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PI Controller Based Performance Analysis of Brushless DC Motor, Utilizing MATLAB Simulink Environment

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Authors' contributions

This work was carried out in collaboration among all authors. Author AR designed the study, performed the analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AR and MB managed the analysis of the study and managed the literature searches. Author MFA provided the final revision and optimized the literature search. All authors read and approved the final manuscript.

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ABSTRACT

Brushless DC Motor (BLDC) is gaining more and more popularity as one of the best electrical drives nowadays due to advantages like high efficiency, low maintenance, good reliability & wide dynamic response. The traditional brushed motor speed regulation is essentially effective in low speed and unable to lower the commutation torque ripple in high speed range. Speed regulation of Brushless DC (BLDC) motor is done by utilizing PI controller. The PI controller output act as the input to the variable voltage block. The mathematical modeling of BLDC motor is additionally shown here. The BLDC motor is supplied from the inverter while the rotor position and speed are the input here. The detailed mathematical model of the anticipated drive system is developed and simulated using MATLAB/Simulink environment. Principle of operation of using component is examined and therefore the simulation results are reported here to verify the theoretical analysis.

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1. INTRODUCTION

Brushless DC Technology is predominantly used in motors where the physical commutation is replaced by electronic commutation. Sensor based Electronics Switching is employed to switch suitable stator winding. In a conventional DC machine rotor has the windings while stator is a permanent magnet, rotor windings are excited with a current supply. Commutator & brushes assembly reverses the current at brush axis to create alternating current in the rotor winding. On contrary, in a Brushless DC motor the rotor is made up of permanent magnet while windings are on the stator as shown in Fig. 1. To make the rotor work, a revolving electric field is compulsory. Normally a 3ϕ Brushless DC motor has three rotor phases, out of only two phases are excited at a time to create a revolving magnetic field. The excitation of the rotor winding depends on the position of rotor hence sequencing of excitation is a function of rotor position. Correct sequencing also averts locking of permanent magnet rotor with the stator. Position information can be obtained by either Hall effect sensors, light encoder, magnetic encoder etc. BLDC motor drives are popular in electric vehicles, chemical industrial applications, robotics, and defense application. In recent years the Brushless dc motors are preferred as small horsepower control motors due to their compact size, high efficiency, low maintenance and reliability in operation [1]. Conventional PID controllers are being used for some control applications. Practical applications require near exact mathematical modeling [2] of machine to designing the controllers. The responses of the system are found to be highly nonlinear and Complex [3]. As the linear systems are approximated to obtain their mathematical model and the controller are designed for such systems may give the satisfactory dynamic responses, transient state and steady state responses but there are no optimum responses [4]. In some of the literature, the system parameters never change during the operating conditions it has been assumed but for the practical applications the mechanical parameter such as the inertia and the friction changes due to their decoupling inertia elements.

The phase resistance of the BLDC motor slightly changes due to their terminal resistance where there are some changes in winding resistance and on-state resistance of the semiconductor switching devices due to temperature changes during operating conditions. The ratio of no load based on the full load friction and the inertia changes [5] from 10-20 times due to decoupling inertia for the positioning applications. The system parameters need to be selected carefully such that it can provide better transient & steady state responses. At different operating conditions this controller is investigated for parameter variations and load disturbances.

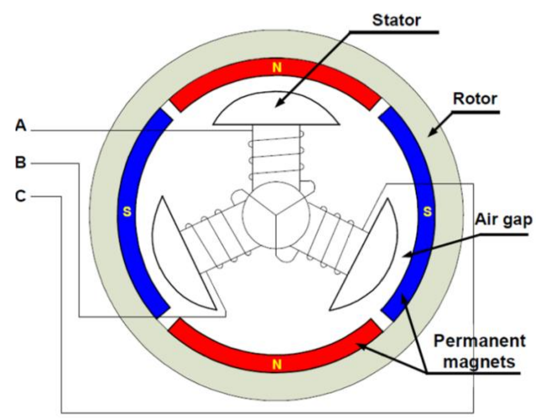

Fig. 1. BLDC motor cross-section

The modeling of BLDC motor and the different control schemes are discussed in this paper in [6]. The dynamic performance of the BLDC motor system, the effect of change in motor parameters is discussed in [7]. In the PI controller several tuning methods are described in [8]. For the desired results, several tuning methods are suggested in [9] and hence trial and error method is adapted for determining parameter gain for the PI controller. Conventionally the motor used for industrial purposes is brush type of the dc motor drive. Though AC motor includes the induction and the brushless dc motors available in the fractional 40 hp range [10]. BLDC motor utilizes a trapezoidal back EMF and the rectangular stator currents to generate a constant electric torque. Traditionally Hysteresis current controller or pulse width modulation (PWM) current controller is employed to obtain the near rectangular currents flowing into the motor.

