Sliding Mode Observer for Torque Control in Sensorless BLDC Motor

Avinash B. Ghule[1] and Subhash S. Sankeshwari[2]

[1]PG Student, M.B.E. Society's College of, Engineering, Ambajogai (M.S), India
[2]PG Department, M.B.E. Society's College of Engineering, Ambajogai (M.S), India

Abstract*: In this paper a method for estimation of torque is proposed in case of sensorless bldc motor. The bldc motor's are used in places that require fast torque response, high effiency, high power density where torque pulsation's problem may occure. A Sliding mode observer combined with extended kalman filter is proposed for bldc motor using matlab simulation for estimation of instantenous torque. Sliding mode observer is a parameter for estimating the phase to phase trapezoidal back-EMF in sensor less mode. The extended Kalman filter (EKF) is the nonlinear version of the Kalman filter which linearizes about an estimate of the current mean and covariance.*

Keywords: *BLDC motor,Sliding mode observer, Extended kalman filter,DTC*

I. Introduction

Now a days brushless dc motors (BLDC) are frequently used in many domestic and industrial applications ranging from servo to traction drives, due to several distinct advantages such as large torque to inertia ratio, high efficiency, high power density, large power rate, fast torque response and simplicity in their control BLDC machine has a trapezoidal back-EMF waveform and a rectangular current waveform [1].

But in BLDC motor undesirable torque pulsation causes speed oscillations and excitation of resonances in mechanical portions of the drive, leading to acoustic noise and visible vibration patterns in high-precision machines. BLDC motor torque pulsations produce noise and vibration in the system[2]. Therefore, minimization or elimination of noise and vibration is a considerable issue in BLDC drive. Also BLDC motor is connected to infinite bus bar in interconnected power system leading to torque pulsations due to non linear load. In this paper, the sensorless direct torque control (DTC) of a BLDC drive is studied.

In order to minimize the torque pulsations, various torque-control methods have been proposed for the BLDC drives. For example, an instantaneous torque controller that is based on a variable structure control in the $d–q$ reference frame was proposed. However, it was only applicable to the 180◦ electrical conduction mode of operation and cannot be used in the 120◦ electrical conduction mode. Another problem in a BLDC motor control is that the PI controller is usually employed, which is simple in realization but difficult to obtain a sufficient high performance in the tracking application[3].

Torque observer techniques based on a Luenberger observer is presented in[4] , in which mechanical equations, involving mechanical parameters which were difficult to obtain accurately, were employed. Furthermore, the estimated load torque could not be directly used in the DTC scheme.

Sliding-mode observers are known to be insensitive to parameter variations and disturbances[5], A sliding-mode observer is employed to estimate the nonsinusoidal back-EMF waveform, while a simplified extended Kalman filter (EKF) is used to estimate the rotor speed and facilitate sensorless control. A significant advantage is that it eliminates the need for low-pass filters. Both are combined to calculate the instantaneous electromagnetic torque, with the effectiveness of the method being validated by simulations and measurements.

II. Bldc Motor

BLDC motors are a kind of synchronous motor. This indicates the magnetic field produced by the stator and the magnetic field produced by the rotor twirls at the same frequency. BLDC motors do not experience the "slip" that is normally observed in induction motors. BLDC motor is built with a permanent magnet rotor and wire wound stator poles . The flux distribution in BLDC motor is trapezoidal and hence the d–q rotor reference frames model is not suitable The derivation of this model is depends on the postulations that the induced currents in the rotor due to stator harmonic fields, iron and stray losses are neglected. The fig.(1) shows the equivalent circuit of BLDC motor.
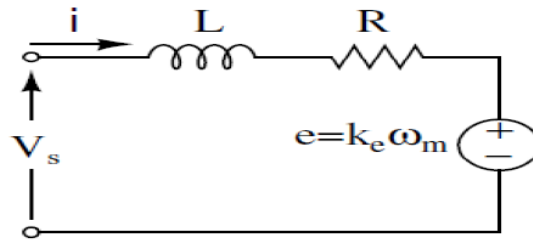
Fig. (1): Equivalent circuit of BLDC motor.

