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Performance and Comparative Analysis of Bldc Motor with Pi and Pid Controllers

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Abstract— The speed control of brushless DC motor (BLDC) using Proportional Integral controller i.e PI controller and Proportional Integral Derivative controller i.e PID controller is compared in this paper. In industries mostly Conventional PI controllers are used. In few industries, the conventional PID controllers are also used because of their simplicity and ease of retuning on-line. The PID and PI controller is compared for various operating conditions and PI controller gives poor performance in few conditions. The PID controller gives an effective speed response. Because of their high reliability, high efficiency, and high starting torque and low electrical noise, the BLDC motor is widely used in industries. For various operating conditions such as rise time, settling time, overshoot percentage, the PID controller performance is compared with PI controller and PID proves to be better controller. The overall methodology is simulated using Matlab/Simulink.

Keywords— BLDC motor, PI controller. PID controller

1. INTRODUCTION

Two types of DC motor are used in industry. Among them, one is conventional DC motor and another one is brushless DC motor. In conventional DC motor, flux is formed by the current through the field coil of stationary pole structure. They are known for excellent characteristics but there are some advantages like regular commutator maintenance, regular brush replacement and high initial cost. The conventional DC motor cannot be used in clean or explosive environment. The second type of motor is BLDC motor. The permanent magnet in brushless DC motor provides necessary air gap flux instead of wire wound field poles. BLDC motors are electronically commutated and its stator is stacked with steel laminations and windings are distributed. The rotor is made up of permanent magnets and has alternate north and south poles.

The speed of the BLDC motor control is controlled by PI, PID. The PI controllers are been used in industries for long time which fails to operate the dynamic conditions. The PID is also widely used in industries because of ease of retuning on-line. Hence the control is simple and effective. The block diagram of the general system is as shown in figure 1.

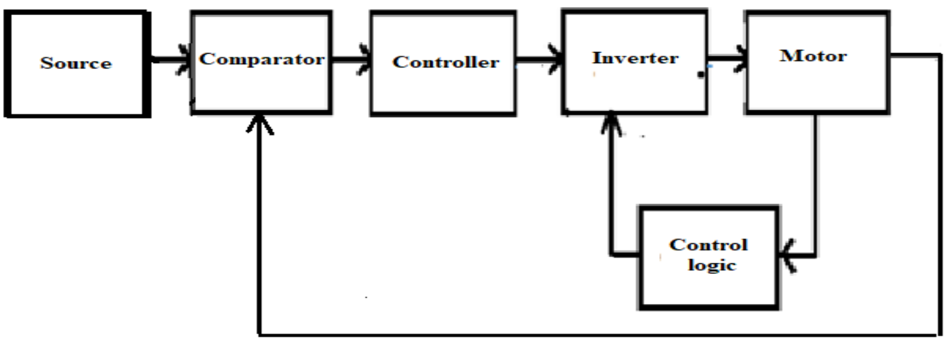

Fig. 1. **Block diagram of genral model**

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2. BLDC MOTOR

A BLDC motor provides large amount of torque over a vast speed range. Hence this motor is considered as high performance motor. The torque and speed performance curve characteristics is same as DC motor, the brushed DC motor as BLDC motor is derivatives of these motors. The major difference between the Brushed DC motor and Brushless DC motor are arrangement of brushes. BLDC motors are electronically commutated and do not have brushes and hence it is called as BLDC motor. The is sinusoidal in case of PMSM, however in BLDC this back-emf is modified to trapezoidal, and due to this modification BLDC motor is said to be a modified form of PMSM i.e Permanent magnet synchronous motor. The “commutation region” of back – emf of BLDC motor is very small. But it should not be very narrow as to make it very difficult to commutate a phase of the motor when driven by current source inverter. For a smooth torque production, the flat constant portion of emf should be 120 degree as shown in figure 2.

