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STUDY OF SPEED RESPONSE OF BRUSHLESS DC MOTOR WITH PID CONTROLLER

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Abstract: In the present scenario load variations are quite common, these variations occurred in domestic and commercial loads. During the morning and nighttime, usage of the load is more than forenoon time. These sudden load variations give the jerky behavior and low voltage problems at load endpoints, sometimes it may lead to loss of stability. Considering all all-issues effective speed control of the motor is necessary. So many motors are available in the market, according to their characteristics but the BLDC motor plays a vital role because of its performance characteristics. It has less noise range, high efficiency, higher torque under the low-speed range, and more power density. Brushes are absent in the BLDC motor so that the overall weight of the motor is less, it can easily be transportable. The present study gives the performance of BLDC motor supplying different types of loads that is no load, sudden gradual application of load. BLDC motor has jerky behavior at the sudden application of load, which can be reduced with the help of a PID controller.

Keywords: Brushless Direct Current – BLDC and PID Proportional Integral Derivative Control.

1. Introduction

Brushless DC motor (BLDC) provides better torque than conventional motors. The block diagram of the BLDC motor is shown in Figure 1. In this diagram, two control loops are used; the first control loop is used to adjust the firing angle of the MOSFET of the voltage source inverter [1,2]. An outer control loop is used to monitor and measure the speed of the BLDC motor. The components that are connected in the inner loop are the Hall sensor, which is mounted on the rotor and used to sense the actual rotor position to the stator.

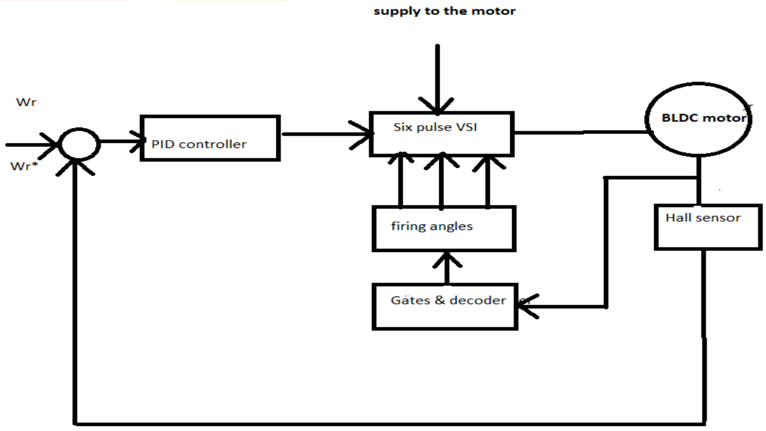

Fig 1: Block diagram of BLDC motor

In BLDC motor Brushes are absent so natural commutation is not possible secondary option is forced commutation. It is electronically implemented with the power electronic amplifier, made with a MOSFETS bridge to form a six-pulse inverter. It converts the Direct voltage and current to Alternating voltage and current. with the help of a hall sensor to adjust the firing angles of the voltage source inverter [2-3]. The decoder is a circuit that is used to convert the N bits of binary information to 2^N bits of the output line. A decoder circuit is used to choose the firing angle of a 3-ph six pulse voltage source converter.

2. Design of voltage source inverter

A Circuit that converts DC power into AC power at desired output voltage and frequency is called an inverter. A line commutated inverter requires at the output terminals an existing ac supply which is used for their commutation. This means that line-commutated inverters can't function as isolated voltage sources and variable frequency generators, from these voltage levels, the frequency on the ac side of the line-commutated inverters cannot be changed [4]. The second type of inverter is the force-commutated one, provided on the independent ac output voltage of adjustable voltage and frequency. The DC power input to the inverter is obtained from the existing power supply network.

The inverter can be classified into two types: Voltage Source Inverter (VSI) and Current Source Inverter (CSI). A voltage source inverter has small or negligible internal impedance and a stiff DC voltage source at its input terminals. Whereas the current source inverter has a high internal impedance and is fed with a stiff current source, output current waveforms are not affected by the generally required output voltage is not affected by the load. The Components that are mainly used in VSI design for the forced commutation purpose are, BJTs, GTOs, PMOSFET, and IGBTs and be turned off by the control of base current [4,5]. The voltage source inverter circuit diagram is shown in Figure 2. In 180-degree conduction mode ωt = Π, for the first 180-degree phase A conducts, If the firing angle is less for the next phase short circuit happened chances are more. The present model is a 120-degree conduction mode of operation [6].

