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Design and Comparison of Controllers for Speed Control of BLDC Motor

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Abstract: *The study aims to find the best speed controller for the BLDC motor. It is important to control the speed of BLDC motor to work at the desired rate. We have various speed control methods for BLDC motor, among all we studied PI controller and Antiwindup PI controller. With the Help of MATLAB/Simulink, we created a virtual model of BLDC motor using these controllers. The speed control analysis is based on the simulation result of these two controllers. This study includes the integral windup or rollover issue that arises in the PI controller and the Antiwindup PI controller eliminates this integral windup arising in the BLDC motor. In this paper, we designed and simulate the BLDC motor model with PI controller and Antiwindup PI controller. Also compared the result of speed response on MATLAB Simulink software.*

Keywords - *Anti windup PI controller, BLDC motor, MATLAB/Simulink, PI controller.*

I. INTRODUCTION

Brushless DC motor (BLDC) is widely used in industries due to its dynamic response, high power factor, noiseless operation, compact size, reliable performance, good efficiency with less maintenance cost. In the traditional motor like the Induction motor and DC motor, the commutation process is done by brushes, while in Brushless DC motor communication is done electronically instead of brushes. Induction motor is also used widely in industries but these motor also have drawbacks such as low starting torque and power factor.

On another side, the BLDC motor is popular because of its high torque and less maintenance they have extra advantages such as high-speed range and long operating life. BLDC Motor does not consist of brushes so they need a special type of electronic controller for commutation. Conventionally we use PI Controller for speed control of BLDC motor. PI controller is closed-loop feedback control mostly used in industrial control systems.

A PI continuously calculates the difference between actual output and desired output. As PI is an old controller it has an issue of integral windup or roll-over in the BLDC motor. Integral windup or roll over is a phenomenon of accumulating the integral component greater than the saturation limits of the system. Because of this, we will get a significant error if the set output increases or decreases suddenly. This error causes the integral component to accumulate with time to make this error zero results in delayed response, large overshoot, and very high settling time. To overcome these phenomena of integral windup or rollover, an Antiwindup pi controller is used. AWPI controller continuously calculates error values and applies a correction signal based on proportional and integral terms. The controller tries to diminish the error after some time by modifying the control variable.

This paper presents the comparison of PI controller and Antiwindup PI controller on the speed control basis on the Simulink MATLAB platform.

II. BLDC MOTOR

A BLDC motor is a permanent magnet BLDC motor in which commutation is done by electronically. The BLDC motor has 3 main parts that are the rotor, stator, and hall sensor. The rotor is a permanent magnet with a north and south direction in it. The speed of the rotor is controlled by the pulse signal of the stator winding. A stator is a stationary part of a motor in which carries the rotor. There are three Hall sensors attached to the stator to sense the position of the rotor and also sense the speed of the rotor.

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The control system observes the rotor position and the proper switching pattern is supplied by a three-phase inverter to motor the combination of the signal of hall sensors determine the sequence of commutation.
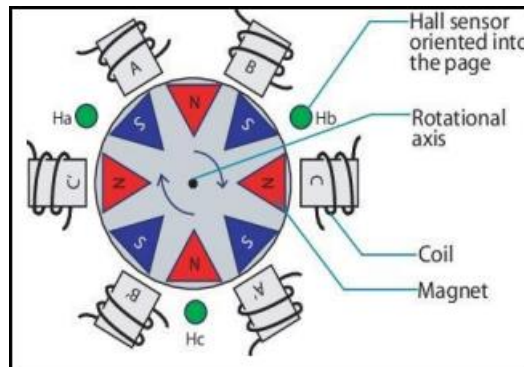

Fig.1. Equivalent Circuit Diagram of 3 Phase BLDC Motor Dynamic modelling of BLDC motor

Consider equivalent circuit diagram of 3 phase BLDC motor with windings, in cylindrical rotor there is uniform air gap,
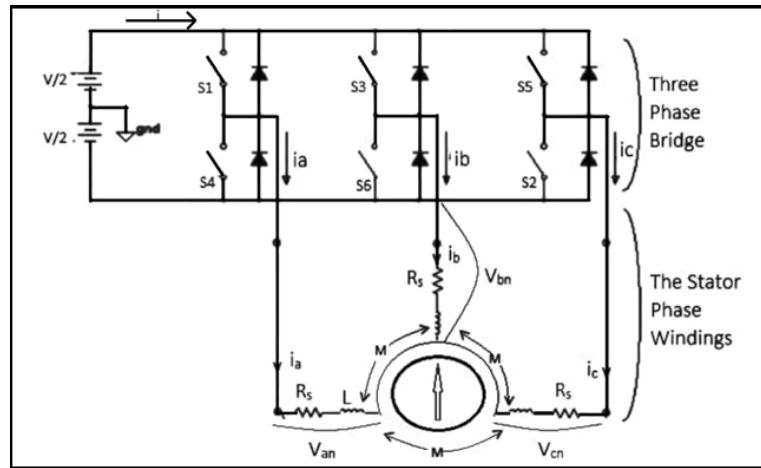

