{n}-X_{id}^{n}) \quad (4)$$

$$X_{id}^{n+1}=X_{id}^{n}+V_{id}^{n+1} \quad (5)$$

Where C1 and C2 are two positive constant. As recommended in Clerc's PSO, the constants are C1=C2=1.494. While rand is random function between 0 and 1, and n represents iteration, is used to calculate particle's new velocity according to its previous velocity and the distances of its current position from its own best experience (position) and the group's best experience. Then the particle flies toward a new position according to equation. The performance of each particle is measured according to a pre-defined fitness function (performance index), which is related to the problem to be solved. Inertia weight, w is brought into the equation to balance between the global search and local search capability. It can be a positive constant or even positive linear or nonlinear function of time. A guaranteed convergence of PSO proposed by Clerc set w=0.729. It has been also shown that PSO with different number of particles (swarm size) has reasonably similar performance. Swarm size of 10-50 is usually selected.

V. IMPLEMENTATION OF PSO-BASED PID TUNING

Stochastic Algorithm can be applied to the tuning of PID controller gains to ensure optimal control performance at nominal operating conditions. PSO is employed to tune PID parameters (Kp, Ki, Kd) in offline using the model in PSO firstly produces initial swarm of particles in search space represented by matrix. Each particle represents a candidate solution for PID parameters where their values are set in the range of 0 to 100. For this 3-dimentional problem, position and velocity are represented by matrices with dimension of 3xSwarm size. The swarm size is the number of particle is considered a lot enough. A good set of PID controller parameters can yield a good system response and result in minimization of performance index. The Structure of PSO - PID Controller as shown fig. 5. The PSO-PID controller algorithm are:

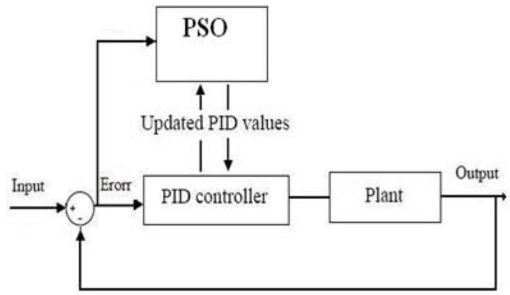

Fig. 5 Structure of PSO - PID Controller

STEP 1: Initialization: First the size of the swarm is determined, which is 25 (from empirical studies the common range of size of the swarm is between 20 and 500). The PSO parameters are assigned as C1=C2=2.05 and k=0.7289. Each particle has its own velocity and position. At the beginning, a random number is assigned to each particle between [100, 150] as initial velocity and between as initial position.

STEP 2: Best Position of Particle: For each particle, the best position so far is recorded in PID based on the evaluation function. For each value of each particle is recorded into the temporary variable and then compared at each iteration, if the new value is smaller than previous one the smaller one is hold. The system is executed for each particle. Then the output voltage is used for fitness function.

STEP 3: Best Particle in Swarm: For all particles, the best particle and its position are recorded in Pgd.

STEP 4: Velocities and Position Update: Velocities and positions of each particle are updated.

STEP 5: Stopping Criteria: If the maximum number of iterations is reached than break the loop and end the program. In this study, the maximum iteration is determined as 100.

In this work, controller's performance is calculating in terms of Integral square error (ISE) and Integral Absolute Error (IAE)

$$\text{ISE} = \int_0^t e^2 dt \quad (6)$$

$$\text{IAE} = \int_0^t |e|\, dt \quad (7)$$

The ISE and IAE weight the error with time and hence minimize the error values closer to zero.

VI. SIMULATION RESULTS

The boost converter parameters are chosen a L=10µH, C=100µF, Rc =10mΩ, RL=30mΩ and R=1.8Ω. A rectified DC of 3V is applied to the boost converter and the reference output value is fixed as 6V. The obtained Boost converter transfer function. Boost converter Closed loop servo and regulatory response of PID and PSO-PID controller shown in figures.

The responses of Boost converter using conventional PID controller and PSO-PID controllers are shown in figures 6, 7, 8 and 9. The figures show that PSO-PID controller will drastically reduce the overshoot, ISE and IAE values as compared to the conventional PID controller. Table 1 shows the performance analysis of the buck converter using conventional PID controller and PSO-PID controller.

TABLE 1: Performance Analysis Of Boost Converter

Parameters	PID	PSO -PID
Peak amplitude	6.92	6.1
Peak time (t_p)	0.0004	0.00022
Settling time (t_s)	0.0016	0.00078
ISE	0.003578	0.003162
IAE	0.0008421	0.000774
K_p	0.055	0.038
K_i	761.2	671.2
K_d	3.287e-6	5.496e-6

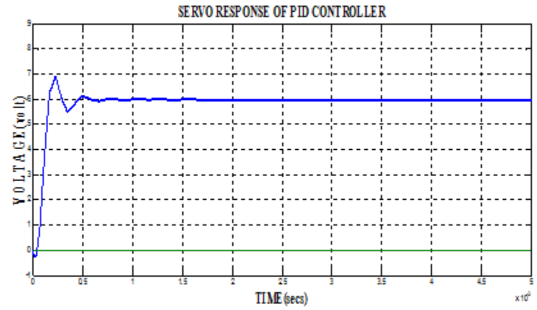

Fig.6 Boost converter Closed loop servo response of PID controller

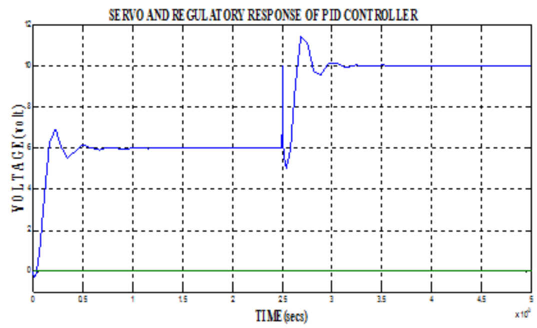

Fig.7 Boost converter Closed loop servo and regulatory response of PID controller (set point changed from 6v to 10v at 0.0025sec)

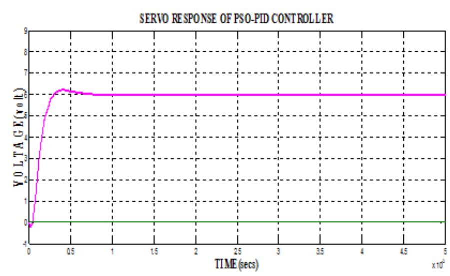

Fig.8 Boost converter Closed loop servo response of PSO-PID controller

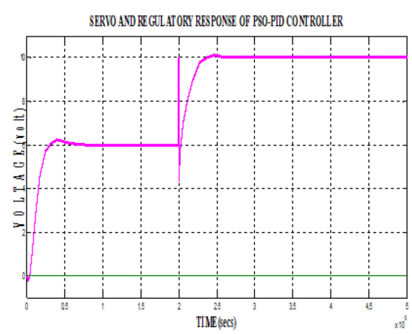

Fig.9 Boost converter Closed loop servo and regulatory response of PSO- PID controller (Set value changed from 6V to 10V at 0.002 seconds).

VI. CONCLUSION

In this paper, Particle Swarm Optimization (PSO) algorithm is developed to tune the PID controller parameters which control performance of DC-DC Boost converter. The simulation results confirm that PID controller tuned with PSO algorithm rejects satisfactorily both the servo and regulatory response. Also the result proved that PSO-PID controller gives the smooth response for the reference tracking and maintains the output voltage of the Boost converter according to the desired voltage.

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