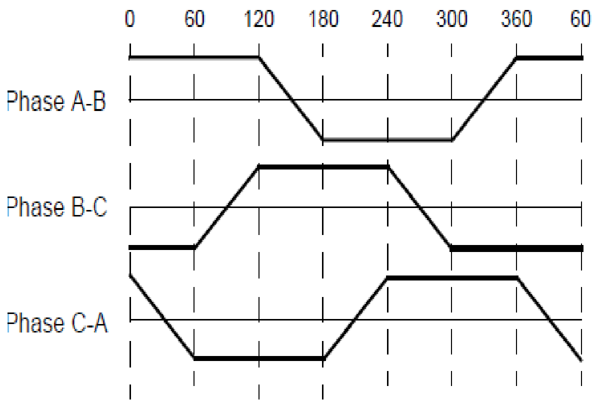

Fig. 2. **Back emf of BLDC motor – Trapezoidal waveform**

a. BLDC motor hall sensors

To rotate the BLDC motor, the stator winding of the BLDC motor must be powered in a sequence. The position of the rotor must be known to determine which winding will be enabled following the energizing sequence. The Hall Effect sensors mounted on the stator can sense the rotor positions. The rotor magnetic poles give a low or high signal whenever it passes near the hall sensors indicating that the north or south beam passes close to the sensors. The combination of these three hall sensors signals determines the exact sequence of commutation. This motor is equipped with three hall sensors to determine the rotor position. These hall sensors are placed at every 120 °. Six different calculations are possible with these hall sensors as shown in figure 3. The commutation of phase depends on the values of the hall sensor. The hall sensor values changes as power supply to the coils changes. The torque remains high and constant with right synchronized commutations

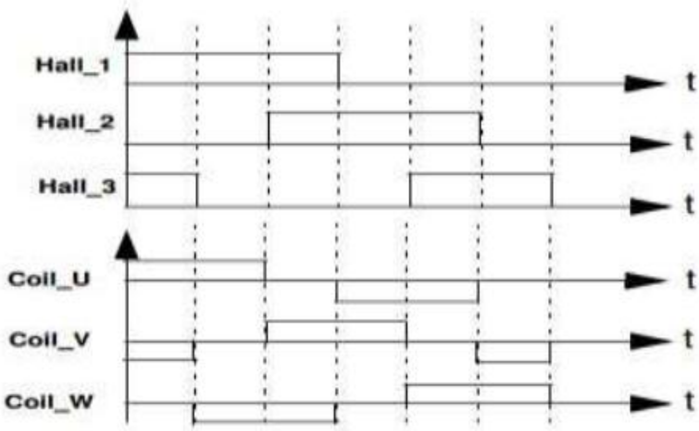

Fig. 3. **Energizing of coil based on hall sensor signal**

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b. Phase commutation

A typical three coil BLDC motor is considered. The phase commutation depends on the hall sensor values. When the coils of motor are rightly supplied, the magnetic field is created and the rotor rotates. The most simple commutation method used to drive BLDC motor is on and off scheme that is either motor is conducting or not conducting. Only two windings are energized at one time and third one is floating. On connecting the coils to power supply and to the neutral bus causes current to flow. This is called as trapezoidal commutation. A power stage with three half bridge with six switches is used to command brushless DC motors. Hall sensor values indicate which switches should be turned off. The figure 4 shows the schematic of a six step inverter.

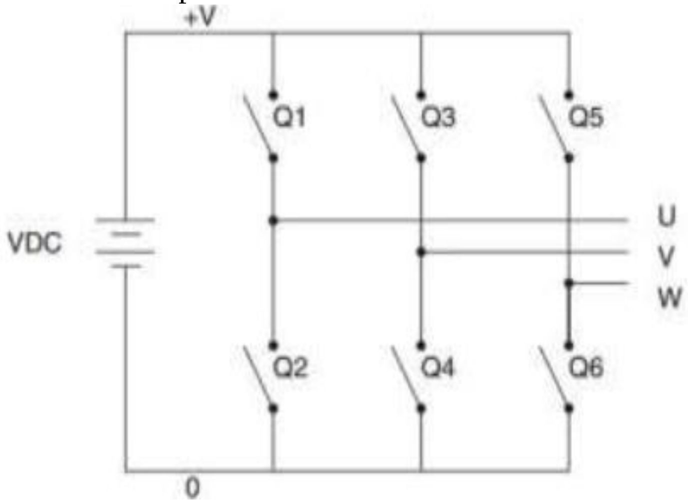

Fig. 4. **Schematic diagram of six step inverter**

c. Operation of Brushless DC Motor

Each commutation sequence is energized as follows: the current enters into the first winding which is energized with the positive power; the current exit from the second winding which is energized with negative power and the third is in a non-energized condition. The magnetic field generated by the stator coils interacts with permanent magnets of the rotor to produce torque. The magnetic field produced by the windings should shift position as the rotor rotates to align with stator in order to keep the motor running. The sequence of energizing the windings is called as “Six-Step Commutation”. Only two windings out of the three BLDC Motor windings are used at a time. Each Step is equivalent to 60 electrical degree, so six steps make a full, 360 degree rotation. The current is controlled by one full 360, due to which there is only one current path. A Six-step commutation is typically useful in applications which require high speed and commutation frequencies. A six step Brushless DC Motor has lower torque efficiency than a PMSM because it is trapezoidal commutated.

