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Research Article

Reduction of Settling Time and Overshoot for Flyback Converter by Using Modern Optimization Based PI Controller Driven DC Servo Motor

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Abstract: In this study, a simple PI controller is presented for regulation of the output voltage of the DC to DC fly back converter driven DC Servo motor with constant frequency. Here a new PI control algorithm implemented in FPGA has been proposed for optimizing the PI parameters using PSO and ABC optimization techniques. A comparison has been made between the two optimization algorithms across different load and voltage variations and their effectiveness in reduction of overshoot and settling time of fly back converter in DC Servo motor drive have been evaluated.

Keywords: ABC, ISE, objective function, overshoot time, PSO, settling time

INTRODUCTION

DC-to-DC converters have been largely dominated and controlled by analog integrated circuit technology and linear system design techniques (Neetu *et al*., 2013). Recently, with the development of advanced high-speed digital circuits, digital control will regularly replace the current use of analog controller in high frequency switching converters. Speed control of DC Servo motor has attracted considerable research and several methods have evolved (Megha and Mohna, 2013; Pavankumar *et al*., 2010; Mishra *et al*., 2013) that require multiple output voltages. Usually, flyback or forward converters with slave-regulated (or cross-regulated) multiple outputs are the suitable implementation schemes when stringent regulation is not demanded (Tacca, 1998; Fanghua and Yangguang, 2009).

Flyback topology has traditionally been the designer's choice for power isolated converters with output power below 100 W with the advantages of simplicity and low cost. This needs the Proportional Integral (PI) controller for regulating the operation of flyback converter (Aswathy and Subathra, 2012). PI controllers are the well known and most widely used controllers in the industries. Simple structure and reliability are the reason behind this.

In process industries, PID controller is used to improve both the steady state as well as the transient response of a process plant. In a closed-loop control system, the controller continuously adjusts the final control element until the difference between reference input and process output is zero irrespective of the internal and/or external disturbance signal (Ali, 2014; Rajinikanth and Latha, 2012). The PI structure is mainly used to achieve the desired output in case of closed loop control systems in most of the industrial applications. However, PI control scheme would lead to large overshoot and long response time when the load increases sharply (Subhojit *et al*., 2014; Zhitong and Lee, 2011).

Nonetheless when the plant to be controlled is highly non linear or is subjected to disturbances or we have less knowledge about it, under these conditions poor performance is obtained when we are using fixed parameter PID as controller (Syed *et al*., 2006; Mitra and Singh, 2013). Thus an expert supervisor is required for online tuning of the controller parameters. In PI controller it is difficult to obtain the proper values of the controlling parameters K_p and K_i (Agnihotri and Waghmare, 2014; Yao *et al*., 2013; Popadic *et al*., 2013). This motivates the need for the design of an optimized algorithm for selection of optimized values for K_p and K_i that provides minimized overshoot and settling time.

In Singh *et al*. (2013) a framework has been presented to carry out a simulation of SIMULINK model of DC drive system to optimize the controller gains for known inputs. Previous studies (Banerjee *et al*., 2010) shows a Particle Swarm Optimization (PSO) method to determine the optimal Proportional-Integral (PI) or Proportional-Integral Derivative (PID) controller parameters, for speed control of a Field Oriented Control (FOC) induction motor.

An optimization of PI Controller Gains in Nonlinear Controller of STATCOM using PSO and GA approach have been presented in Farokhnia *et al*. (2010).

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A bidirectional dc-dc converter for use in low power applications has been carried out (Jain *et al*., 2000). In Ramesh *et al*. (2009) an optimization of PI Coefficients in DSTATCOM nonlinear controller for regulating DC voltage using Particle Swarm Optimization was made.

Ibtissem *et al*. (2012) have proposed a method for tuning PID Controller using Multi objective Ant Colony Optimization algorithms.

The traditional ACO suffered from certain drawbacks such as the convergence of ACO is slower than other Heuristics. Also increase in number of nodes decreases the performances and also there is no centralized processor to guide towards a better solution. Recent research has identified some drawbacks in GA performance. The limitations of genetic Algorithm are that of its slow convergence and it lacks in rank based fitness function. Also, there is no method that deals effectively with minimization of Integral Square Error.

In this proposed study, a new PI control algorithm implemented in FPGA has been presented that deals effectively in reduction of overshoot and settling time in flyback converter driven DC Servo motor.