FIG.2. Equivalent Circuit Diagram of 3 Phase BLDC Motor

$$V_{an} = R_s i_a + L\frac{di_a}{dt} + M\frac{di_b}{dt} + M\frac{di_c}{dt} + e_a$$

$$V_{bn} = R_s i_b + L\frac{di_b}{dt} + M\frac{di_c}{dt} + M\frac{di_a}{dt} + e_b$$

$$V_{cn} = R_s i_c + L\frac{di_c}{dt} + M\frac{di_a}{dt} + M\frac{di_b}{dt} + e_c \qquad 1$$

Where, V_{an}, V_{bn} and V_{cn} are stator voltage in Volts per phase; i_a, i_b and i_c are stator current in amp here per phase; e_a, e_b and e_c are back emf in per phase; L are the motor self inductance in henry per phase; M is Mutual inductance between two phase; R_s is stator resistance in ohms per phase;

Mathematical model of BLDC motor can be represented by following equation,

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & L & M \\ M & L & L \\ M & M & L \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad 2$$

$e_a \propto r$; k_a is constatnt of position of rotor;

$$e_a = k_a \omega r, e_b = k_b \omega r, e_c = k_c \omega r$$

Since the stator current are balanced,

$$i_a + i_b + i_c = 0$$

$$i_b + i_c = -i_a$$

$$V_{an} = R_s i_a + L\frac{di_a}{dt} + M\frac{d(i_b + i_c)}{dt} + e_a$$

$$V_{an} = R_s i_a + L\frac{di_a}{dt} + M\frac{d(i_a)}{dt} + e_a$$

$$V_{an} = R_s i_a + LS\frac{di_a}{dt} + e_a \dots (L_s = inductance\ of\ each\ per\ phase)$$

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Similarly, we get for V_{bn} and V_{cn}

$$V_{bn} = R_s i_b + LS\frac{di_b}{dt} + e_b$$

$$V_{cn} = R_s i_c + LS\frac{di_c}{dt} + e_c$$

$$\begin{bmatrix}\frac{di_a}{dt}\\\frac{di_b}{dt}\\\frac{di_c}{dt}\end{bmatrix} = \left\{\begin{bmatrix}V_{an}\\V_{bn}\\V_{cn}\end{bmatrix} - \begin{bmatrix}R_s & 0 & 0\\0 & R_s & 0\\0 & 0 & R_s\end{bmatrix}\begin{bmatrix}i_a\\i_b\\i_c\end{bmatrix} - \begin{bmatrix}e_a\\e_b\\e_c\end{bmatrix}\right\}\frac{1}{L_s}$$

3

Mechanical power of BLDC motor is

$$P_m = (e_a i_a + e_b i_b + e_c i_c)$$

Torque of BLDC motor is

$$T = \frac{P_m}{\omega rm} = \frac{P}{2}\frac{Pm}{\omega r} = \frac{P}{2}\left(\frac{e_a i_a + e_b i_b + e_c i_c}{\omega r}\right)$$

$$T = \frac{P}{2}\left(\frac{k_a i_a + k_b i_b + k_c i_c}{\omega r}\right)\omega r \quad (e_a = k_a\omega r, e_b = k_b\omega r, e_c = k_c\omega r)$$

$$T = \frac{P}{2}(k_a i_a + k_b i_b + k_c i_c)$$

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III. PI CONTROLLER

The proportional Integral (PI) controller gives continuous variation in output with the help of a control close loop feedback system to precisely control the process, by eliminating oscillation of output and increasing process efficiency.