3. CONTROL SYSTEM OF BLDC MOTOR

As shown in figure 1 the speed control system of BLDC motor consists of 2 control loops. The inside loop controls the inverter gates with electromotive force. The outside loop controls the speed of the motor with the help of controller.

a. Current control loop

The inverter gate signals are produced by decoding the Hall Effect signals of the motor. The three phase outputs of inverter are applied to BLDC stator windings. The switching sequence of the IGBT determines the rotor position and is detected by hall sensors mounted on stator. The hall effect sensors senses the current or flux and generates 3 digit signals (+1, -1, 0) for every 60 degrees till the completion of one full cycle i.e 360 degrees. The induced emf signals are decoded by logic gates and six gate signals

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are generated for every 60 degrees. The inverter voltage applied to the motor winding is controlled by these gate signals. The following table 1 shows gate logic signals.

Hall A	Hall B	Hall C	EMF A	EMF B	EMF C	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	-1	1	0	0	0	1	1	0
0	1	0	-1	1	0	0	1	1	0	0	0
0	1	1	-1	0	1	0	1	0	0	1	0
1	0	0	1	0	-1	1	0	0	0	0	1
1	0	1	1	-1	0	1	0	0	1	0	0
1	1	0	0	1	-1	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0	0	0	0

Table 1. Gate logic signals

In IGBT inverter, each switch conducts for 120 degrees and only two switches conducts for every 60 degrees. This is used to control BLDC control due to its trapezoidal waveform and it has 6 modes of operation. Hence current and motor torque is controlled.

Cycle (in degrees)	Switching Sequence
0 - 60	5,6
60 - 120	6,1
120 – 180	1,2
180 – 240	2,3
240 – 300	3,4
300 - 360	4,5

Table 2. Switching signals

b. Speed control loop

The inverter gate signals are produced by decoding the Hall Effect signals of the motor. The three phase outputs of inverter are applied to BLDC stator windings. The switching sequence of the IGBT determines the rotor position and is detected by hall sensors.

1. PI Controller

PI controller is used to eliminate the steady state error. It is the output sum of two terms, proportional and integral. The P controller uses the gain K_p and produces the output which is proportional to the current error value. The system becomes unstable when the proportional gain is high. To make the system stable, integral action comes into the action. It does not have ability to predict the upcoming errors of the system as it cannot decrease rise time and eliminate the oscillations. The output of PI controller in time domain is as shown as follows:

$$\mathrm{Output} = K_p e(t) + K_i \int_0^t e(t)dt \quad (1)$$

Where $K_p$is proportional gain, K_i is integral gain. The figure 5 shows the block diagram of PI controller.

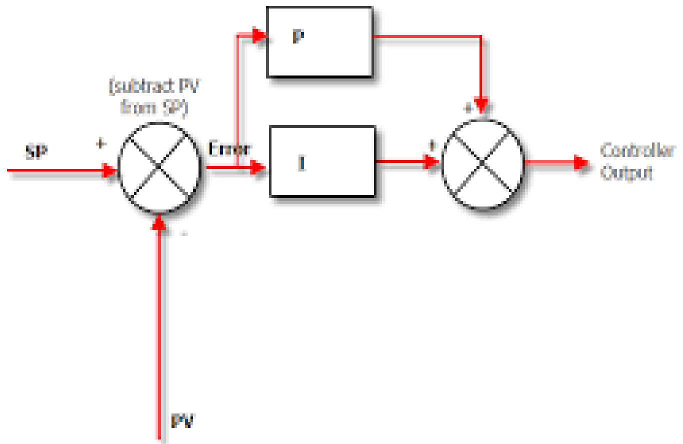

Fig. 5. **Block diagram of PI controller**

2. PID Controller

In PID controller derivative gain component is added in addition to the PI controller to eliminate the overshoot and the oscillations occurring in the output response of the system. It is the output sum of three terms, proportional, integral and derivative term. The controller gives zero steady error, fast response, no oscillations and high stability. The output of Proportional Integral Derivative controller in time domain is shown as follows:

$\mathrm{Output} = K_p e(t)$ **Table 3. Specificationn of BLDC motor rating**

$$+ K_i \int_0^t e(t)dt + K_d \frac{de}{dt} (2)$$

Where $K_p$is proportional gain, K_i is integral gain, K_d is derivative gain. The figure 6 shows the block diagram of PID controller.

