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Torque Ripple Reduction in BLDC Motor by a Novel Method

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Abstract:**Brushless DC motors are gaining a lot of popularity due to the several advantages of the motor. This motor has mainly attracted the designers of electric vehicle systems and other industrial applications. This motor is commercially obtaining demand due to its high torque density. Even though the magnitude of the torque is high in the BLDC motor, there are some problems still associated with its performance.***

One of the significant drawbacks of the BLDC motor is the presence of ripples in the torque waveform. The drives, aerospace, and other machine tools require shallow ripples in torque waveform. This will decrease the average value of the torque obtained by the BLDC motor. This is a very challenging problem in the current research trends.

In this paper, the primary focus is on the torque ripple minimization in the BLDC motor using modern/novel techniques. The technique presented in this work will considerably reduce the ripples in the torque waveform of the BLDC motor. Entire work is done in the MATLAB/SIMULINK software. The mathematical model of the BLDC motor is used to analyse the torque ripples presented in the waveform. The simulation waveforms of the torque waveform are shown in the results.

Keywords: BLDC motor, EV's, Torque Ripples, Drives.

I. INTRODUCTION

In this section, the general introduction of the BLDC motor is presented. This will give a clear understanding of the various aspects of BLDC motors. Following are the various components that exist in any drive system.

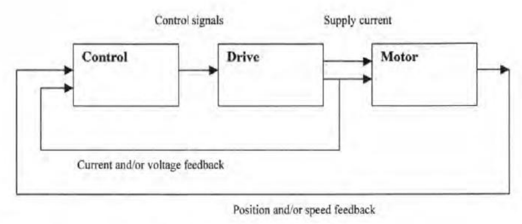


Figure 1: Components of a drive system

The general drive system consists of the following things.

Motor
The drive circuit
The control circuit
Current/voltage feedback.
Position/speed feedback.

The design differs for different types of motor. The type of motor that we used requires different control circuits, driver circuits, and feedback mechanisms. The vital thing in the control of a machine drive is the control loop. The control loop is used to control the speed, torque, and other motor parameters that are employed in the drive system.

A. Types of Motors:

Following are the various types of motors that are available to use in drive systems.

DC Motor drives.
Induction motor drives.
Synchronous machine drives.
Brushless motor drive.
Switched reluctance motor drives.
Synchronous reluctance motor drives.

B.DC Motor drives:

The DC motor drive schematic diagram is shown in the below figure. The DC motor drives are the oldest drives that are used for several applications.

Due to the developments in DC-DC converters, these drives are gaining importance. But due to the commutation problems associated with the DC motor, the rating of this drives cannot be very high. Hence, the applications of these drive systems are limited.

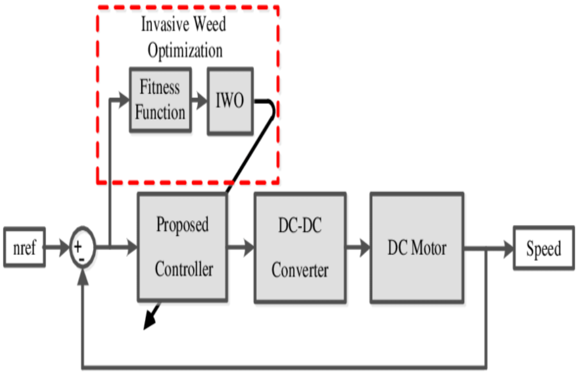


Figure 2: DC motor drive

*C. Induction motor Drives***:**

Induction motor drives are used in most applications, mainly industrial applications. The induction motor drive cost is less than less, and the induction motors are very robust in construction. Hence, these are used in several applications. The following figures show the schematic of the induction motor drive systems.