MATERIALS AND METHODS

Conventional system design: Conventional system for speed control of DC servo motor by PI controller consists of the PI controller in series with the DC servo motor through a flyback converter. The main function of the converter is to provide a constant voltage to the drive circuit of the DC servo motor. Figure 1 illustrates the components used in the system design.

The basic design principles of flyback converter are illuminated in Fig. 2.

The transfer function for flyback converter used here can be framed as:

$$TF = \frac{25S+5}{S^3+5S^2+25S+5}$$

and based on this transfer function the overall operation is carried on in this proposed topology.

Minimizing the overshoot and settling time for conventional system: The optimization algorithm is tailored to fetch an optimized K_p and K_i values for dramatic reduction in overshoot and settling time. The initial set of K_p and K_i values are fed as input to the optimization algorithm and the optimized output is obtained.

Objective function for minimization of Integral Square Error (ISE): The objective of minimizing ISE is to eliminate small errors and the transfer function can be formulated as:

$$F_1(x) = \int_0^\infty |e(t)|^2 dt \quad (1)$$

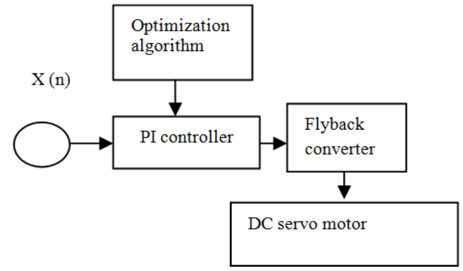


Fig. 1: Block diagram of system model

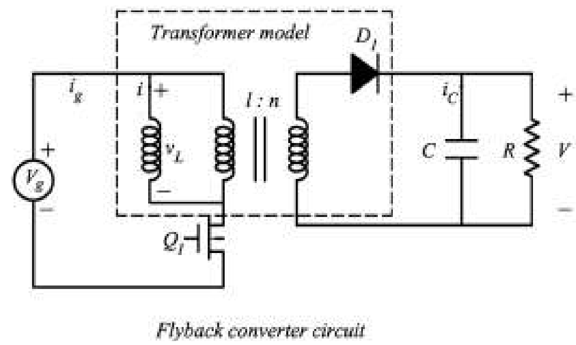


Fig. 2: Typical flyback design

with respect to the constraints $0 <= K_p <= 5$, $0 <= K_i <= 5$ and the fitness function can be evaluated as:

$$Ft_i = \frac{1}{Fi(x)} \quad (2)$$

where, as the particle with better Ft_i values can be further explored.

Particle Swarm Optimization (PSO): The overall process of PSO in PI controller parameter optimization is explained in Fig. 3.

Artificial Bee Colony optimization (ABC): The detailed algorithm for the ABC optimization in obtaining tuned PI controller values can be as follows Algorithm:

Step 1 : Initial the population x_{ij}, where, i = 1, 2, …, SN and j = 1, 2,…, D
Step 2 : Evaluate the Ft_i at each point of the population
Step 3 : Cycle = 1
Step 4 : Produce new candidate solution v_{ij} using Eq. (1)
Step 5 : Evaluate the Ft_i values at each point of v_{ij}
Step 6 : Select the solutions that provide better Ft_i value, i.e., apply the greedy selection process
Step 7 : Evaluate the probability p_i for each eligible solution
Step 8 : Produce new candidate solution v_{ij} using Eq. (2) from the eligible x_{ij}