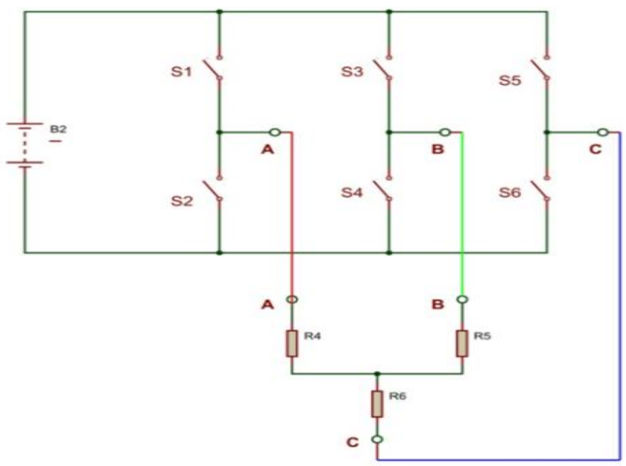

Fig 2: Voltage source inverter

2.1 Construction of Voltage source Inverter

In the 120degree conduction mode of VSI, each Thyristor conducts for 120 ^{0} of a cycle. Inverters require six steps, which each Thyristor conducts for 60^{0} durations, to complete one cycle of the output ac voltage [4-7]. The Obtained output voltage waveforms are shown in Figure 3.

If the load is resistive and star-connected, then the voltages are as follows:

$V_{ao} = V_s/2$ (1)

$V_{ob} = V_s/2$

$V_{CO} = 0$

$V_{BO} = -Vs/2$

Line voltages $V_{ab} = V_{ao} - V_{bo}$ (2)

$V_{bc} = V_{bo} - V_{co}$

$V_{ca} = V_{co} - V_{ao}$

$$V_{ao} = \sum_{n=1,3,5}^{\infty} \frac{2Vs}{n\pi} cosn\pi/6sinn\left(wt+\frac{\pi}{6}\right) \quad (3)$$

$$V_{bo} = \sum_{n=1,3,5}^{\infty} \frac{2Vs}{n\pi} cosn\pi/6sinn\left(wt-\frac{\pi}{2}\right)$$

$$V_{co} = \sum_{n=1,3,5}^{\infty} \frac{2V_s}{n\pi} \cos n\pi/6 \sin n(wt + 5\pi/6)$$

The Fourier analysis of line voltage waveform V ab

$$V_{ab} = \sum_{n=6k\pm1}^{\infty} \frac{3V_s}{n\pi} \sin n(wt + \pi/3) \quad (4)$$

