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Model Predictive Current Control for PMSM Drives With Low Parameter-dependent Model

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ABSTRACT

Aiming at the effects of motor parameter perturbation errors, this paper proposes a low parameter-dependent model MPCC method for PMSM drivers. The method is applied to surface mounted permanent magnet synchronous motor (SPMSM), and the parameter values of inductance and flux are extracted from the difference between the ideal case without parameter perturbation and the q-axis predicted currents under the actual operating conditions, and brought into the current prediction model for real-time updating. Finally, the reference currents for the action of candidate voltage vectors are calculated by the enumeration method, and the optimal voltage vectors are selected by the cost function and acted on the motor by the inverter. As verified by simulation, the method reduces the dependence of the current prediction model on the motor parameters and enhances the robustness of the system parameters.

I. the Proposed LPM-MPCC Method

The relevant literature has demonstrated that resistance parameter mismatch almost has no effect on the control system, whereas inductance and magnetic flux mismatch can lead to a degradation of the overall system performance. Therefore, the focus of this paper is to solve the problem of inductance and magnetic flux parameter mismatch. In Eq. 2, since the value of $T_s R/L$ is much less than 1, the value of $1-T_s R/L$ can be approximated as 1. The simplified current prediction model is Eq. 1:

$$\begin{cases} i_d(k+1)=i_d(k)+T_s\omega_e i_q(k)+\dfrac{T_s}{L(k)}u_d(k) \\ i_q(k+1)=i_q(k)-T_s\omega_e i_d(k)+\dfrac{T_s}{L(k)}[u_d(k)-\omega_e\psi_f(k)] \end{cases} \tag{1}$$

The simplified current prediction model containing the actual motor parameters can be expressed as Eq.2：

$$\begin{cases} i_d^{rel}(k+1)=i_d(k)+T_s\omega_e i_q(k)+\dfrac{T_s}{L^{rel}(k)}\cdot u_d(k) \\ i_q^{rel}(k+1)=i_q(k)-T_s\omega_e i_d(k)+\dfrac{T_s}{L^{rel}(k)}\cdot[u_d(k)-\omega_e\psi_f^{rel}(k)] \end{cases} \tag{2}$$

The ideal case without parameter perturbation and the parameter error case under real operating conditions can be expressed in Equation 3:

$$\begin{cases} L^{rel}(k)=L(k)+\Delta L(k) \\ \psi_f^{rel}(k)=\psi_f(k)+\Delta\psi_f(k) \end{cases} \tag{3}$$

By using the Euler discretization method to discretize the *q*-axis voltage mathematical equation of the PMSM, the *q*-axis magnetic flux expression can be obtained as follows:

$$\begin{aligned} \psi_f^{rel}(k)=&\frac{u_q(k)-Ri_q(k)}{\omega_e} \\ &-L^{rel}(k)[\frac{i_q(k)-i_q(k-1)}{T_s\omega_e}-i_d(k)] \end{aligned} \tag{4}$$

From the above equation, it is clear that the magnetic flux changes with the change in inductance of the *dq*-axis as shown in Eq. 5:

$$\psi_f^{rel}(k)=f\left(L^{rel}(k)\right) \tag{5}$$

In order to facilitate the derivation of the current error equations for the *q*-axis in the ideal case without parameter perturbation and in the actual working condition, it is assumed that the flux of the *q*-axis is constant and its error perturbation is small in practice. According to the simplified current prediction model, the current error equation of *q*-axis is as follows:

$$\begin{aligned} E_q(k+1)&=i_q^{rel}(k+1)-i_q(k+1) \\ &=\left(D^{rel}(k)-D\right)*\left(u_q(k)-\omega_e\psi_f^{rel}(k)\right) \end{aligned} \tag{6}$$

Where $D^{rel}(k)$ denotes the value of T_s/L under the actual working condition, $D^{rel}(k)=T_s/L^{rel}(k)$, denotes the value of T_s/L under the ideal working condition without parameter perturbation, $D^{rel}(k)=T_s/L(k)$, and it is worth noting that D is invariant under the ideal condition, so the values of the *k* moment and the *k*-1 moment should be equal.