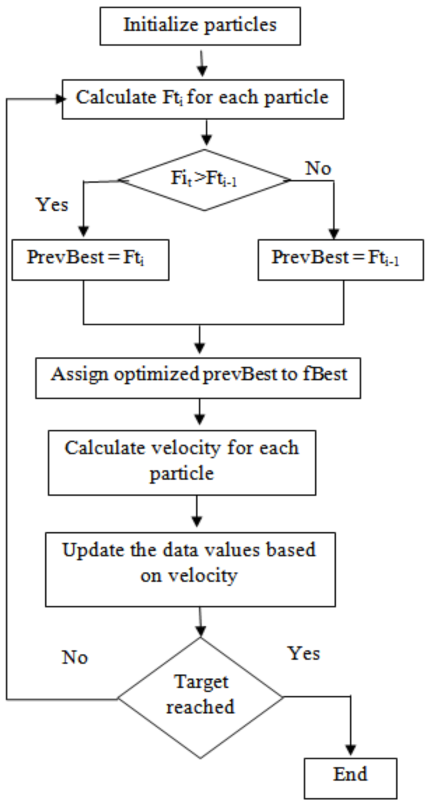


Fig. 3: PSO algorithm in selection of tuned values for PI controller

Step 9 : Evaluate the probability p_i for each eligible solution
Step 10: Replace the abandoned solutions with new possible solutions using Eq. (2)
Step 11: Memorize the best solution obtained so far
Step 12: Cycle = cycle +1
Step 13: Repeat until cycle = MCN

The optimized algorithm discussed above works well in selection of optimized K_p and K_i values for reduction of overshoot and settling time in PI controller and provide speed control in DC Servo motor.

Table 1: Optimized K_p and K_i values

Parameter	PSO	ABC
K_p	1.9	1.76
K_i	9.9	8.81

RESULTS AND DISCUSSION

Simulation model: Figure 4 shows the simulation diagram of the system using MATLAB SIMULINK.

Simulation results:

Flyback converter subjected to an input voltage variation: The optimized algorithm is implemented in MATLAB and the tuned values for the PI controller parameter are obtained. Table 1 shows the tuned values obtained by the optimization techniques.

The input voltage is varied with the set point 6 v and the effectiveness of the controller with respect to overshoot and settling time is studied.

Figure 5 shows the output voltage plotted against time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 v irrespective of the input voltage variation.

Flyback converter subjected to load variations: The flyback converter is subjected to a variation of load from 3 to 6 Ω with the set point 6 v and the effectiveness of the controller with respect to the overshoot and settling time at the time of load variations is studied.

Figure 6 shows the output voltage plotted against time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 v irrespective of a variation of load.

Performance comparison: Comparison has been made between the performance of PSO and ABC from the simulation result and is presented in Table 1.

From Table 2, it can be inferred that the performance of ABC is better than PSO in terms of overshoot and settling time.

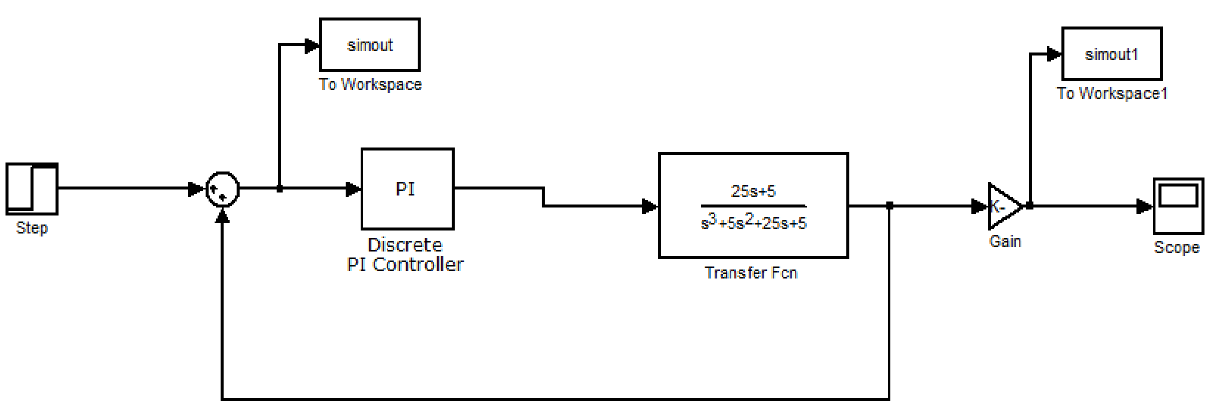


Fig. 4: Software implementation of the system

Table 2: Comparison of PSO and ABC

	PSO		ABC	
Parameter	Input voltage variation	Input load variation	Input voltage variation	Input load variation
Overshoot (volt)	0.3	0.8	0.2	0.6
Settling time (sec)	1.5	1.7	0.9	1.5

