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Torque Estimation of BLDC Motor Using SMC Technique

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ABSTRACT

The Brushless DC motors are widely used in many industrial and traction applications because of their high efficiency, high torque, low maintenance, less noise and low volume. The BLDC motor can act as an alternative for traditional motors like Brushed DC motor, induction motor, switched reluctance motors etc. The performance of BLDC motor is analyzed using Matlab with motor on load. The torque characteristics of BLDC motor is very important factor in designing BLDC motor drive system. After development of simple mathematical model of three phase BLDC motor with trapezoidal waveforms of back emf, the motor is modeled by using MATLAB/ SIMULINK. The speed, phase current, back emf waveforms are also obtained using this model. The PID controller is used to control the position of a BLDC motor by changing the current flow to control the average voltage and thereby the average current.

Keywords: *— Brushless DC motor, Electro motive force(EMF), PID controller, Sliding mode control(SMC), Direct torque control (DTC).*

I. INTRODUCTION

Permanent magnet brushless drives are commonly classified as brushless ac (BLAC) and brushless dc (BLDC) to reflect their current and back-electromotive -force (EMF) waveforms. An idealized BLAC machine has sinusoidal back-EMF and current waveforms, while a BLDC machine has a trapezoidal back-EMF waveform and a rectangular current waveform. The Brushless DC (BLDC) motors have been widely used in many applications. BLDC Motor have many advantages over conventional DC motors like: Long operating life, High dynamic response, High efficiency, Better Speed vs. Torque characteristic, Noiseless operation, Higher speed range and Higher Torque-Weight ratio. Due to high power to weight ratio, high torque, good dynamic control for variable speed applications, absence of brushes and commutator make Brushless DC (BLDC) motor, best choice for high performance applications. A BLDC Motor is a permanent magnet synchronous motor that uses position detectors and an inverter to control the armature currents.

PID is the most common and most popular feedback controller used in Industrial Process today. A PID controller calculates an "error" value as the difference between a measured process variable and a desired 'set point'.

PID controller is also known as three term control:- the proportional (P), integral(I) and derivative (D). By tuning these three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements.

III. MODEL OF BLDC MOTOR

A motor converts supplied electrical energy into mechanical energy. Various types of motors are in common use. The Brushless DC motors are widely used in many industrial and traction applications because of their high efficiency, high torque, low maintenance, less noise and low volume. The BLDC motor can act as an alternative for traditional motors like Brushed DC motor, induction motor, switched reluctance motor etc.

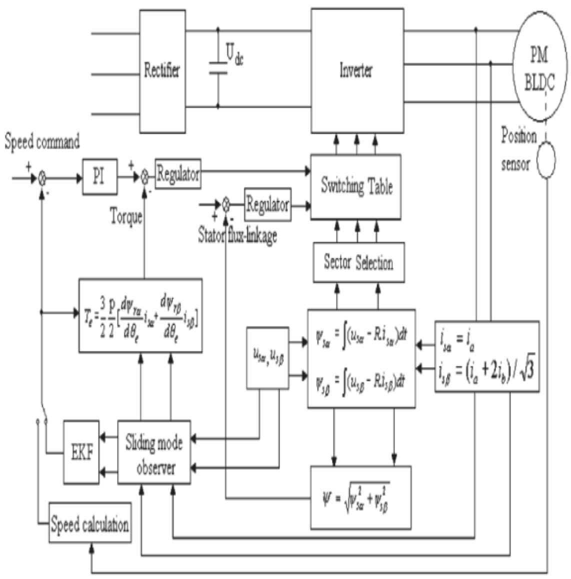

Figure1: Schematic of the sensorless DTC BLDC drive.

BLDC Motor have many advantages over conventional DC motors like: Long operating life, High dynamic response, High efficiency, Better Speed vs. Torque characteristic, Noiseless operation, Higher speed range and Higher Torque-Weight ratio. Due to high power to weight ratio, high torque, good dynamic control for variable speed applications, absence of brushes and commutator make Brushless DC (BLDC) motor, best choice for high performance applications. Due to the absence of brushes and commutator there is no Problem of mechanical wear of the moving parts. As well, better heat dissipation property and ability to operate at high speeds make them superior to the conventional dc machine. However, the BLDC motor constitutes a more difficult problem than its brushed counterpart in terms of modelling and control system design due to its multi-input nature and coupled nonlinear dynamics. Due to the simplicity in their control, Permanent-magnet brushless dc motors are more accepted and used in high-performance applications. In many of these applications, the production of ripple-free torque is of primary concern. There are three main sources of torque production in BLDC motor. A BLDC Motor is a permanent magnet synchronous motor that uses position detectors and an inverter to control the armature currents. Its armature is in the stator and the magnets are on the rotor and its operating characteristic resembles those of a DC motor. Fixed brushes supply electric energy to the rotating commutator. As the commutator rotates, it continually flips the direction of the current into the coils, reversing the coil polarities so that the coils maintain rightward rotation. The commutator rotates because it is attached to the rotor on which the coils are mounted.

III. SLIDING MODE CONTROLLER

SMC is a nonlinear control method that alters the dynamic of a nonlinear system by application of a discontinuous control single that forces the system to "slide" along a cross section of the system's normal behavior.

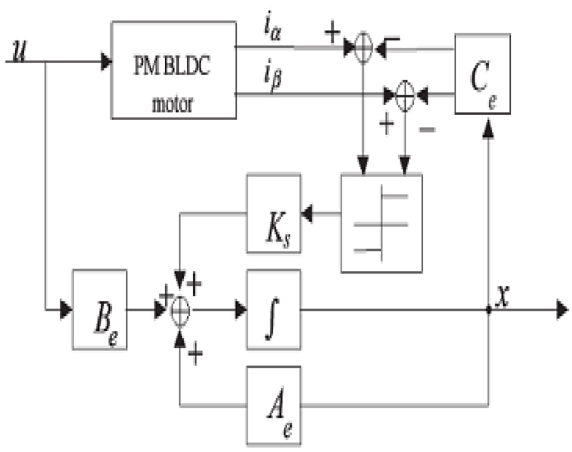

Figure 2: Block diagram of the sliding mode observer.

Mathematical model

Instantaneous Torque Estimation:- Electromagnetic-Torque Estimation:- For a BLDC motor equipped with a surface-mounted magnet rotor and having a nonsinusoidal back-EMF waveform, the

electromagnetic torque can be expressed as,

$$T = \frac{3}{2}\frac{P}{2}\left[\frac{d\psi r\alpha}{d\theta e} is\alpha \quad \frac{d\psi r\beta}{d\theta e} is\beta\right] \qquad (1)$$

where, p = number of poles,

θe = rotor electrical angle,

ψrα, ψrβ, isα and isβ are the α-and β- axis rotor flux linkages and stator currents in the stationary reference frame, respectively.

Figure 3 shows the trapezoidal back emf wave form. Here we have considered 1200 mode of operation. Back emfs are developed in stator winding due to mutual inductance between Permanent magnet and stator winding. Due to trapezoidal back emf torque developed by the BLDC motor is constant and having less ripples than sinusoidal back emf.

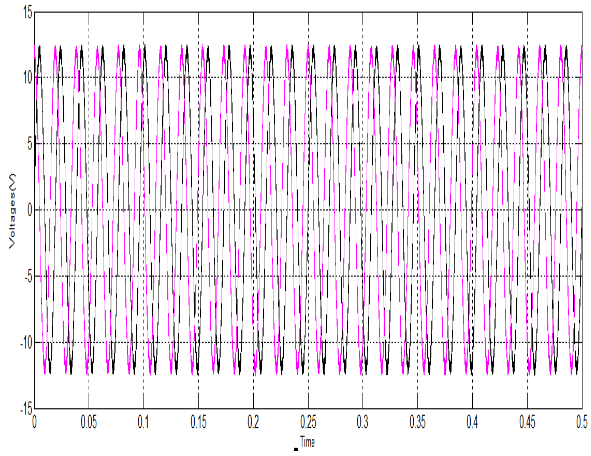

Figure 3: Measured phase and line back-EMF waveforms.

By way of comparison, the electromagnetic torque for a BLAC motor can be expressed as,

$$T = \frac{3}{2}\frac{P}{2}\ (\psi s\alpha\ is\beta\ -\ \psi s\beta\ is\alpha) \qquad (2)$$

Where $\psi s\alpha$ and $\psi s\beta$ are the α- and β- axis stator flux- linkages in the stationary reference frame, respectively.

The normalized non-sinusoidal back-EMF waveform can be derived from the ratio of the back-EMF to the electrical angular velocity, i.e.

$$\frac{d\psi r\alpha}{d\theta e} = \frac{1}{\omega e}\frac{d\psi r\alpha}{d\theta e}\frac{d\theta e}{dt} = \frac{1}{\omega e}\frac{d\psi r\alpha}{dt} = \frac{e\alpha}{\omega e} \qquad (3)$$

$$\frac{d\psi r\beta}{d\theta e} = \frac{1}{\omega e}\frac{d\psi r\beta}{d\theta e}\frac{d\theta e}{dt} = \frac{1}{\omega e}\frac{d\psi r\beta}{dt} = \frac{e\beta}{\omega e} \qquad (4)$$

Where $\omega e = \frac{d\theta e}{dt}$ is the electrical angular velocity of the rotor and eα and β are the α- and β- axis back-EMFs in the stationary reference frame, respectively.

EMF Waveform Estimation by Sliding-Mobe Observer :-

sliding- mode observer:- The voltage equations for a BLDC motor can be expressed as,

By assuming $\overline{\psi_s} = L_s\,\overline{i_s} + \overline{\psi_r},$

$$u_\alpha = i_{s\alpha} R_s + L_s \frac{d_{is\alpha}}{d_t} + e_\alpha \qquad (5)$$

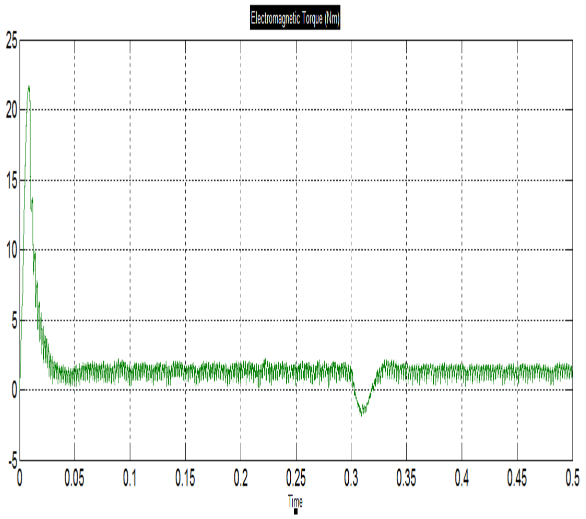

Figure 4: Electomagnetic Torque (Nm)

$$u_\beta = i_{s\beta} R_s + L_s \frac{d_{is\beta}}{d_t} + e_\beta \qquad (6)$$

where $= \overline{\psi_s}$ the stator flux-linkage vector,$= \overline{\psi_r}$ the rotor ux-linkage vector,$= \overline{i_s}$ the stator current vector.

The following state-variable equations can be established,

$$y = Ce_x \qquad (8)$$

Where x $[i_{s\alpha}, i_{s\beta}, e_\alpha, e_\beta]^T$ is the vector of state variable, $u[u_\alpha, u_\beta]^T$ is the input vector.

$$\dot{x} = A_e x + B_e u \qquad (7)$$

Where y = $[i_{s\alpha}, i_{s\beta}]^T$ is the output vector. From (5) and (6)

$$\frac{di_{s\alpha}}{dt} = -\frac{R_s}{L_s} i_{s\alpha} - \frac{e_\alpha}{L_s} + \frac{u_\alpha}{L_s} \qquad (9)$$

$$\frac{di_{s\beta}}{dt} = -\frac{R_s}{L_s} i_{s\beta} - \frac{e_\beta}{L_s} + \frac{u_\beta}{L_s} \qquad (10)$$

The time derivatives of the back-EMF terms can be assumed to be zero, i.e.

$$\frac{de_\alpha}{dt} = 0 \qquad (11)$$

$$\frac{de_\beta}{dt} = 0 \qquad (12)$$

Therefore,

$$A_e = \begin{bmatrix} \frac{-R_s}{L_s} & 0 & \frac{-1}{L_s} & 0 \\ 0 & -\frac{R_s}{L_s} & 0 & -\frac{1}{L_s} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad (13)$$

$$B_e = \begin{bmatrix} \frac{1}{L_s} & 0 \\ 0 & \frac{1}{L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \qquad (14)$$

$$C_e = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \qquad (15)$$

From (7) and (8), the sliding-mode observer can be constructed as,

$$\dot{x} = A_e x + B_e u + K_s \operatorname{sign}(y - C_e x) \qquad (16)$$

It is worth noting that, although the last two rows in the matrices Ae and Be are zero, the corresponding two state variables are not constant, since the associated third term on the right-hand side of (16) is nonzero. Due to the symmetry of the and components in the state-variable equations, Ks can be assumed to have the following form:

V. PID CONTROLLER

PID is the most common and most popular feedback controller used in Industrial Process today. A PID controller calculates an "error" value as the difference between a measured process variable and a desired 'set point'. PID controller is also known as three term control:- the proportional (P), integral(I) and derivative (D). By tuning these three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The derivative of the process error is calculated by determining the slope of the error overtime and multiplying this rate of change by the derivative gain Kd. The magnitude of the contribution of the derivative term to the over all control action is termed the derivative gain, Kd. The equations of pid controller as,

$$G_{c(s)=} \text{ P+I+D} = K_p + \frac{k_i}{s} + k_{ds} \qquad (17)$$

Or

$$G_{c(s)} = K_p(1 + \frac{1}{T_{is}} + T_{ds}) \qquad (18)$$

Where, k_p = proportional gain,

k_i = integration coefficient,

k_{d} = derivative coefficient.

$$U = k_p + k_i \int e_{dt} + k_d \frac{d_e}{dt}$$

The controlled output from PID controller,

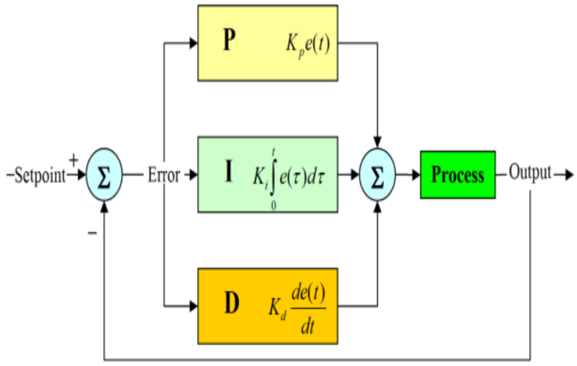

Figure 5 : Diagram of PID controller

IV. SIMULATION AND SIMULATION RESULT

Figure 6 shows the rotar speed of BLDC motor as shown below;