Where, is the output of the PI controller, is the proportional gain, is the integral gain, and is the instantaneous error signal.[2] The advantage of adding an integral part of the PI controller is to reduce the constant error in the system. However, the integral controller has a limitation when the system goes under saturation, and if the system stays in under saturation condition integral component of the controller starts accumulating which results in the delayed response. This phenomenon is known as windup or roll over and can be eliminated by applying limiter to the integral component of the controller before summing its output to the PI controller. Refer to Fig.3 for the PI controller block diagram:

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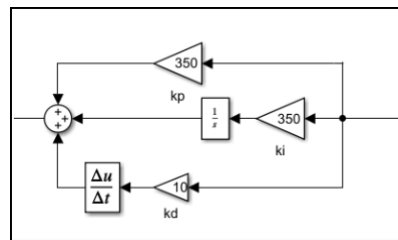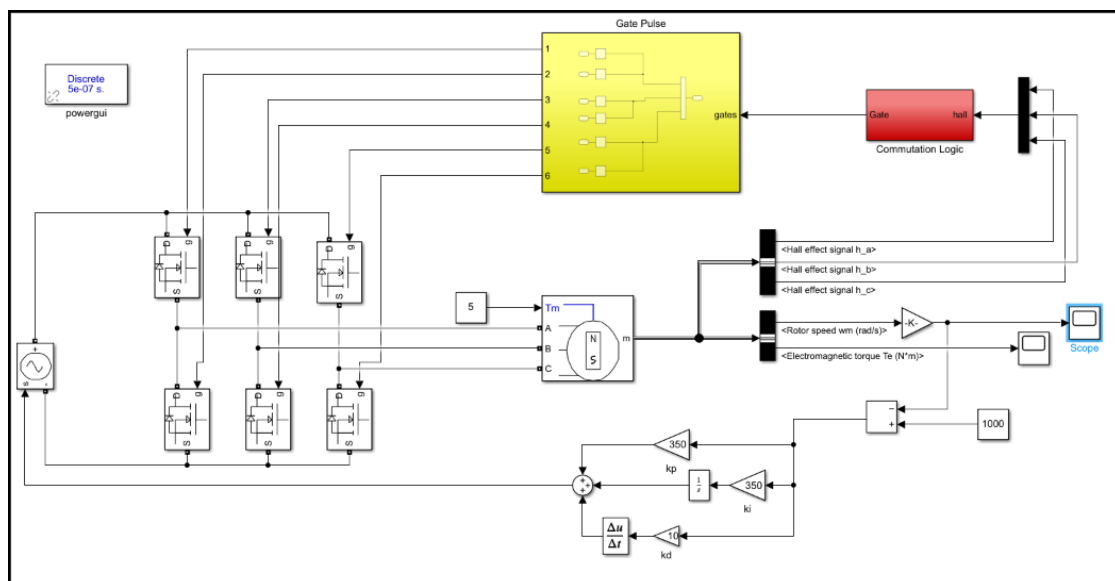$$\mathbf{V(t)} = kK_p e(t) + K_I \int_0^t e(\tau) d\tau$$