The differential equation governing the electrical part of the model can be written as,

$$v = iR + L\frac{di}{dt} + E \qquad (1)$$

where, V=DC voltage applied in Volts.
L=Inductance of the windings in Henry.
R=Resistance of the windings in Ohms.
E = Kbω =Back emf of the motor.
Kb =Back emf constant in Volts/ rad/ sec.
ω=Speed in rad/ sec.
E=Disturbance as input

For a BLDC motor equipped with a surface-mounted magnet rotor and having a non sinusoidal back-EMF waveform, the electromagnetic torque can be expressed as

$$T = \frac{3}{2}\frac{p}{2}\left[\frac{d\psi_{r\alpha}}{d\theta_e}i_{s\alpha} + \frac{d\psi_{r\beta}}{d\theta_e}i_{s\beta}\right] \qquad (2)$$

Where p is the number of poles, θe is the rotor electrical angle, and $\psi_{r\alpha}$, $\psi_{r\beta}$, $i_{s\alpha}$, and $i_{s\beta}$ are the α- and β-axis rotor flux linkages and stator currents in the stationary reference frame, respectively. The back-EMF waveform is sinusoidal and represents the fundamental component of the electromagnetic torque. The normalized nonsinusoidal back-EMF waveform can be derived from the ratio of the back-EMF to the electrical angular velocity.

III. Sliding Mode Observer For Bldc Motor

Sliding mode observer (SMO) shown in figure 2 is used to estimate the stator flux. It is a non-linear control method that may modify the system performance. The SMO can be designed with two approaches. In the first approach the system equations can be converted into two suitable sub systems. The second approach is for designing the state observer. SMO is also used to estimate the back-EMFs accurately. By assuming $\overline{\psi}_s = L_s\overline{i}_s + \overline{\psi}_r$, where $\overline{\psi}_s$, $\overline{\psi}_r$ and $\overline{i}_s$ are the stator flux linkage vector, the rotor flux-linkage vector, and the stator current vector, respectively, the voltage equations for a BLDC motor can be expressed as,

$$u_\alpha = i_{s\alpha}R_s + L_s\frac{di_{s\alpha}}{dt} + e_\alpha \qquad (3)$$

$$u_\beta = i_{s\beta}R_s + L_s\frac{di_{s\beta}}{dt} + e_\beta \qquad (4)$$

where Rs and Ls are the stator winding resistance and inductance

The sliding-mode observer can be constructed in the form of state variable equation as

$$\dot{x} = A_e x + B_e u + k_s \sin n\,(y - C_e x) \qquad (5)$$

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

$$B_e = \begin{bmatrix} \frac{1}{L_s} & 0 \\ 0 & \frac{1}{L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$C_e = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}.$$

$$K_s = \begin{bmatrix} k_{S1} & 0 \\ 0 & k_{S1} \\ k_{S2} & 0 \\ 0 & k_{S2} \end{bmatrix}$$
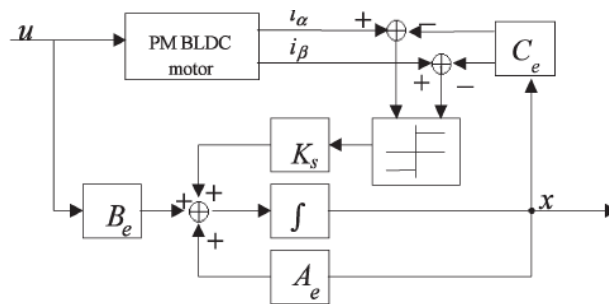
Ks is the gain matrix

Fig. (2) Block diagram of the sliding-mode observer

IV. Extended Kalman Filter

The DTC algorithm does not require rotor-position information and needs only a stator flux-linkage vector information . In this paper, the speed is estimated by employing a simplified EKF similar to the one used in which extracted the rotor speed and position from the relatively noisy output of a resolver. The estimated speed is used for speed feedback and electromagnetic-torque calculation to realize sensorless control and instantaneous torque estimation.