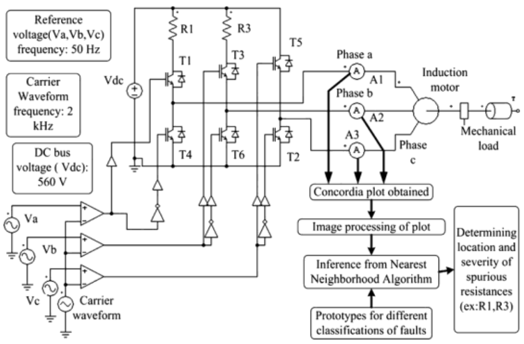


Figure 3: Induction motor drive system schematic

II. Torque Ripple analysis in BLDC Motors

In this scetion, the dynamic models of the BLDC motor are explained. Using the dynamic model, the torque ripple analysis is carried out. After that, some methods are proposed and explained to reduce torque ripples in a BLDC motor drive. Even though there are many advantages to the BLDC motor drive, it suffers from the following drawbacks.

The design of the controller is a very tedious task in the case of the BLDC motor.

Complexity in power electronic converter design.

Variation of the duty cycle has a direct effect on the variation of the torque.

The mathematical model needs to be derived accurately to reduce the above drawbacks, and the torque ripple analysis needs to be carried out.

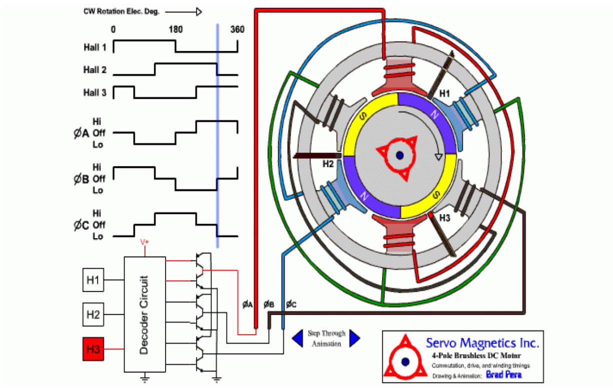


Figure 4: BLDC motor operation

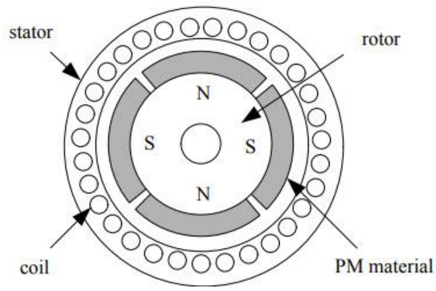


Figure 5: PM BLDC motor

A. Mathematical Model of BLDC motor:

Following is the mathematical model that is derived for the BLDC motor. It is derived using the stator and rotor parameters such as the resistance and the inductance of the windings in stator and rotor circuits.

Following are the dynamic equations of the three phases

$$V_{an} = R_s + L\frac{di_a}{dt} + M\frac{di_b}{dt} + M\frac{di_c}{dt} + e_a \tag{1}$$

$$V_{bn} = R_s + L\frac{di_b}{dt} + M\frac{di_c}{dt} + M\frac{di_a}{dt} + e_b \tag{2}$$

$$V_{cn} = R_s + L\frac{di_c}{dt} + M\frac{di_c}{dt} + M\frac{di_b}{dt} + e_c \tag{3}$$

Where

L is armature self-inductance [H],

M is armature mutual inductance [H],

R is armature resistance [Ω],

V_{an}, V_{bn} and V_{cn} are terminal phase voltage [V],

i_a, i_b and i_c are motor input current [A],

e_a, e_b and e_c are motor back -EMF [V].

The above model can be written in matrix form as follows.