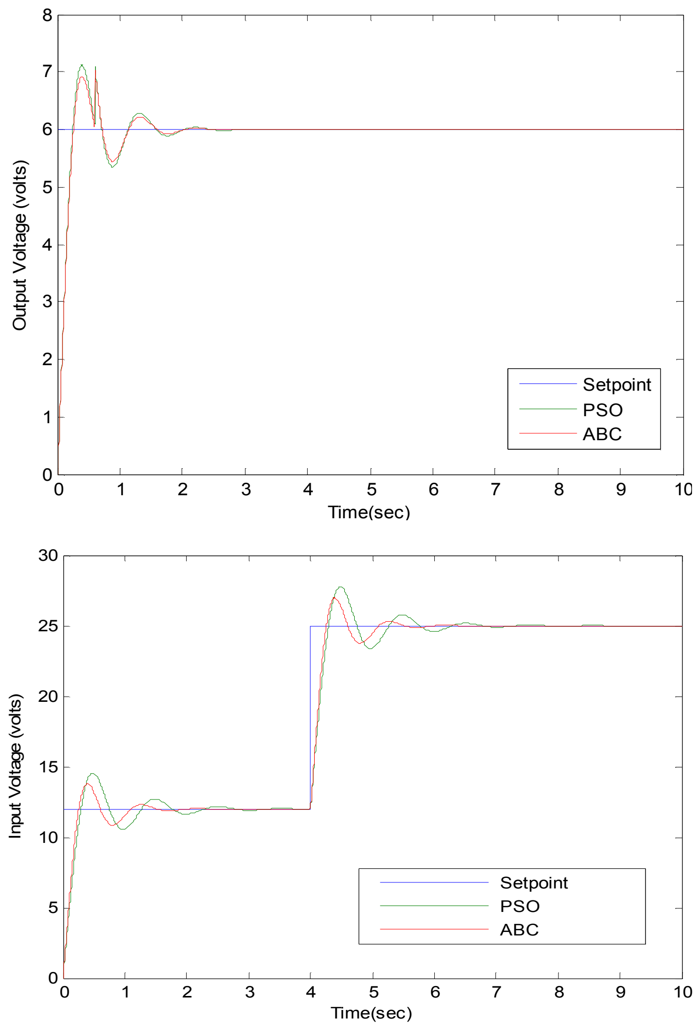
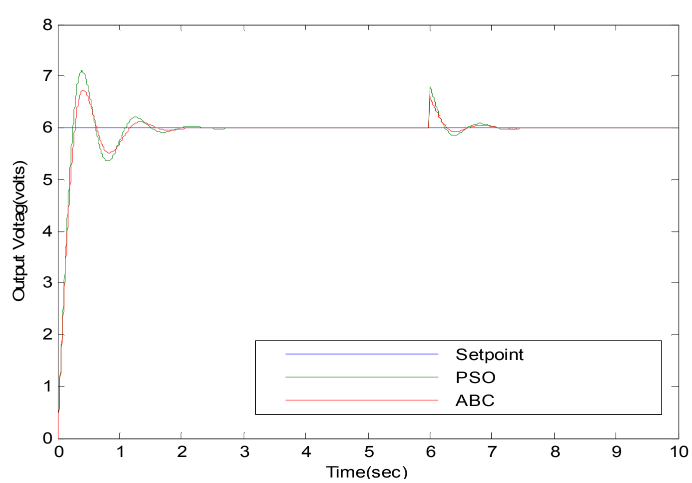


Fig. 5: Performance evaluation of PSO and ABC based on increased input voltage variation



