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Control Strategy & Mathematical Modeling of BLDC Motor in Electric Power Steering

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***Abstract*—The aim of the paper is to design a control strategy of the BLDC motor used in EPS system is proposed, then a simulation model of control system using in BLDC motor. In the developed model of BLDC motor, the characteristics of the speed, torque, back EMF, voltages as well as currents are effectively monitored and analysed which serve a design method for a further research of BLDC motor in EPS.**

***Index Terms*---Electric Power Steering (EPS); Brushless DC (BLDC) motor; mathematical modelling; PID controller; simulation analysis.**

I. Introduction

NOWADAYS as the technology improved, the steering which is hydraulic previously was changed to electric power steering. Previously the motor used for electric power steering is dc sevo motor. Because of the advantages of the BLDC motor, it is used in the electric power steering. BLDC motor consists of stator and rotor. Stator is having a 3 phase winding housed in the slots. Rotor is made up of the permanent magnet. The permanent magnet motors are classified as PM Synchronous motor and PM Brushless DC Motor depending on the back emf s produced. If the back emf produced is sinusoidal then it is called as PM Synchronous motor and if the back emf is trapezoidal then it is called as PM Brushless DC motor.

The BLDC are typically permanent synchronous motor, they are well driven by dc voltage. They have a commutation that is done mainly by electronics application .Some of the man y advantages of a brushless dc motor over the conventional brushed dc motors are highlighted below :

1. Better speed versus torque characteristics
2. High dynamic response
3. High efficiency
4. Long operating life
5. High speed ranges
6. Low maintenance (in terms of brushes cleaning; which is peculiar to the brushed dc motor).

II. Electric Power Steering

The reduction of steering effort on vehicles by using external source to assist in turning the wheels is known as power steering. The steering effort is increased with higher vehicle mass and wider tires. For modern vehicles it is difficult to manage at low speeds during parking without assistance. Electric power steering systems have an advantage in fuel efficiency because there is no hydraulic pump constantly running. The electrically assisted power steering system consists of BLDC motor. Electrically assisted power steering is shown in fig 1. It needs several parts such as torque sensor, engine speed sensor, vehicle speed sensor, steering column, torsion bar and electronic control unit.

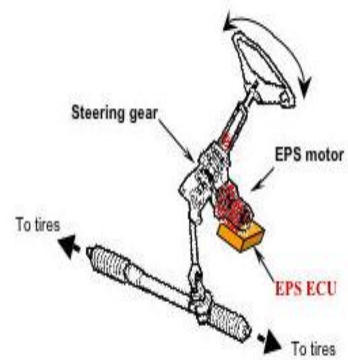

Fig. 1: Electrically Assisted Power steering [5].

III. Proposed Techniques

Two controllers are used in the proposed technique. The inner controller is Hysteresis controller and the outer controller is the PID controller. The values of the proportional, integral and differential constants are decided by the Ziegler-Nichols method. The general equation of the PID controller is given by

$$u(t)=MV(t)=K_p e(t)+K_i\int_0^t e(t)+K_d\frac{de(t)}{dt}$$

Where

Kp: Proportional gain, a tuning parameter
Ki: Integral gain, a tuning parameter
Kd: Derivative gain, a tuning parameter: Error
t: Time or instantaneous time (the present)
τ: Variable of integration; takes on values from time 0 to the present t.

There are two types of torque required to move the locomotive. They are namely static torque and dynamic torque. The static torque is the torque required to move the locomotive parts without any accelerating force. The torque of the cars drive axle down the highway is taken as rotating static torque. But in the cars engine both the torques are produced and they are differentiated depending on where it is measured. The dynamic torque is the torque produced with the acceleration. In the motor used for the power steering is of lesser rating it is not possible to produce that much torque required for moving the locomotive. Therefore in this paper I have used the higher rating motor which can produce the torque required for the movement of the locomotive.

IV. Mathematical Modeling

The BLDCM is very similar to the standard wound rotor synchronous machine except that the BLDCM has no damper windings and excitation is provided by a permanent magnet instead of a field winding. Since the rotor is made up of permanent magnet, saturation of magnetic flux linkage is same as that of synchronous machines. The stator is having three phase winding and fed with the three phase source. Therefore the stator can be modeled by using the following equations.

The voltage equation of BLDC motor can be represented as

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

Where,

R = Phase resistance
L = Phase inductance
Va , Vb, Vc = Phase voltages ia, ib, ic = Phase currents ea, eb, ec = Back EMFs.

The equation of BLDC motor electromagnetic torque canbe written as and its motion equation can be depicted by

$$T_e = \frac{1}{\omega}(e_a i_a + e_b i_b + e_c i_c)$$

$$\dot{\omega} = \frac{T_e - T_L - B\omega}{J}$$

V. The Establishment Of Simulation Model And Simulation Results

A. The double-loop control system

In this paper, one outer speed loop and one inner current loop as the double-loop control system is introduced, shown in Fig. 2. In the double-loop control system, a discrete PID controller is adopted in the speed loop and a hysteretic current controller is adopted in the current loop on the principle of hysteretic current track PWM inverter.

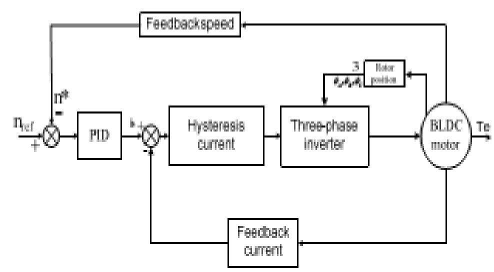

Fig. 2: The double-loop control diagram of BLDC motor [4].

B. Modeling of Quadrant Determination subsystem

The set speed and the actual speed determine the operating mode of the motor. Based on the quadrant in which the motor operates, the required reference currents are generated.

