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Modeling And Simulation Of Brushless Dc Motor With PI Speed Control

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Abstract: Brushless DC motor has many advantages such as simple structure, high torque to weight ratio, high efficiency, etc. Hence it is widely used in aerospace, robotics and office automation. This paper presents the mathematical model of Brushless DC (BLDC) motor and shows the values of various technical parameters by using MATLAB/ SIMULINK and study of speed control of BLDC motor drive with proportional integral (PI) control. The simulation is carried out for 120 degree mode of operation. Finally a PI controller is applied for closed loop under various load conditions.
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Keywords: BLDC motor, Modeling of BLDC motor, PI-controller

INTRODUCTION

BLDC motor is defined as a type of self-synchronous rotary motor controlled by electronic commutation unlike DC motors have mechanical commutator. As BLDC motor neither has mechanical commutator nor slip rings, so it has great advantages more than conventional DC motor and induction motor such as better speed-torque characteristics, high efficiency, high dynamic response and wide speed ranges (Pillay and Krishnan, 1989) . The proportion integral (PI) controller is used for amplify the speed error and adjust gate pulse signal to control the six switches of the three phase bridge

Nomenclatures

u_A, u_B, u_C	are phase voltage (V)
i_A,i_B,i_C	are phase current (A)
e_A,e_B,e_C	are phase back e.m.f (V)
R	is phase resistance (ohm)
L	is self inductance (H)
M	is mutual inductance (H)
T_e	is electromagnetic torque(N.m)
T_L	is load torque (N.m)
B	is damping constant (N.s/m)
J	is moment of inertia (kg.m^2)
K_e	coefficient of line back-EMF
K_T	the torque coefficient
K_i	integral gain
K_P	proportional gain
T_i	integral time constant
Greek Symbols	
Ω	is angular velocity (rad/s)
$Ω_r$	is reference angular velocity (rad/s)
Abbreviations	
PI	Proportion integral controller
BLDC	Brushless DC Motor

MATHEMATICAL MODEL OF THE BLDC MOTOR

Typically, the mathematical model of a brushless DC motor is not totally different from the conventional DC motor. The major difference is the phases involved in the operation of BLDC motor drive will peculiarly affect the resistive and the inductive nature of the BLDC model arrangement (Pillay and Krishnan, 1989). The equivalent circuit of BLDC motors shown in Fig.1.

The dynamic equations of BLDC motor can be expressed in this matrix form:

$$\begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} L\text{-}M & 0 & 0 \\ 0 & L\text{-}M & 0 \\ 0 & 0 & L\text{-}M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \quad (1)$$

The electromagnetic torque developed by the motor is given by

$$T_e = \frac{e_A i_A + e_B i_B + e_C i_C}{\Omega} \quad (2)$$

The motion equation has to be included as

$$T_e - T_L = J\frac{d\Omega}{dt} + B_v \Omega \quad (3)$$

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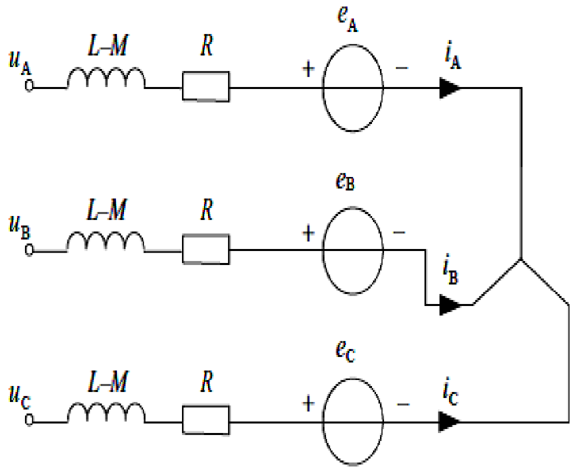

Figure 1 :Equivalent Circuit of BLDC Motor

The transfer function of BLDC motor is expressed by

$$G_u(s) = \frac{\Omega(s)}{U_d(s)} = \frac{K_T}{L_a J S^2 + (r_a J + L_a B_v)S + (r_a B_v + K_e K_t)} \tag{4}$$

$$G_L(S) = \frac{\Omega(S)}{T_L(S)} = -\frac{r_a + L_a S}{L_a J S^2 + (r_a J + L_a B_v)S + (r_a B_v + K_e K_T)} \tag{5}$$

Where $K_e = 2P\psi_m = 4PNSB_m$

$K_m = 2P\psi_m$

MATLAB/SIMULINK MODELS

Figure.3 shows the BLDC motor model and describing the blocks using for it .The commutation block consists of subsystem which including three phase inverter model as shown in "Fig.4". The BLDC motor block consists of three subsystem back e.m.f equation, state equation and mechanical equation as shown in "Fig.2". Speed generator block is mechanical part of BLDC motor .By using this model the actual speed (w) of BLDC motor can be obtained by using the mechanical and electrical equation. The speed generator block is shown in "Fig.5". current generator block to obtain the stator phase current (i_A,i_B,i_C) by using state equation as shown in "Fig.6","Fig.7". Back e.m.f generator block is used to create Back e.m.f of BLDC motor as shown in "Fig.8" and "Fig.9".

