Optimal Performance Analysis of Boost Converter fed DC Drive with Optimized PI Controller

G. Ramu, Umme Salma, Ch Dharma Raj

***Abstract*: In this paper, an attempt has been made to highlight the importance of optimizing parameters of PI controller to control the speed of DC drive fed by the boost converter. In this paper, the designing procedure of boost converter is presented to minimize the switching losses. The effectiveness is examined in open loop and closed loop operations. The conventional DC motor and brushless DC motors speed can be controlled to a preset value by choosing the appropriate control parameters using effective algorithm. In this, the objective function formulated is based on the performance times. The stated hypothesis is verified using necessary diagrammatical and numerical results.**

***Index Terms*: Optimal boost converter; Tuning PI controller parameters; brushed DC drive; brushless DC drive; Speed control of dc drive.**

I. INTRODUCTION

There are numerous converter topologies to obtain the required control operation [1]. Boost converter is used to increase the output voltage level by changing the switching operations of the converter. The duty cycle plays major role in changing the output voltage level [2]. There are some methodologies used to manage the stability using pole placement techniques [3].

Boost device is also a DC-DC increase device accustomed increase the output voltage by dynamic shift frequencies of the device switches. These 2 basic processes of energy absorption and injection represent a shift cycle [2]. Some management ways have specific the matter of management through pole placement [3]. The static and dynamic performance of the converter is enhanced using different controllers in feedback system. Commonly used controllers are proportional and integral controllers [4]. The gains of these controllers are optimized in order to maximize the system performance. A breadth first (BF) algorithm is used in [5] to optimize the PI controller gain values. It is a nature inspired algorithm and powerful tool to solve constrained optimization problem. Due to this, the time of computation is decreased as speed of convergence is increased [6]. A particle swarm optimization based controller is developed in [7] to optimize the controller gain parameters.

By taking advantage of optimization, in this paper, a new methodology based on PSO is implemented. The remaining paper is organized as follows: The basic circuit diagrams along with modes of operation are explained in section-2, schematic diagrams and design parameters are explained in sections 3 and 4. The developed implementation methodology, PSO algorithm and obtained results are depicted in sections 5 to 7. At last, paper concluded in section-8 with directions for future work.

II. BASIC CIRCUITS OF BOOST CONVERTER FED DC DRIVE

In open loop control system, the effect of boost converter is analyzed on a given DC drive by connecting them in series as shown in Fig.1.

Fig.1 Block diagram of proposed open loop boost fed DC drive

The effect of closed loop boost converter driven DC drive is shown in Fig.2.

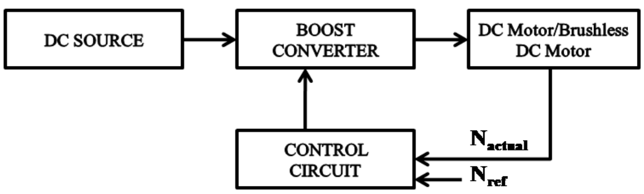

Fig.2 Block diagram of proposed closed loop boost fed DC drive

The DC motor speed can be controlled by changing converter input appropriately. The actual speed is can be made to required speed by changing the respective duty ratio of the converters.

The boost converter basic circuit is shown in Fig.3. It is equipped with two non-linear elements. One inductor connected in series with supply and one capacitor connected in parallel to the load. The basic configuration consist one MOSFET switch with the support of parallel

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connected diode.

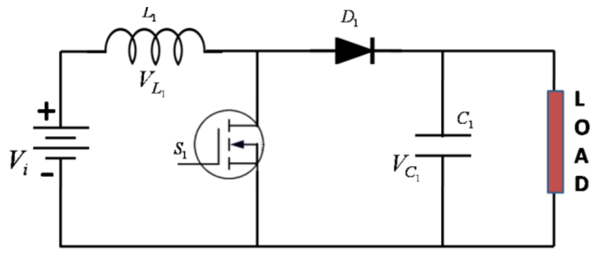


Fig.3 Basic circuit diagram of boost converter

The basic circuit of boost converter is shown in Fig.4. It is also equipped with two non-linear elements. One inductor and one capacitor connected in parallel across the supply and load respectively. The basic configuration consist one MOSFET switch connected in series with the supply.

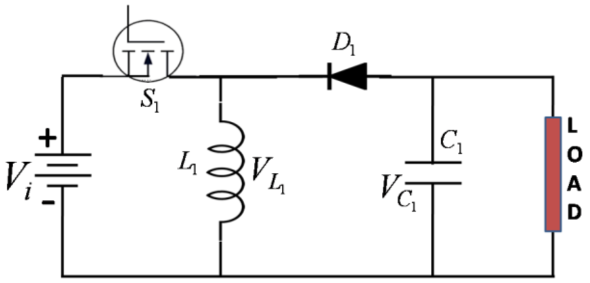


Fig.4 Basic circuit diagram of boost converter

III. SCHEMATIC DIAGRAM OF BOOST CONVERTER FED DC DRIVE

The schematic diagram of the boost fed DC drive is shown in Fig.5.

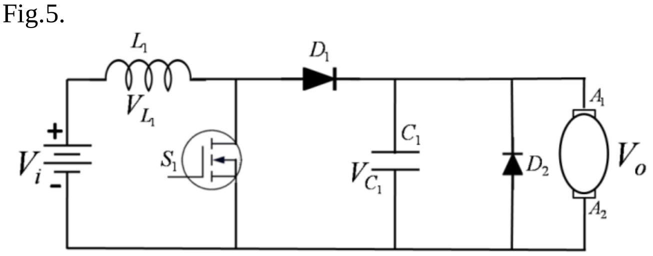
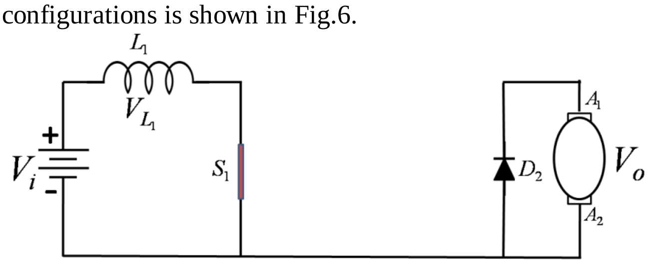
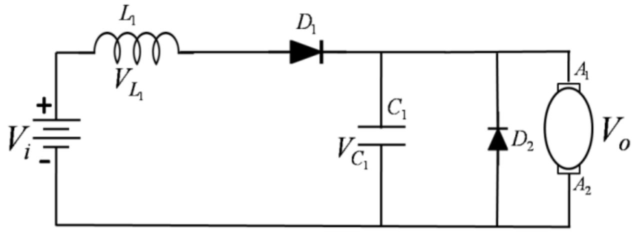