When making a current prediction for the next moment in the current prediction model, the value of $D^{rel}(k)$ in the actual working condition should be the same as the value of D in the ideal case, and thus can be obtained:

$$\begin{aligned} D^{rel}(k)&=D \\ &=D^{rel}(k-1)-\frac{E_q(k)}{u_q(k-1)-\omega_e\psi_f^{rel}(k)} \end{aligned} \tag{7}$$

According to the above equation, the actual inductance and flux parameter values at time *k* can be solved, thus completing the extraction of the inductance and flux parameters, and the joint equation is given in the following equation:

$$\begin{cases} L^{rel}(k)=\dfrac{T_s}{D^{rel}(k-1)-\dfrac{E_q(k)}{u_q(k-1)-\omega_e\psi_f^{rel}(k)}} \\ \psi_f^{rel}(k)=\dfrac{u_q(k)-Ri_q(k)}{\omega_e} \\ \qquad -L^{rel}(k)[\dfrac{i_q(k)-i_q(k-1)}{T_s\omega_e}-i_d(k)] \\ \psi_{f-3}(k)=\dfrac{\psi_f^{rel}(k)+\psi_f^{rel}(k-1)+\psi_f^{rel}(k-2)}{3} \end{cases} \tag{8}$$

The control block diagram of proposed LPM-MPCC method with one-step delay compensation is shown in Fig. 1.