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} R_S & 0 & 0 \\ 0 & R_S & 0 \\ 0 & 0 & R_S \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{4}$$

$$e_a = K_a f_a(\theta)\omega_r, e_b = K_b f_b\left(\theta - \frac{2\pi}{3}\right)\omega_r, e_c = K_c f_c\left(\theta - \frac{2\pi}{3}\right)\omega_r \tag{5}$$

$$V_{an} = R_s + L\frac{di_a}{dt} + M\frac{d(i_b + i_c)}{dt} + e_a \tag{6}$$

$$V_{an} = R_s + L\frac{di_a}{dt} - M\frac{di_a}{dt} + e_a \tag{7}$$

$$V_{an} = R_s + (L - M)\frac{di_a}{dt} + e_a \tag{8}$$

$$V_{an} = R_s + L_S\frac{di_a}{dt} + e_a \tag{9}$$

$$V_{bn} = R_s + L_S\frac{di_b}{dt} + e_b \tag{10}$$

$$V_{cn} = R_s + L_S\frac{di_c}{dt} + e_c \tag{11}$$

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} R_S & 0 & 0 \\ 0 & R_S & 0 \\ 0 & 0 & R_S \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L_S \begin{bmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \\ \frac{di_c}{dt} \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{12}$$

$$\begin{bmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \\ \frac{di_c}{dt} \end{bmatrix} = \left\{ \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} - \begin{bmatrix} R_S & 0 & 0 \\ 0 & R_S & 0 \\ 0 & 0 & R_S \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \right\} \frac{1}{L_s} \tag{13}$$

By using the above matrix, the following expressions can be derived for the torque

$$P_m = (e_a i_a + e_b i_b + e_c i_c) \tag{15}$$

$$T_e = \frac{P_m}{\omega_{rm}} = \frac{(e_a i_a + e_b i_b + e_c i_c)}{\omega_r}\frac{P}{2} \tag{16}$$

$$T_e = \frac{(K_a i_a + K_b i_b + K_c i_c)\omega_r}{\omega_r}\frac{P}{2} \tag{17}$$

$$T_e = \frac{P(K_a i_a + K_b i_b + K_c i_c)}{2} \tag{18}$$

The equation of mechanical part is represented as follows

$$T_e - T_L = \frac{Jd\omega_{rm}}{dt} + B\omega_{rm} \tag{19}$$

$$\frac{Jd\omega_r}{\frac{P}{2}dt} + \frac{B\omega_r}{\frac{P}{2}} + T_L = T_e \tag{20}$$

$$\frac{d\omega_r}{dt} = \frac{P}{2J}\left(T_e - T_L - \frac{2B}{P}\omega_r\right) \tag{21}$$

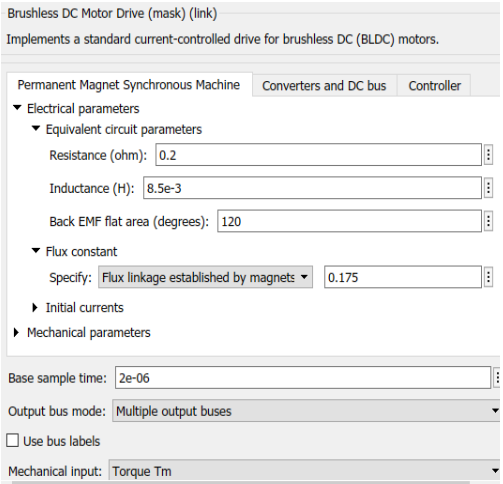
Expression (18) and (19) represents the torque that is derived from the BLDC motor.

III. SIMULATION RESULTS

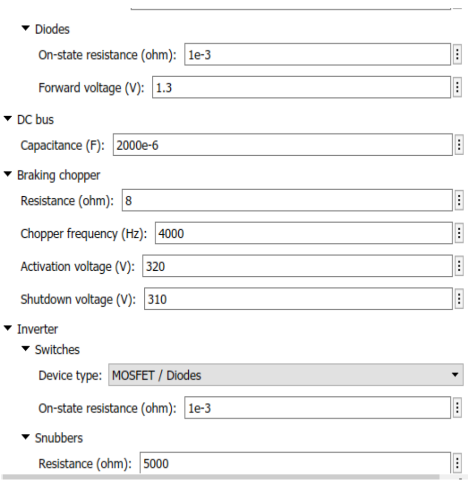
This section presents the simulation carried out to reduce the torque ripple in the BLDC motor. All the simulations are carried out in MATLAB/SIMULINK. Various output waveforms are obtained, and plots are shown for various parameters of the BLDC motor. The dynamic model is used to minimize the torque ripple.

A. Specifications of the BLDC motor

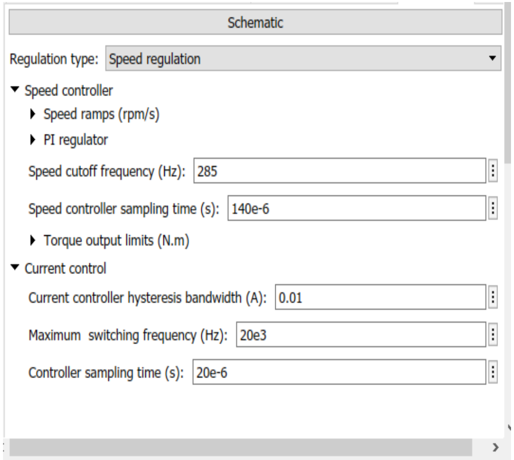
Following are the specifications of the BLDC Motor drive considered for the simulation.



B. Converter and DC bus parameters



C. Controller parameters



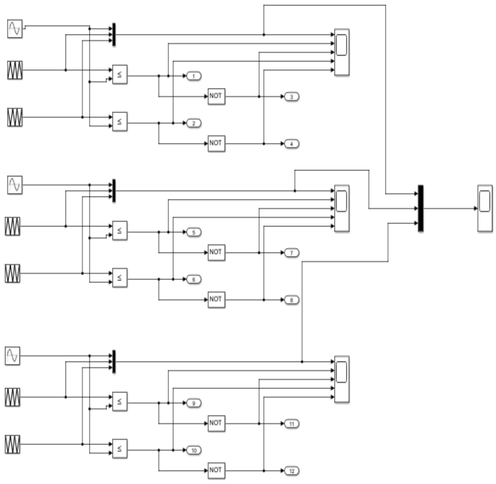
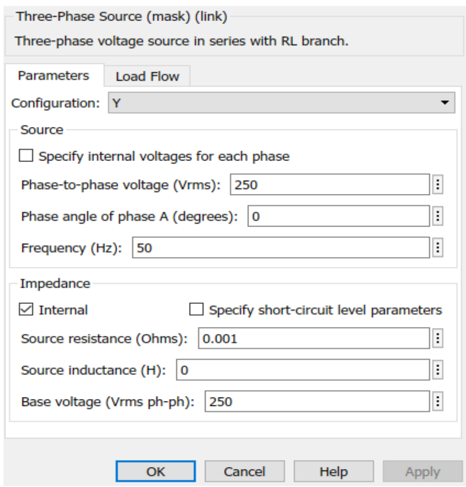


Figure 6: PWM pulse generator for the converter.



Source Parameters

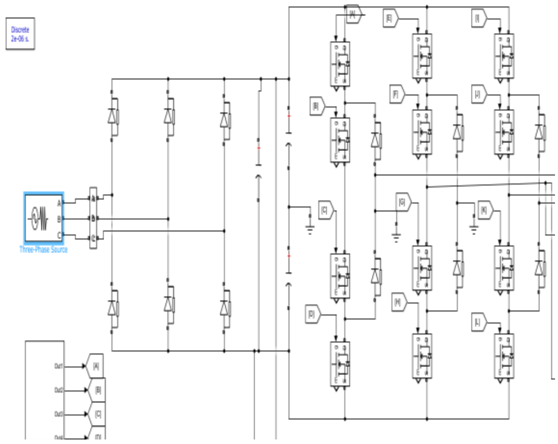


Figure 7: MLI configuration used for control of BLDC.

