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Speed Control of BLDC Motor Using Fractional Order PID Controller

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ABSTRACT: A closed loop speed control of Brush Less Direct Current (BLDC) motor with Fractional order PID (FOPID) controller runs the motor very close to the reference speed, provides a good performance and robustness compared with a corresponding system using conventional PID controller. This paper presents a BLDC motor drive with FOPID controller using PWM technique and back EMF technique. The effectiveness of the proposed controller is verified through simulation and there results are compared with a conventional PID controller.

KEYWORDS: BLDC motor, FOPID controller, simulation, pulse width modulation (PWM).

I.INTRODUCTION

BLDC motors are widely used in applications such as robotics and automation, electric vehicle and military drive systems. They have many advantages over brushed DC motors and induction motors, such as a better speed versus torque characteristics, high efficiency and reliability, long operating life (no brush erosion) and higher speed ranges.
The BLDC motor is energized by three phase inverter whose switches are exited based on the rotor position information obtained from the hall sensors, resolvers or absolute position encoders. The control of BLDC motor can be done on sensor or senor less mode. Sensor less control is more reliable and cheaper. There are different sensor less control technique developed for BLDC motor. Some of the technique presented [1][4][5] in the literature are based on position sensing using back EMF zero detection crossing, terminal voltage sensing, sensing third harmonics of the motional EMF integration of the back EMF, Extended Kalman filter estimation.
The controllers like PI, PID, FOPID, fuzzy logic controllers etc are presented [2][6] in the literature are used in the closed loop speed control of the BLDC motor. FOPID and fuzz logic controller improves the overshoot, the rising time, settling time, steady state error, provides more flexibility and robust stability compared to other controllers.
Different PWM techniques like Sinusoidal, multiple sinusoidal, 60^{o} modulation etc. are available in literature [1][9] of which sinusoidal PWM technique is used for the speed control of BLDC motor, because it is easy and less time consuming.
This paper presents a BLDC motor drive with FOPID controller using PWM technique and back EMF technique. The effectiveness of the proposed controller is verified through simulation and there results are compared with a conventional PID controller.
The organization of this paper is as follows. Section II describes the proposed drive system. Section III describes the control strategy of the closed loop speed control. Section IV describes about FOPID controllers. Section V presents the simulation results of the proposed method. Section VI presents the conclusion.

II. PROPOSED DRIVE SYSTEM

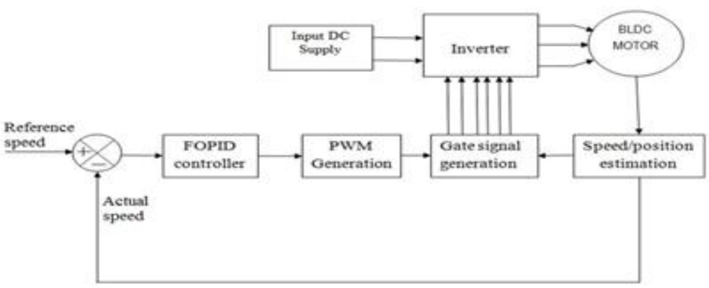

Fig. 1 Proposed drive system

Fig 1 given above is the block diagram of the proposed drive system for the precision speed control of a BLDC motor. The drive system mainly consists of a BLDC motor, three phase inverter and a controller. A closed loop is used to control the speed where the actual speed is measured using a speed encoder and compared with the reference speed to find the error signal and the error signal is supplied to the FOPID controller.
The controller output is compared with the reference signal to generate PWM signal. The rotor position is found out by back EMF method which is explained in later section Control Strategy. PWM signal along with the position signal generate required gate signal which provide proper commutation for inverter. The output of the inverter controls the speed of the BLDC motor and thus implements our aim.