2. MATHEMATICAL MODELLING OF BLDC MOTOR

BLDC motor which is modeled in this paper is a 3 phase 8 pole motor. A Permanent magnet rotor, synchronous motor can also be considered as BLDC motor, the only difference is in the rotor construction due to which the dynamic characteristics of the machine altered and the 3-ϕ voltage source is fed to the motor. A sinusoidal square wave is not necessarily be used as source, other wave shape can also be used, but it should not outdo the maximum voltage limits. The equations for the armature winding voltage are given below:

$$Va = Ria + L\ dia/dt \tag{1}$$

$$Vb = Rib + L\ dib/dt \tag{2}$$

$$Vc = Ric + L\ dic/dt \tag{3}$$

where

L-armature self-induction in [H]
R-armature resistance in [Ω]
Va, Vb, Vc –terminal phase voltage in [V]
ia, ib, ic-motor input current in [A]
ea, eb, ec-motor back-Emf in [V]

Back-Emf of each consecutive phase has a phase displacement of 120° electrical and back-Rotor position & Emf are linked via some function. The governing equation is shown below:

$$ea = K_w\ (\theta e) \tag{4}$$

$$eb = K_w\ (\theta e - 2\pi/3) \tag{5}$$

$$ec = K_w\ (\theta e + 2\pi/3) \tag{6}$$

where

K_w = back-Emf constant of each phase, θe = rotor angle in degree electrical, ω = rotor speed

Electrical angel l (θe) & Mechanical angle (θm) are related as:-

$$\theta_e = P/2\theta_m \tag{7}$$

where, P = Total no of rotor poles

Thus total generated electromagnetic torque (Te) can be expressed as follows:-

$$Te = (eaia + ebib + ecic)/\omega \tag{8}$$

The mechanical torque transferred to the motor shaft:-

$$Te - Tl = Jdw/dt + B\omega \tag{9}$$

Where, T*l* = load torque, J= inertia of the rotor shaft, B = friction constant

3. CONTROL SCHEME FOR BLDC MOTOR

A variable dc link voltage control scheme for BLDC motor control has been utilized in this work. Reference speed signal along with BLDC motor speed feedback creates the necessary error signal. Generated error signal is used to control ideal voltage source block with the help of PI controller signal. PI controller is one of the most accepted controllers in industries. PI controller algorithm can be implemented as:

$$Y(t) = Kp\ e(t) + KI \int e(t)dt$$

where,

Y(t) = output and e(t) = error
Kp = proportional error constant
KI = Integral error constant

The corrective actions of controller directly trigger a controlled voltage source which further modifies the amplitude of inverter to achieve the targeted speed control. The values of KI and Kp were chosen by trial and error method. Tuning of controller is done manually, during the tuning process system is maintained online, initially Kd and KI gain values are set as zero. Than value of kd is set to one. Response of the system is observed. Gain Kp Increased until the output of the loop oscillates, then value of Kp gain is set to nearly half of that value for a "quarter amplitude decaying" type response. Then Ki gain increased until offset is removed in sufficient time for the process. However, too much Ki gain will lead to instability. Manual tuning of the controller results in the following gain constant values.

Table 1.Controller parameter

Kp	Ki
0.15	75

4. SIMULINK MODEL

It is important to give precise value of torque to the model in order to design effective BLDC Motor drive system, where torque is function of back-Emf [4]. For energizing the stator winding in correct sequence the knowledge of rotor position is necessary since in order to rotate the rotor, stator winding has to be energized sequentially and also commutation has to be done electronically. The speed control has been done through variable dc link voltage control technique and finally the results are verified.