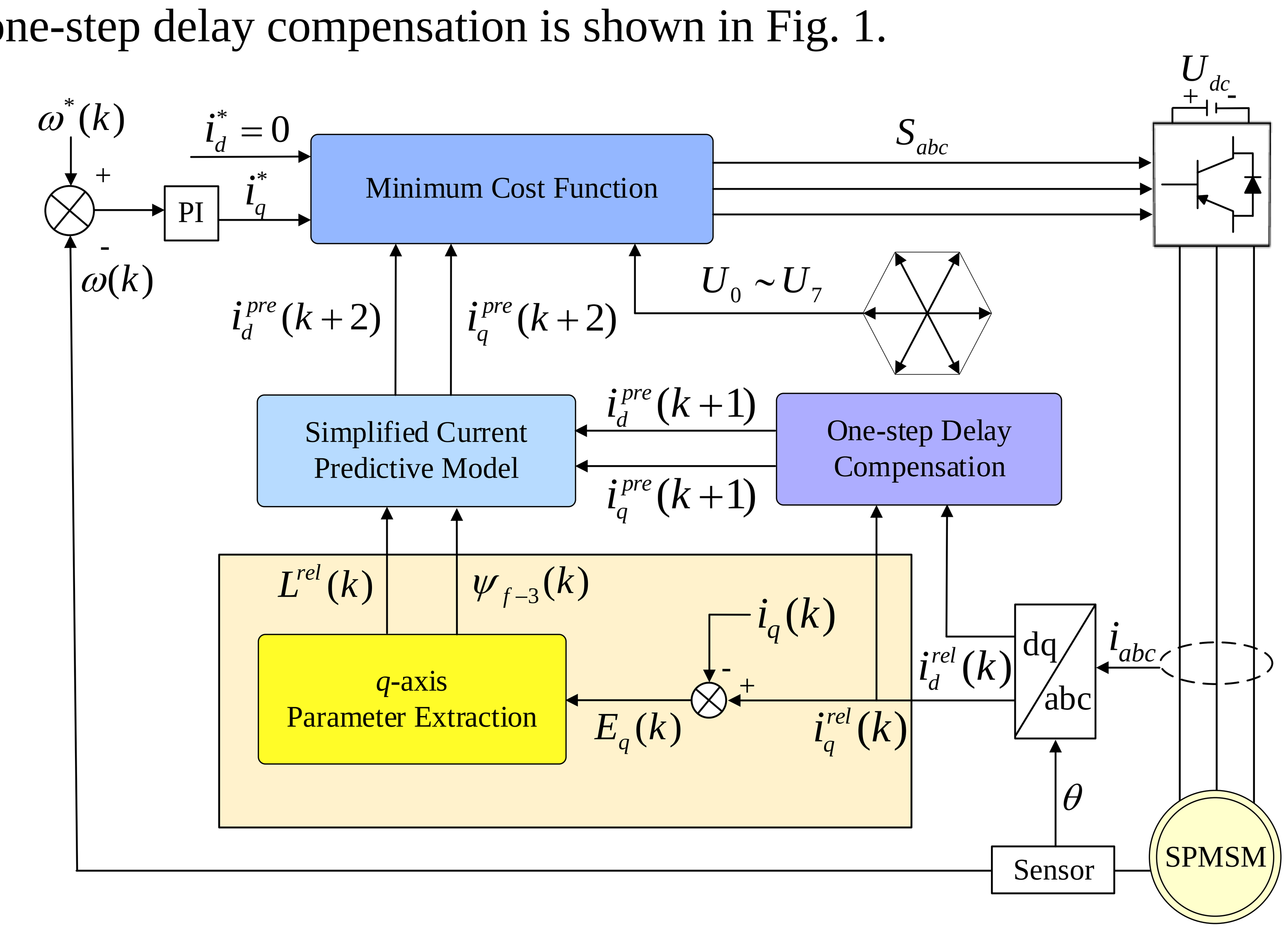
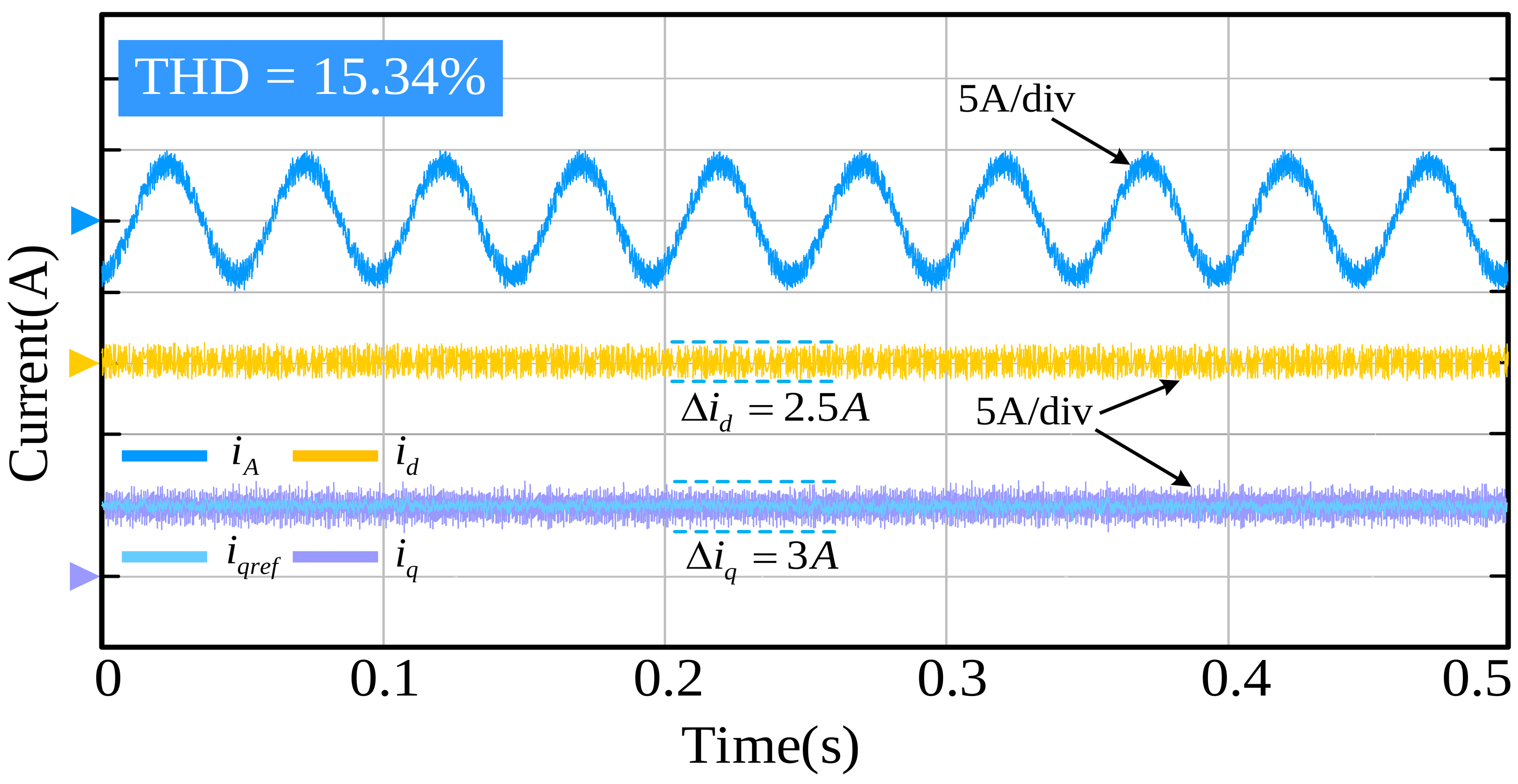


Fig. 1. Control block diagram of the LPM-MPCC method

II. Simulation Results

In order to verify the effectiveness of the proposed method, simulation experiments are carried out on MATLAB/Simulink. The control frequency in the simulation experiment is 10kHz.