Fig.5 Schematic diagram of boost converter fed DC drive

There are two modes of operation based on switching operation of MOSFET switch. The series inductor is charged when switch is closed and it starts discharging through diode D1 when switch is opened. The schematic representation of configurations is shown in Fig.6.



(a) when switch is closed



(b) when switch is opened

Fig.6 Configuration of boost fed DC drive based on switching operation

IV. DESIGN PARAMETERS OF BOOST CONVERTERS

Comparatively, the output voltage in continuous and discontinuous modes of operations can be expressed as follows:

Mode of operation	Boost converter
Continuous conduction mode	$V_o = \left(\frac{1}{1-D}\right)V_i$
Discontinuous conduction mode	$V_o = \left(1+\frac{V_i D^2 T}{2L_1 I_o}\right)V_i$
Inductor value	$L_1 = \frac{V_i D}{f\Delta\Delta}$
Capacitor value	$C_1 = \frac{D}{2f_r R}$
Percentage ripple	$\%\,\text{Ripple} = \frac{\text{Change in parameter value}}{\text{Mean parameter value}}\times 100 = \frac{\text{Max. value} - \text{Min. value}}{\text{Mean value}}\times 100$
Angular velocity	$\omega = \frac{2\pi N}{60}$
Torque	$T = \frac{P_m}{\omega}$

Where, 'T' is the total time period, 'D' is the duty ratio of the converter, Io is the output current.

V. IMPLEMENTATION METHODOLOGY

A. Optimization problem

The optimization problem is formulated to identify a set of optimal control parameters/variables to optimize the system performance subjected to satisfying system constraints. These constraints may be equality and/or inequality constraints. This optimization problem can be mathematically expressed as

$$\text{Minimise } f(x,u)$$
$$\text{Subject to } g(x,u) = 0;\ h(x,u) \le 0$$

where

u : a set of control parameters
x : a set of state parameters
g(x,u) : Considered equality constraints
h(x,u) : Considered in-equality constraints

For this, system transfer function is formulated by converting

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ordered differential equation into linear model using "linmod" in MATLAB

without closed loop

$$\frac{-9.31e12\, s^2 - 1.028e16\, s - 2.082e17}{5.788e14\, s - 4.031e17}$$

For this system, closed loop is provided using PI controller which has transfer function

$$\frac{Kp\, s + Ki}{s}$$

Inequality constraints considered for this problem are Kp ranges → [0 0.4] and Ki ranges → [0 5].

Here, we are using Hybrid Cuckoo search algorithm.

B. Objective function

The objective function in this paper is formulated as

f(x,u)= min(Rise time)+min(Settling time)+min(Peak time)

This objective function enhances the system performance to obtain the required speed. This problem is solved using PSO method explained in next section.

VI. PARTICLE SWARM OPTIMIZATION

The fundamental PSO algorithm is developed by Kennedy in 1995. This is a nature inspired algorithm by considering the behaviors of fish schooling and birds flocking. This a kind of swarm intelligence based technologies used to solve constrained optimization problems. The basic flow chart of this method is shown in Fig.1.

At first, this method is developed for two variables problem and later on it is extended to multi dimensional search space problems.

In this method, each control variable/particle is maintained with certain speed and moves in solution search space. After performing algorithmic operation, new velocity is calculated. Using this, the new position of the control variables is calculated. Out of this, the local best and global best positions and respective objective values are identified.

This can be formulated as an equation:

$$V_{ij}^{(iter+1)} = w.V_{ij}^{iter} + c_1.rand_1.\left(Pbest_{ij} - P_{ij}^{iter}\right) + c_2.rand_2.\left(Gbest_{ij} - P_{ij}^{iter}\right)$$

$$P_{ij}^{(iter+1)} = P_{ij}^{iter} + V_{ij}^{iter}$$

where

i = 1, 2,...., P and j = 1, 2,......, N

N	:	No. of iterations
P	:	No. of control parameters
W	:	Weight factor
C1,C2	:	Chaotic constants considered to be equal
rand1,rand2	:	random values generated between 0 and 1.
V_{ij}^{iter+1}	:	New velocity of ith particle in jth dimension.
P_{ij}^{iter}	:	Present position of ith particle in jth dimension

In this process, the inertia weight is deceased make issue w is rising performance in looking for optimum resolution. Its worth is decreased linearly from concerning wmax to wmin throughout the method. Appropriate choice of the load provides a balance between international and native search, associate degreed leads to less iteration to search out an optimum resolution. Its worth is ready consistent with the subsequent equation.

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}}$$

where

w_{max} : Maximum inertia weight

w_{min} : Minimum inertia weight

$iter_{max}$: Total number of iterations

Iter : Present iteration number

The basic flow chart of the PSO algorithm is shown in Fig.7.