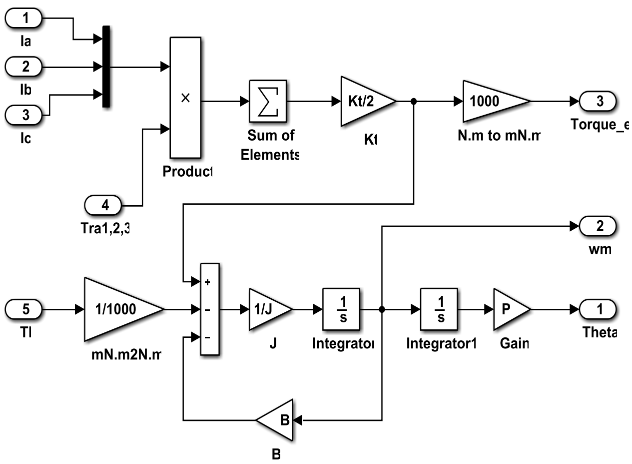

Fig. 2: Structure diagram of BLDC motor with load torque

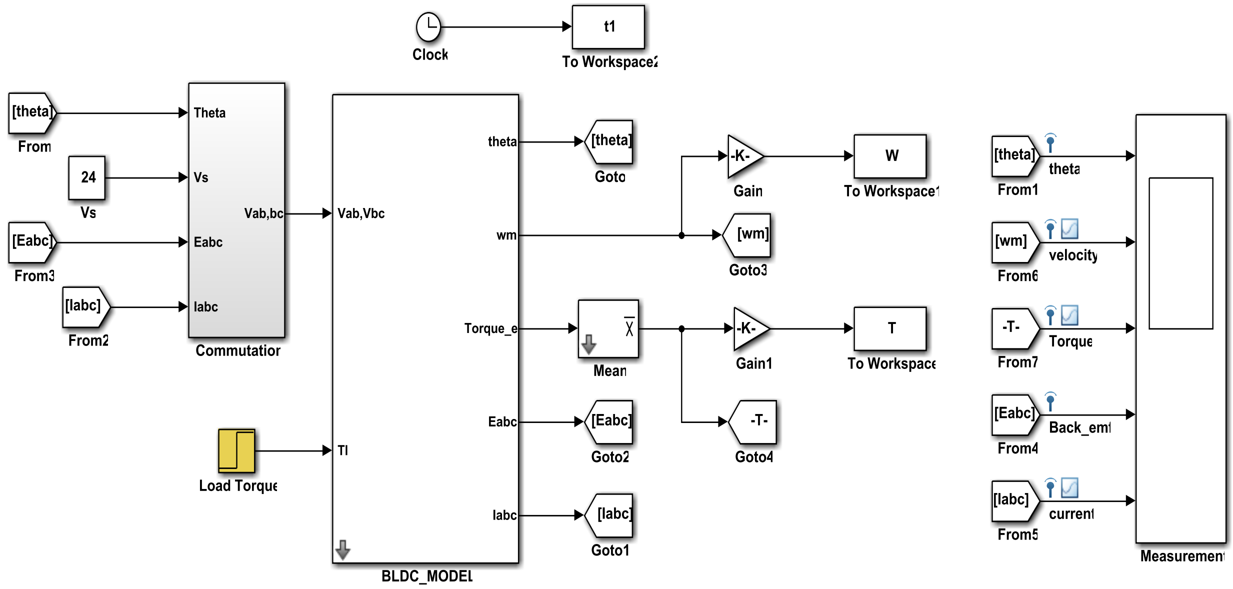

Fig. 3: BLDC motor simulink model

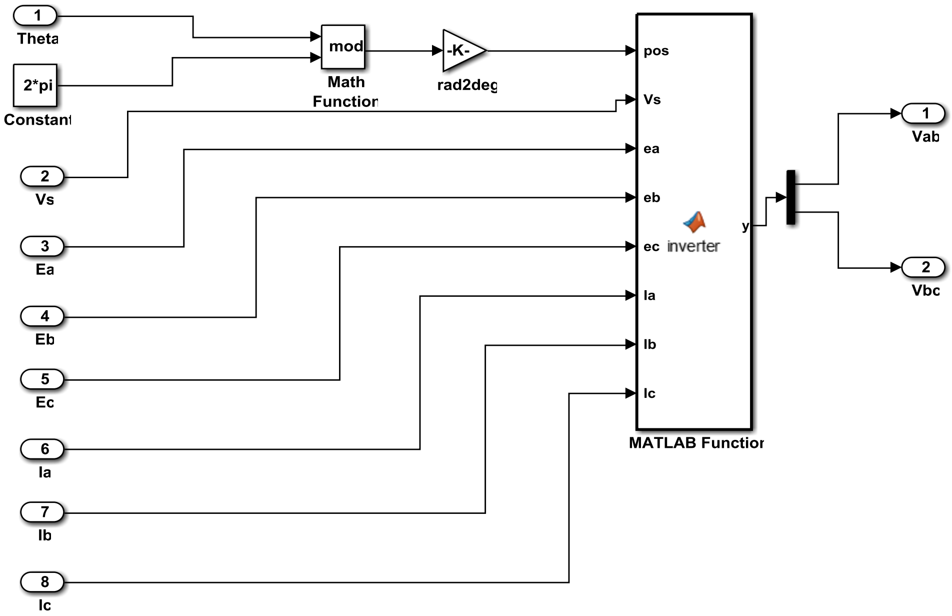

Fig.4: Three phase inverter model

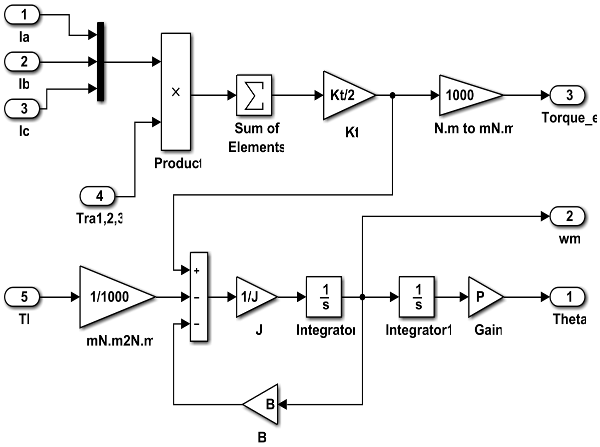

Fig. 5: Speed generator model

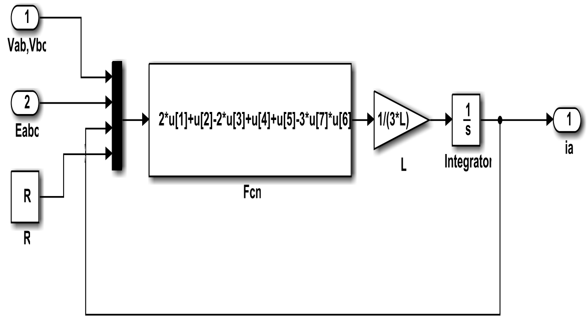

Fig. 7: State equation model

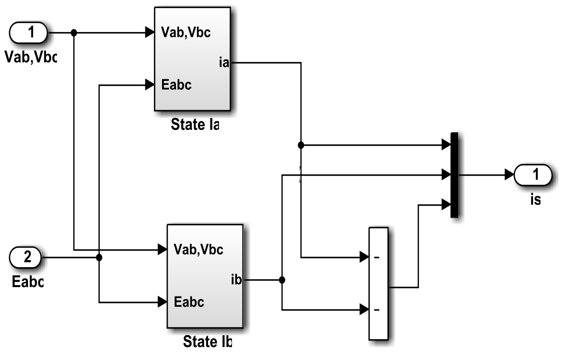

Fig.6: Current generator model

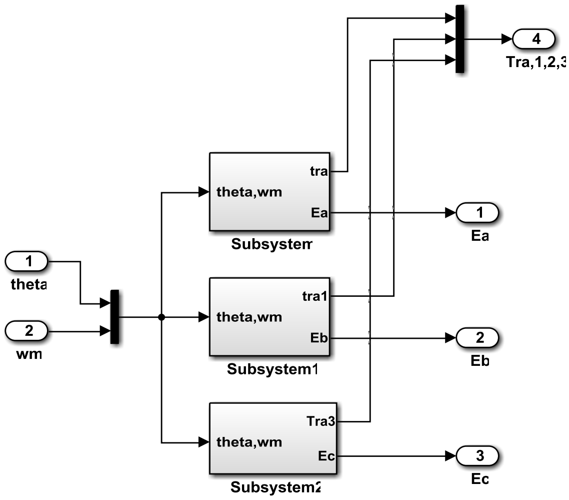

Fig. 8: Back e.m.f generator model

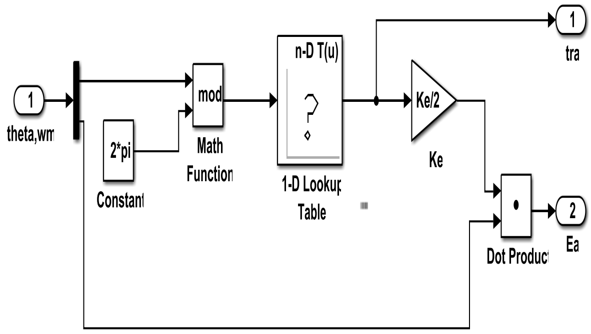

Fig. 9 :Back e.m.f subsystem

CONTROLLERS

PI Speed Controller

The actual speed of BLDC motor is obtained by using the speed position encoder. The actual speed of the motor compared with reference speed and the resulting error is estimated as

$$\Omega_e = \Omega_r - \Omega_{r*} \tag{6}$$

The resulting error is given to PI controller. The transfer function of of PI controller is estimated as

$$G_s(S) = K_P\left(\frac{1+1}{T_i S}\right) \tag{7}$$

The PI speed controller as shown in "Fig.10" is used as the input of reference current block

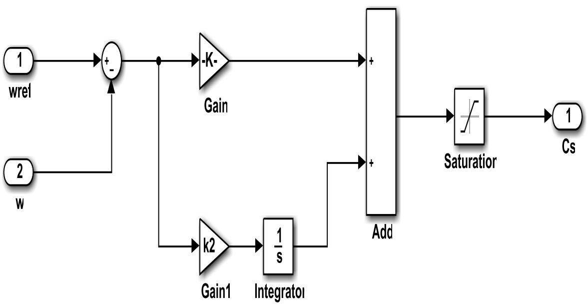

Figure 10: PI Speed Controller Sub Block

RESULTS AND DISCUSSION

The simulation results includes the different parameter of BLDC motor such as motor speed, electromagnetic torque, stator phase current, phase back e.m.f with respect

Motor Performance –Time Curves At Load Torque (TL=0)

Motor performance-time curves at different armature voltages

For different armature voltages, the motor speed, the stator phase current and developed torque are calculated for interval time from 0 to 0.1 sec there are shown in "Fig.11","Fig.12","Fig.13",Fig.14".