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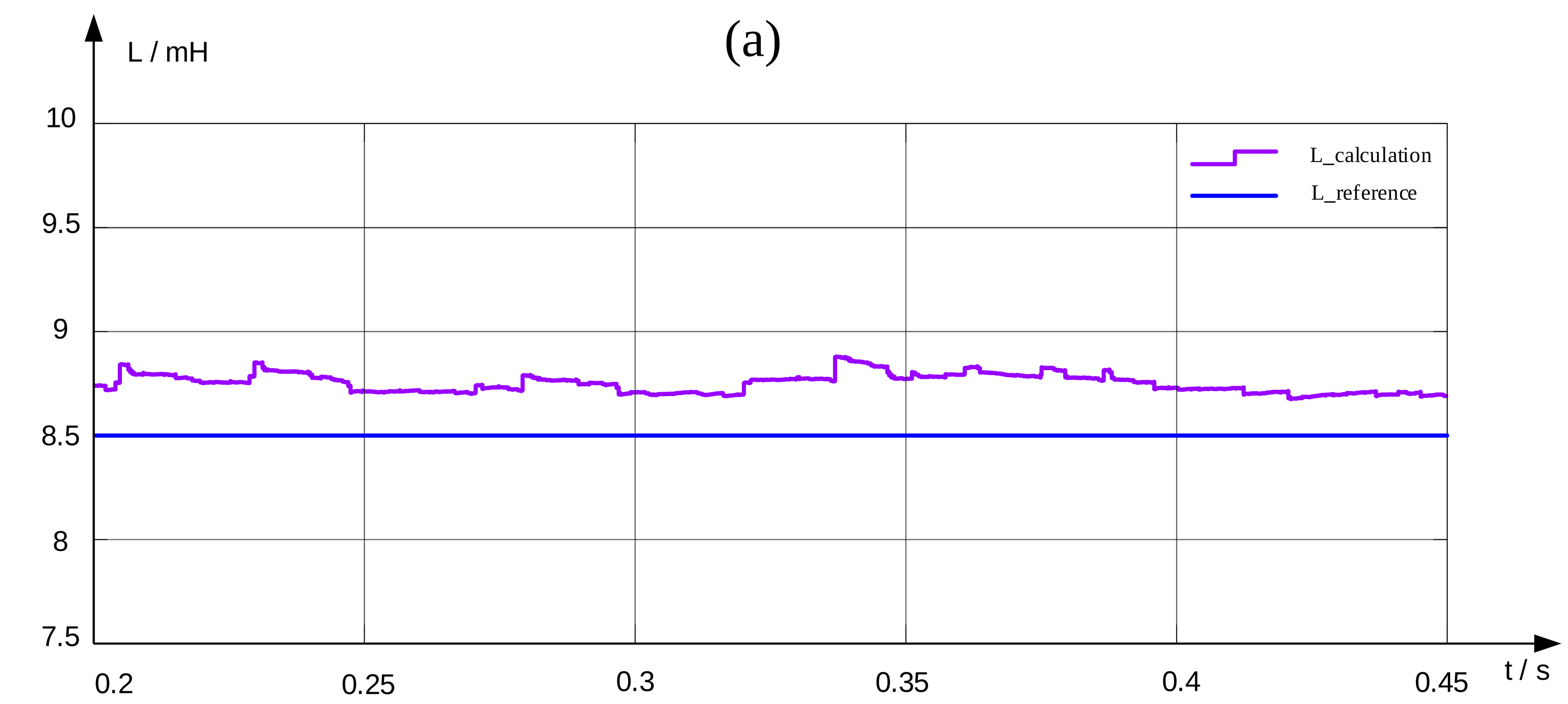