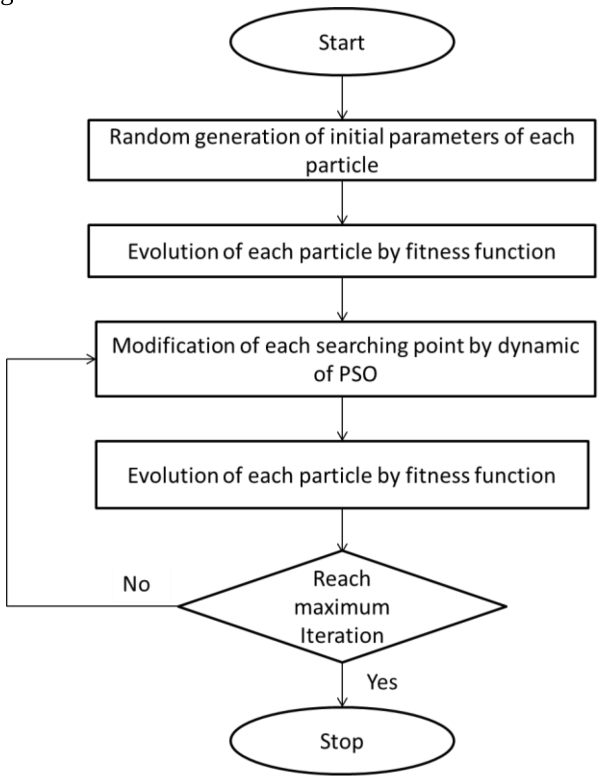


Fig.7 General flow chart of PSO

After executing PSO, the global best Kp and Ki values are placed in closed loop boost fed brushed/brushless DC drive and simulation is carried out.

VII. RESULTS AND ANALYSIS

To analyze the effect of operation of boost converter on the system performance such as output voltages, input and output currents, output power, speed and torque are analyzed.

Case-1: Performance of boost converter (open loop) on Brushed DC motor.

Case-2: Performance of boost converter (closed loop) on Brushed DC motor.

Case-3: Performance of boost converter (open loop) on Brushless DC motor.

Case-4: Performance of boost converter (closed loop) on Brushless DC motor.

To show the effectiveness of the proposed methodology is analyzed in terms of output voltage, input and output currents, output power, speed and torque for the given input voltage.

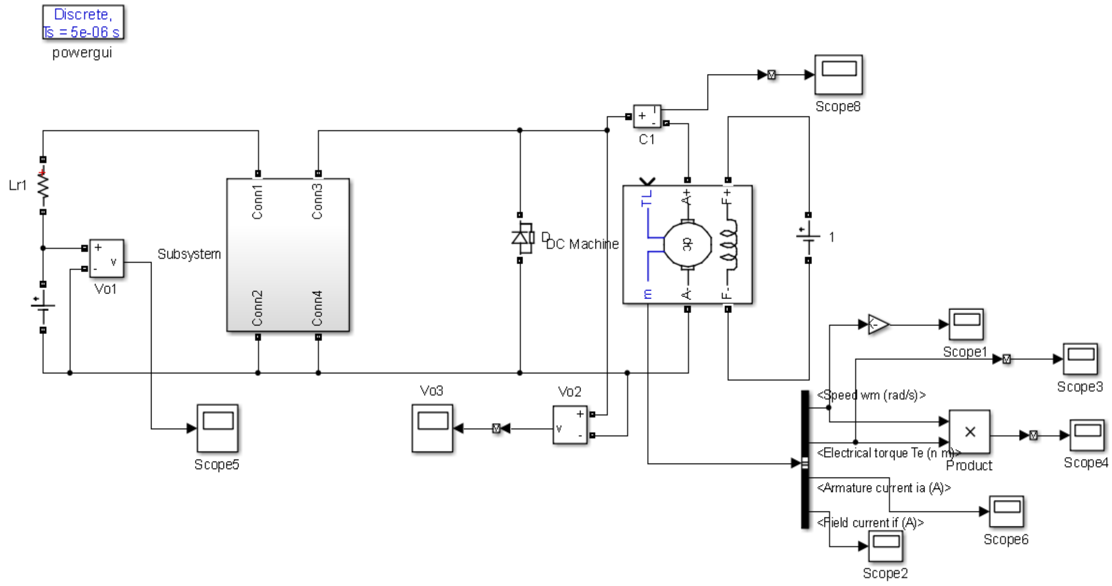
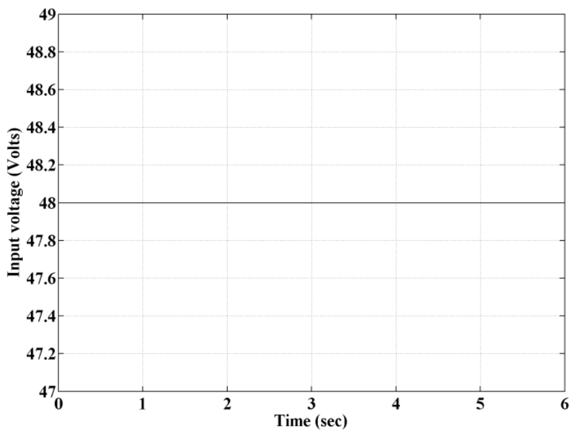
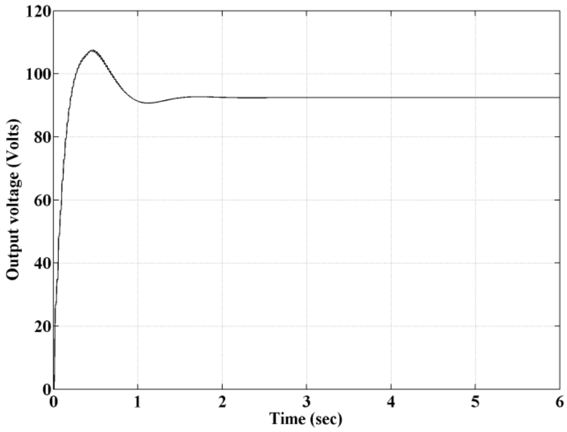


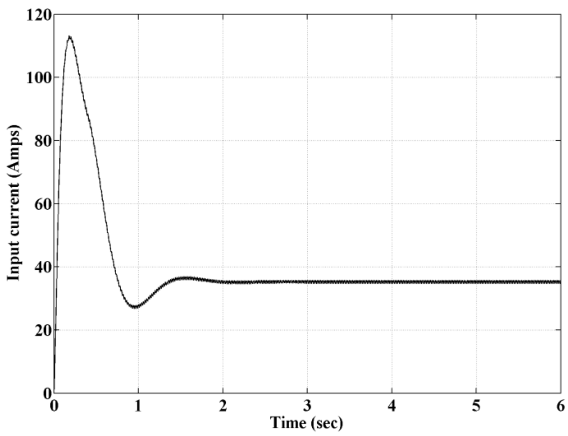
Fig.8 Open loop boost converter fed brushed DC drive



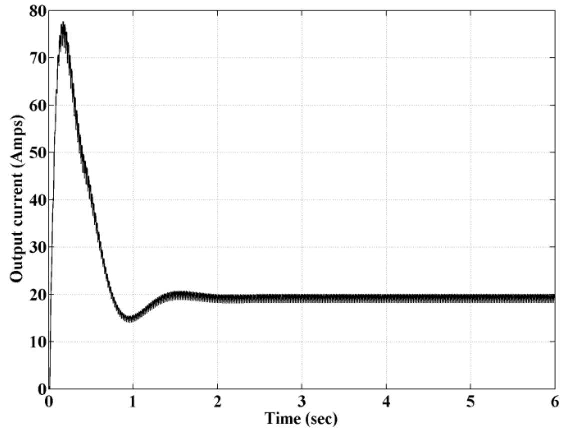
(a) Input voltage



(b) Output voltage



(c) Input current



(d) Output current

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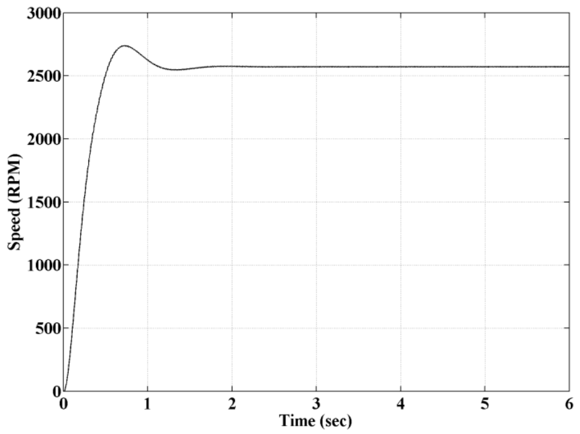
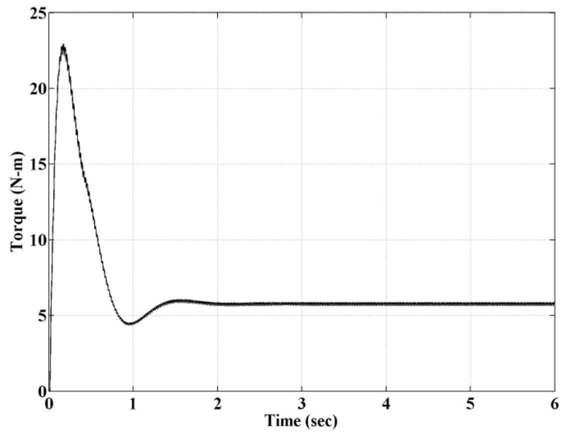
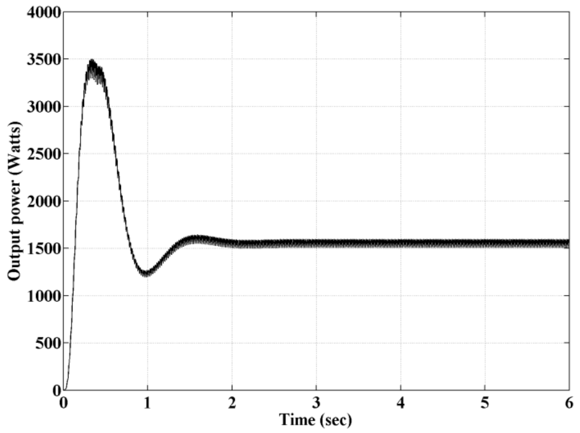