III. CONTROL STRATEGY

BACK EMF FROM TERMINAL VOLTAGE

The BLDC motor is driven by a three phase inverter in which the devices are excited according to the rotor position. The stator three phase voltage equations can be written as

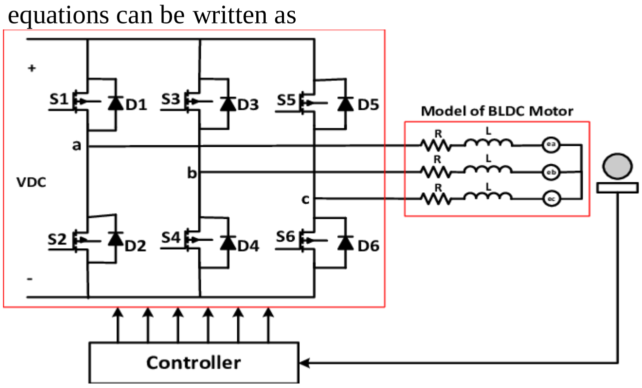

Fig. 2 Equivalent circuit of BLDC motor drive

$$V_a = i_a R + L\frac{di_a}{dx} + e_a \quad (1)$$
$$V_b = i_b R + L\frac{di_b}{dx} + e_b \quad (2)$$
$$V_c = i_c R + L\frac{di_c}{dx} + e_c \quad (3)$$

Where V_a, V_b and V_c are the terminal voltages.
i_a, i_b and i_c are the input current.
e_a, e_b and e_c are the back EMF.
R is the terminal resistance
L is the stator self inductance per phase

From the above equation

$$V_{ab} = V_a - V_b = R(i_a - i_b) + L\frac{d(i_a - i_b)}{dt} + (e_a - e_b) \quad (4)$$
$$V_{bc} = V_b - V_c = R(i_b - i_c) + L\frac{d(i_b - i_c)}{dt} + (e_b - e_c) \quad (5)$$
$$V_{ca} = V_c - V_a = R(i_c - i_a) + L\frac{d(i_c - i_a)}{dt} + (e_c - e_a) \quad (6)$$

Taking the difference of terminal voltages measured,

$$V_{abbc} = V_{ab} - V_{bc}$$
$$= R(i_a - 2i_b + i_c) + L\frac{d(i_a - 2i_b + i_c)}{dt} + (e_a - 2e_b + e_c) \quad (7)$$

Considering the time interval where phases A and C are conducting and phase B is open. In this time interval, phase A winding is connected to the positive terminal of the dc supply, phase C is connected to the negative terminal of the dc supply and phase B is open. Therefore, i_b=0 and i_a=i_c. V_{abbc} can e written as

$$V_{abbc} = V_{ab} - V_{bc} = e_a - 2e_b + e_c = -2e_b \quad (8)$$

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So, V_{abbc} gives phase B back EMF
Similarly V_{bcca} gives phase C back EMF and V_{bcca} gives phase A back EMF. Therefore, the back EMF waveforms can be estimated indirectly from the three terminal voltages of the motor

GATE SIGNAL FROM BACK EMF

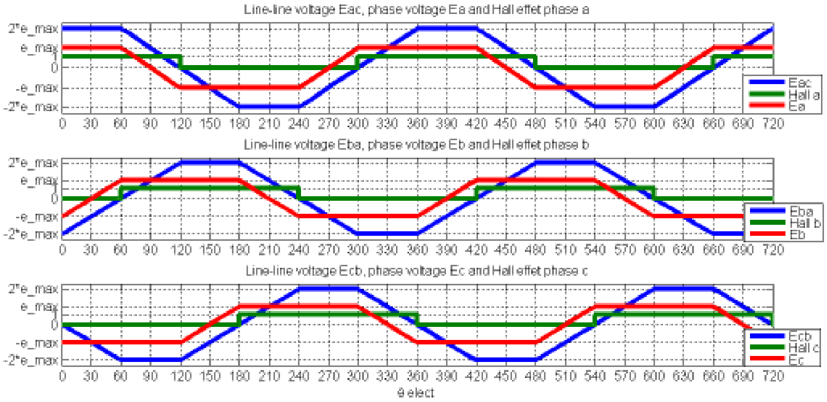

Fig. 3 Line voltage, phase voltage and hall signal

According to the back EMF zero crossing detection method zero crossing of line to line back EMF gives the commutation instant. Line to line back EMF is obtained by taking the difference of phase back EMF. Using this idea hall signal is obtained from the line to line back EMF by comparing it with zero. If the value of line back EMF is greater than zero, then Hall output is '1' else Hall output is '0'.
The function of the inverter is to excite the BLDC motor stator winding according rotor position so as to synchronize the rotating stator magnetic field with the rotating permanent magnetic field. The rotor position of the motor is obtained from three Hall signals. In 120° conducting mode, only two devices are in ON state. One device is from the positive side switch and is connected to one phase, and the second device is from the negative side switch and is connected to the other phase. The third phase is floating. The inverter is commutated at every 60 electrical degrees.
Table I shows the six switching states of the inverter for forward rotation

Table I

Hall A	Hall B	Hall C	Switches ON
1	1	0	S3 and S6
0	1	0	S2 and S3
0	1	1	S2 and S5
0	0	1	S4 and S5
1	0	1	S4 and S1
1	0	0	S1 and S6

PWM TECHNIQUE

PWM technique is one of the most popular speed control techniques for BLDC motor. PWM technique controls the power electronics devices with maximum efficiency and power saving. In this technique switching signals of VSI is multiplied by a high frequency chopper signal with specific duty cycle. Therefore it is possible to vary output voltage of the inverter by controlling duty cycle of switching pulses of inverter. Use of PWM signal is generated by comparing controller output with a triangular wave. If the value of controller output greater than triangular wave, then PWM is '1' else PWM is '0'.

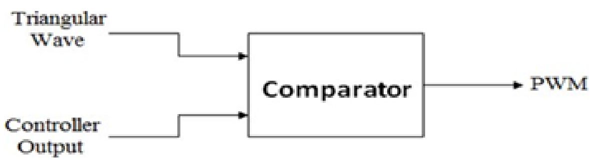

Fig. 4 PWM generation logic

IV. FRACTIONAL ORDER PID CONTROLLER

The Fractional order PID controller is an extension of conventional PID controller where a new integral factor λ and a new derivative factor μ having a fractional value which increases flexibility and making the system less sensitive to parameters changes. Fractional order PID controller improves the overshoot, the rising time, settling time, steady state error and provides flexibility and robust stability as compared to the same system using conventional PID controller.
The Laplace transfer function of Fractional order PID controller can be described as

$$G(s) = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu} \quad (9)$$

Where Kp is the proportional constant gain, Ki is the integration constant gain, Kd is the derivative constant gain, λ is the order of integration, and μ is the order of differentiator
The equation for FOPID controller output in the time domain is:

$$u(t) = K_p e(t) + K_d D^{\lambda} e(t) + K_i D^{\mu} e(t) \quad (10)$$

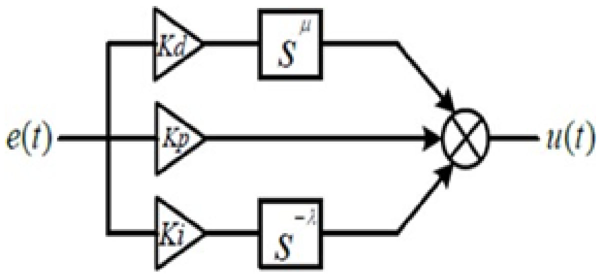

Fig. 5 Fractional order PID controller

V. RESULT AND DISCUSSION

Closed loop speed control of BLDC motor is simulated in MATLAB/SIMULINK. The machine parameters are shown in the Table II.

Table II

PARAMETERS	VALUE
Power	1HP
Rated speed	1800 RPM
Rated voltage	320 v
Rated current	2.83 A
Number of poles	8
Rated torque	3.8 Nm
Constant stall torque	4 Nm
Constant stall current	3.1 A
Peak torque	9.5 Nm
Torque constant	1.58 Nm/A
Voltage constant	95.8 V/KRPM
Resistance	7.88 Ω
Inductance	34.4mH
Speed at 320 v bus	1800 RPM
Maximum speed	7000 RPM

SIMULINK DIAGRAM

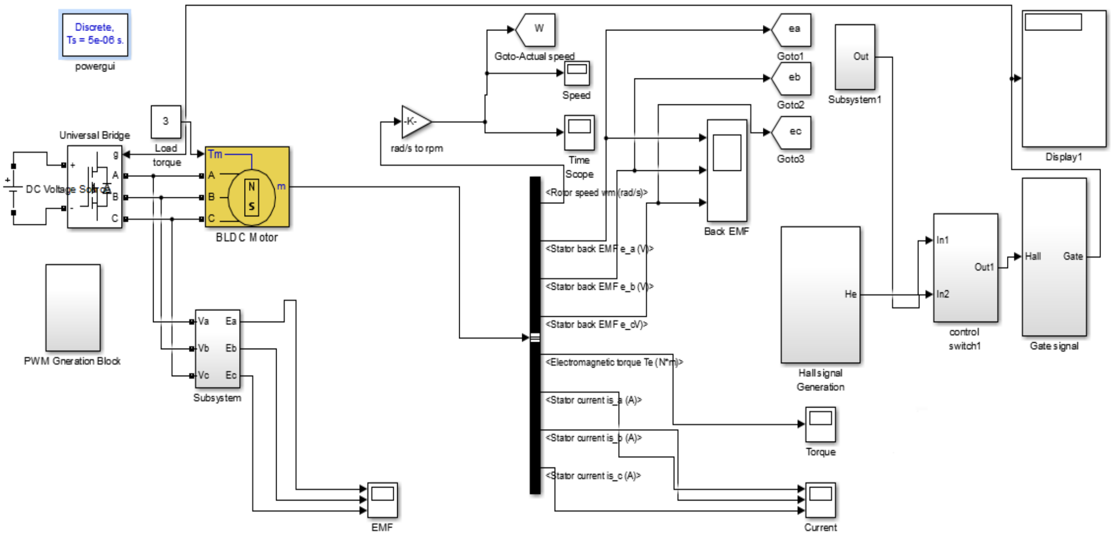

Fig. 6 Simulink Diagram of speed control using PWM technique

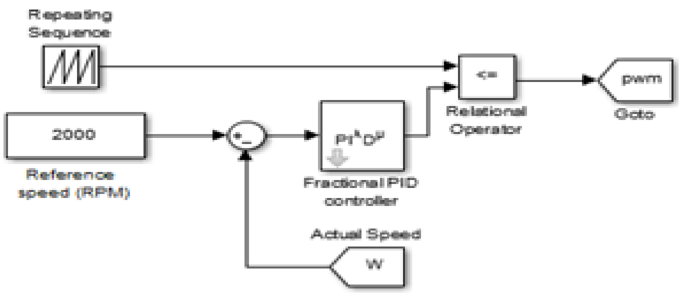

Fig. 7 PWM generation block

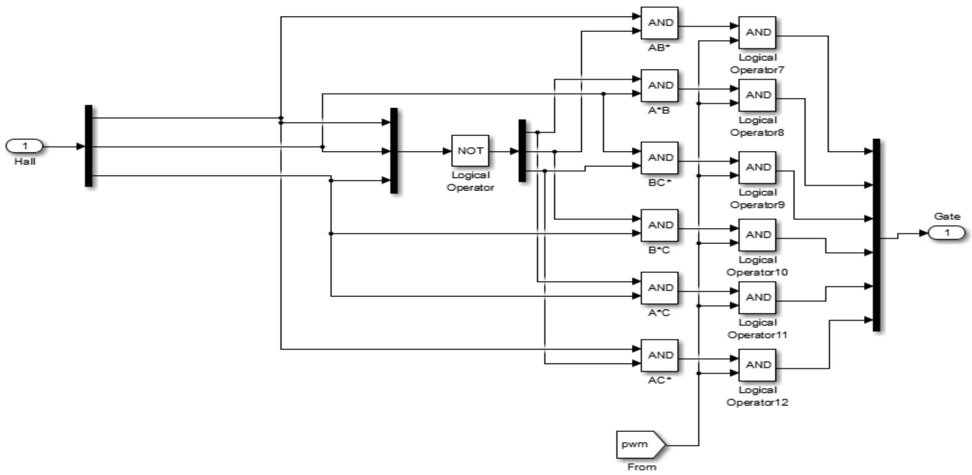

Fig. 8 Gate signal generation

Figure 6 shows the simulink diagram of closed loop system using PWM technique. The input voltage of 320 V is given to three phase inverter. In the closed loop system, 2000 RPM is set as the reference speed and load torque of 3 Nm is applied to the motor at zero seconds. The speed, torque, stator current and the back EMF are shown in Figures given below