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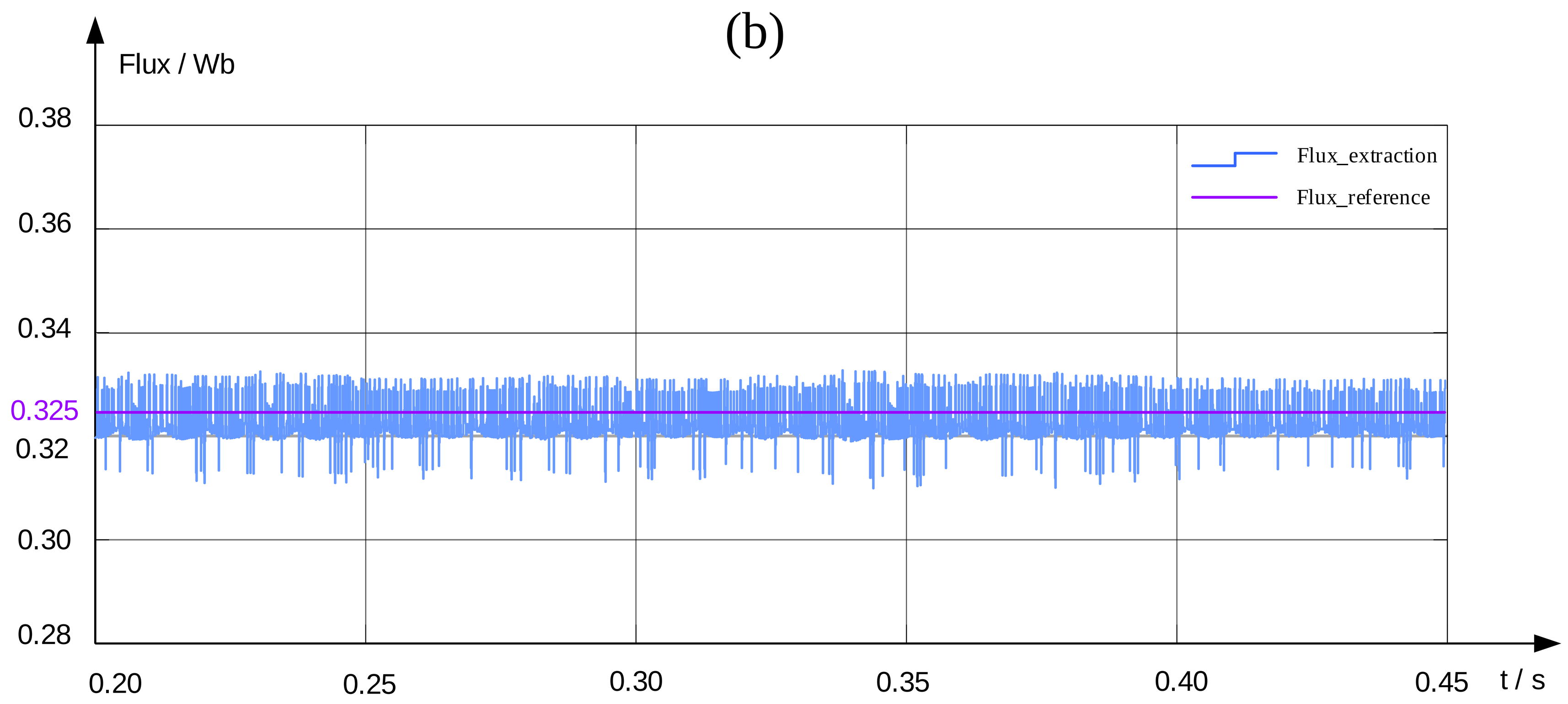