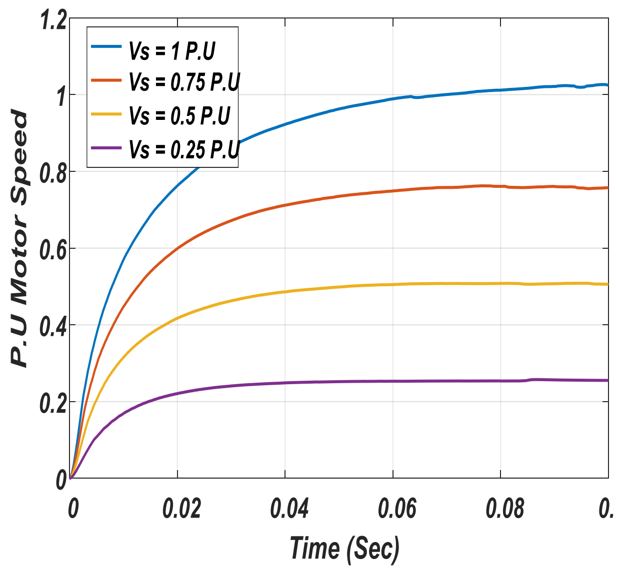

Fig.11: Relation between p.u speed and time (sec) at different motor voltages

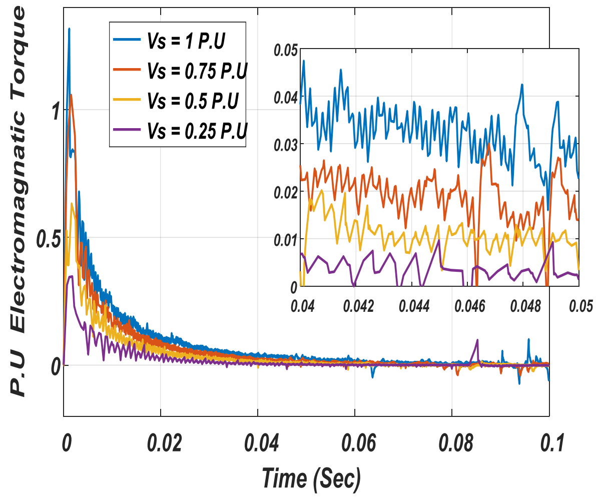

Fig.12: Relation between p.u electromagnetic torque and time (sec) at different motor voltages

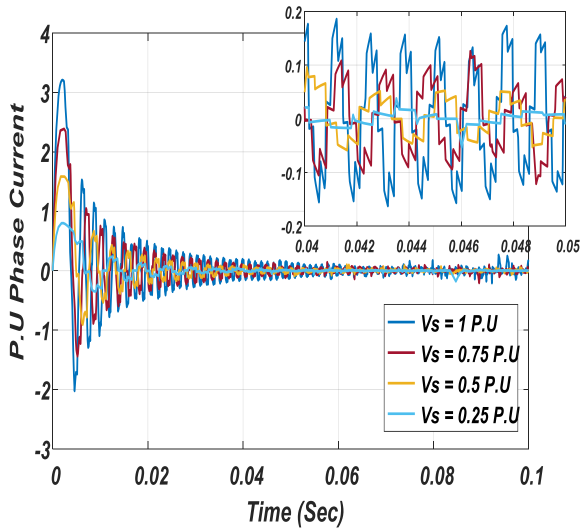

Fig.13: Relation between p.u phase current and time (sec) at different motor voltages

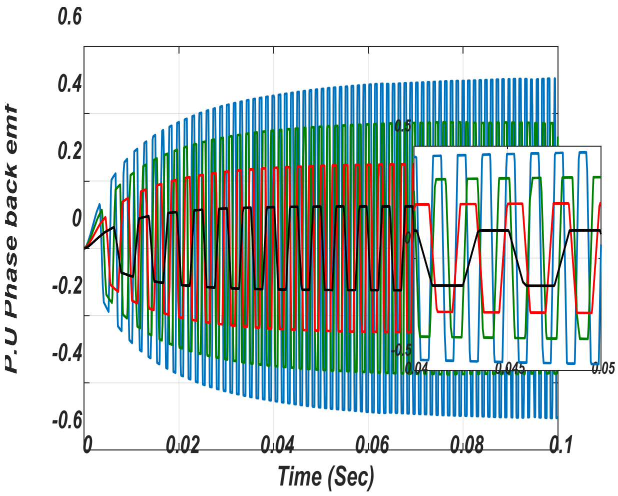

Fig.14: Relation between p.u phase back e.m.f and time (sec) at different motor voltages

Motor Performance-Time Curves at Different Armature Inductance

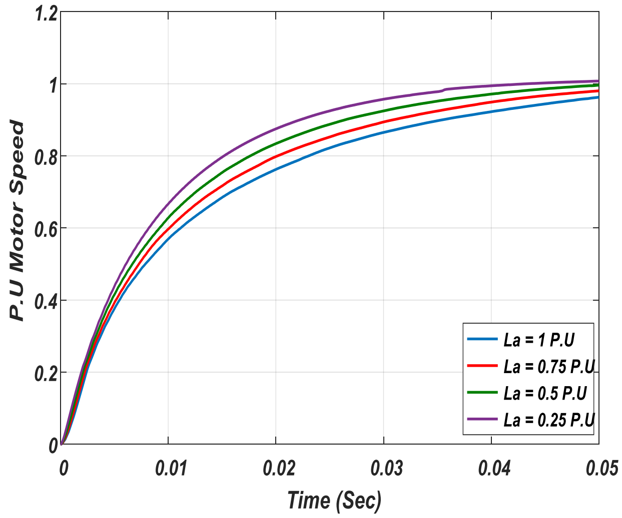

Fig.15: Relation between p.u speed and time (sec) at different armature inductances