SIMULATION RESULTS

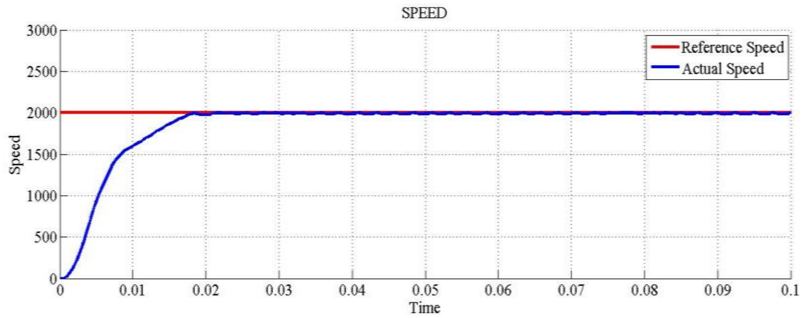

Fig. 9 Speed waveform of BLDC motor using PID controller with PWM technique

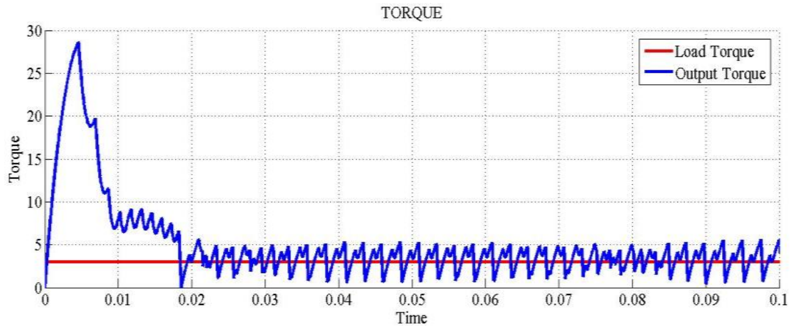

Fig. 10 Torque waveform of BLDC motor using PID controller with PWM technique

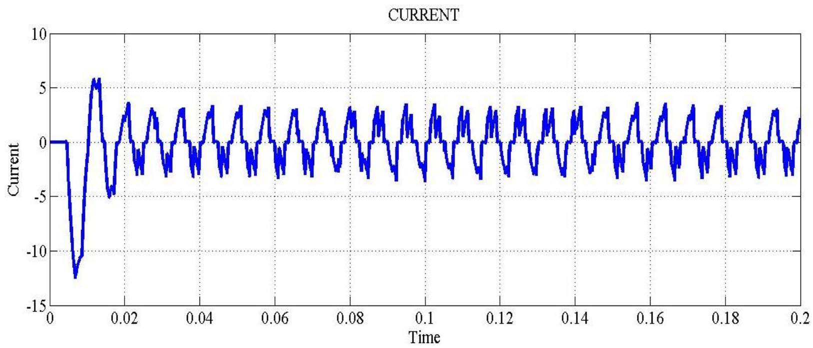

Fig. 11 Current waveform of BLDC motor using PID controller with PWM technique

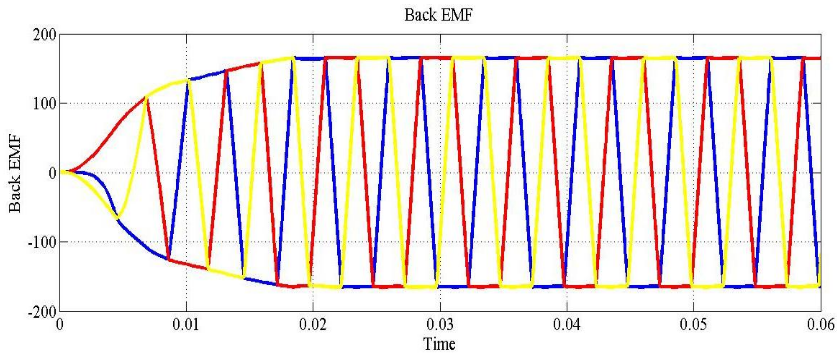

Fig. 12 Back EMF waveform of BLDC motor using PID controller with PWM technique

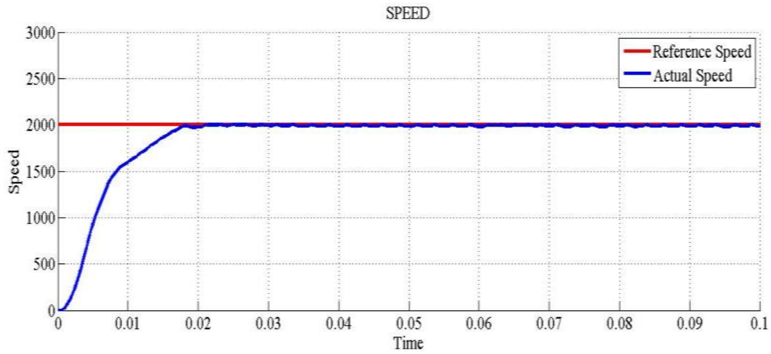

Fig. 13 Speed waveform of BLDC motor using FOPID controller with PWM technique

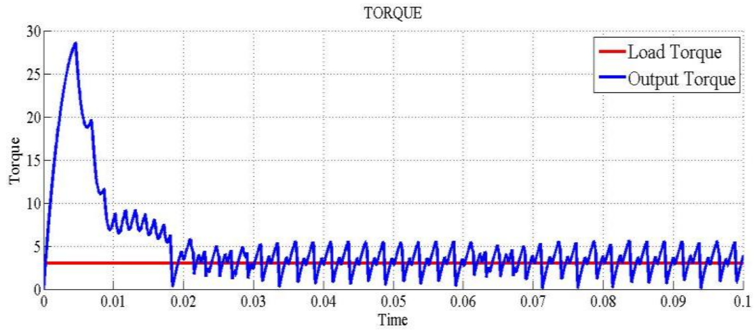

Fig. 14 Torque waveform of BLDC motor using FOPID controller with PWM technique

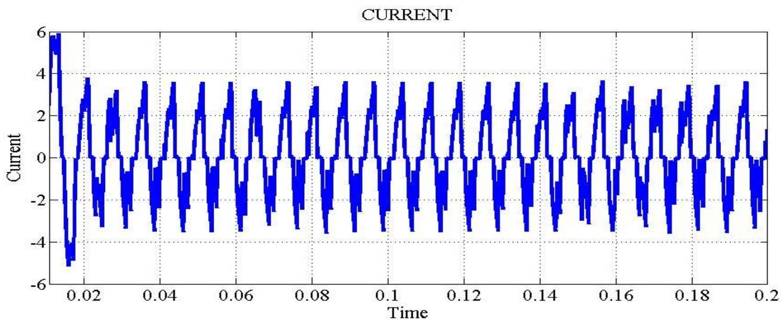

Fig. 15 Current waveform of BLDC motor using FOPID controller with PWM technique

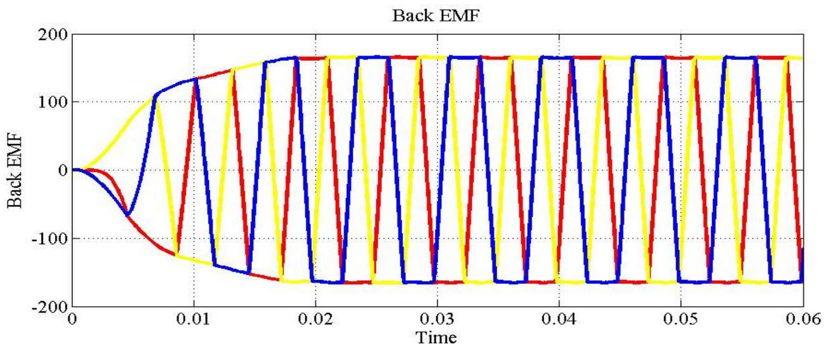

Fig. 16 Back EMF waveform of BLDC motor using FOPID controller with PWM technique

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COMPARISON OF SPEED CONTROL OF BLDC MOTOR USING PWM TECHNIQUE WITH PID AND FOPID CONTROLLER

For PID controller: K_p=2, K_i=0.001241, K_d=0.000310

For FOPID controller: K_p=2, K_i=0.001241, K_d=0.000310, λ = 0.8, μ = 1.2

Table III

Time Domain specification	PID	FOPID
Rise Time	19.231 ms	18.279 ms
Settling time	20.019 ms	19.052 ms
Overshoot	0.482 %	0.450 %

VI. CONCLUSION

Simulation of closed loop speed control of BLDC motor using PID and FOPID controller based on PWM technique is presented. From the comparison of simulation results, it can be concluded that the proposed FOPID controller improves, the rising time, settling time and provides flexibility and robust stability as compared to the same system using conventional PID controller.

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