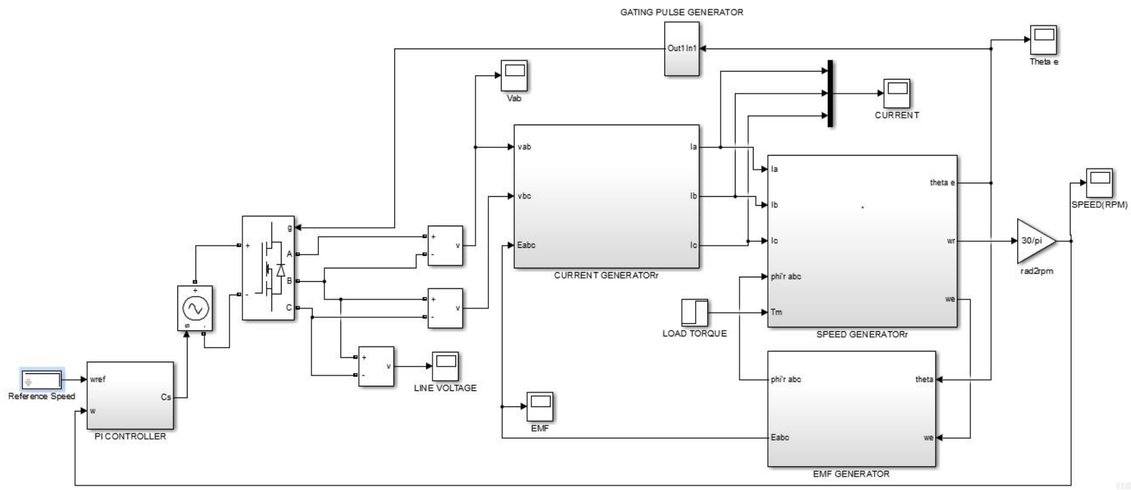

Fig. 2. Model of BLDC motor drive

Table 2. BLDC motor parameter

No. of poles	8
No. of phases	3
Types of connection	Star
Vdc	500V
HP	35 hp
Resistance/phase	2.875Ω
Stator inductance	0.0085H
Moment of inertia, J	00008kg-m/s^2
Damping constant, B	0.001N-m/rad/s

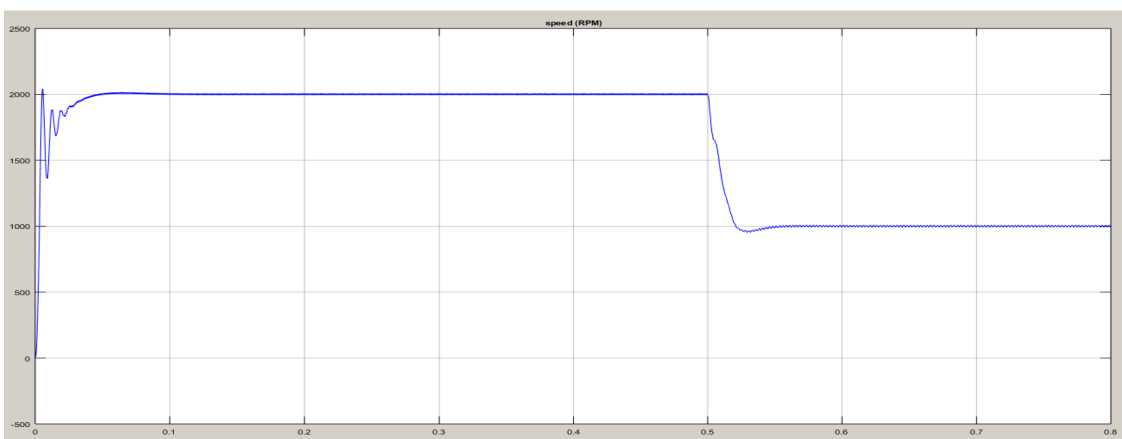

Fig. 3. Speed vs. Time

With the above design consideration, the simulation has been done and the result is presented here. Speed is set at 3000 rpm and load torque disturbance is applied at 0.01 sec. the speed regulation is obtained at the set speed. The back Emf and current waveform are shown by the simulation waveform and it shows that back-Emf and phase voltage both are displaced by 120 degrees each. Fig. 5 shows stator currents are of quasi sinusoidal in nature and also displaced by 120 degrees.

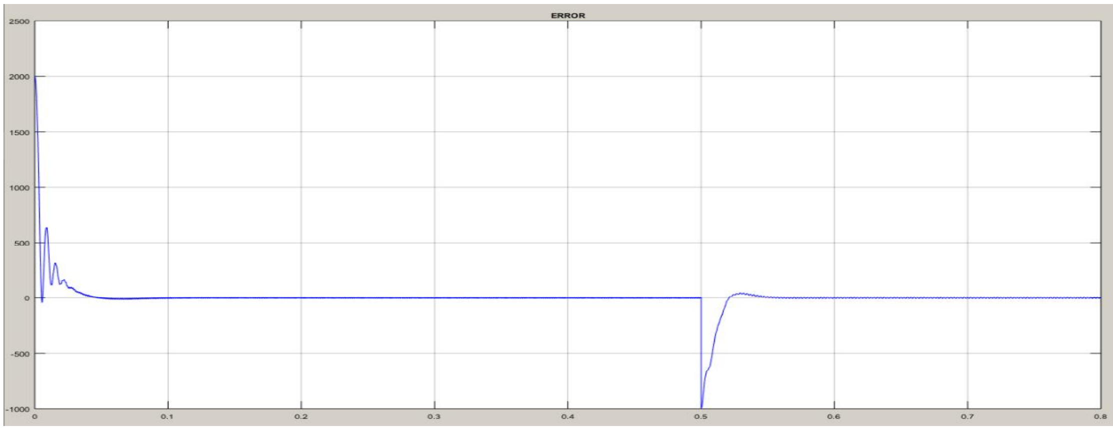

Fig. 4. Error vs. Time

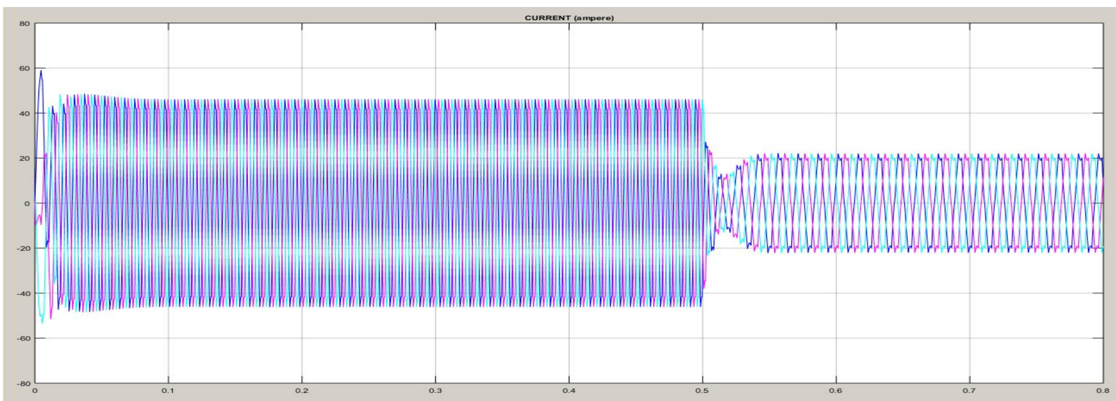

Fig. 5. Current vs. Time

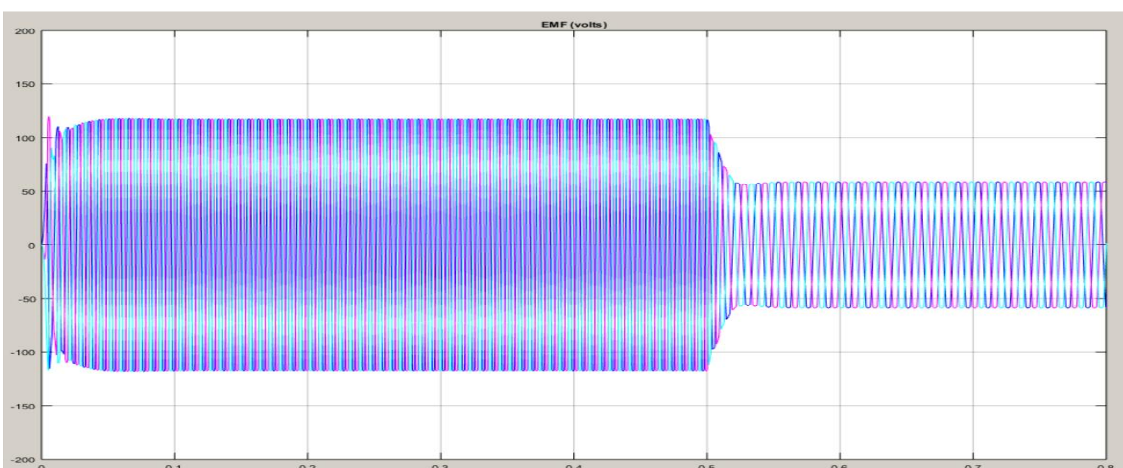

Fig. 6. Back EMF vs. Time

5. RESULTS AND DISCUSSION

The speed response of the brushless DC drive system using PI controller is as shown in above figure. The reference speed is set at 2000 rpm with the motor at rest stage with a settling time 0.05 seconds. Motor speed reaches the reference speed with a % overshoot of 2.083 as shown in Fig. 3. The phase currents during the time of starting getting transient due to zero initial phase back emfs of machine. When the speed reaches reference speed, phase currents attains the reference current. The reference speed of the BLDC motor changed to 1000 rpm at 0.5 sec. The Fig. 6 above shows the EMF variation of BLDC motor using PI controller and Fig.3 shows the undershoot by the rotor is 2.56% of final speed. Time taken by rotor speed is to settle is 0.032 sec. The speed response of the BLDC drive with PI speed controller of the drive is quite satisfactory. Improved speed response in this work is of great value to industrial applications.

6. CONCLUSION

The PI controller is designed for the BLDC motor drive to enhance the dynamic performance and to improve the speed characteristic of the drive. The simulation has been carried out for various operating conditions using PI controller. The simulation results from the proposed controllers are presented on the basis of rise time & settling time for steady state and for dynamic state for sudden variation in load and set speed change. Effectiveness of the controller is proved by performance over a wide range of operating conditions. While using Controller the dynamic capabilities is enhanced and based on the advantages parameter change and load perturbation are controlled. All the simulation results are of theoretical aspects and can be utilized for practical implementation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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