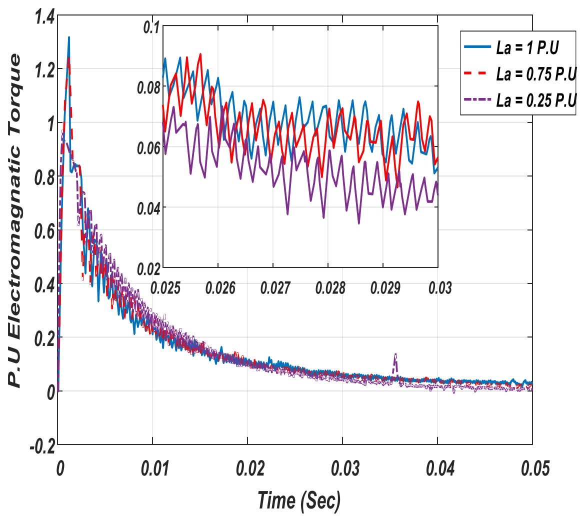

Fig.16: Relation between p.u electromagnetic torque and time (sec) at different armature inductances

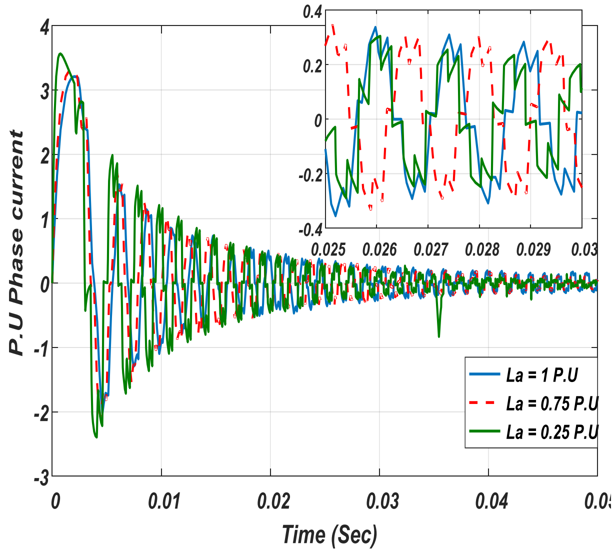

Fig.17: Relation between p.u phase current and time (sec) at different armature inductances

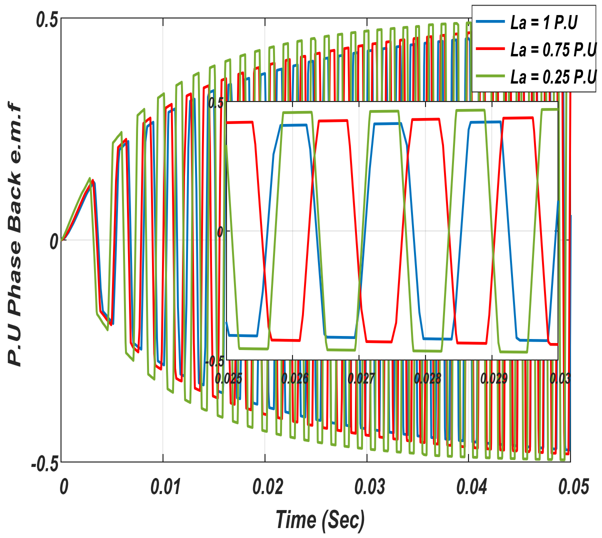

Fig.18: Relation between p.u phase back e.m.f and time (sec) at different armature inductances

Motor Performance-Time Curves at Different Torque coefficient

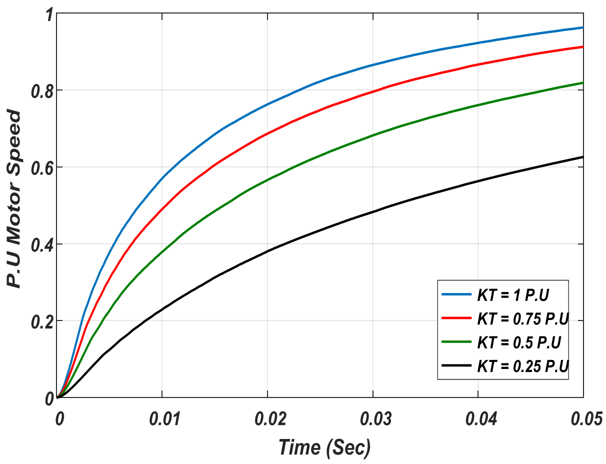

Fig.19: Relation between p.u speed and time (sec) at different Torque coefficient