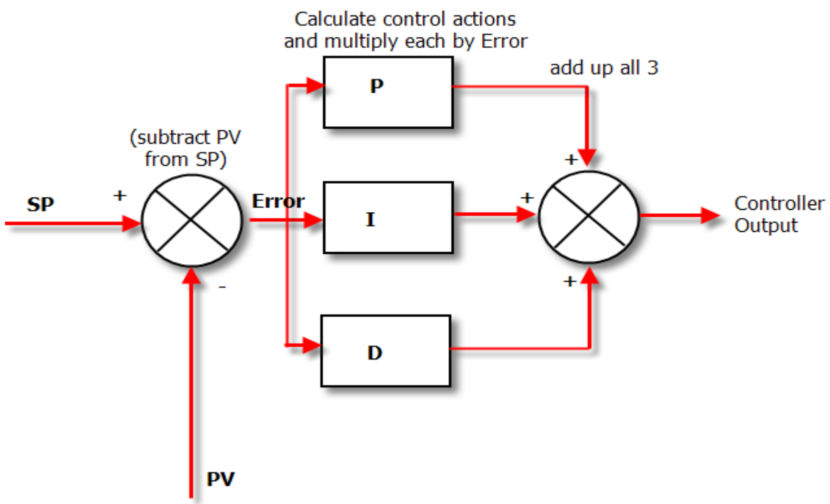

Fig. 6. **Block diagram of PID controller**

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4. RESULTS AND DISCUSSION

The BLDC motor rated 1kW, 500V, and 3000 rpm is driven by six step inverter and is simulated in MATLAB using different controllers like PI, PID. The performance of rotor and other operating conditions such as rise time, settling time, percentage of overshoot and stability phenomenon. The speed from the output response is compared with the reference speed and the error signal is given to the respective controller. The output of the controller is given to the six step inverter whose gate signal is produced by decoding the Hall Effect signals. The table 3 shows the specification of BLDC motor rating. Hence the process is continued till the desired speed is obtained. The figure 7 shows the Matlab Simulink model of Speed control of BLDC motor with PI controller.

BLDC Motor rating	
Supply voltage	96
No. of poles	5
Rated speed	3000 rpm
Motor rating	1KW

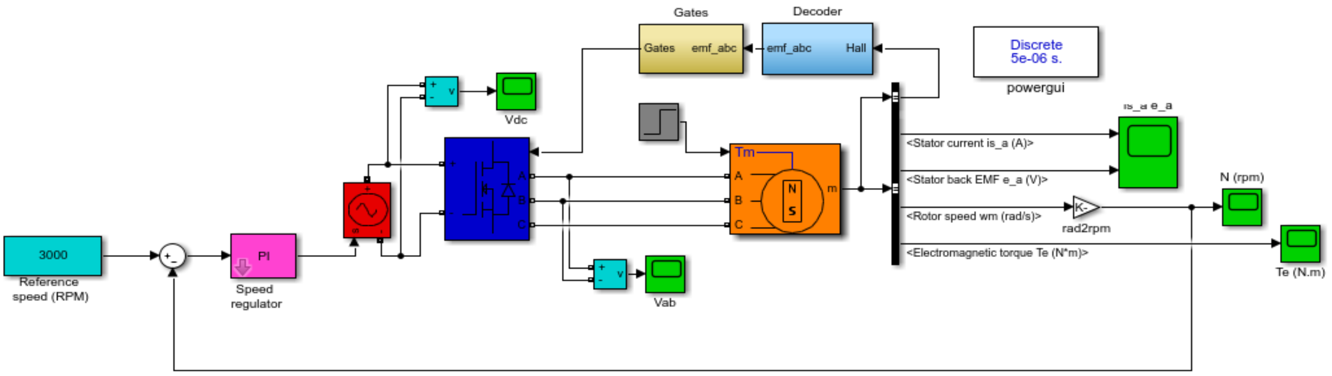

Fig. 7. **Simulink model of speed control of BLDC motor with PI controller**

The figure 8 shows the Matlab Simulink model of Speed control of BLDC motor with PID controller. The speed of BLDC motor is controlled using PI, PID. These controllers can control the duty cycle and therefore control the applied voltage to BLDC motor. The speed of BLDC motor is directly proportional to the voltage applied. Reference speed is set to speed of BLDC motor. Any change in speed is given as error signal to the Proportional Integral and Proportional Integral Derivative controller. It takes the signal and accordingly increases as well as decrease the duty cycle of the gate signal applied.