$$V_l = 0.7071V_s$$

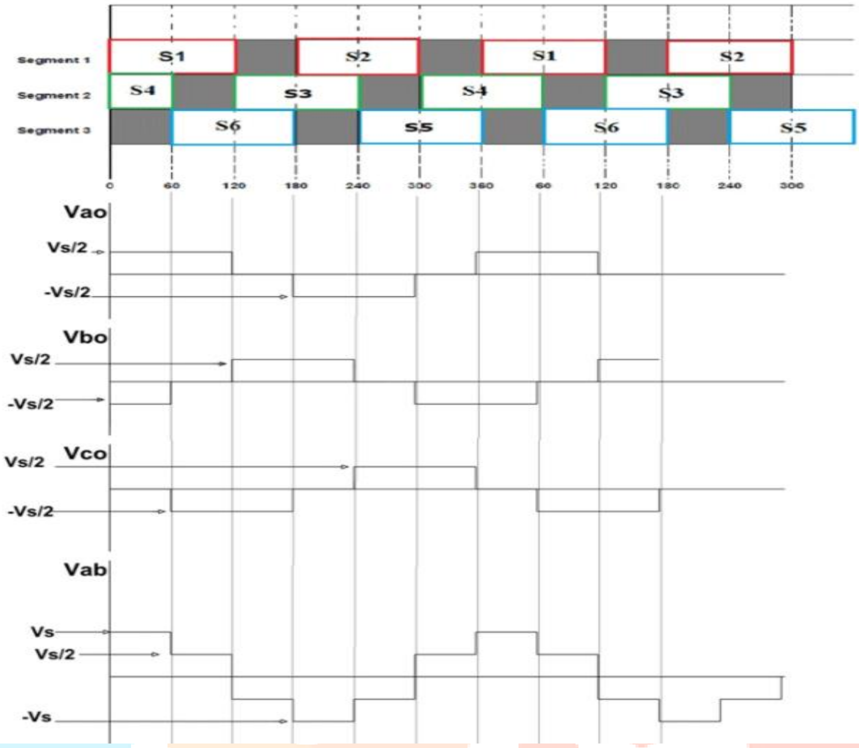

Fig 3: Output line voltage Waveform of Voltage source inverter

Parameters

Power electronic devices = MOSFETS

Snubber resistance = 5000 ohms

Snubber capacitance = $1*10^{-6}$

Input resistance = $1*10^{-3}$ ohm

3. Design of PID controller

PID controller is a standard feedback control mechanism to check and corrects the error between the measured variable and desired value. The block diagram of the PID controller is shown in Figure 3. The structure of the PID controller comprises the three controls namely proportional, integral, and derivative. These controls combined to generate better output that gives the minute steady-state error, less settling time, less rise time, and maximum peak overshoot. PID controller gives better performance characteristics.

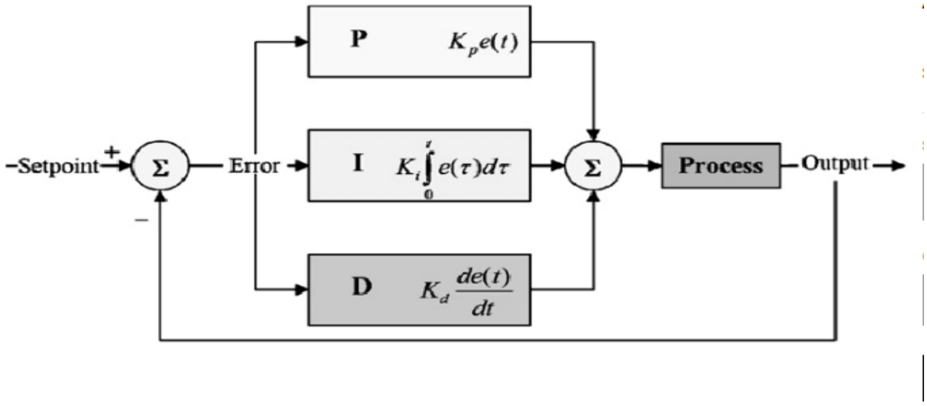

Fig 4: Block diagram of PID controller

$$H(S) = P + I + D$$

$$= K_P + K_I/S + K_d S \quad (5)$$

K_P = Proportional Co-efficient

K_I = Integral Co-efficient

K_d = Derivative Co-efficient

4. Decoder circuit:

A Decoder is a logic circuit that converts an N-bit binary input code to M-output lines such that only one output is activated for each one of the possible combinations of inputs. A decoder block diagram is shown in Figure 5.

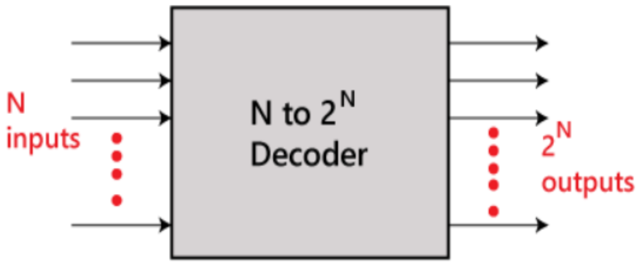

Fig 5: N to 2^N line decoder circuit

A sensor is used to give feedback to the motor when the rotor is reached the required position. In the BLDC motor three hall effect sensors are placed on the stator or rotor, each sensor having 120-degrees space from the other is used to give 0 to 360 phase angle position. when the rotor crosses each of the sensors, it generates the signal low or high depending on whether it is the south or north pole of the rotor that passed. The internal block diagram of a decoder is shown in Figure 6. As the rotor crosses the whole sensor, it gives a low or high signal for every 60-degree angle.