$$x(k + 1) = f(x(k), k) + g(u(k), k) + w(k) \tag{6}$$

$$y(k) = h(x(k), k) + v(k) \tag{7}$$

Where u(k) and y(k) are the input and output signals, respectively, and w(k) and v(k) are the process noise and measurement noise, respectively. x(k) is the state vector, which can be estimated by the EKF and is given by

$$\hat{x}(k + 1) = f(\hat{x}(k), k) + g(u(k), k) + Ke[y(k) - h(\hat{x}(k), k)] \tag{8}$$

The simplified EKF method extracts speed information from the fundamental components of the nonsinusoidal back-EMFs, while other harmonic components are considered as measurement noise. Hence, it is much more appropriate than the conventional method, which employs the "arctan" function to obtain rotor position information and derives the speed by differentiation. Hence, for speed estimation, only the fundamental components of eα and eβ are required.

the rotor electrical angular velocity and position can be estimated from the following equations

$$\varepsilon(k) = y2(k)\cos \hat{\theta}e(k) - y1(k) \sin\hat{\theta}e\,(k) \tag{9}$$
$$\hat{\theta}e(k + 1) = [\hat{\theta}e(k) + T_s\,\hat{\omega}e(k) + k_{e1}\varepsilon(k)] \tag{10}$$
$$\widehat{\omega}e(k + 1) = \widehat{\omega}e(k) + \omega'(k) + k_{e2}\varepsilon(k) \tag{11}$$
$$\omega'(k + 1) = \omega'(k) + k_{e3}\varepsilon(k) \tag{12}$$

Where $\hat{\theta}e$ and $\hat{\omega}e$ are the estimated rotor electrical position and angular velocity

V. Simulation Result

The overall block diagram of sensorless direct torque control of BLDC drive is simulated by MATLAB/Simulink. We can calculate the torque which is controlled by sliding mode observer as shown in fig. (3)
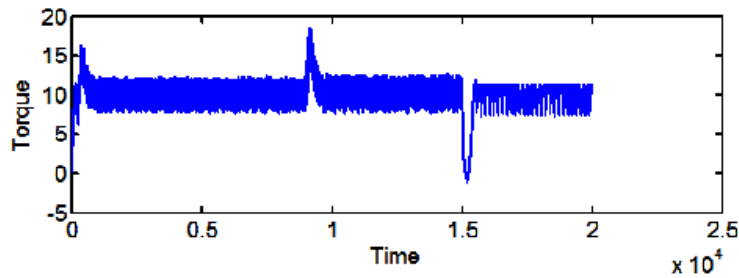

Fig.(3) Estimated Torque

Then speed estimation is shown in fig. (4) .The roter speed can be calculated by using kalman filter.
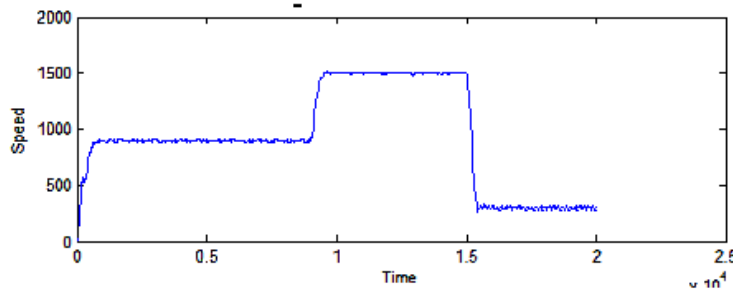