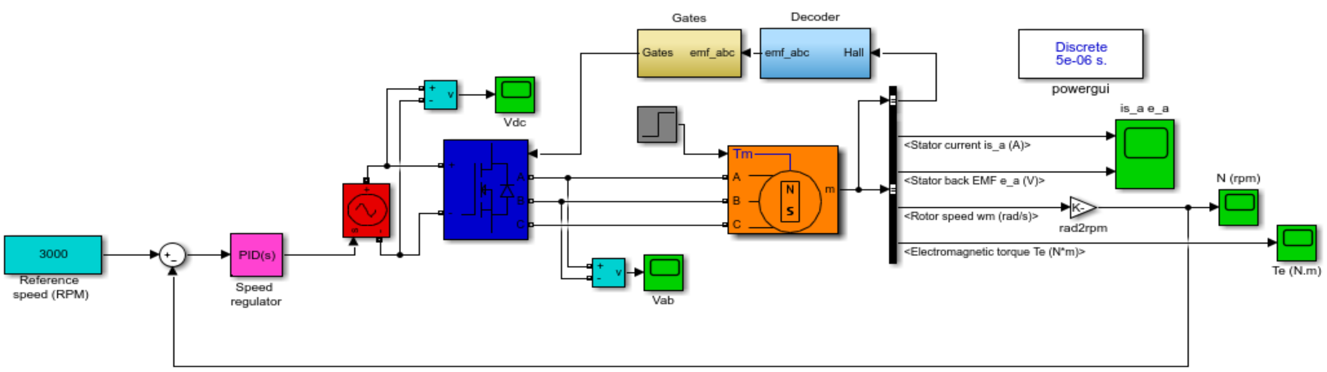

Fig. 8. **Simulink model of speed control of BLDC motor with PID controller**

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The figure 9 shows DCvoltage fed to the inverter with various controllers.

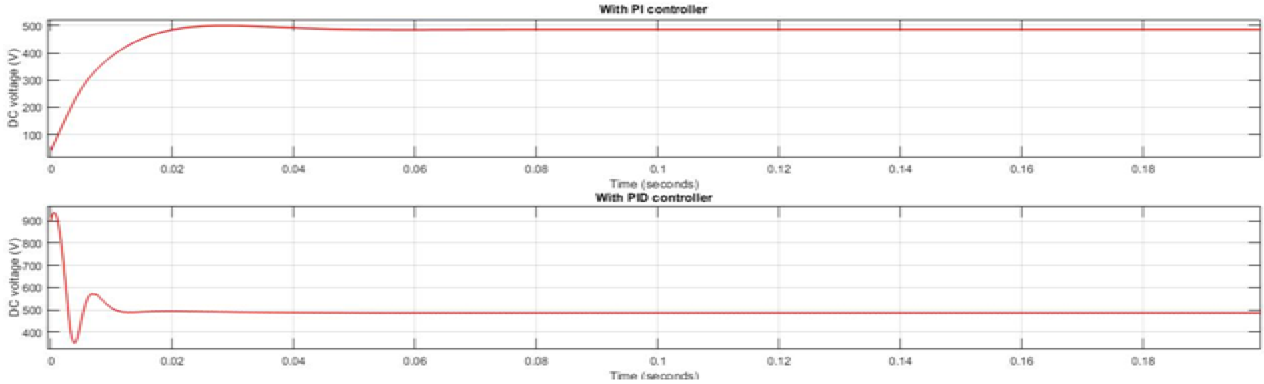

Fig. 9. **Source voltage**

Thefigure 10 shows ac voltages of the six step inverter for various controllers. The inverter converts DC to AC.Theoutput voltage from the inverter is applied to the BLDC motors stator windings.