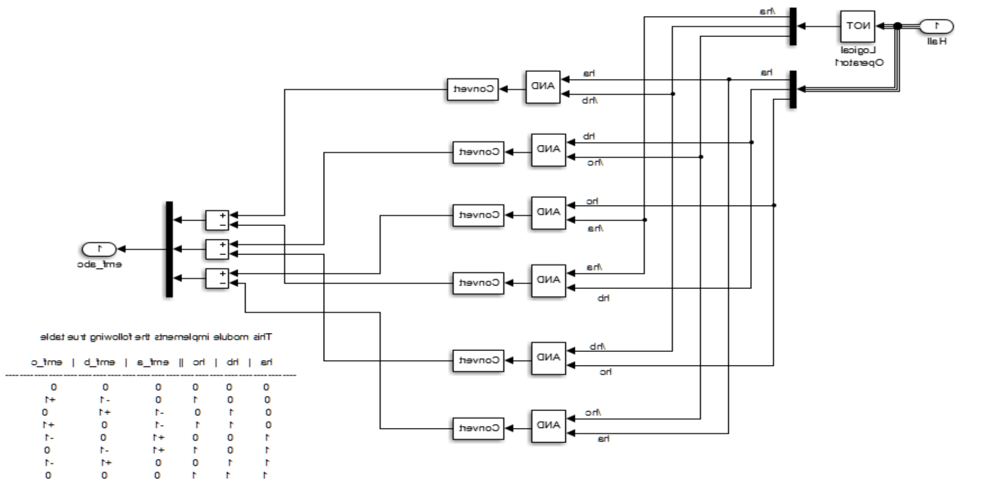

Fig 6: logic diagram of BLDC motor decoder circuit

This truth table is derived from the reading of the Hall effect sensor. The firing and commutation of each thyristor is depending on the signal of the respective sensor. AND logic gates are used to generate each phase state whether it is under the north or south pole. The truth table of the decoder is shown in table 1.

Table 1: Truth table of Decoder circuit

Ha	Hb	Hc	Thyristor states	
1	0	0	T3	T2
1	0	1	T3	T6
0	0	1	T1	T6
0	1	1	T1	T4
0	1	0	T5	T4
1	1	0	T5	T2

V. Modeling of BLDC Motor

Speed control of BLDC motor is used to develop and study the performance of motor under no-load/sudden application of load. The motor speed is sent back through the reference speed of 3000 revolutions per minute with the help of a comparator which is fed to the PID controller. PID controller improves the transient response of the motor. BLDC motor phase voltage control can be done with help of a voltage source inverter and hall sensor. 3 Phase VSI is used to maintain stiff and balanced output voltages [8,9]. The output of the controller is fed to the controlled voltage source. External DC supply is fed to the inverter circuit for the commutation of each MOSFET, and the output of the voltage source inverter is fed to the Permanent magnet synchronous machine. The model diagram of the brushless DC motor is shown in Figure 7. Here two control loops are used to monitor and control the speed of the BLDC motor [10,11]. The inner loop is used to control the firing angles of MOSFETS with the help of a hall sensor, encoder, and Gate circuit. The outer loop is used to monitor the speed of the BLDC motor with the help of the PID controller.