(e) Speed



(g) Torque

Fig.9 Performance parameters of open loop boost converter fed brushed DC drive



(f) Output power

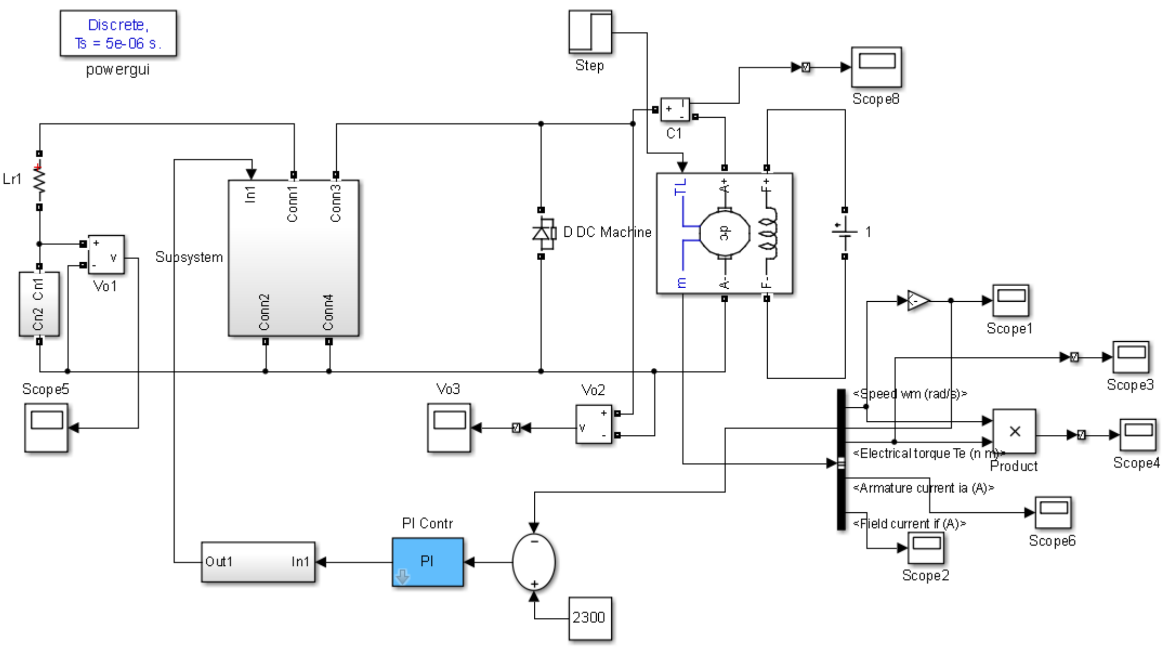


Fig.10 Closed loop boost converter fed brushed DC drive

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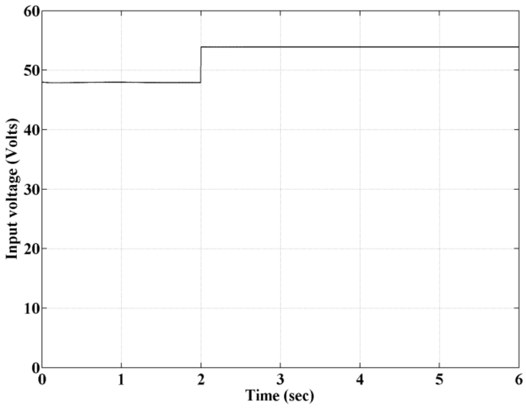
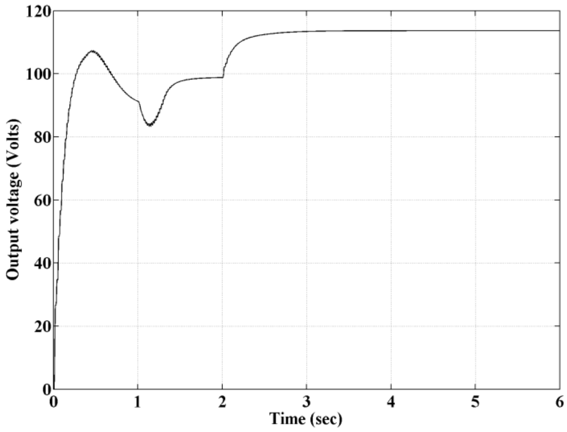
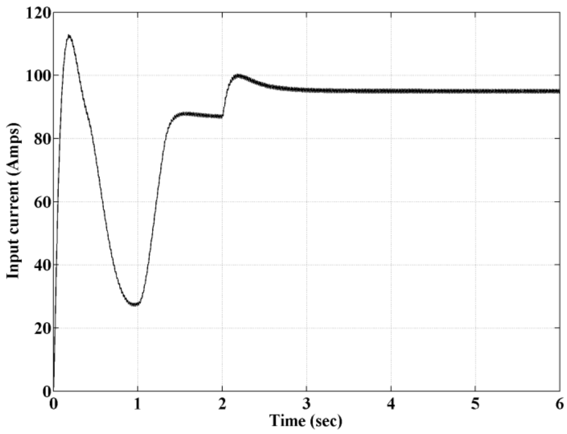


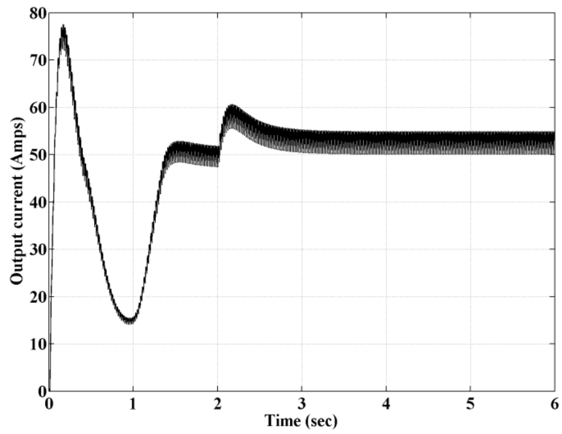
(a) Input voltage



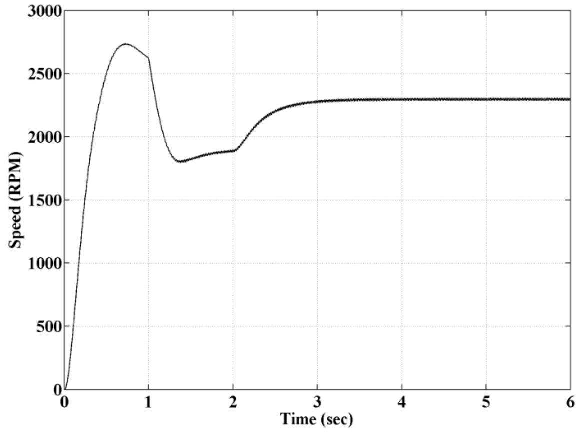
(b) Output voltage



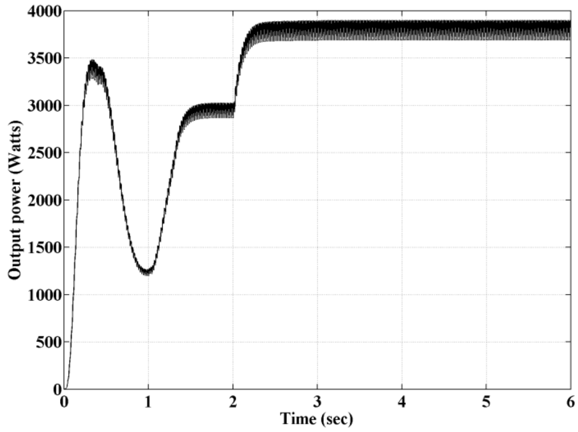
(c) Input current



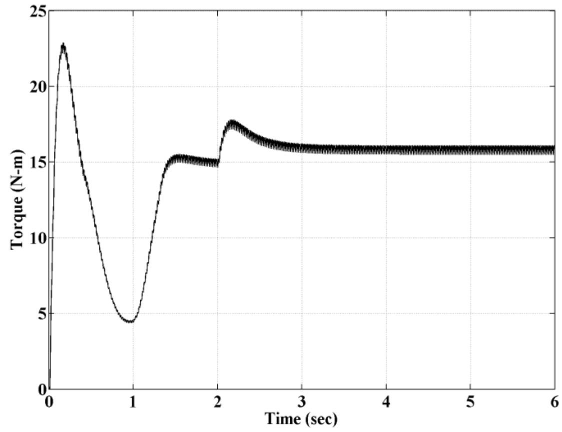
(d) Output current



(e) Speed



(f) Output power



(g) Torque

Fig.11 Performance parameters of closed loop boost converter fed brushed DC drive

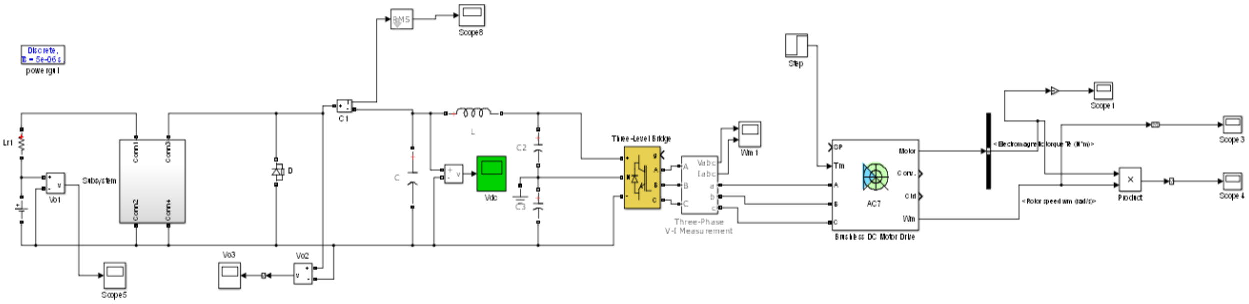
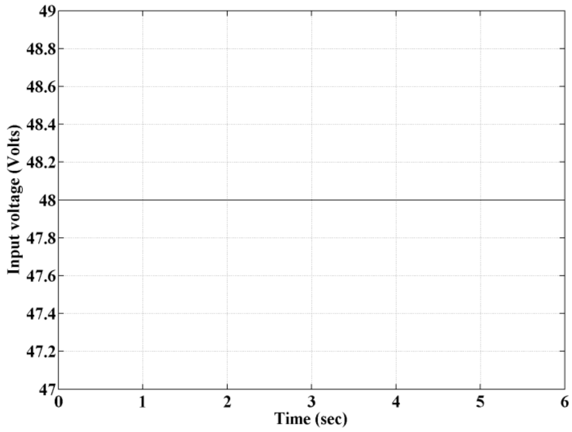
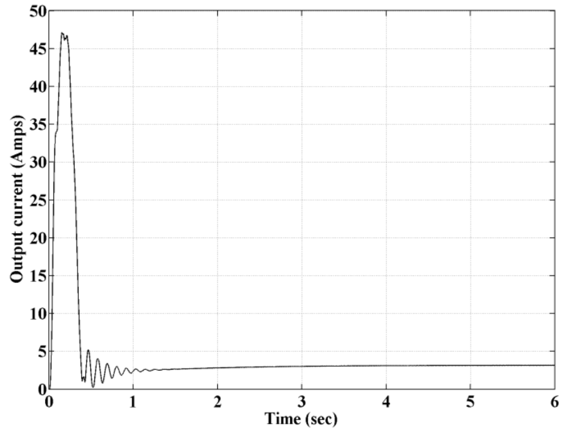


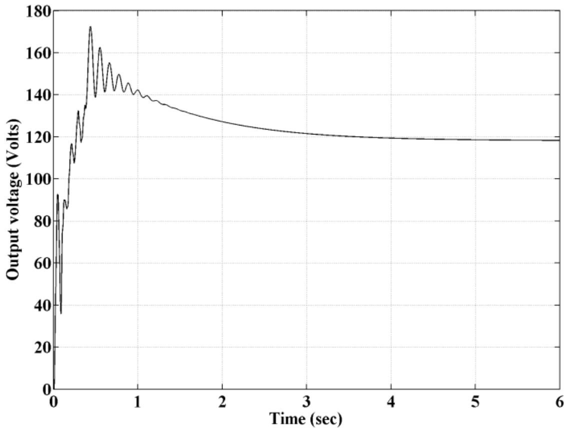
Fig.12 Open loop boost converter fed brushless DC drive