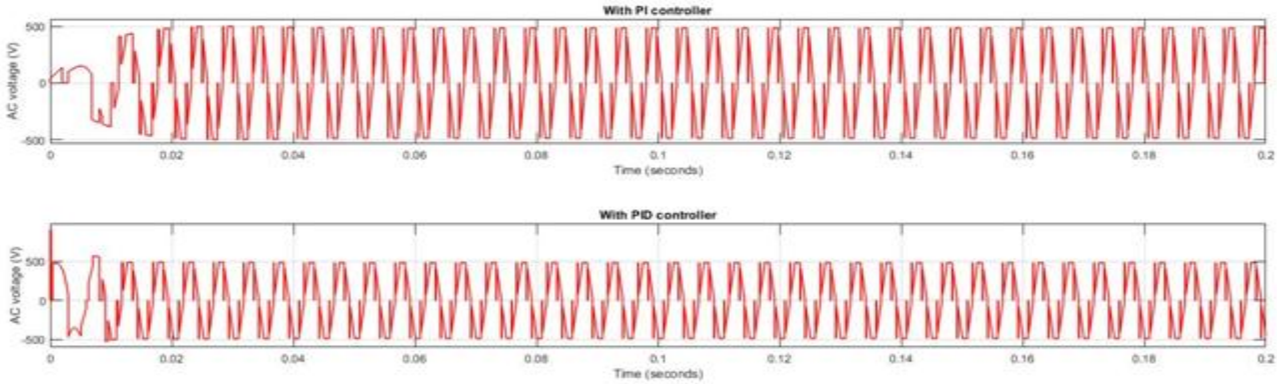

Fig.10. Six step Inverter voltage

The figure 11shows the back emf of stator windings of the motor for various controllers. It is seen from the figure that phasor voltages are displaced by 120 deg. It is observed that the stator currents are quasi sinusoidal in shape and displaced by 120 deg. The stator current waveforms are shown in figure 12.

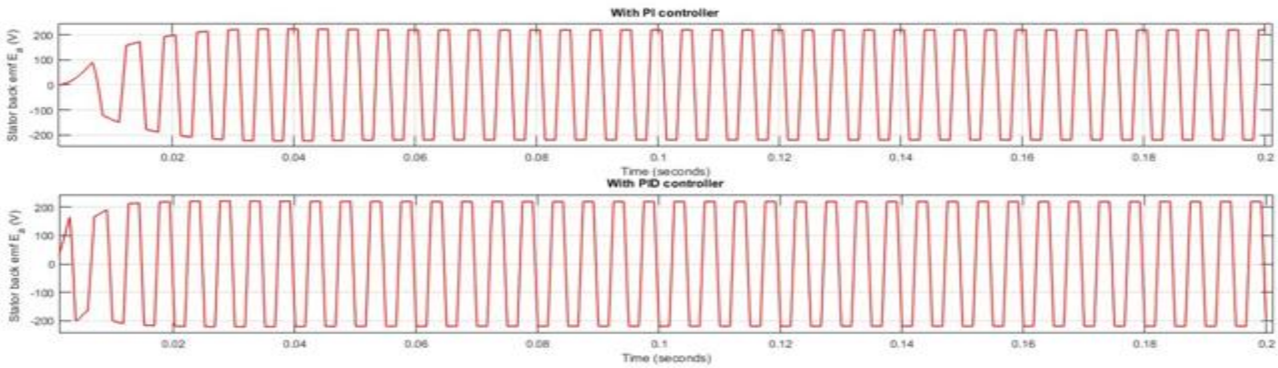

Fig.11. Stator back emf of BLDC motor

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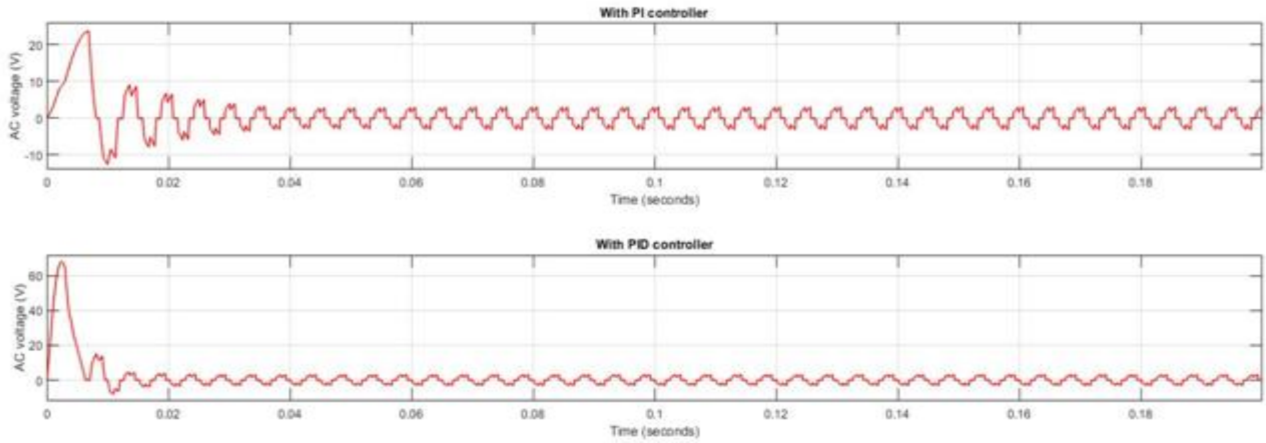