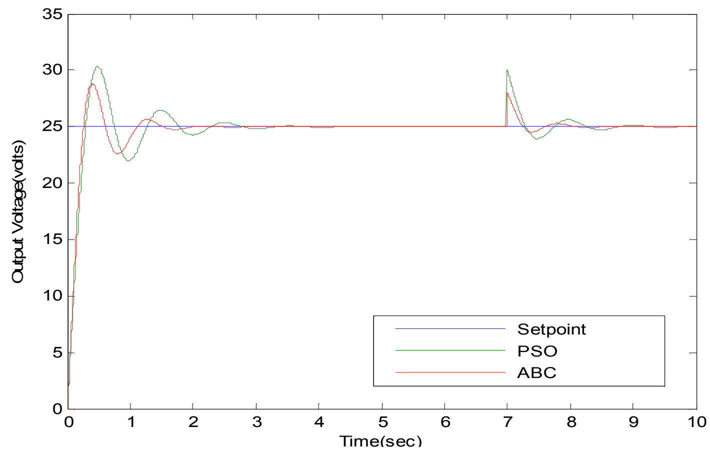


Fig. 6: Performance evaluation of PSO and ABC based on increased load variations

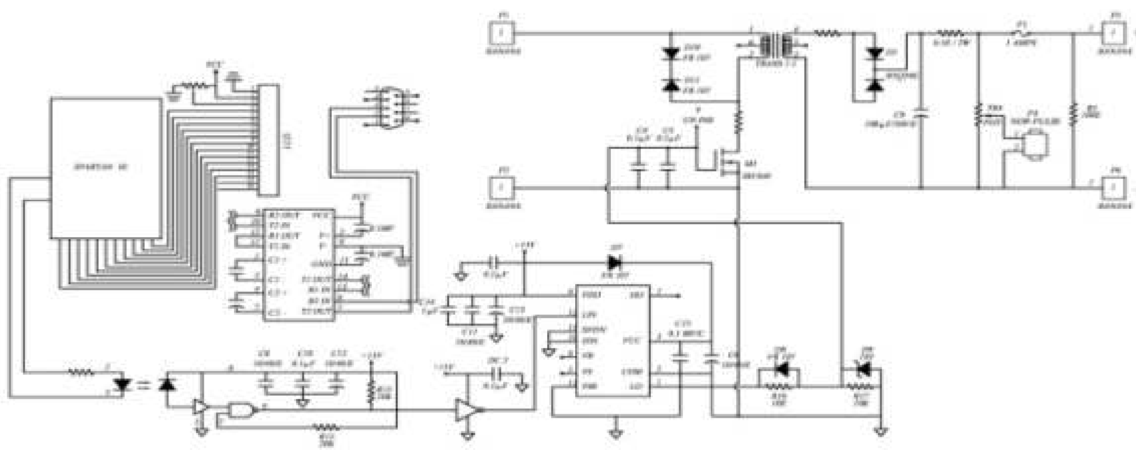


Fig. 7: Hardware implementation of the system

Hardware implementation: The components as well as the circuits used in the design of FPGA based PI controller to drive DC Servo motor drive is shown in Fig. 7.

Hardware result analysis: Experimental investigations have been performed for the various input voltage and load condition to the flyback converter with PI control algorithm implemented using FPGA.

Flyback converter subjected to an input voltage variation: The PI control algorithm is implemented in FPGA based PI controller to drive the actual circuit of the flyback converter with the tuned values of K_p and K_i obtained by PSO and ABC. The input voltage is varied from 1 to 4 v. The set point of the output voltage is 6 v. The effectiveness of the controller with respect to overshoot and settling time is studied.

Figure 8 shows the output voltage plotted with respect to time. It is found that the controller acts very effectively and maintains the constant output voltage of 6 v irrespective of the input voltage variation. The peak overshoot voltage at the time of input voltage variation is 60% and the settling time is 90 msec.

Figure 9 shows the variation of output voltage vs. time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 v, irrespective of a variation of input voltage from 2 to 4.2 v. The peak overshoot voltage at the time of input voltage variation is 10% and the settling time is 75 msec.

Flyback converter subjected to load variations: The flyback converter is subjected to a variation of load from 3 to 6 Ω both in an increasing and decreasing manner. The effectiveness of the controller with respect to the overshoot and settling time at the time of load variations is studied.

Figure 10 shows the variation of output voltage vs. time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 v, irrespective of variation of the load from 3 to 6 Ω. The peak overshoot at the time of load variation is 20% and the settling time is 150 msec.