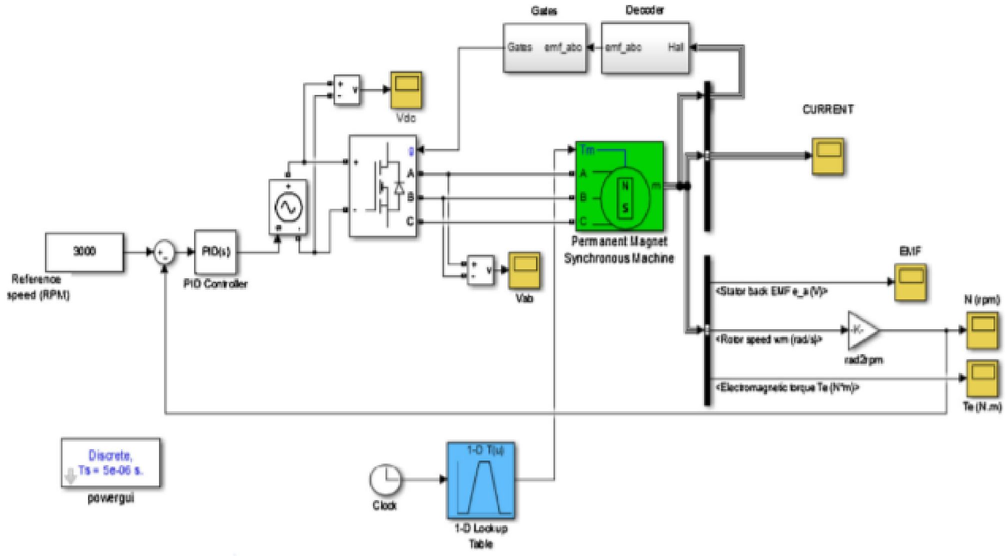

Fig 7: Simulink diagram of BLDC motor with PID controller

The output of the BLDC motor in terms of Back emf, rotor speed, and electromagnetic torque is taken out for measurement [11-13]. The present model is developed on MATLAB/SIMULINK 2015a.simulation is carried out under different operating conditions such as starting and gradual application of load, and sudden removal of load.

The simulation parameters are shown as follows

Type: Fixed step
Integrator Type: Runge -Kutta, ode4
Sample time: 5e-6
Stop time: 0.2

6. RESULTS

In this section, the performance characteristics of BLDC motor under a different type of loads is studied. The simulation is carried out to find the rotor speed, electromagnetic torque, and current.

The variations are observed in 3 steps.

No-load		0 s to 0.1s
Gradual application of a load of	0- 3 NM	0.1s to 0.2s
Sudden load removal		0.2 to 0.3 s

No Load

The response curves of BLDC drive with Proportional, integral, and derivative controller under sudden and gradual application of load are observed. At the time of starting, motor under no-load condition, the percentage of overshoot is 2.94%, peak time 0.041sec, and the rise time is 0.0218.

Gradual application of load

From the time t = 0.1 s to 0.2 s the load is applied gradually. Under that condition settling time 0.067, the percentage of overshoot is 5.35%

The sudden removal of the load

From the time t = 0.2 s to 0.3 s. The load on the motor is suddenly removed. Here motor gives some jerks, Dynamic characteristics of the motor may change due to sudden removal of road. settling time is 0.098s peak overshoot is 5.37%. The simulation results are shown in the Table 2. It is observed that sudden load variations give more setting time and peak overshoot.

Table 2: Simulation results of BLDC under different types of load applications.

Load variations	Characteristics	Time interval (s) (s)	Overshoot%	Peak time (s)	Rise Time (s)	Steady-State error	Setting time (s)
Gradual load variation	Starting	0 - 0.1	8.41	0.0205	0.013	0	0.0948
	Loading application	0.1 - 0.2	-0.59	0.0196	0.013	2	0.068
	Loading	0.2-0.3	0.143	0.019	0.013	0	0.056
	Load removal	0.3-0.4	0.58	0.0193	0.013	14	0.071
Sudden load variation	Starting	0 -0.1	8.41	0.0205	0.013	0	0.0948
	Loading	0.1 - 0.4	-4.57	0.0078	0.013	2	0.089
	Load removal	0.4	4.56	0.008	0.013	0	0.086

Rotor Speed and Electromagnetic torque waveforms

The rotor speed waveform and electromagnetic waveforms are shown in Figure 8. The reference speed is 3000 rpm, when the motor starts rotating it attains the speed of 3500 rpm due to inertia after some oscillations at attains the speed of 2800rpm and stabilized at that point.