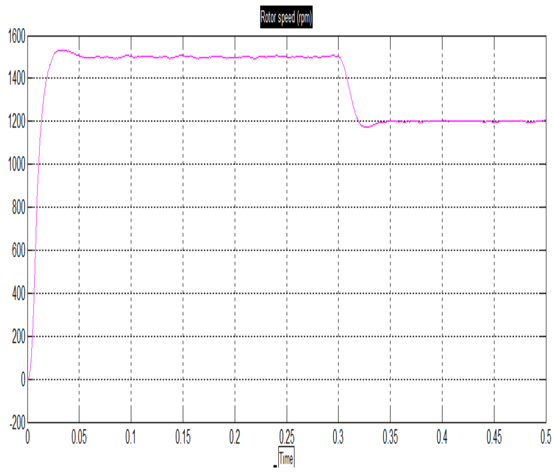

Figure 6: The rotar speed of motor

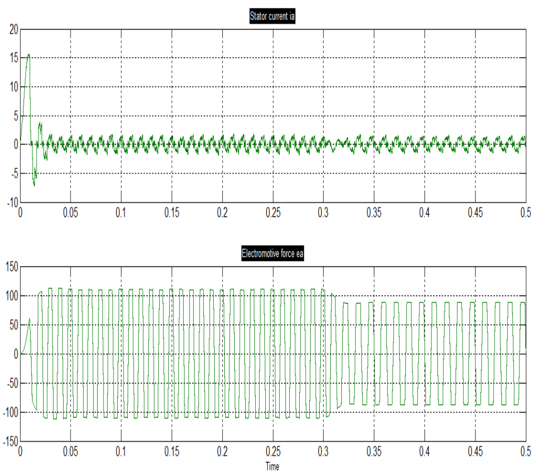

Figure7 :- The stator current (i_a) & Electromotive force (e_a)

Figure 8 e_a shows the Input voltage, Input current, V_{dc} & Speed in used motor according to work,

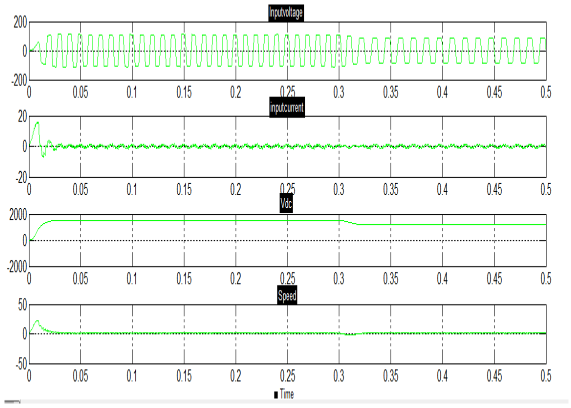

Figure 8: Input voltage, Input current V_{dc} & Speed

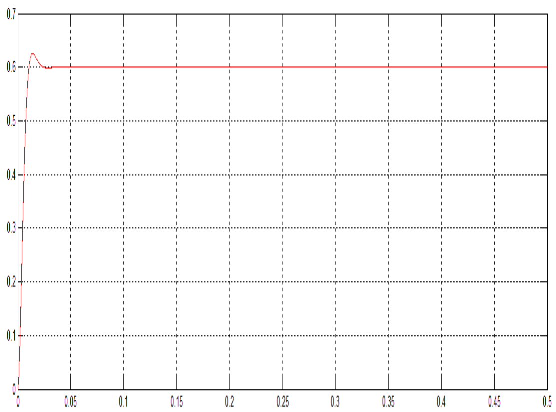

Figure 9: The output of PID Controller

VI. CONCLUSION

The modeling and the simulation of PID control of BLDC motor speed and its torque results are tested it started with the analysis and reasons why an absolute précised control is important in drives particularly the BLDC motor and then the mathematical modeling. Permanent-magnet brushless dc motors is more accepted used in high-performance applications because of their higher efficiency, higher torque in low-speed range, high power density, low Maintenance and less noise than other motors. The torque characteristics of BLDC motor presents a very important factor in design of the BLDC motor drive system, so it is necessary to predict the precise value of torque, which is determined by the waveforms of back emf. This work is intended to use the exponential Reaching law for successful design of SMC for BLDC motors using mathematical modeling. Also it is intended to compare the two Controllers namely, Proportional-Integral (PI) controller and sliding mode controller (SMC) for the speed control of a brushless DC motor.

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