FIG.3. PI Controller

Fig.4. Simulink Model of BLDC Motor with PI Controller

III.   Antiwindup PI controller

Every real-life system has limitations and every system saturates but in the control system, we never accounted for this limitation till now. We assume that the system is linear and the output will keep rising as we keep increasing the commanded input.
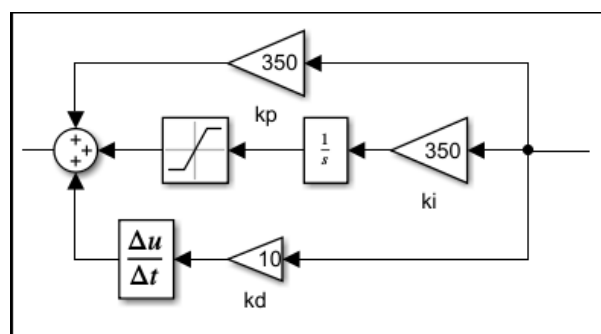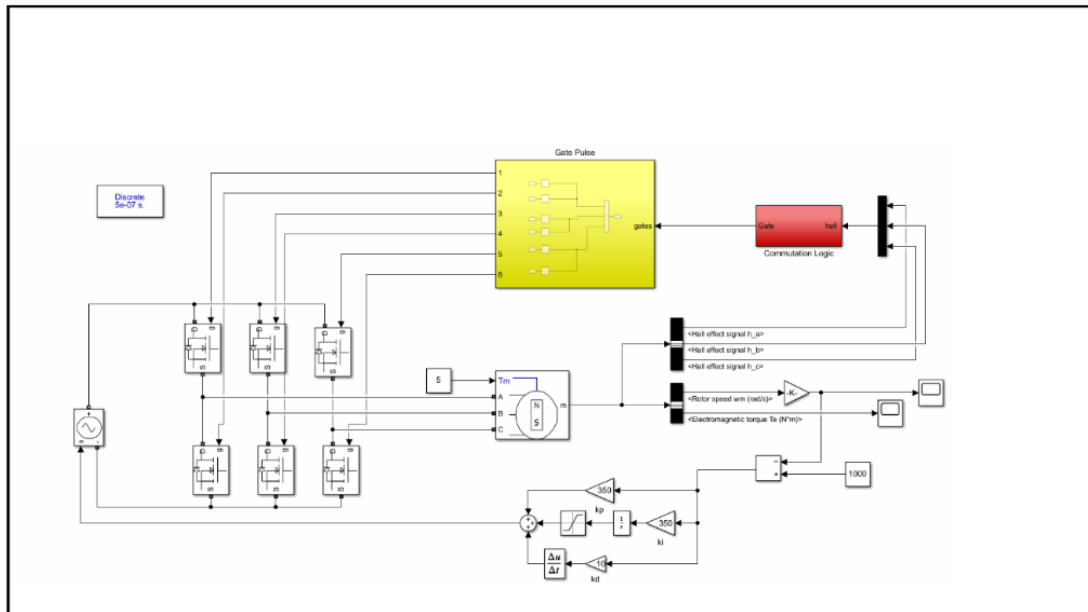

FIG.4. Anti Windup PI Controller

Fig.4. Simulink Model of BLDC Motor with Anti windup PI Controller

The PI Controller has an only problem is the phenomenon of windup or rollover, therefore we compare the actual input and the commanded input. If they are the same, the saturation is not in effect. Antiwindup controller calculates the error value of e(t) and it applies a correction signal based on proportional and integral terms. This error causes the integral component to accurate with time to bring the error to zero which results in delayed response, large overshoot, and very high settling time. This controller is used to minimize error over time by adjusting the control variable.
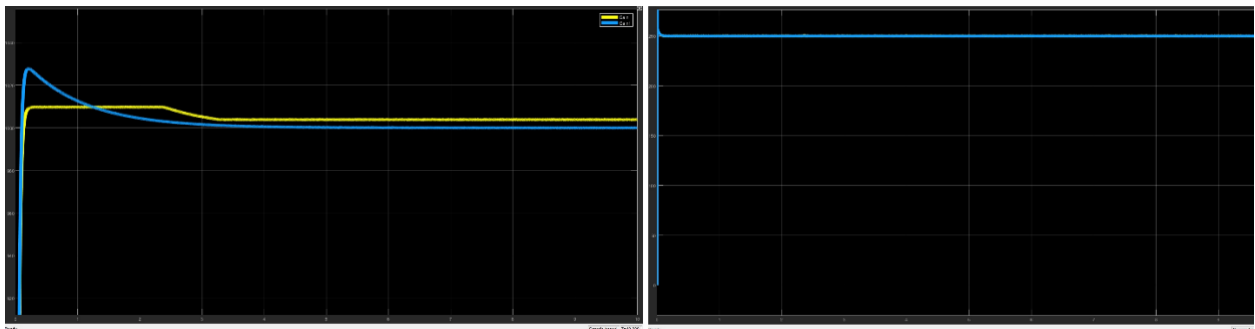

Fig.5. Graphs of Speed response and Torque output

IV.   METHODOLOGY

In this project, we obtain a mathematical representation of the BLDC motor. Basis of Mathematical representation of BLDC Motor reference representation of BLDC motor we designed to observe the ideal response of the motor. Then we designed a representation of BLDC motor which is controlled by PI and Anti windup PI controller and simulated mathematical model on Simulink and by the help of simulation results of PI and Anti windup based controller for BLDC motor are compared with each other. By the result of the Simulink model, we will conclude that Anti wind PI controller is the efficient controller for the BLDC motor.

V.   CONCLUSION

We can compare these techniques for better speed control and load variation for BLDC motor. We designed and simulated a mathematical model of the BLDC motor with these controllers on MATLAB Software. By changing or controlling input Speed to the motor we can conclude, by comparing the Anti windup controller with the conventional PI controller, we compared the performance of the BLDC motor, hence we conclude Anti wind PI controller is the best suitable for less overshoot and time identify the best suitable method.

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