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Effective Torque Ripple Reduction of Permanent Magnet Brushless DC Motor

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Abstract - To reduce commutation torque ripple, a model predictive control (MPC) for permanent brushless DC motors (BLDCM) is presented (CTR). Torque ripples cause vibration noise and decrease efficiency. The suggested MPC system is constructed by forecasting the phase current with the aim of minimizing the BLDCM's CTR and taking into consideration the CTR sources. The method presented in this paper is a unique methodology for suppressing CTR over the whole speed range, avoids more complex current controllers or modulation models, and overcomes the challenges of commutated-phase-current control. The ideal switching state is instantly selected and implemented during the next sample period according to the preset cost function in order to match the slope rates of outgoing and incoming phase currents during commutation, ensuring the minimum of commutation torque ripple. The modelling and experiment findings show that the suggested method can effectively reduce CTR over a wide speed range and achieve the better CTR minimization performance. The results are then compared to the outcomes of various torque ripple reduction(TRR) techniques.

Key words- Model Predictive Control(MPC), Brushless DC motor(BLDCM), Commutational Torque Ripple(CTR)

I. INTRODUCTION

Permanent magnet brushless dc motors (BLDCMs) have been widely used in a variety of fields, including aerospace, robots,home appliances' industry,automotive electronics, and office automation due to their high power density, torque to inertia ratio, simple structure, power efficiency, and robustness [1]-[5].Torque ripple, which comprises current ripple, cogging torque ripple and CTR, is still a key issue for permanent-magnet BLDCM. The most significant of them is commutation torque ripple, which limits the use of permanent-magnet BLDCM in high-performance regions [6]-[10].

The Current study focuses on minimizing commutation torque ripple. The CTR is dependent on the connection between and dc-link voltage and back electromotive force (EMF), according to an early analytical study of CTR described in [11]. The effects of hysteresis current regulated pulse-width modulation (PWM) on commutation torque ripple discussed in [12], which concludes that the current ripple and length of commutation phase during commutation changes with speed and are dependent on the phase current amplitude. In [13][14], a unique approach to reduce CTR is presented, which is accomplished by adjusting the duty ratio of the PWM based on the voltage of the non-commutated phase before commutation and during commutation maintaining the average voltage of the non-commutated phase. An enhanced permanent magnet direct torque control

BLDCM is presented in [15] to maintain constant electromagnetic torque, hence avoiding ripple in commutation torque. Unfortunately, these traditional approaches for reducing CTR are implemented independently at low speed and high speed, making them rather complex over the full speed range. Thus, the cut-off point of high speed and low speed is necessary, and performance may decrease if the cut-off point is inaccurate. Current control schemes have a significant effect on the CTR of permanent-magnet BLDCM. According to the aforementioned study, the present control solutions for decreasing CTR are almost always PWM-based. Recent research has focused on the finite control set model predictive control (FCS-MPC) technique, which is conceptually novel. Rodriguez proposed the model predictive control approach and applied it to nonlinear current regulation in 3-phase inverters [16]. The model of a controlled system makes projections about the actions that will be taken by the controlled variables in the future for each switching state. An inverter circuit provides a limited number of potential switching states, from which the ideal switching state is chosen and then applied during the subsequent sampling period in accordance with the minimalized preset cost function.. In a 3-phase inverter, the newly created model predictive control approach was used. [16]–[20], current control for VSI-driven asymmetrical dual 3-phase ac machines [21]–[24], and multiphase-current control [25], [31].

In the research, FCS-MPC and other TRR approaches are compared with regard to their ability to lower the CTR of permanent-magnet BLDCM. In order to find a solution to the issue of CTR, research was done on the three conduction states that take place in inverter circuits during the commutation interval as well as the impact those states have on the commutation current. Because of the timely construction of the appropriate switching state for the forthcoming sample period based on the suggested predictive model and the present cost function, the CTR dropped by a significant amount.

II. COMMUTATIONAL TORQUE ANALYSIS

A. Mathematical Analysis Of Computational Torque

PMBLDCM generally operates in a two-phase 120 (electrical) conducting mode, which includes both a commutation area and a non-commutation portion inside its structure. This work is being done with the intention of lowering the CTR in the commuter zone. Fig 1 illustrates the connection that exists between the trapezoidal back EMF and the BLDCMHall sensor signal

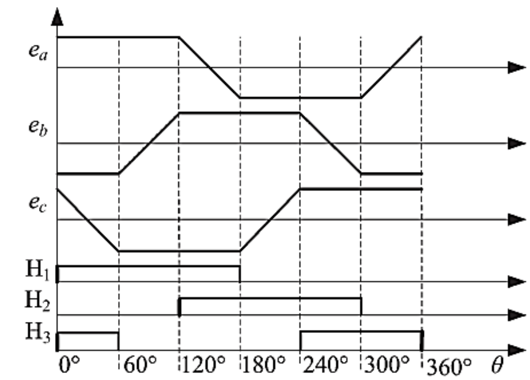

Fig 1 Back EMF and Hall signals of BLDCM

The mathematical model of BLDCM can be expressed as

$$u_{a0} = Ri_a + L_s \frac{di_a}{dt} + e_a + u_n$$

$$u_{b0} = Ri_b + L_s \frac{di_b}{dt} + e_b + u_n \qquad (1)$$

$$u_{c0} = Ri_c + L_s \frac{di_c}{dt} + e_c + u_n$$

$$i_a + i_b + i_c = 0 \qquad (2)$$

where u_{a0}, u_{b0}, and $u_{c0}$are the 3-phase winding's terminal voltages, i_a, i_b, and $i_c$are the 3-phase winding's phase currents, e_a, e_b, and $e_c$are the 3-phase winding's back EMFs, R and L_s are the phase resistance and equivalent phase inductance, un is the neutral point voltage.

The commutation of the motor from phase A → phase C conduction to phase B → phaseC conduction is taken as an example of commutation process, shown in Fig. 2.

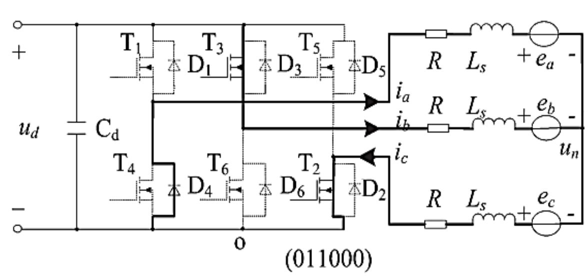

Fig 2 Current flow of commutation process

Generally, the torque developed by BLDCM given as

$$T_e = \frac{1}{\omega_r}(e_a i_a + e_b i_b + e_c i_c) \quad (3)$$

where Te is the electromagnetic torque and ω_r is the rotor angular velocity.

Opposing that back EMF maintains fixed value E during commutation, theBLDCM's torque can be expressed as

$$T_e = \frac{1}{\omega_r}(E i_a + E i_b + (-E) i_c) \quad (4)$$

where$E$ is the value of the back EMF.

The research reveals that the amount of commutation torque that is created during the commutation process is related to the amount of phase current that has not been commutated.

III. MODEL PREDICTIVE CONTROL TECHNIQUE

The block diagram of the traditional permanent magnet brushless direct current (BLDC) motor's predictive current control idea is shown in Fig 3. The current reference value of d axes is set to zero, while the q-axes current reference value is created by PI adjustment in the speed outer loop. The projected current controller will follow the d- and q-axes reference currents as they change.

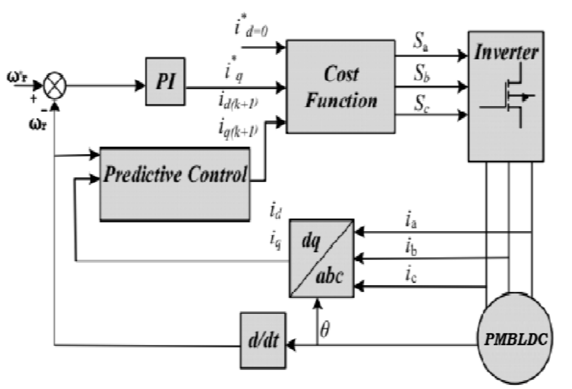

Fig 3 Block diagram of MPC with BLDC motor

The one step prediction is given by,

$$i_d(k+1) = i_d(k) + \left(\frac{\Delta t}{L}\right) * (V_d(k) - (\text{R}*i_d(k)) + (\omega(k)*\text{L}*i_q(k))) \quad (5)$$

$$i_q(k+1) = i_q(k) + \left(\frac{\Delta t}{L}\right) * (V_q(k) - (\text{R}*i_q(k)) + (\omega(k)*\text{L}*i_d(k))) \quad (6)$$

The recorded current and voltage must be converted to d-q variables, as previously stated. The sum of squared errors of currentswas chosen as the objectives function in this study.

$$J = \left(i_d(k) - i_d(k+1)\right)^2 + \left(i_q(k) - i_q(k+1)\right)^2 \quad (7)$$

It is possible to use the simple sum of errors of the currents in d and q as the target function; however, the sum of squared error is better for big tracking since the objective function expands as the difference between the reference and forecast currents increases.

IV. MATLAB SIMULATION AND RESULTS

The simulation is done with different CTR reduction technique. Mainly in this paper focused on FCS MPC technique. And the Results are compared with PID controller, Field Oriented Control and Hysteresis current control techniques. The BLDC motor drive system is simulated with different control technique to know the performance and effectiveness of the system. Table 1 shows the parameters of the BLDC motor.

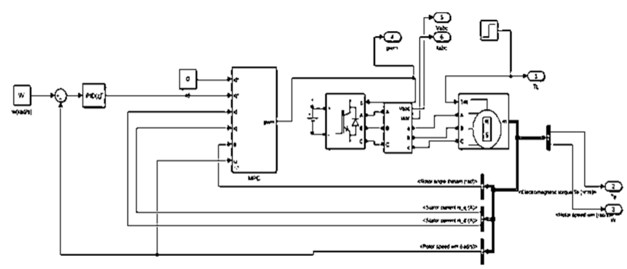

Fig 4 Simulation BLDC driving s/m with MPC

Table 1 BLDC motor parameters

PARAMETER	VALUE
Vdc(v)	220
Rated speed(rpm)	1500
Nominal load (Nm)	0.8
Pole pairs	6
Phase resistance(ohm)	0.0485
Phase inductance(mH)	0.395
Inertia constant(kg.m)	0.015

1. Low speed at constant load operation

In low speed case the motor is tested at the speed of the 500RPM and the Constant load torque is taken as 0.5N-m. Based on the results shown in Figures. we can see that torque ripples are reducing.

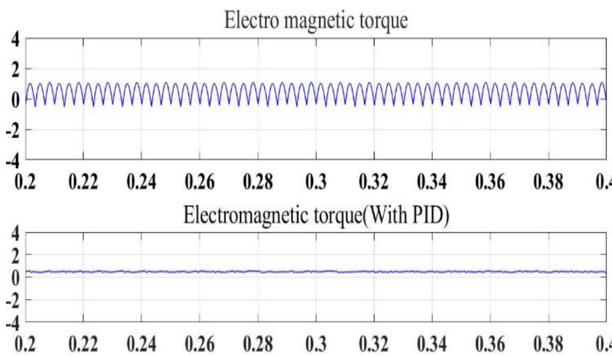

Fig 5 Electromagnetic torque with PID controller and Without PID controller

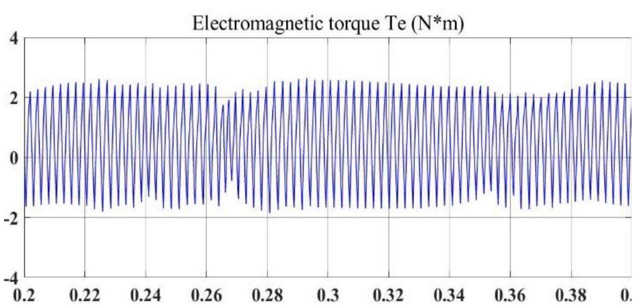

Fig 6 Electromagnetic torque with Hysteresis Current Control

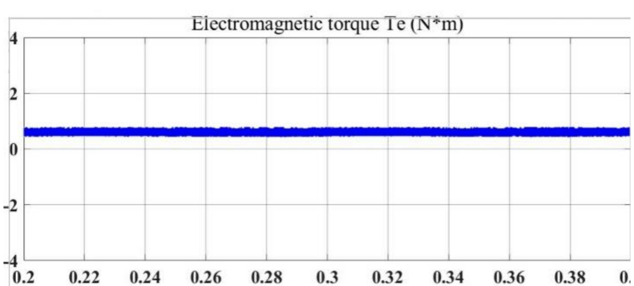

Fig 7 Electromagnetic torque with FOC Control

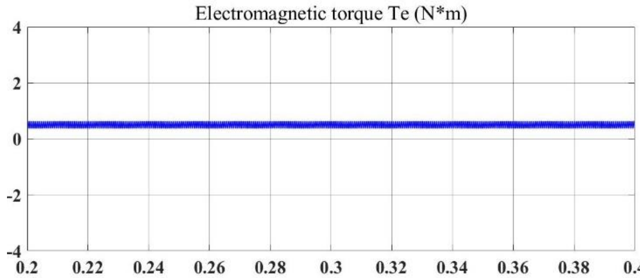

Fig 8 Electromagnetic torque with MPC control

2. High speed at constant load operation

In high speed case the motor is tested at the speed of the 1000RPM and the Constant load torque is taken as 0.5N-m. Based on the results shown in Fig. we can see that torque ripples are reducing. So, results shows that proposed scheme is performing well.

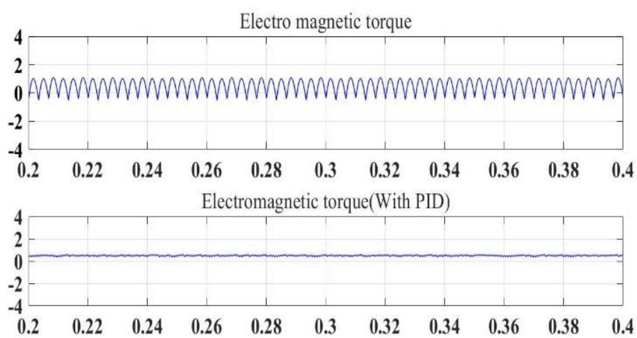

Fig 9 Electromagnetic torque with PID controller and Without PID controller

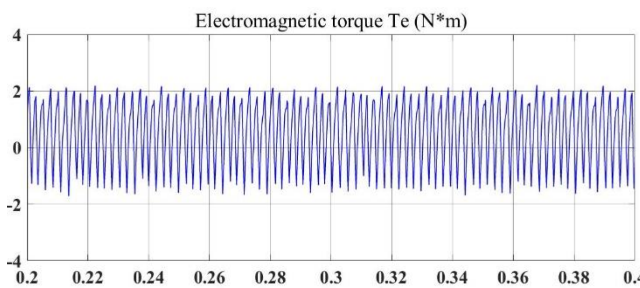

Fig 10 Electromagnetic torque with Hysteresis controller

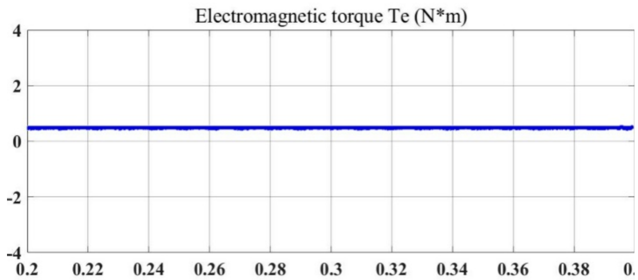

Fig 11 Electromagnetic torque with FOC controller

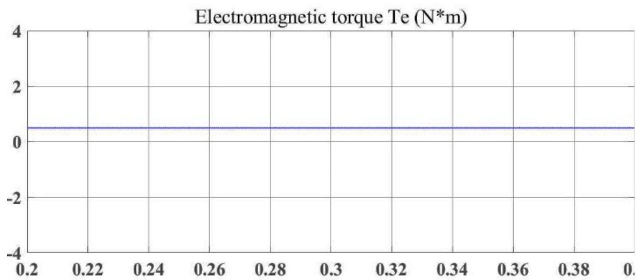

Fig 12 Electromagnetic torque with MPC controller

V. CONCLUSION

Within the scope of this work, FCS-MPC is used with the goal of reducing permanent-magnet BLDCM commutation torque ripple. There are two types of CTR: torque dips in the high-speed range and torque peaks in the low-speed range. Both are caused by a mismatch between the slope rates of rising and falling current during commutation intervals. Torque dips occur at the high-speed and torque peaks occur at the low-speed. The primary contribution that comes from this study is an in-depth description of the algorithm design process for CTR reduction via the use of BLDCM. The purpose of this paper is to overcome the challenges of commutated-phase-current control by avoiding complex current controllers and modulation models, and to propose an integrated method for reducing CTR across a wide speed range without taking into account different current cases at low and high speeds.

The findings of this study indicate that CTR may be effectively reduced by switching between the power inverter's three conduction states in an exact manner during the commutation process. The power inverter's design and the dc-link voltage's design do not need to be altered in any way in order to implement the FCS-MPC technique that has been presented. Commutation does not need the computation of a PWM duty ratio or a modulation model, and there is no significance to the relationship between the dc voltage and the back EMF of the BLDCM. Both of these things are inconsequential. According to the results of the study, the approach that was proposed is superior in terms of lowering CTR across the board.

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