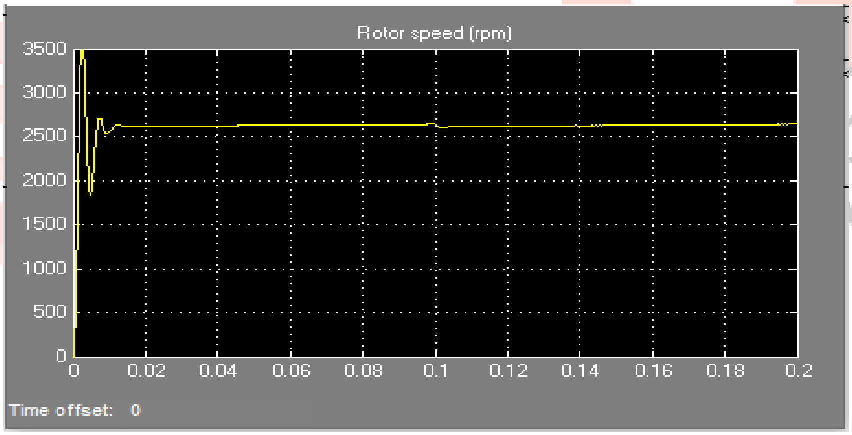

Fig 8: Simulation results of rotor speed waveform of BLDC motor

The electromagnetic torque waveform is shown in Figure 9. During the motor starting at attains the value of 28NM after 0.1 s it reaches 0 NM. After some time 0.1s to 0.3 s torque rises to 3 NM. when the load is removed suddenly it reaches 0NM again.

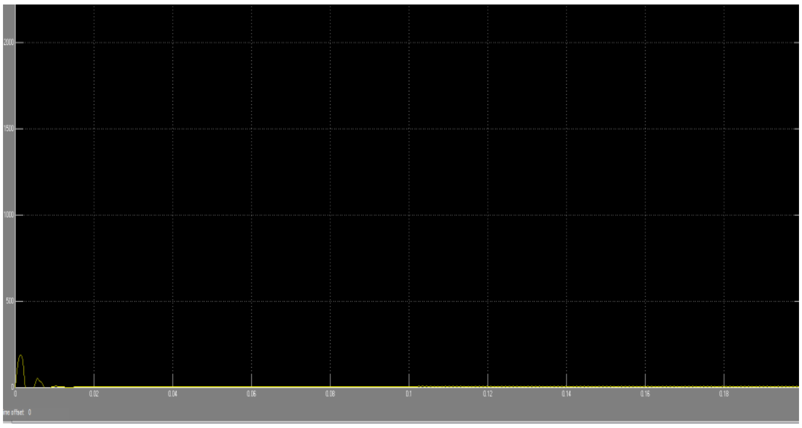

Fig 9: Simulation results of Electromagnetic torque waveform of BLDC motor

Output current and electromagnetic force waveforms are shown in Figure 10. when a motor starts at attains highest point after some time it reaches its steady-state value. Electromagnetic force always maintains the value of 200V.

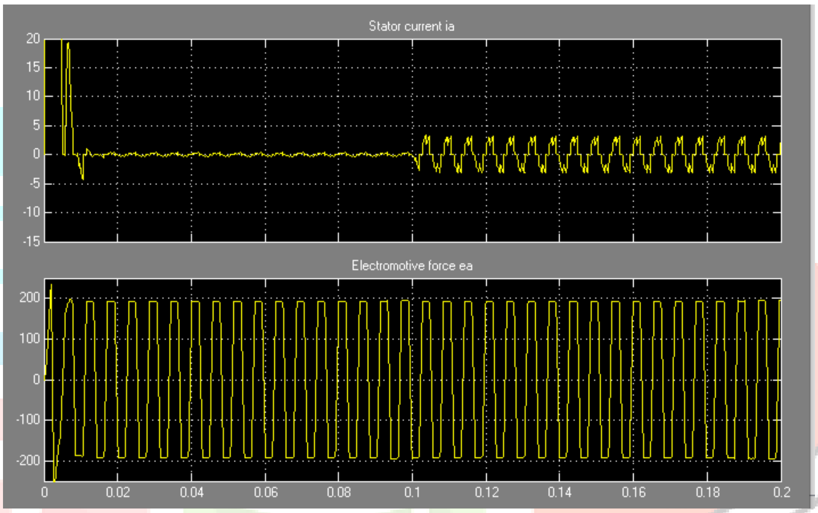

Fig 10: Simulation results of stator current and emf waveform of BLDC motor

Conclusion

In this paper, the BLDC motor is studied in detail. BLDC motor is popularly used in industrial and commercial applications. Speed control of the BLDC motor with a PID controller improves the overall performance of the motor. Irrespective of the controller used, the gradual application of load gives better results. But the sudden application of load gives the jerky behavior that can be improved with the help of the PID controller.

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