Fig.12. Stator currents of BLDC motor

The figure 13 shows the saw tooth waveform of the electromagnetic torque signal Te for various controllers. The figure 14 shows rotor speed of BLDC motor using various controllers. It is observed that the motor achieves the speed of 3000 rpm in all cases but with different rise time, settling time and stability. The figure 15 shows the comparison of speed for various controllers.

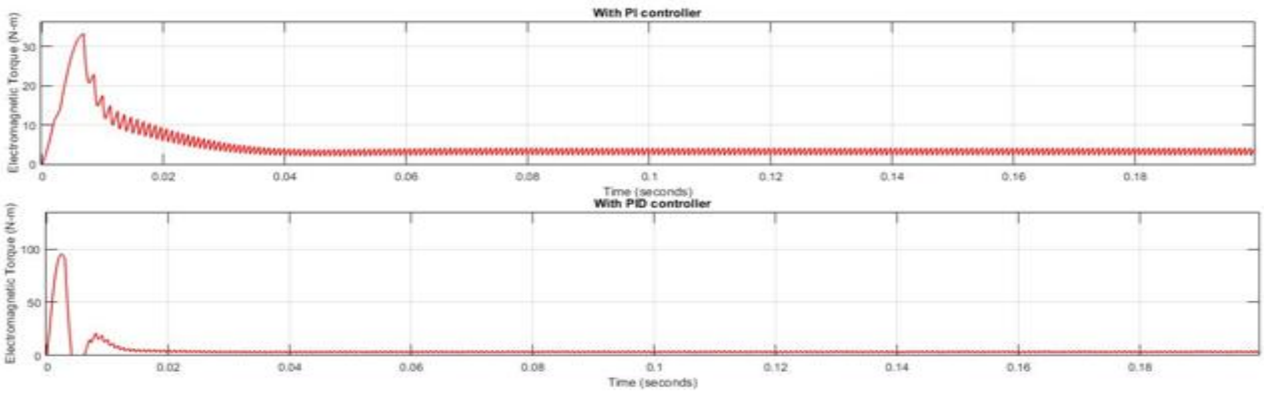

Fig.13. Electromagnetic torque of BLDC motor

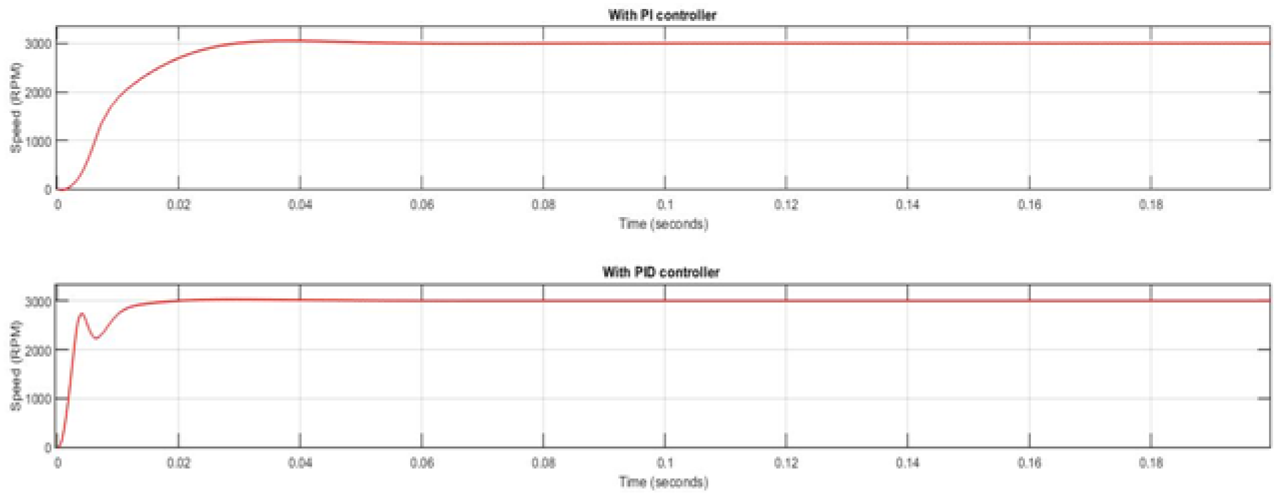

Fig.14. Rotor speed of BLDC motor

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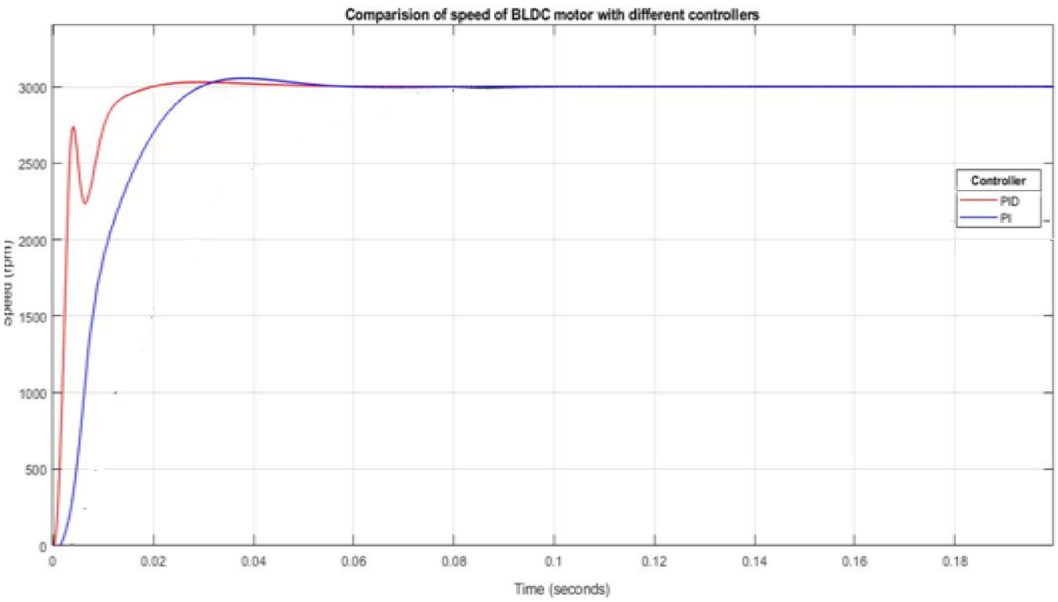

Fig.15. Comparision of speed of BLDC with different controllers

The table 4 shows the comparison of various operating conditions such as rise time, settling time and overshoot percentage.

Controller	Rise time T_R (sec)	Settling time T_S (sec)	Overshoot Percentage (%)
PI controller	0.03	0.06	1.7
PID controller	0.01	0.06	0.9

Table 4. Characteristics of speed response

The rise time of PID controller is lessthan the PI. The settling time of PID is less than PI controller. The overshoot percentage of PI is 1.7% more and overshoot percentage of PID 0.9%. The PID controller overshoot percentage is less than PI controller.

5. CONCLUSION

A six switch, three half bridge inverter is powered by controlled volatge source which drives the three-phase BLDC motor rated 1 kW, 500 Vdc, 3000 rpm. The model is simulated using Matlab/Simulink and its performance is analyzed with different controllers

The gate signals to the inverter are generated by decoding the hall effect signals of the motor. The inverter output is applied to the BLDC stator windings. The motor current has quasi sinusoidal waveform. and the emf has sawtooth waveform. The spped of the bldc motor is controlled by PI, PID controller. The stator emf, stator current, rotor speed and electromagnetic torque are analyzed. The operating conditions such as rise time, settling time and overshoot percenatge is calculated. The PID controller proves to be better controller than the PI controller in terms of rise time and settling time and overshoot percentage. But there is an slight overshoot occurred due to PID. Hence for future work an fuzzy controller and Fuzzy –PID controller can be designed to overcome these conditions

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