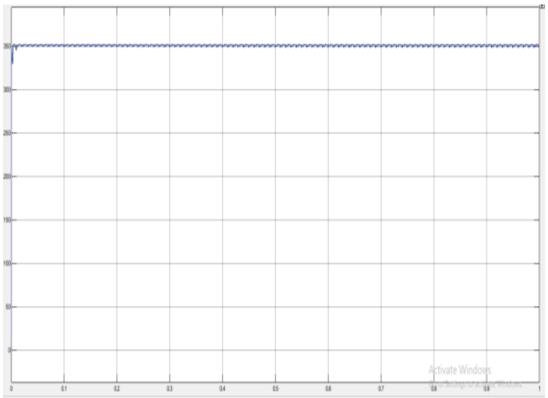


Figure 8: DC bus voltage

The above figure shows the DC bus voltage given to the multilevel inverter, in which the dc voltage is constant throughout the operation. The constant magnitude of 300 volts is maintained throughout the operation of the drive.

The figure below represents the three-phase voltage of the inverter terminals. The Dc is converter into AC. It is feeding the machine.

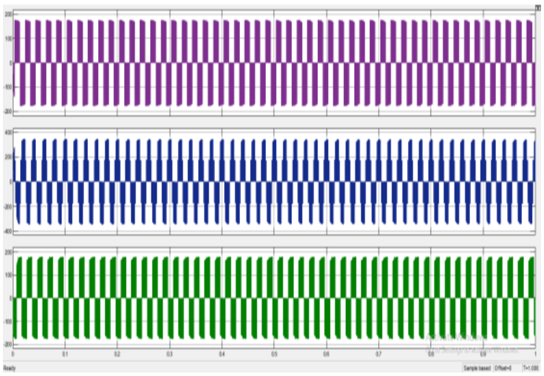


Figure 9: Three-phase voltages of MLI

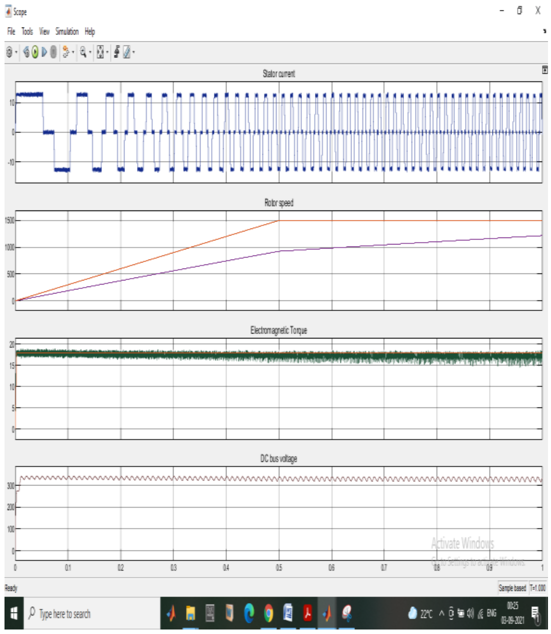


Figure 10: Motor parameters

The above figure shows the following motor parameters,

1. Stator current
2. Rotor speed.
3. Electromagnetic Torque
4. DC bus voltage during the operation of the machine.

The torque waveform shows that the ripples are presented in the torque waveform, but the magnitude of the ripples is significantly less.

The table below shows the torque ripple obtained at various speeds for using the proposed method for the BLDC motor drive.

Speed (rpm)	% Torque ripple
100	14.69
300	29.67
1000	44.87

Without using the PWM-based controller, the torque ripple at 100 rpm is 17.36%, at 300 rpm, it is 36.48%, and at 1000 rpm it is 59.63 %.

Hence, the simulation results proved that the PWM-based control method reduced the torque ripples in the BLDC motor considerably.

IV. CONCLUSION

The torque ripple reduction problem is considered in this report. From the simulation results following conclusions are made.

By using PWM-based methods, the torque ripple is reduced considerably at all the speeds in the BLDC motor.

The PWM-based method is effective in reducing the torque ripples.

The PWM based method is also simple and easy compared to other methods.

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