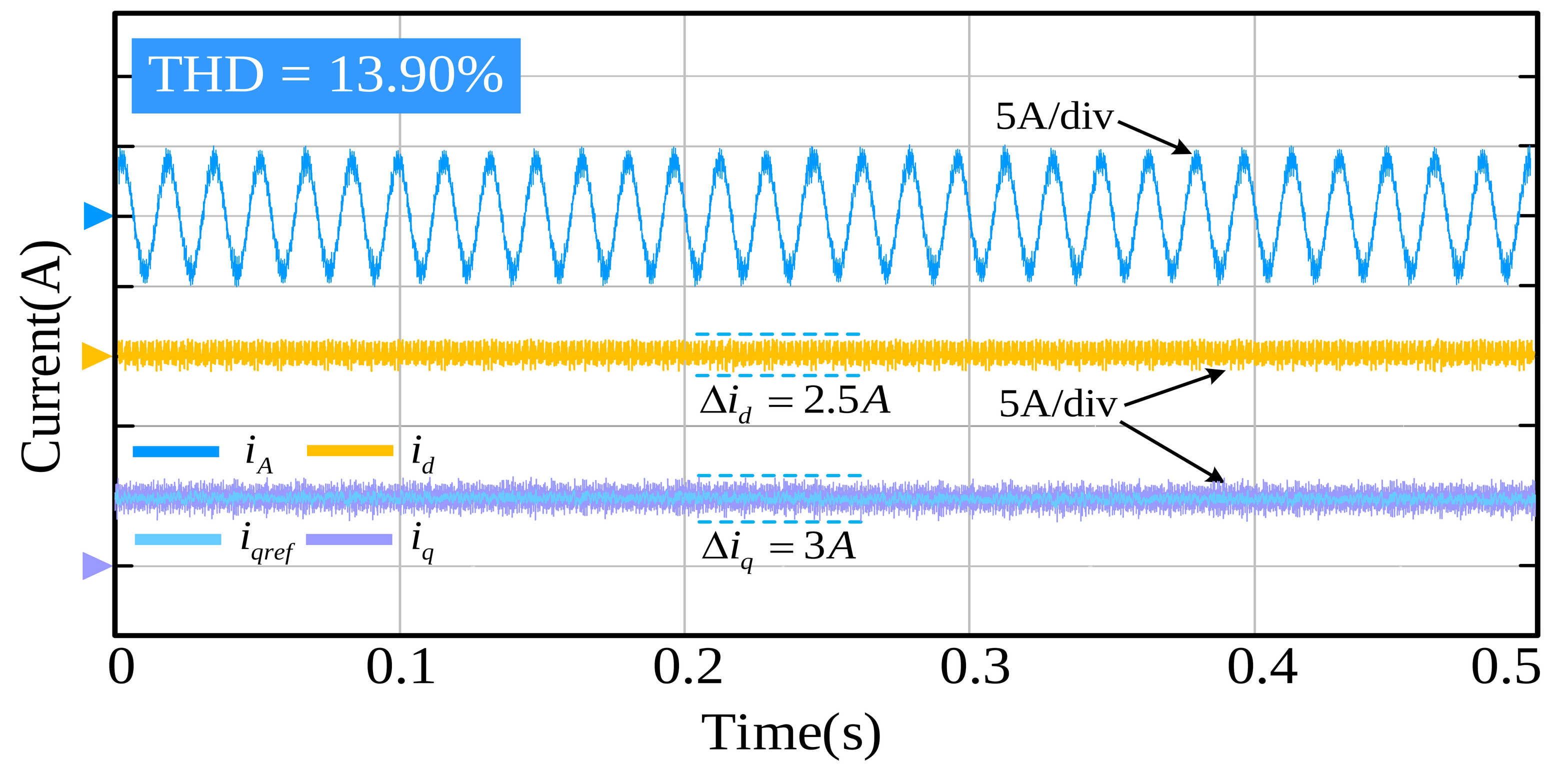
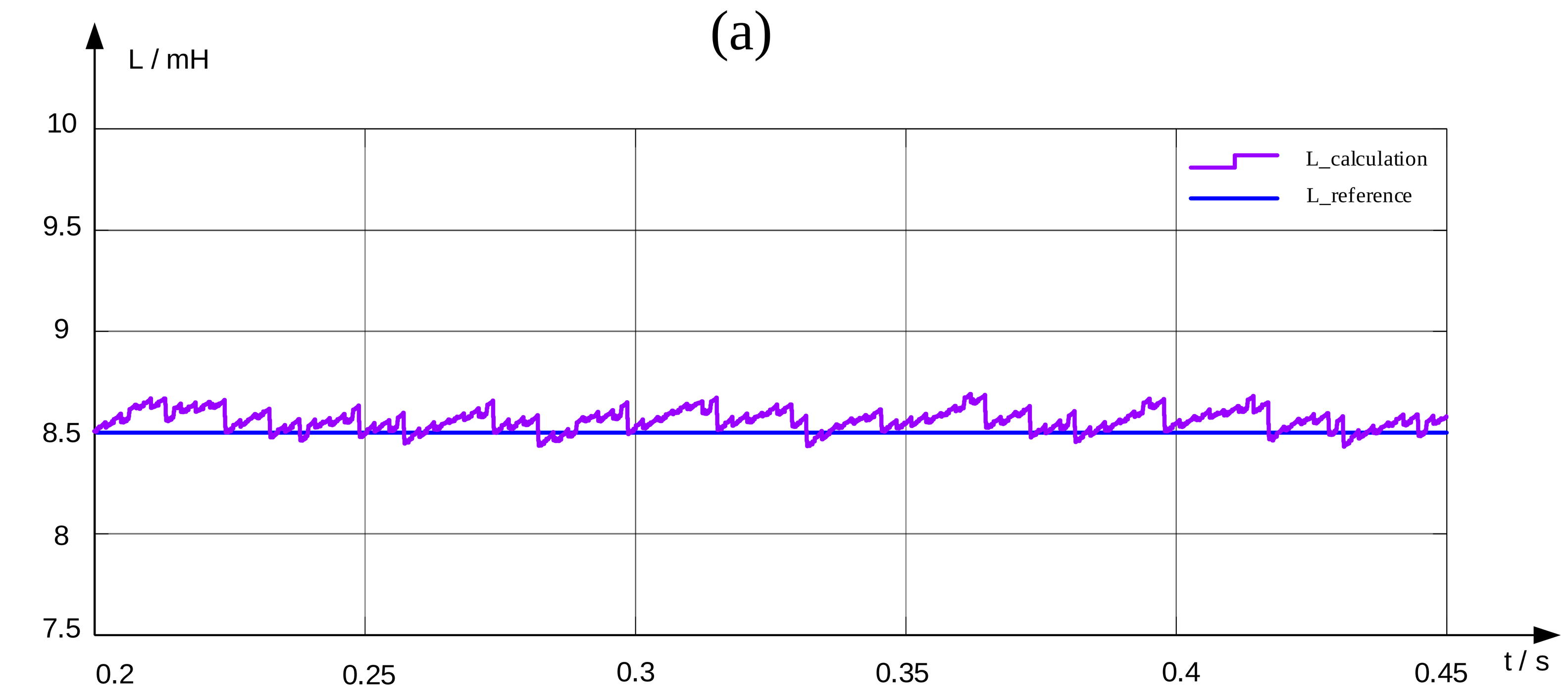


