Torque Ripple Minimization of BLDC Motor by Kalman Filter

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Abstracts
In classical control of brushless dc motors, flux distribution is assumed trapezoidal and fed current is controlled rectangular to obtain a desired constant torque. However, in reality this assumption may not be correct due to non-uniformity of magnetic materials and design trade-offs. These factors together with current controller limitation, can lead to an undesirable torque-ripple. Hence torque-ripple has been the main issue of the servo derive systems, in which the speed fluctuation, vibration and acoustic noise should be minimized. This torque-ripple also deteriorates the precision of the parameters of brushless dc motors. To minimizing of torque ripples we are using an adaptive filter technique i.e., kalmanfilter(KF) is using minimizing the torque ripples. KF design framework for general nonlinear systems, the key of which includes the single-domain nonlinear filtering and segmentation over domain of interest (DOI). The estimation error system is firstly transformed into a polytopic system through a global linearization procedure, such that the KalmanFilter(KF) is formulated by linear matrix inequalities (LMIs). The torque ripple minimization in BLDC motor by using kalman filter. Torque ripples are minimized by using so many methods like by using improved dc-dc converters, by using micro controllers, by using implementation of zero crossing detectors, by using extended kalman filter etc. These all cannot be accurately minimize the ripples. they all can be minimize the ripples up to 60%. Kalman filter is used based on the estimation of the previous instants. It can be resolved b step by step process we can get ripples up to 40%. The reduction variable have to select basedin the trial and error method.so that we cannot achieve 100% torque ripple minimization. The simulation results validate the effectiveness of the proposed scheme.

Keywords-BLDC Motor, Kalman Filter, Torque ripple reduction

1.Introduction:-
1.1 Brushless DC Motors:-
The brushless DC motor drive system incorporating motors with permanent magnet excitations are being used in a rapidly expanding range of applications, including computer peripherals, automotive and machine tool industries applications such as robot, electric bicycle, wheelchairs and home appliances due to the high power density and efficiency with an excellent maintenance characteristic. Furthermore, small BLDC motor are much interested in the unmanned aero vehicles such as a drone. The usage of high power, high speed BLDC motor are dramatically increased in these markets. Although BLDC motors have an excellent torque characteristics, the output torque has ripple due to the non-linear back-EMF of the motor and the commutation current ripple. As well known, the back-EMF of the motor is effected by the characteristics of the permanent magnet and stator, and has high order harmonics due to the slot effect and magnetization direction of the magnet with concentrated phase windings. These harmonics make torque ripple with a constant phase current in the conduction region. Furthermore the current ripple in the commutation region where the conducting phase changing region, makes additional torque ripple. The shaft position sensors, such as Optical or Hall-effect sensors are usually used to detect exact rotor position. The brushless DC motor has trapezoidal Electro Motive Force (EMF) and quasi-rectangular
current waveforms. Three Hall Effect sensors are usually used for every 60 degree electrical (Jardic, M and Teric, B 2001). In addition to servo drive application with high stationary accuracy of speed and rotor position, the brushless DC motor requires a rotor position sensor, such as a revolver or an absolute encoder. Recently, DC motors have been gradually replaced by the BLDC motors as industrial applications require more powerful actuators in small sizes. Elimination of brushes and commentators also solves the problem associated with contacts and gives improved reliability and enhances life. The BLDC motor has low inertia, large power to volume ratio, and low noise when compared to the permanent magnet DC servo motor having the same output rating.

1.2 Kalman Filter:-
The nonlinear filtering plays a significant role in both military and civilian applications and has been widely studied in the past decades. Among all, the extended Kalman filter (EKF) is commonly used due to its simplicity and ease of implementation. The sigmamapoint Kalman filters (SPKFs) were also proposed to improve the filtering performance under strong non-linearity. These non-linear filters update the filter gain at each time step so that an extensive computational power becomes a must. Under the circumstances with limited computation resources such as nanosatellites, micro-aerial vehicles, portable devices and wearable equipment and so on, an efficient filter is inevitable due to necessity. A practical design of an efficient and computationally simple non-linear filter is, therefore, significant. The Kalman filter (KF) can be an appropriate alternative in terms of this concern, which is prepared off-line instead of the real-time update of filter gain.

Use the Kalman Filter block to predict or estimate the state of a dynamic system from a series of incomplete and/or noisy measurements. Suppose you have a noisy linear system that is defined by the following equations:

\[ X_k = A \cdot X_{k-1} + W_{k-1} \]  \[ Z_k = HX_k + V_k \]  \[ \text{(1)} \]

This block can use the previously estimated state, \( \bar{X}_{k-1} \), to predict the current state at time \( k \), \( \bar{X}_k \), as shown by the following equation:

\[ \bar{X}_k = A \bar{X}_{k-1} \]  \[ \text{(3)} \]

\[ P_k = AP_{k-1}A^T + Q \]  \[ \text{(4)} \]

The block can also use the current measurement, \( Z_k \), and the predicted state, \( \bar{X}_k \), to estimate the current state value at time \( k \), \( \bar{\bar{X}}_k \), so that it is a more accurate approximation:

\[ K_k = P_k \bar{H}^T(HP_k \bar{H}^T + R)^{-1} \]  \[ \text{(5)} \]

\[ \bar{X}_k = \bar{X}_k + K_k(Z_k - HX_k) \]  \[ \text{(6)} \]

\[ P_k = (I - K_kH)P_k \]  \[ \text{(7)} \]

Where \( A \) is state transition matrix; \( W \) is process noise; \( H \) is measurement matrix; \( V \) is measurement noise; \( P \) is estimated error covariance; \( P_2 \) is predicted error covariance; \( Q \) is process noise covariance; \( k \) is kalman gain; \( R \) is measurement noise covariance; \( I \) is identity matrix.