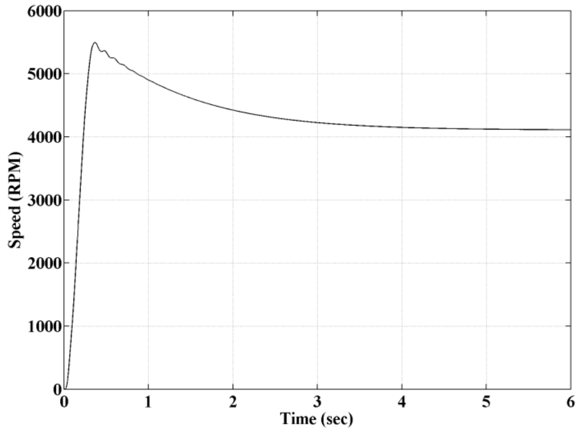
(a) Input voltage



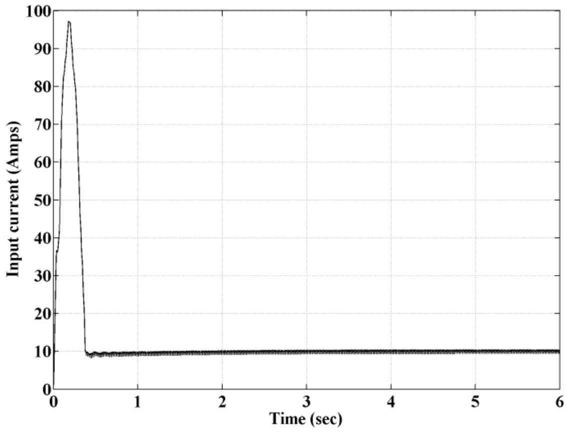
(d) Output current



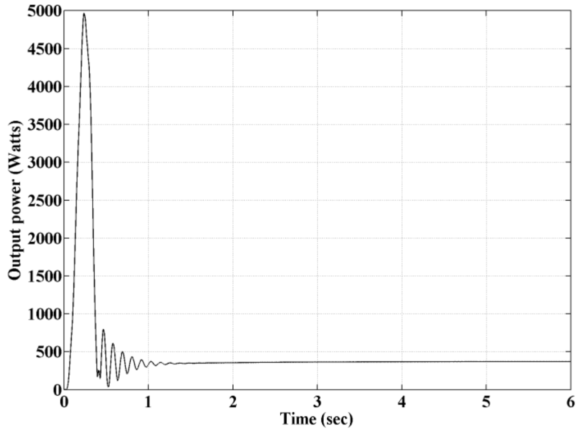
(b) Output voltage



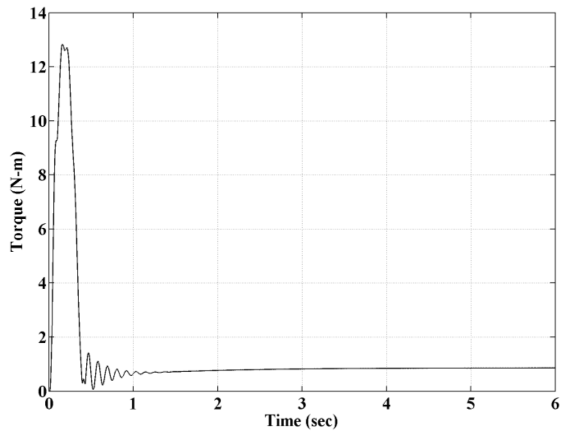
(e) Speed



(c) Input current



(f) Output power



(g) Torque

Fig.13 Performance parameters of open loop boost converter fed brushless DC drive

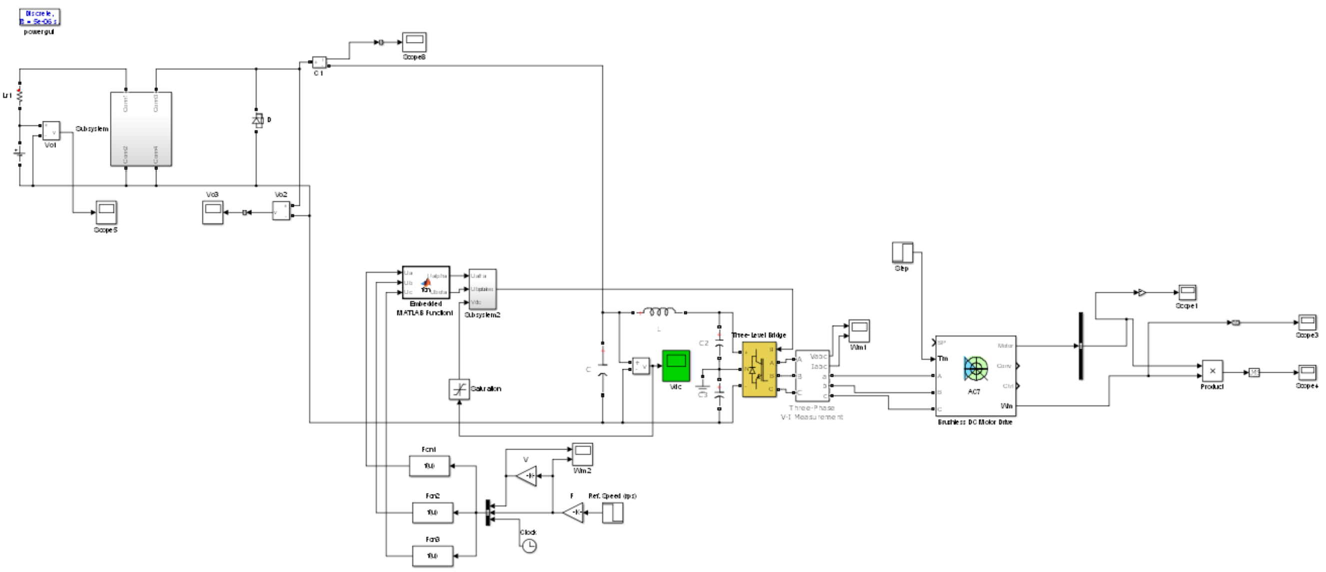
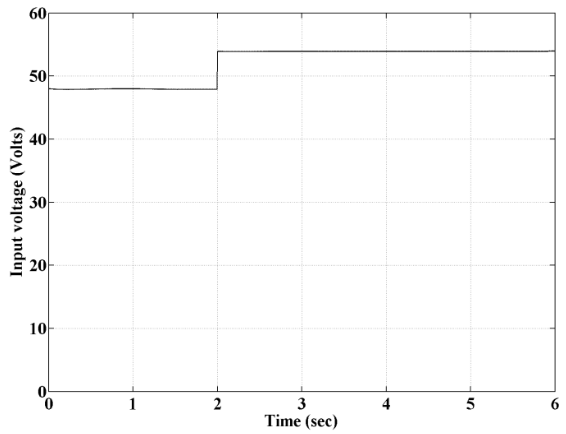
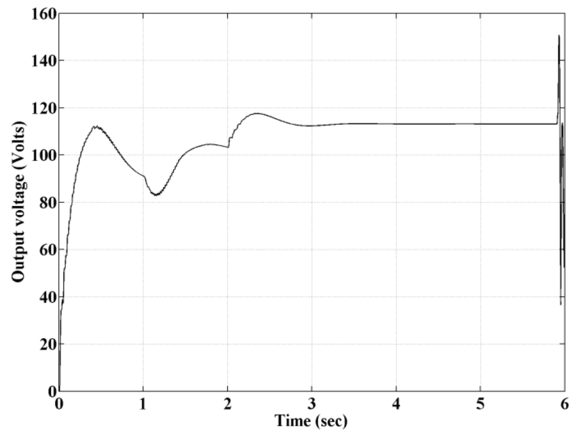


Fig.14 Closed loop boost converter fed brushless DC drive



(a) Input voltage



(b) Output voltage

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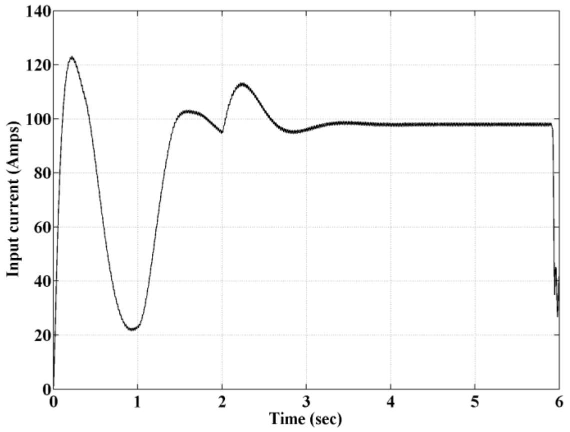
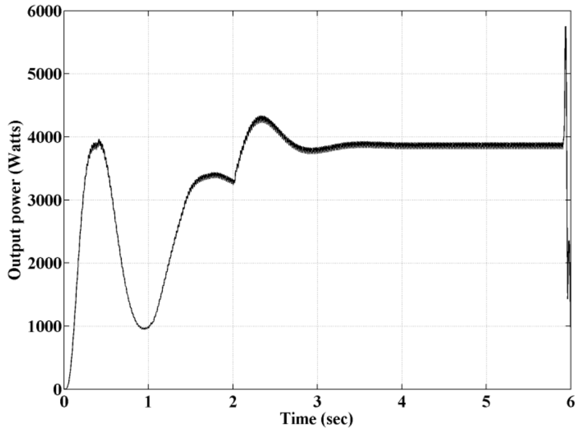
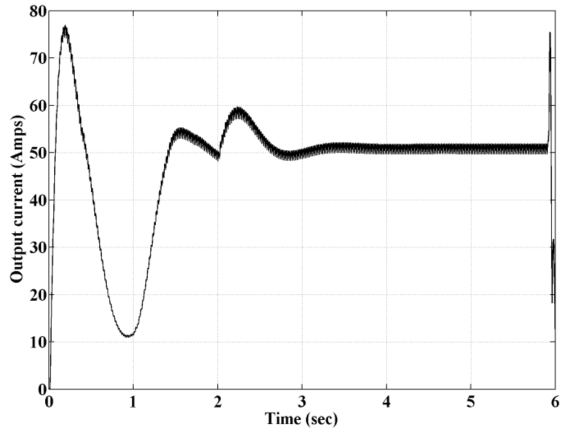


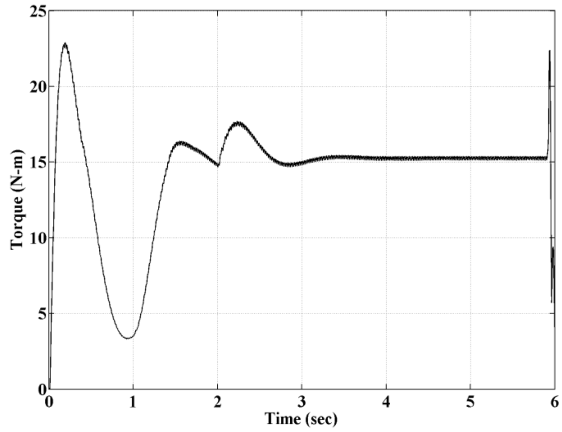
(c) Input current



(f) Output power

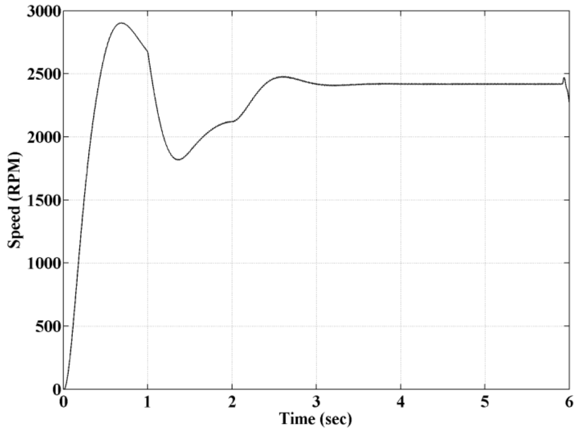


(d) Output current



(g) Torque

Fig.15 Performance parameters of closed loop boost converter fed brushless DC drive



(e) Speed

Table.1 Numerical results of performance parameters of Boost converter fed DC drives

Parameters	Brushed DC motor				Brushless DC motor			
	Open loop		Closed loop		Open loop		Closed loop	
	Actual	Ripple	Actual	Ripple	Actual	Ripple	Actual	Ripple
Output voltage (Volts)	92.45	0	113.66	0	118.38	0.09	93.73	0.01
Input current (Amps)	35.25	2.97	95.01	1.42	9.92	1.05	9.27	1.47
Output current (Amps)	19.14	9.31	52.47	9.19	3.15	1.26	4.28	1.52
Speed (RPM)	2571.52	0.28	2296.87	0.85	2114.88	0.1	2369.06	0.19
Torque (N-m)	1549.92	5.6	3795.91	5.52	3201.41	0.73	3277.53	0.51
Output power (Watts)	5.76	3.73	5.8	3.68	8.59	0.59	12.88	0.48

Identifications

- With less input current rated speed can be achieved using brushless DC motor.
- Torque developed is high with brushless motor.

VIII. CONCLUSIONS

In this paper, a methodology to optimize parameters of PI controller has been presented to control the performance parameters of boost converter fed DC drive. Here, the performance has been analyzed on both brushed and brushless DC drives. The parameters of PI controller have been optimized so as to maximize the system performance in terms of various time constants. The simulation has been performed for the four cases and the obtained graphical and numerical results have been presented. This type of analysis can be extended for the different load levels, ramp loads and can be extended for different converters like, buck-boost, sepic, etc.

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