(c)

Fig. 3. Simulation results at rated load 5N and speed of 500 r/min: (a) Simulation results of LPM-MPCC method; (b) Inductance extraction results; (c) Magnetic flux extraction results.



(a)



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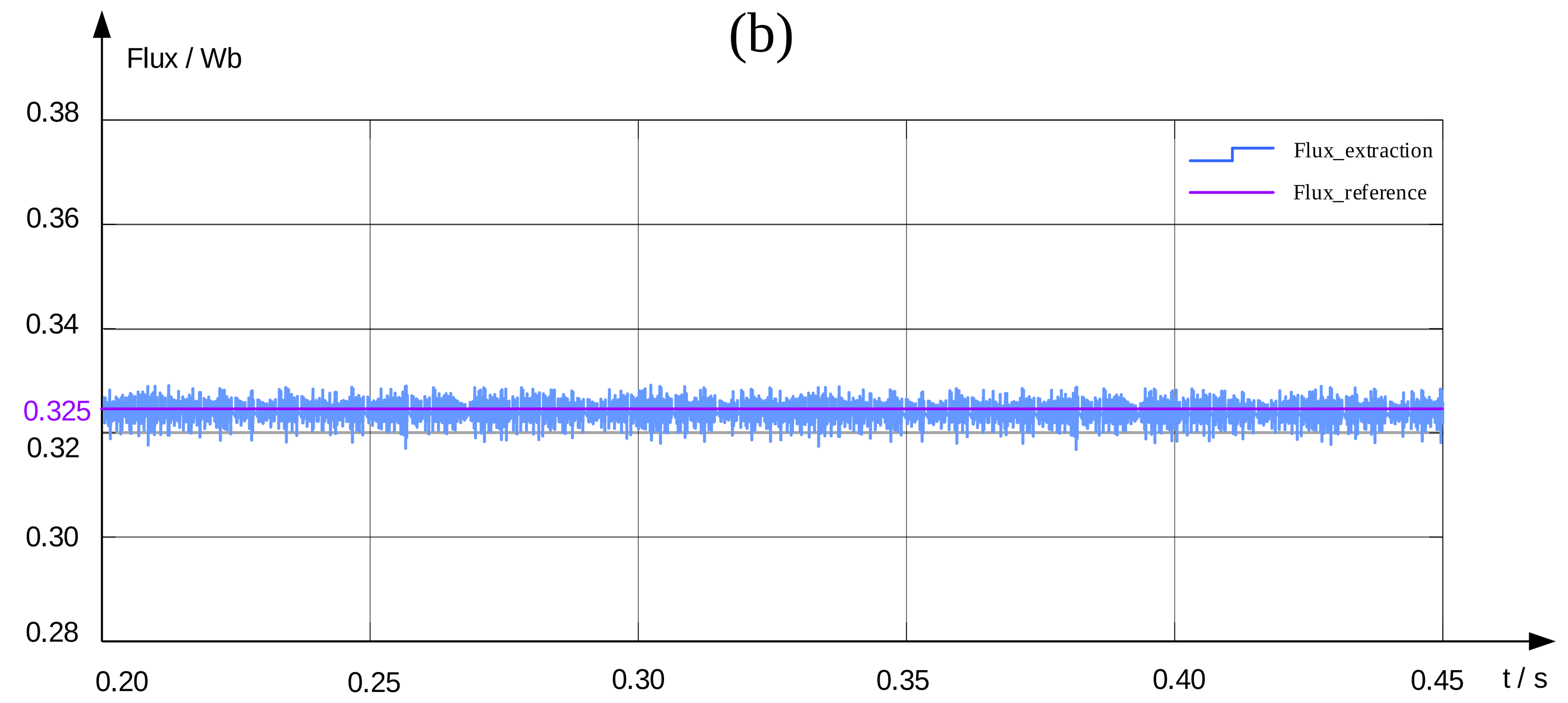

(c)

Fig. 4. Simulation results at rated load 5N and speed of 1500 r/min: (a) Simulation results of LPM-MPCC method; (b) Inductance extraction results; (c) Magnetic flux extraction results.