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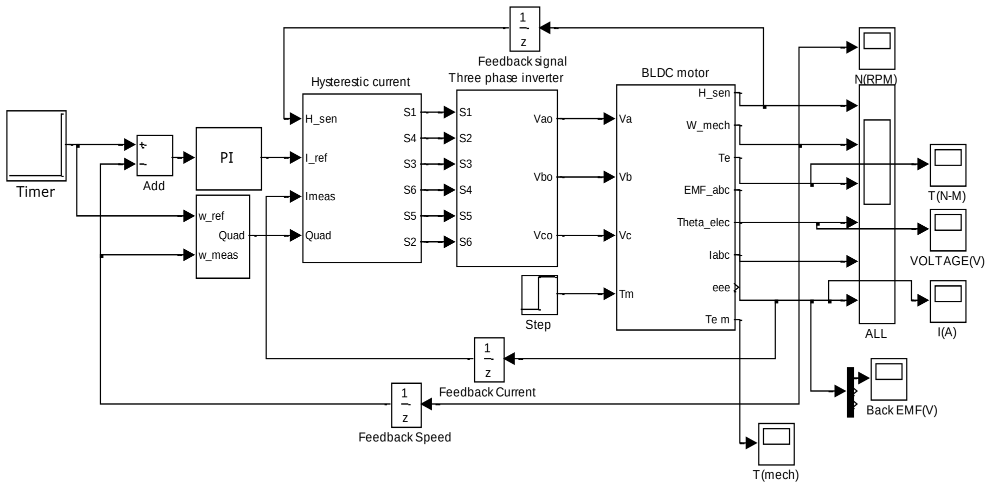

Fig. 3: The simulation model of BLDC motor

The parameters of BLDC Motor used in simulation are shown in Below TABLE I

symbol	Description	Value	unit
R	Stator phase winding resistance	0.7	Ω
Lt	Self inductance Stator winding	0.00521	H
Ke	Back-EMF coefficient	0.13658	$V/(rad.s^{-1})$
Kt	error constant	0.13658	-
J	Motor inertia	0.0022	$kg.m^2$
F	Trapezoidal function	0.1	Hz
Vd	DC input voltage	380	V
Vf	DC Field voltage	0.1	V
n_p	Poles	4	-

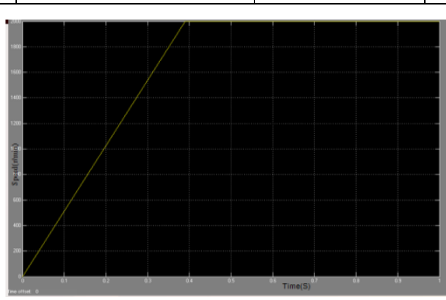

Fig 4: Speed -Time Characteristics

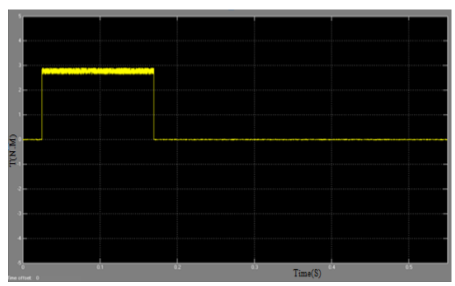

Fig 5: The torque response waveform

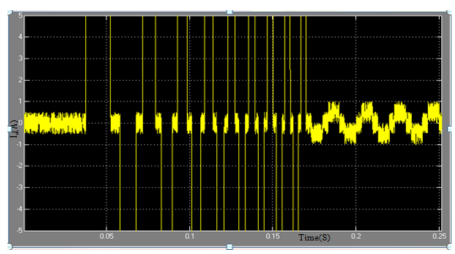

Fig 6: Phase A Current at Starting and No-Load Condition

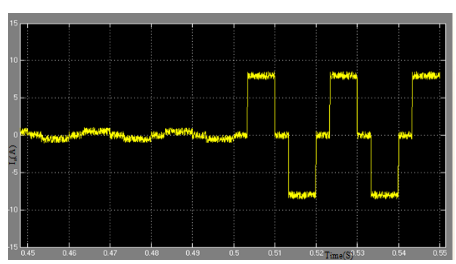

Fig 7: Phase A Current under Load Condition

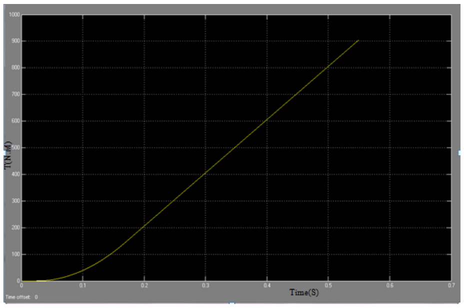

Fig 8: Mechanical Torque Wave form

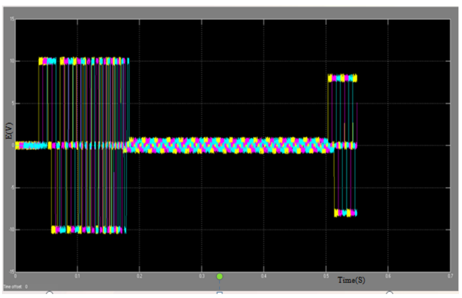

Fig 9: Three phase back-EMF waveform

VI. CONCLUSIONS

Motor is established in Matlab/Simulink on the basis of the motor performance of the requirements in the column–type EPS system and the electromagnetic equations of BLDC motor. The fruitful simulation results show that the proposed control strategy of the BLDC motor is valid. Based on the study above, according to the specific characteristics of EPS, changing the part of the functional modules or control strategies is convenient, so a more precise current control strategy of BLDC motor for EPS will be further researched.

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Biographies

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