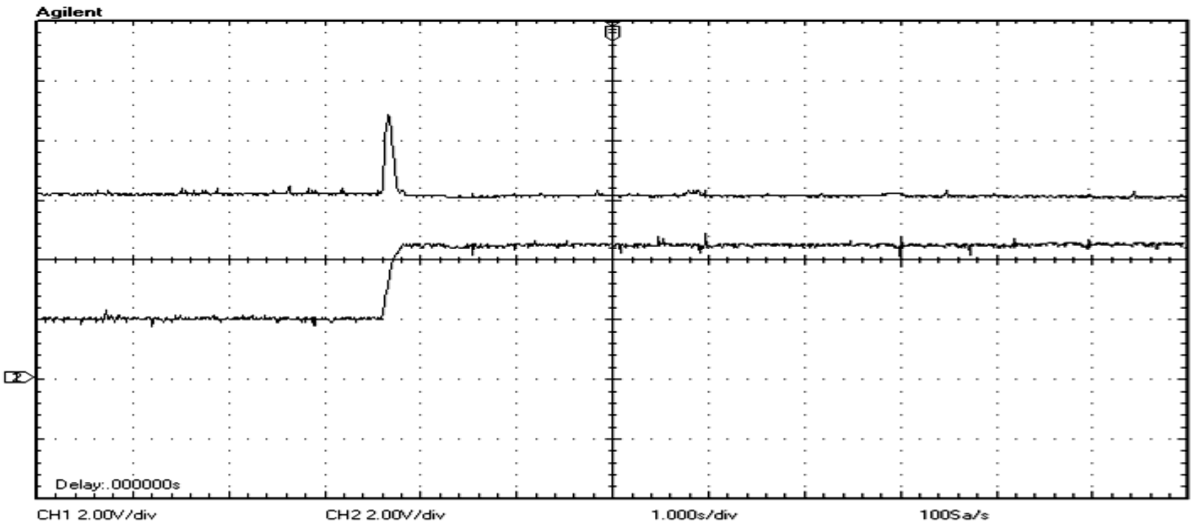


Fig. 8: Input voltage variation with K_p and K_i obtained from PSO

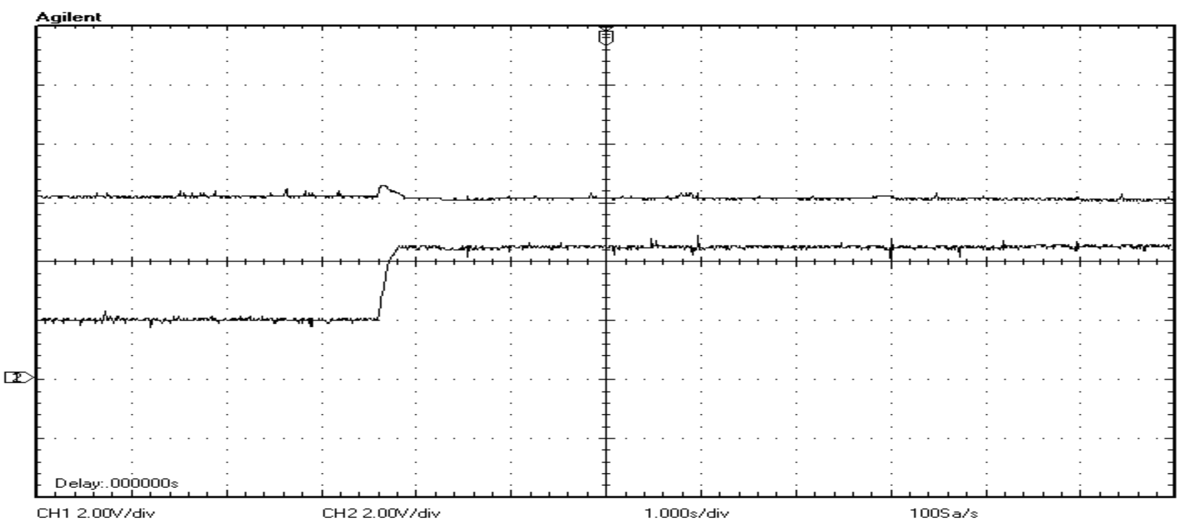


Fig. 9: Input voltage variation with K_p and K_i values obtained from ABC

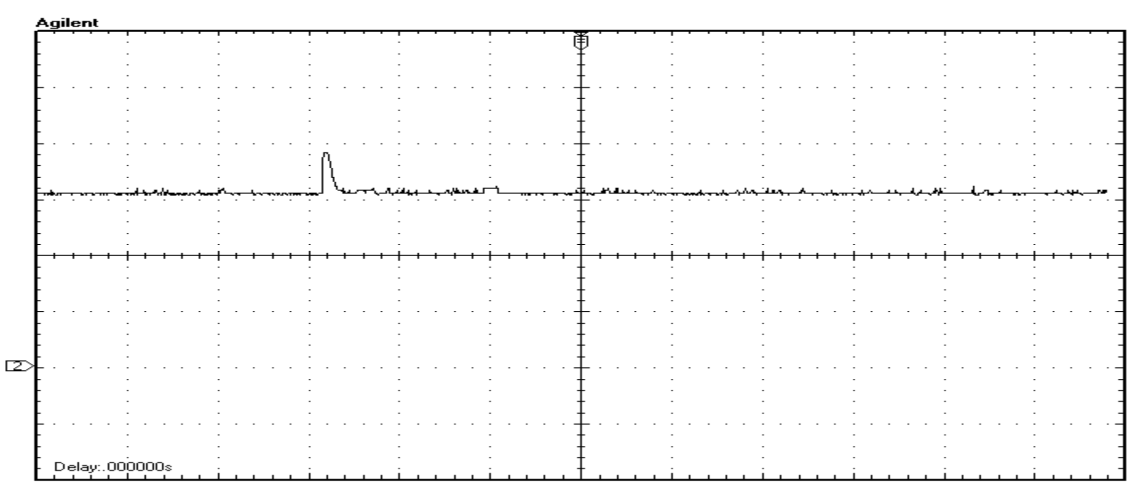


Fig. 10: Input load variation with K_p and K_i obtained from PSO

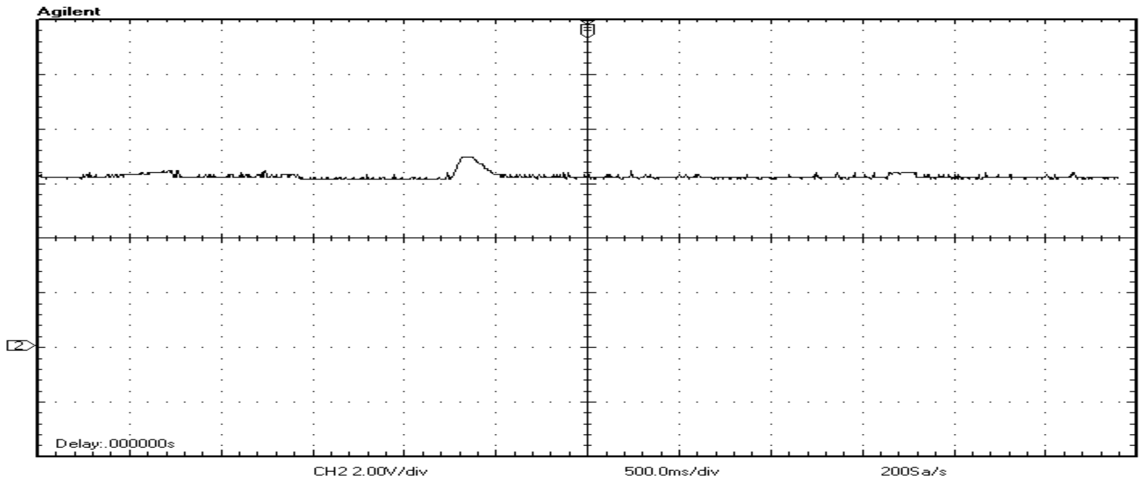


Fig. 11: Input load variation with K_p and K_i obtained from ABC

Table 3: Performance evaluation of PI control algorithm

	PSO		ABC	
Parameter	Input voltage variation	Input load variation	Input voltage variation	Input load variation
Overshoot (volt)	60%	20%	10%	40%
Settling time (msec)	90	150	40	100

Set point = 6 v

Figure 11 shows the output voltage vs. time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 v irrespective of the variation of load from 3 to 6 Ω. The peak over shoot at the time of load variation is 40% and the settling time is 100 msec.

Performance evaluation: From the hardware result analysis, the performance of PI control algorithm implemented in FPGA for minimization of overshoot and settling time with different optimized PI controller parameter values obtained from PSO and ABC are discussed in Table 3.

By implementing the above topology the performance of flyback converter increased and it works effectively in electrical equipments.

CONCLUSION

In this study an efficient design method for determining the PI controller parameters of a flyback converter driven DC Servo motor by using PSO and ABC method is presented. In order to emphasize the advantages of proposed method, the result are compared with conventional controller. Through the simulation result, it is shown that the proposed method is able to obtain the optimal PI controller parameter to achieve better performance. The comparison result shows that ABC tuned controller yields better result in terms of overshoot and settling time than PSO. The hardware result also shows that the same tuned PI controller parameter values obtained from PSO and ABC give better performance and ABC yields better than PSO in overshoot and settling time reduction.

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