Fig.(4) Estimated rotor speed

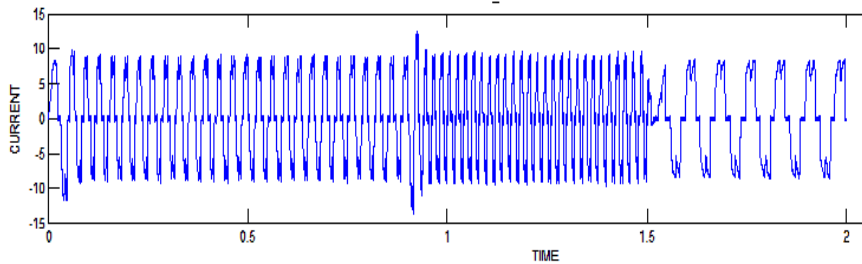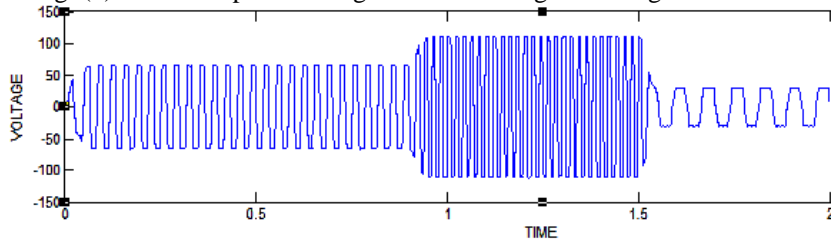The below fig. (5) shows the phase current in which change of current at various time instants

Fig.(5) Estimated Current

The below fig. (6) shows the phase voltage in which change of voltage at various time instants

Fig(6) Estimated Current

From the analysis of these results, it is shown that the estimated outputs are accurate. However there is a problem of chattering effect in the estimated waveforms. By neglecting that effect of chattering, sliding mode observer is a very good sensorless method for the estimation of Torque and speed. Voltage and current are combinely used for the purpose of speed and torque estimation. By neglecting that effect of chattering, sliding mode observer is a very good sensorless method for the estimation of phase-to-phase back-EMFs, rotor position and angular velocity.

VI. Conclusion

The paper proposes technique for minimization of torque pulsations. A sliding mode observer together with a simplified EKF has been successfully used to estimate the instantaneous torque, as confirmed by both the simulations and measurements. Sliding mode observer is efficient to all other controllers. Simulation results shows SMO with saturation function has better speed response, reduced torque ripple and the less effect of chattering in the estimation of rotor position .

References

[1]. M. Rameshkanna ,Mrs. S. Sivaranjani,"Analysis of Sliding Mode Observer Based SVPWM Inverter Fed BLDC Motor", IJSTE International Journal of Science Technology & Engineering, Volume 1, Issue 11,May 2015

[2]. Yong Liu, Zi Qiang Zhu and David Howe , "Instantaneous Torque Estimation in Sensorless Direct-Torque-Controlled Brushless DC Motors".IEEE transactions on industry applications, vol. 42, no. 5, september/october 2006

[3]. Teck-Seng Low, Tong-Heng Lee, King-Jet Tseng, and Kai-Sang Lock, "Servo Performance of a BLDC Drive with Instantaneous Torque Control" ieee transactions on industry applications, vol. 28, no. 2, marchjapril **1992**

[4]**.** D.Suganyadevi, Dr. M. Sathiskumar, "Direct Torque Control In BLDC Motor Using Four Swich Inverter", International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 12, December 2014

[5]. "Brushless DC Motors",http://www.portescap.com

[6]. Becerra, R.C.; Ehsani, M.,"High-Speed Torque Control of Brushless Permanent Magnet Motors", IEEE Trans. Ind. Electron. 1988, 35, 402-406.

[7]. T. S. Low, T. H. Lee, K. J. Tseng, and K. S. Lock, "Servo performance of a BLDC drive with instantaneous torque control," IEEE Trans. Ind. Appl.,vol. 28, no. 2, pp. 455–462, Mar./Apr. 1992.

[8]. Qian Yuan, Zhong-ping Yang, " Sensorless Control of Permanent Magnet Synchronous Motor with Stator Flux Estimation", JOURNAL OF COMPUTERS, VOL. 8, NO. 1, JANUARY 2013

[9]. Girija P.K, Prince A, "Sliding Mode Observer based Sensorless Control of Brushless DC Motor under DTC Scheme", international Journal Of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2, Nov13