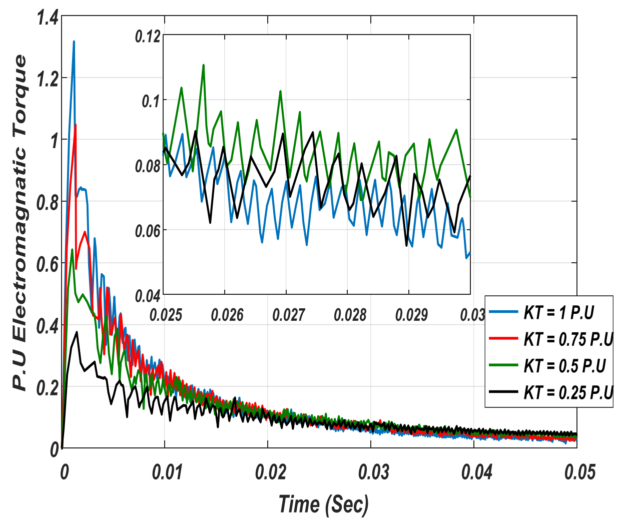

Fig.20: Relation between p.u electromagnetic torque and time (sec) at different Torque coefficient

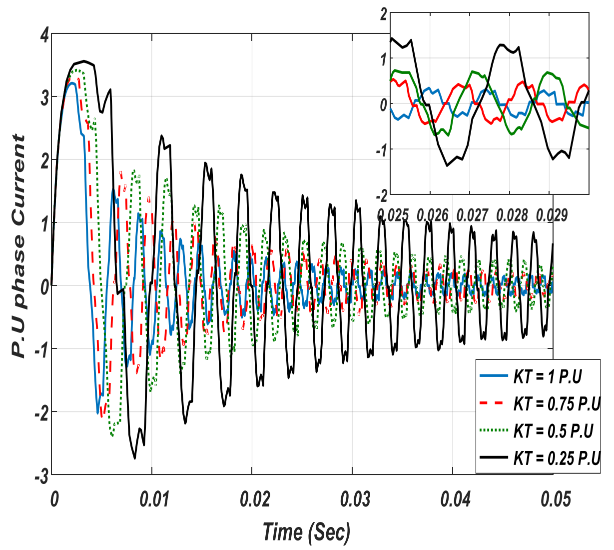

Fig.21: Relation between p.u phase current and time (sec) at different Torque coefficient

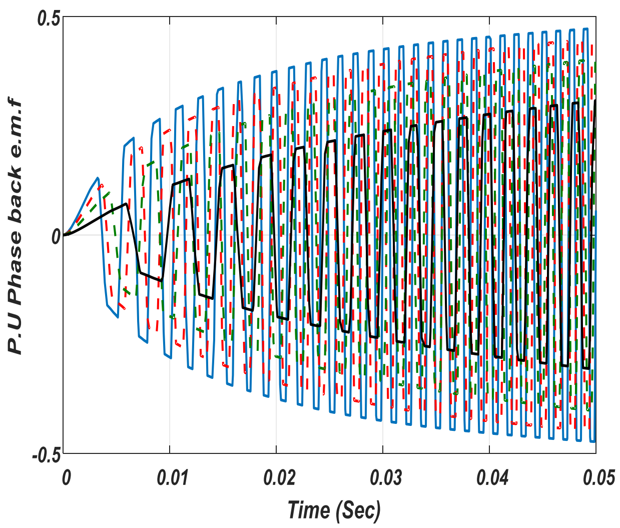

Fig.22: Relation between p.u phase back e.m.f and time (sec) at different Torque coefficient

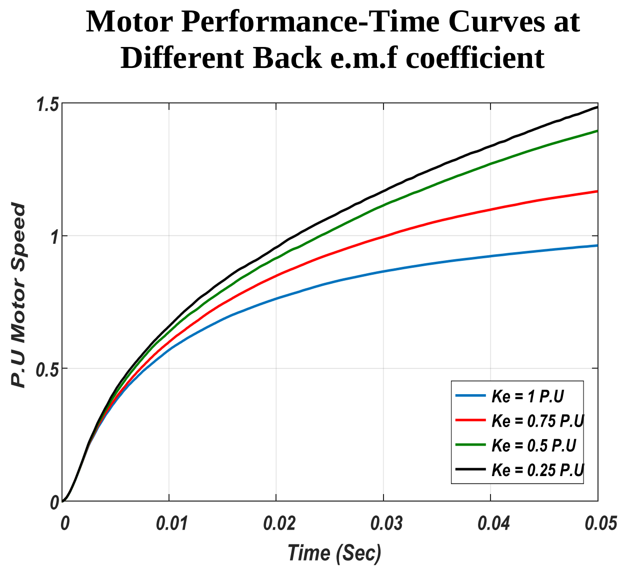

Fig.23: Relation between p.u speed and time (sec) at different back e.m.f coefficient

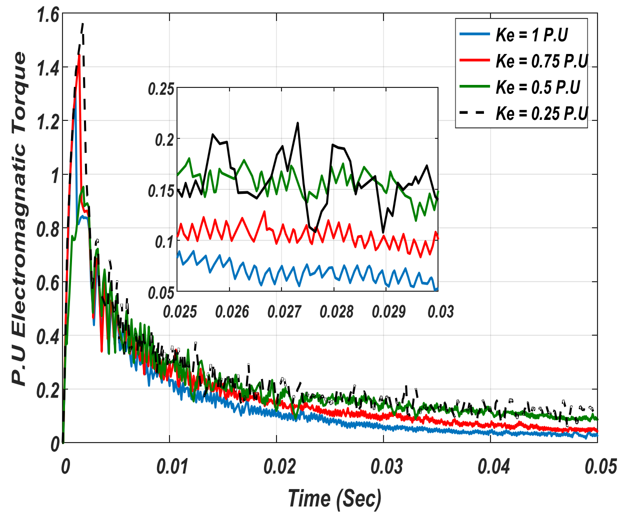

Fig.24: Relation between p.u electromagnetic torque and time (sec) at different back e.m.f coefficient