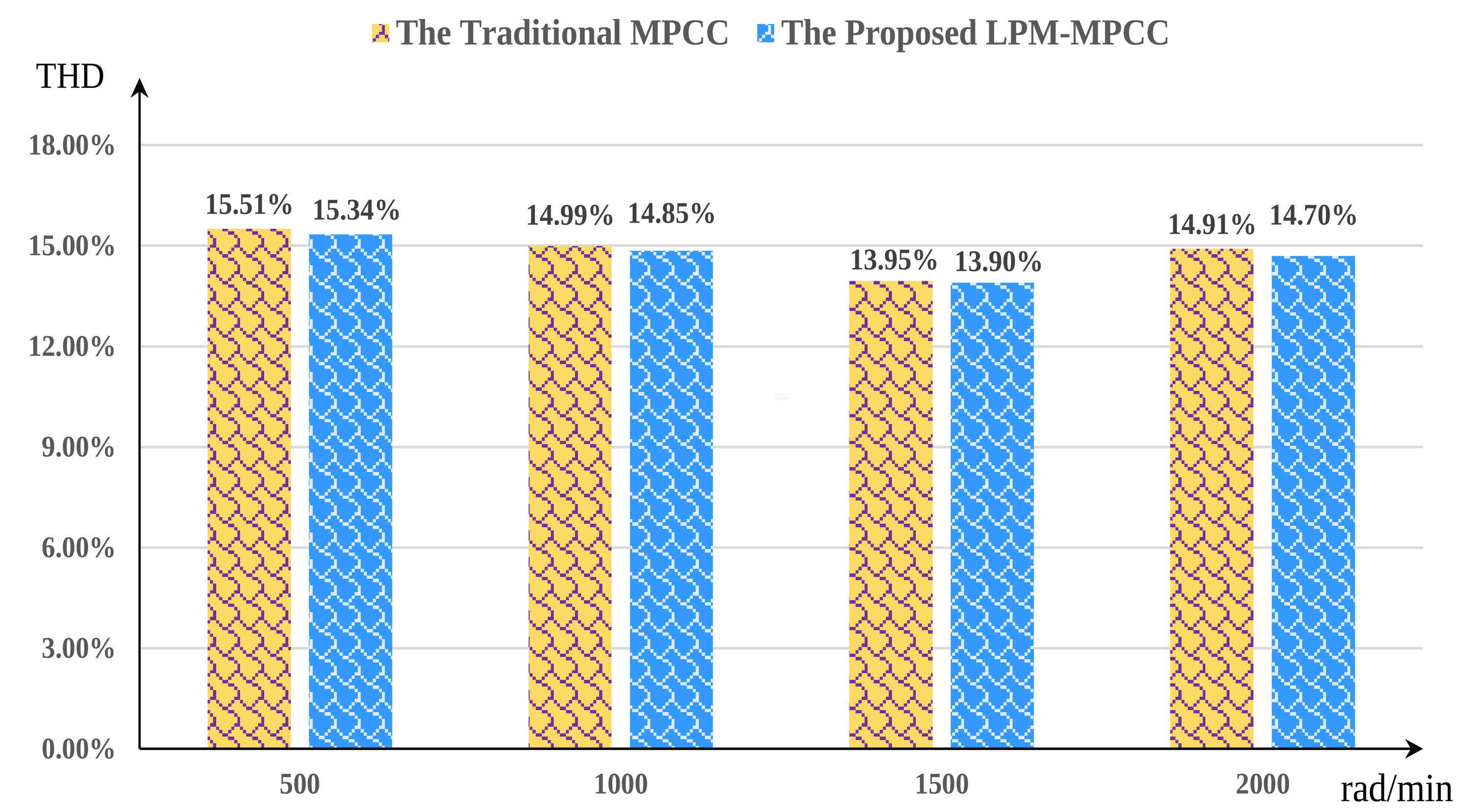

Fig. 5. Histogram of total harmonic distortion of phase current for conventional MPCC method and proposed LPM-MPCC method.

III. CONCLUSION

Aiming at the negative effects of motor parameter perturbation errors, this paper proposes and verifies the effectiveness of the LPM-MPCC method. The motor parameters are extracted from the current errors of *q*-axis under ideal and actual operating conditions, and then the extracted motor parameters are brought into a simplified current prediction model for real-time updating prediction, which makes the current prediction model more accurate and enhances the parameter robustness of the drive control system.