2. Proposed Scheme Of BLDC Motor:-
2.1 Conventional Method:-
Though the advantages of brushless dc motor make more popular in industrial and household applications, it has two major challenges on which the improvements required for the permanent magnet brushless dc motor drive systems are:

a) Harmonics existing in the voltage and current input to the motor
b) The ripple content present in the torque output of the motor.

Current and voltat harmonics become a real problem to be addressed in motor drives in order to enhance the performance characteristics of the motor. Due to the power electronic commutator present in the drive system of BLDC motor, the fundamental component of the stator current and voltage are combined with harmonic components. The fundamental frequency of the power system will be constant irrespective of applications. But in the case of motor drives (BLDCM), the fundamental frequency will vary with the instantaneous speed of the motor.

Conventional BLDC drive system use two level voltage source inverter for commutation purpose. But, as it does not provide smoother voltage profile the total harmonic distortion (THD) produced is high. Hence it should be driven by Smoother voltage to have less THD and less ripple content in torque. Here in this paper the performance of BLDC motor fed by two different levels of inverters are compared with and without using variable DC link converter is compared.

![Block diagram of voltage source inverter fed PMBLDC motor](image)

**Fig.2.1 Block diagram of voltage source inverter fed PMBLDC motor**

### 2.1.1. Conventional Voltage source inverter fed BLDC motor:

Traditional inverter is a conventional inverter which is fed directly by a single voltage source or a single voltage cell. This dc voltage is converted into ac by means of the 3 phase inverter and fed to the BLDC motor. Fig.2.1 and 2.2 exhibits block diagram and simulation model of conventional voltage source inverter fed BLDC motor, which is controlled by position of rotor feedback. This position of rotor is sensed at every switching instant of 60°, by hall sensors to control logic circuit or to the controllers. The gates pulses generated from the logic circuit are given to the voltage source inverter to switch the stator windings according to the rotor position. For ideal conditions the shape of stator current motor can be sinusoidal or trapezoidal based on shape of Back-EMF. But in practice at every switching instant of 60°, there is a deviation from ideal case due its phase inductance and finite inverter voltage, due to which pulsating (harmonic) currents are generated which in turn leads to torque ripples.
Fig. 2.2 simulation model of voltage source inverter fed PMBLDC motor

Fig. 2.3 Block diagram of adaptive filter controlled PMBLDC motor

Proposed Method:
The proposed method is controlling of BLDC motor by using adaptive filter technique. In this motor, torque ripples are due to some non-sinusoidal distribution of flux in the motor. Due to this, currents are distributed in non-sinusoidal manner. In the same manner, torque also gets ripples. So to eliminate the torque ripples, we are implementing the kalman filter. Torque is taken as input variable to kalmanfilter, and another variable is measurement matrix (H). H is decided based on trial and error method and is constant. If we get the required response then it can be taken as best value of this method. It cannot take inputs as in matrix form. We have to convert single value to matrix form. It take inputs as Z and H. By using these values KF will predict the future values and estimate current states by using the equations 3 and 4 we predict the states and using equations 5, 6 and 7 we estimate the states and update the values of filter. In this we are comparing their THD and Torque ripple calculations.
Fig. 2.4 simulation model of Adaptive Filter control of PMBLDC Motor

Results And Analysis:-
1. The voltages of conventional and Adaptive controlled BLDC motor are

Fig. 3.1 voltages at low speed of conventional BLDC Motor

Fig.3.2 voltages at low speed of Adaptive controlled BLDC Motor

2.
Fig. 3.3 currents at low speed of conventional BLDC Motor

Fig. 3.5. currents of low speed of adaptive controlled BLDC Motor

3. Rotor speed, Rotor angle and Electromagnetic torque of conventional and adaptive controlled BLDC motor are

Fig. 3.6. speed, angle and torque of low speed conventional BLDC Motor
4. Total Harmonic Distortion (THD) of conventional and Adaptive controlled BLDC Motor are

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<tr>
<th>THD Comparison of BLDC motor</th>
<th>Conventional BLDC Motor</th>
<th>Adaptive controlled BLDC Motor</th>
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<td>Total Harmonic Distortion(THD)</td>
<td>52.63%</td>
<td>40.6%</td>
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Conclusion:

Torque-ripple has been the main issue of the servo derive systems, in which the speed fluctuation, vibration and acoustic noise should be minimized. This torque-ripple also deteriorates the precision of the parameters of brushless dc motors. Adaptive filter controlled BLDC motor method is reducing its 53% of torque ripples into 40% torque ripples. Voltages, currents and torques as shown in Fig 3.1,3.3 and 3.5 having their torque ripples upto 53%. Voltages, currents and torques as shown in Fig. 3.2,3.4 and 3.6 having their torques ripples upto 40%. The conservative scheme is not 100% and it has another disadvantage, it doesn’t applicable for the high speed systems.

References: