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Minimization of Torque Ripple in the Brushless Dc Motor Using Direct Torque Control

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Abstract—

Permanent Magnet Brushless DC Motor (PMBLDC) is one of the best electrical drives that have increasing popularity, due to their high efficiency, reliability, good dynamic response and very low maintenance. Due to the increasing demand for compact & reliable motors and the evolution of low cost power semiconductor switches and permanent magnet (PM) materials, brushless DC motors become popular in every application from home appliances to aerospace industry. The conventional techniques for controlling the stator phase current in a brushless DC drive are practically effective in low speed and cannot reduce the commutation torque ripple in high speed range. This paper presents the direct torque control PI and Fuzzy controller for minimizing torque ripples of BLDC motor. The BLDC motor is fed from the inverter where the rotor position and current controller is the input. Effectiveness of the proposed control method is verified through MATLAB/SIMULINK

Keywords— Terms—Brushless direct current (BLDC) motor, electromagnetic torque ripple, position sensor drive, variable-speed drive.

I. INTRODUCTION

Permanent magnet machines are applicable in key applications of critical importance, such as aerospace industry, tool drives, actuators and electric vehicle propulsion system since these needs to cater to servo applications. Hence, the necessity for precise control with quick response time is evident and obvious. Further these applications warrant the weight-density to be low and torque speed characteristics to be good. Also the inherent disadvantages of the conventional DC machines which necessitate the use of mechanical brushes and commutator problems have obviated these motors applied to such high performance applications**.** In this project PMBLDC motor, which can cater to large torque for high acceleration and deceleration rates is evaluated for its performance with respect to the parameters of the motor which need to include also the effects of reluctance variations and other effects of magnetic saturation. The modelling of the PMBLDC. The PMBLDC drive system which involves inherently an inverter controller arrangement which controls the duty cycle of the Inverter using PWM technique has been taken up for implementation.

Brushless dc motor (BLDCM) has been widely used in industrial fields that require high reliability and precise control due to its simple structure, high power density, and extended speeding range .The performance of such motors has been significantly improved due to the great development of power electronics, microelectronics, magnetic performance of magnets, and motion control technology. However, commutation torque ripple, which usually occurs due to the loss of exact phase current control, has always been one major factor in preventing BLDCM from achieving high performance. So far, many studies have been performed to reduce commutation torque ripple. A new control technique of BLDC was developed as Direct Torque Control (DTC). Using DTC it is possible to obtain a good dynamic control of torque without any mechanical transducers. The following papers were referred for torque ripple minimization for various methods.

Dae-Kyong Kim, Kwang-Woon Lee et al., discussed A commutation torque ripple reduction Method for a position sensorless BLDC motor drive for the air conditioner. Since the proposed method uses terminal voltage for measuring the commutation interval, the method does not require current sensors and a current control loop so that it is suitable for a low cost BLDC motor drive. Experimental results have proved that the proposed control method considerably reduces not only the pulsating currents but also up to 31% of the total vibrations for the BLDC motor.

G. H. Jang, M. G. Kim et al., discussed A method to detect the improved commutation position of a BLDC motor by utilizing the symmetric terminal voltages of the non energized phase at the beginning and end of the commutation period. It also develops a DSP-based sensorless BLDC motor controller to implement the proposed method and to verify its effectiveness experimentally. The proposed method can be effectively applied to improve the performance of a BLDC motor.

Hung-Chi Chen Chang-Ming Liaw et al., discussed The driving performance improvement of a sensorless BDCM drive via robust winding current control and intelligent commutation instant tuning has been studied in this paper. First, a current command generation scheme for the sensorless inverter-fed BDCM drive is established, wherein the commutation instants are determined by the proposed coarsely and finely tuning processes. For achieving better motor torque generating characteristics, the motor drawn line current minimization is employed as the performance index in making the commutation tuning. Simultaneously, a robust current controller is proposed to speed up the square wave winding current tracking response with parameter insensitive control performance. The measured results have shown that the winding current tracking response, the motor torque generating capability and the speed dynamic response of the sensorless BDCM drive are significantly improved by the proposed control methods.

Joong-Ho Song, Ick Choy et al., discussed A commutation torque ripple reduction method has been proposed for brushless dc motor drives using a single dc current sensor. In such drives, the dc-link current sensor cannot give any information corresponding to the motor currents during the phase current commutation intervals. Using the commutated phase current waveforms synthesized from the measured dc current, a duty ratio control strategy has been devised to equalize the two mismatched commutation time intervals. By being directly linked with the deadbeat current control scheme, the proposed control method accomplishes successful suppression of the spikes and dips superimposed on the current and torque responses during the commutation intervals.

Olaf Moseler Rolf Isermann et al., discussed A method for the detection of faults in brushless Dc motors was proposed. Using parameter estimation technique, a detailed diagnosis of the motor is possible by measuring only few accessible signals. Even small parameter changes can be detected. Therefore, a model was derived which is based on the bridge supply voltage/current and the rotor velocity. The fault detection capability was demonstrated with simulated and experimental data. The approach can be applied to both end-of-line check and online fault detection. Further research will concern the application of parity equations for the generation of additional symptoms. In particular, in the case of online supervision, where sensors can also fail, parity equations could provide useful information.

II. ANALYSIS OF COMMUTATION TORQUE RIPPLE IN BLDC DRIVES

Idealized back-EMF and current waveforms for a 120◦- elec.-conduction-mode three-phase BLDC drive are shown in Fig. 8. Since it can produce a higher electromagnetic torque per ampere than that which results with three-phase 180◦ elec. conduction, it is the most commonly used mode and, hence, is considered in this paper. The principle of DTC when applied to a BLDC drive is described the current and torque ripple which result due to commutation events in a 120◦-elec.-conduction three-phase star-connected BLDC drive are analyzed, in a similar way to that given in a controllable three-phase switching mode is then introduced during the commutation periods, and the resulting current and torque ripple are analyzed. Finally, the two operating modes are combined to minimize the commutation torque ripple in a DTC BLDC drive.

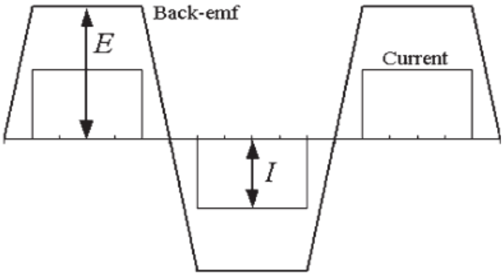

Figure 1 Idealized back-EMF and current waveforms in BLDC drive.

The stator-phase voltage equations can be simplified as

$$U_{an} = i_a R_s + e_a + L_s \frac{di_a}{dt} \quad (1.1)$$

$$U_{bn} = i_b R_s + e_b + L_s \frac{di_b}{dt} \quad (1.2)$$

$$U_{cn} = i_c R_s + e_c + L_s \frac{di_c}{dt} \quad (1.3)$$

where *uan*, *ubn*, *ucn*, *ea*, *eb*, *ec*, *ia*, *ib*, and *ic* are the phase voltages, back-EMFs, and currents of phases *a*, *b*, and *c*, respectively, and *Rs* and *Ls* are the stator winding resistance and inductance, respectively. However, the winding resistance is neglected in order to simplify the analysis. The equations for the phase-winding terminal-to-ground (*n*0) voltages *uan*0, *ubn*0, and *ucn*0 are

$$U_{ano} = U_{an} + U_{nno} \quad (1.4)$$

$$U_{bno} = U_{bn} + U_{nno} \quad (1.5)$$

$$U_{cno} = U_{cn} + U_{nno} \quad (1.6)$$

where *unn*0 is the neutral point-to-ground voltage.

The sum of the phase-winding terminal-to-ground voltages is

$$\begin{aligned} U_{ano} + U_{bno} + U_{cno} &= U_{an} + U_{bn} + U_{cn} + 3U_{nno} \quad (1.7) \\ &= e_a + e_b + e_c + 3U_{nno} \end{aligned}$$

III. DIRECT TORQUE CONTROL METHOD

Direct torque control was originally developed for induction machine drives and directly controls the flux linkages and electromagnetic torque, considering the electrical machine, the power electronic inverter ,and the control strategy at the system level .A relationship is established between the torque ,the flux and the optimal inverter switching so as to achieve a fast torque response .it exhibits better dynamic performance than conventional control methods, such as vector control, is less sensitive to parameter variations, and is simpler to implement DTC has successfully applied to brushless DC machine.

To control the motors variable frequency method is mostly used in industries. In this method to get the good dynamic performance direct torque control is preferred. Based on the measured stator voltage and currents the flux and torque is calculated and a relationship is established between the obtained flux and torque. The fig 4.1 shows the block diagram of direct torque control. This method involves two stages to estimates the required quantities. In first stage by integrating the stator voltages the stator flux linkage is estimated and the torque is estimated by cross product of obtained stator flux linkage and measured motor currents. In stage two the control signals are obtained by comparing the reference value and estimated values. If any error is produced then the signals are generated based on the demanded values of the torque and stator flux. Thus the dynamic response and torque control is achieved. Hence it is known as one form of the hysteresis control.

The electromagnetic torque of a permanent-magnet brushless machine in the synchronously rotating d –q reference frame can be expressed as [4.1]

$$T_e = \frac{3}{2}\frac{p}{2}\left[\left(\frac{dL_d}{d\theta_e}i_{sd} + \frac{d\varphi_{rd}}{d\theta_e} - \varphi_{sd}\right) i_{sd+\left(\frac{dL_q}{d\theta_e}i_{sq}+\frac{d\varphi_{rq}}{d\theta_e}-\varphi_{sq}\right)} i_{sq}\right] \qquad (4.1)$$

$$\varphi_{sd} = \varphi_{rd} + L_{di_{sd}} \qquad (4.2)$$

$$\varphi_{sq} = \varphi_{rq} + L_{qi_{sq}} \qquad (4.3)$$

For applying direct torque control to BLDC motor, the electromagnetic torque is expressed in stationary α-β reference frame

$$\mathrm{T_e} = \frac{3}{2}\frac{\mathrm{p}}{2}\left[\left(\frac{\mathrm{d}\varphi_{r\alpha}}{\mathrm{d}\theta_e}\right) \mathrm{i}_{sd+\left(\frac{\mathrm{d}\varphi_{r\beta}}{\mathrm{d}\theta_e}\right)} \mathrm{i}_{s\beta}\right]$$

TABLE 1.1 SWITCHING TABLE FOR DTC

C_Ψ	C_T	Sector I	Sector II	Sector III	Sector IV	Sector V	Sector VI
1	1	V_2(110)	V_3(010)	V_4(011)	V_5(001)	V_6(101)	V_1(100)
	0	V_7(111)	V_0(000)	V_7(111)	V_0(000)	V_7(111)	V_0(000)
	−1	V_6(101)	V_1(100)	V_2(110)	V_3(010)	V_4(011)	V_5(001)
0	1	V_3(010)	V_4(011)	V_5(001)	V_6(101)	V_1(100)	V_2(110)
	0	V_0(000)	V_7(111)	V_0(000)	V_7(111)	V_0(000)	V_7(111)
	−1	V_5(001)	V_6(101)	V_1(100)	V_2(110)	V_3(010)	V_4(011)

IV. SIMULATION RESULT

SIMULATION DIAGRAM OF BLDC MOTOR WITH OUT USING DTC METHOD

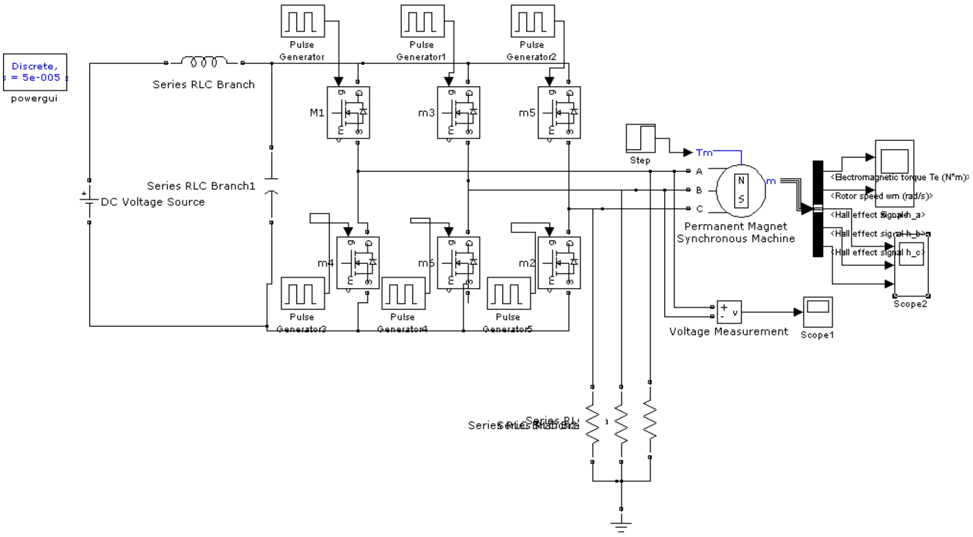

Figure 2 Brushless dc motor simulation diagram

TORQUE AND SPEED

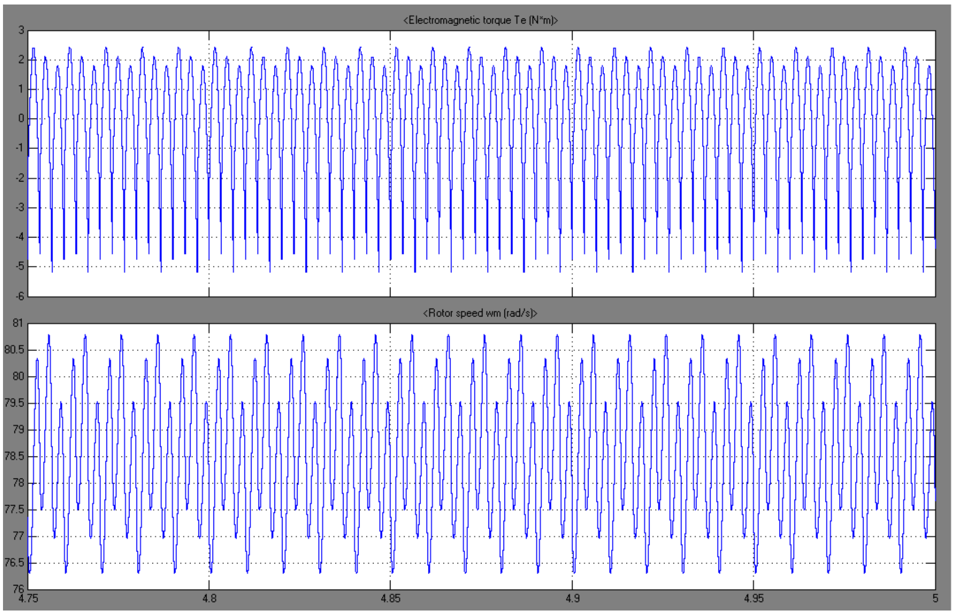

Figure 3 speed and torque output

BRUSHLESS DC MOTOR ALONG WITH DIRECT TORQUE CONTROL

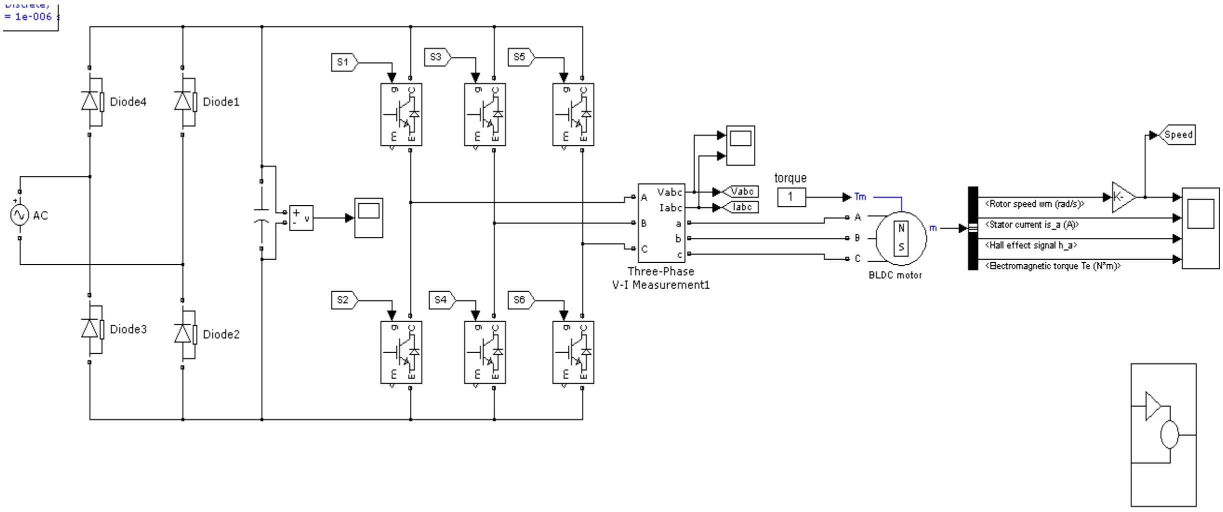

Figure 4 waveform of BLDC motor

OUTPUT WAVEFORM FOR DIRECT TORQUE CONTROLLER ALONG WITH PI

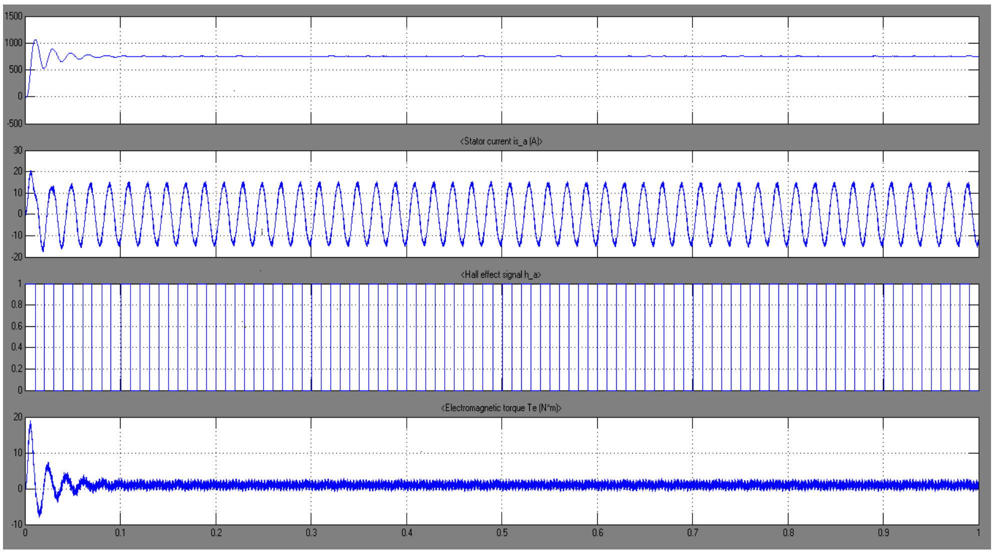

Figure 5 Output waveform for DTC

V. CONCLUSION

The phase-current waveform and torque ripple which result during commutation events in a DTC two-phase 120◦-elec.- conduction permanent-magnet BLDC drive have been analyzed, and an improved DTC, PI and fuzzy logic controller has been proposed to minimize the commutation torque ripple. During commutation periods at high rotational speeds, it automatically combines two- and three-phase switching modes by minimizing the error between the commanded torque and the estimated torque. The torque ripple due to commutation events is, thereby, reduced significantly, as has been demonstrated by both simulation results.

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