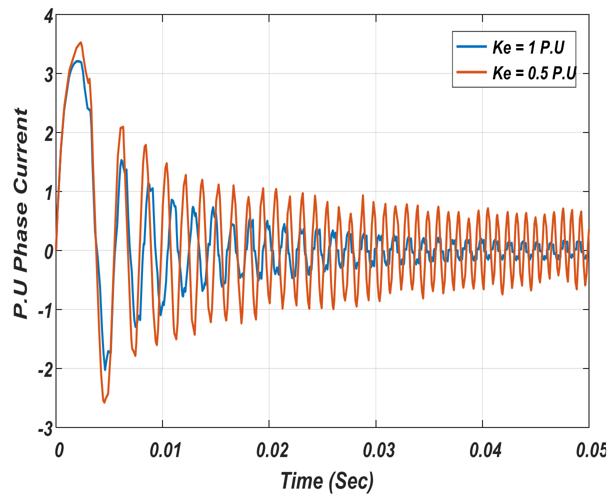

Fig.25: Relation between p.u phase current and time (sec) at different back e.m.f coefficient

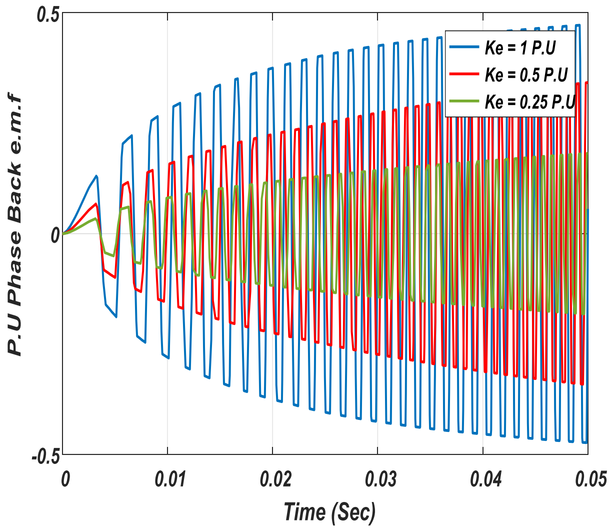

Fig.26: Relation between p.u phase back e.m.f and time (sec) at different back e.m.f coefficient

Motor Performance–Time Curves At Load Torque (TL=constant) & (TL= step load)

All results below of MATLAB program are used to obtain the main operating parameters, namely, the motor speed (n), the stator phase current (i_a) and developed torque (T_{el}) as function of time during constant load torque (T_l = 6 N.m = 0.3 P.U) and step load torque at constant other operating parameters such as (V_a, R_a,L_a,T_a,J,..)

CONCLUSION

This paper is propose to evaluate the mathematical model of BLDC motor and the performance of PI controller for speed control of BLDC motor drive system.

➔ Fig.12,13,14,15 show the motor speed, stator phase currant , developed torque and phase back e.m.f respectively as function of time with motor voltage (V_s) as a parameter. the effect of motor voltage on the motor performance is clear when the motor voltage increases the speed of the motor, phase current, developed torque and phase back e.m.f are increased.

➔ Fig.16,17,18,19 show the effect of stator inductance on the motor performance is clear when the stator inductance decreases the speed of the motor, phase back e.m.f are increased, phase current, developed torque are decreased.

➔ Fig.20,21,22,23 show the effect of Torque coefficient on the motor performance is clear when the Torque coefficient increases the speed of the motor, developed torque and phase back e.m.f are decreased but phase stator current increased.

➔ Fig.24,25,26,27 The effect of back e.m.f coefficient on the motor performance is clear when the back e.m.f coefficient increases the speed of the motor, developed torque and stator current are decreased but Phase back e.m.f is increased.

The dynamic simulation results of the BLDC motor with step load are shown in Fig.28,29,30,31.

➔ In Fig.28,29,30,31, the motor starts with no load, and then accelerates freely to the steady state. Note that when the load increases suddenly (i.e. jumps from 0 to 6N m at 0.025s), the motor speed will decrease with the cycle of the phase voltage and phase current becoming longer. The increase in the current will lead to an increase of the torque so as to balance the increased load torque. In addition, the amplitudes of the current and torque ripple are also increased. When the load decreases suddenly (i.e. varies from 6N m to 4N m at 0.045 s), the motor speed will increase with the cycle of the voltage and current becoming shorter. Moreover, the amplitude and the ripple of the current and the torque will become smaller. As discussed above, the speed is high enough at 0.025 s, i.e. the back-EMF is large enough. So, the current cannot quickly respond to the sudden increase of the load with constant bus voltage. Hence, the change of speed is relatively slow. In this condition, the boost circuits can be used to increase the voltage so as to accelerate the response speed of the current. Similarly, when the load decreases suddenly, we can use the PWM control method to reduce the voltage of the armature winding.

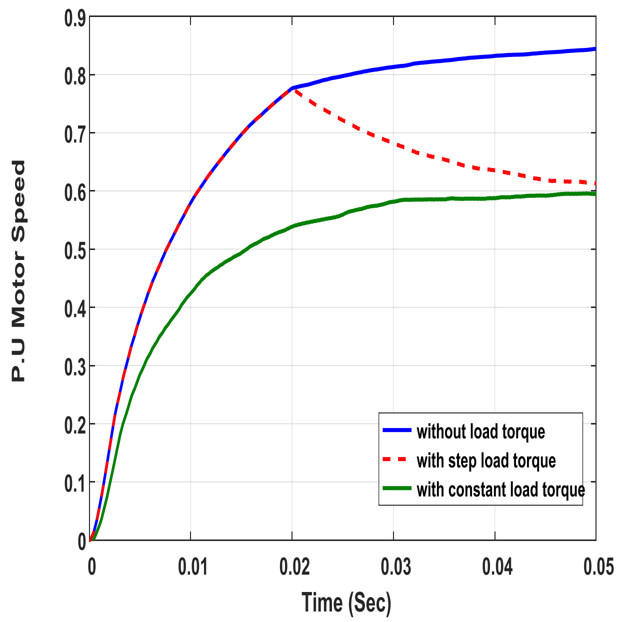

Fig.27: Relation between p.u speed and time (sec) at different load torque condition

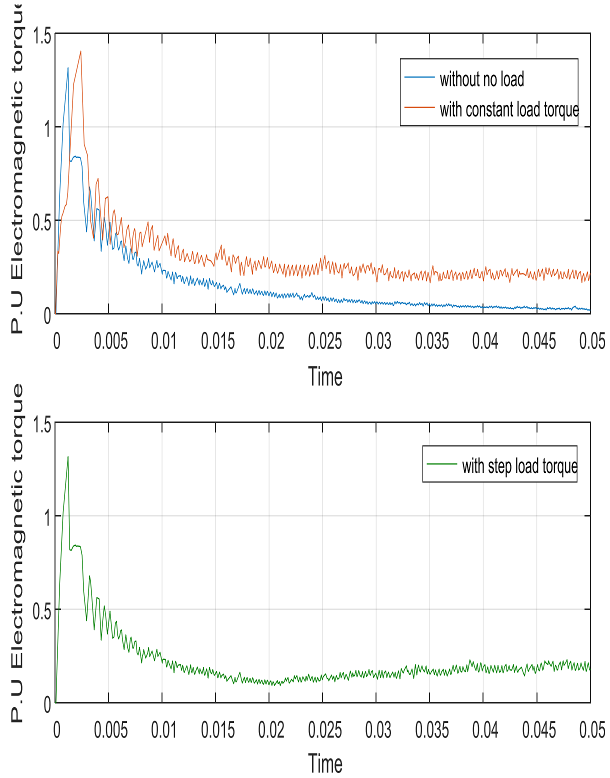

Fig.28: Relation between p.u electromagnetic torque and time (sec) at different load torque condition

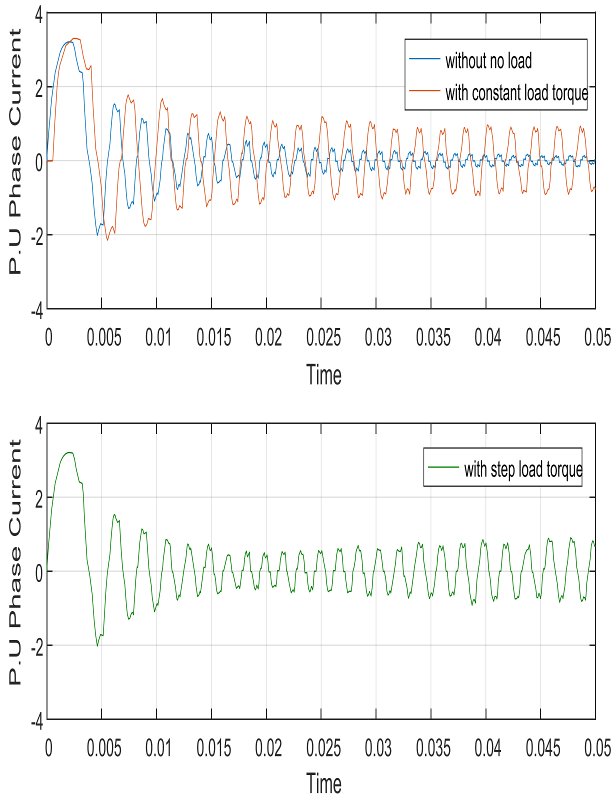

Fig.29: Relation between p.u phase current and time (sec) at different load torque condition

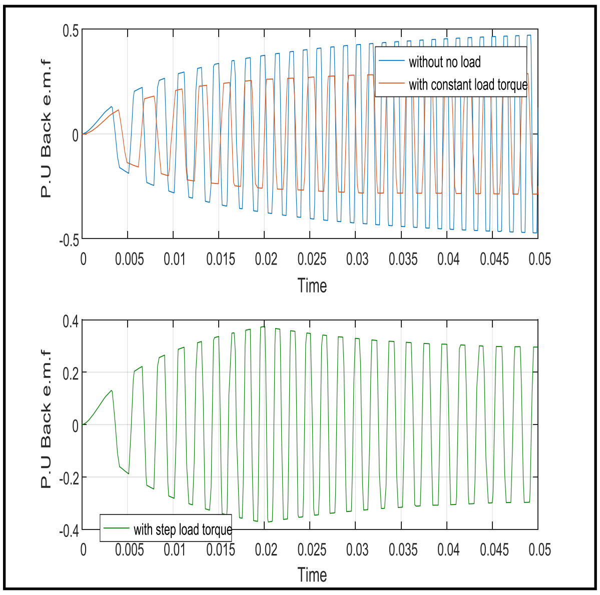

Fig.30: Relation between p.u phase back e.m.f and time (sec) at different back e.m.f coefficient

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