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A Robust Dual-Vector Model Predictive Current Control for PMSM Drives

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ABSTRACT

Given the high dependence of traditional model predictive current control (MPCC) methods on the accuracy of motor parameters, this paper proposes a robust dual-vector MPCC (DV-MPCC) method. In this control strategy, separate value functions are designed for the d-axis and q-axis based on sampled information. Subsequently, through the computation of these value functions and rolling optimization, the actual parameters of the motor are estimated. Simultaneously, this estimation information is used to dynamically adjust the predictive model in real-time, thereby achieving strong parameter robustness in control performance. Finally, simulation experiments are conducted to validate the effectiveness of the proposed method in reducing sensitivity to DV-MPCC parameters.

The Theory of Proposed Robust DV-MPCC Method

A. Establishment of a robust prediction model

Since the paper adopts control based on , and $T \cdot R / L \cdot i_d^*$ is much less than 1, this part can be ignored. At this point, prediction model can be expressed as

$$\begin{cases} i_{dx}^{p}(k+1)=i_d(k)+\frac{T}{L}u_d(k)+T\omega_e i_q(k) \\ i_{qx}^{p}(k+1)=\left(1-\frac{TR}{L}\right)i_q(k)+\frac{T}{L}u_q(k)-T\omega_e i_d(k)-\frac{T\psi_f\omega_e}{L} \quad (x=1,2) \\ \quad =i_q(k)+\frac{T}{L}u_q(k)-T\omega_e i_d(k)-\frac{T\omega_e}{L}(\psi_f+\frac{Ri_q(k)}{\omega_e}) \end{cases} \tag{1}$$

where x=1 denotes the selected first VV and x=2 denotes the selected second VV.

From (1), it is evident that the d-axis prediction model only includes the inductance parameter, while the q-axis prediction model incorporates resistance, inductance, and magnet chain parameters. To remove motor parameter information from the prediction model, this paper employs T/L and $\psi_f + R \cdot i_q / \omega_e$ as two consolidated parameters for real-time computation, thereby obtaining accurate motor parameter information during operation. Consequently, the updated prediction model is formulated as

$$\begin{cases} i_{dx}^{p}(k+1)=i_d(k)+Xu_d(k)+T\omega_e i_q(k) \\ i_{qx}^{p}(k+1)=i_q(k)+Xu_q(k)-T\omega_e i_d(k)-\omega_e XY \end{cases} \tag{2}$$

where $X=T/L$, $Y=\psi_f + Ri_q/\omega_e$

B. Motor Parameter Estimation

Given that the aggregate parameter X, containing inductance information, appears exclusively in the d-axis prediction model, this paper employs X as a performance index for designing the d-axis value function to accurately determine T/L during motor operation. Similarly, the aggregate parameter Y, which encompasses magnetic chain and resistance information, appears only in the q-axis prediction model. This paper also utilizes Y as a performance index to construct the q-axis value function. The specific steps are outlined as follows.

First, the value functions for the d-axis and q-axis are formulated as follows

$$CF_1=\underbrace{\left[i_{ds}^{p}(k+1)-i_d(k+1)\right]^2}_{term1}+H_d\underbrace{\left[X(k+1)-X(k)\right]^2}_{term2} \tag{3}$$

$$CF_2=\underbrace{\left[i_{qs}^{p}(k+1)-i_q(k+1)\right]^2}_{term1}+H_q\underbrace{\left[Y(k+1)-Y(k)\right]^2}_{term2} \tag{4}$$

where H_{dq} denotes the weighting coefficient between the dq-axis current and the aggregate parameters X, Y.

From the two value functions, it can be observed that as $term1$ approaches 0, it indicates minimal current error. As $term2$ approaches 0, it signifies that the calculated information of the aggregate parameter sets at the two moments is very close. If both of these conditions are satisfied simultaneously, the most suitable X and Y can be obtained. Therefore, it is necessary to compute the partial derivatives of $X(k+1)$ and $Y(k+1)$ in (1) and (2) to find the minimum values of CF_1 and CF_2 that satisfy these conditions, which can be formulated as

$$\frac{\partial CF_1}{\partial X(k+1)}=2\left[i_d^{p}(k+1)-i_d(k+1)\right]u_d(k) +2H_d\left[X(k+1)-X(k)\right] \tag{5}$$

$$\frac{\partial CF_2}{\partial Y(k+1)}=2\left[i_q^{p}(k+1)-i_q(k+1)\right]\left[-X(k)\omega_e\right] +2H_q\left[Y(k+1)-Y(k)\right]. \tag{6}$$

Let (3) and (4) be equal to 0. In this case, the optimal values of $X(k+1)$ and $Y(k+1)$ are obtained and expressed as

$$X(k+1)=X(k)-\frac{u_d(k)\left[i_{ds}^{p}(k+1)-i_d(k+1)\right]}{H_d} \tag{7}$$

$$Y(k+1)=Y(k)+\frac{\left[i_{qs}^{p}(k+1)-i_q(k+1)\right]\left[X(k)\omega_e\right]}{H_q} \tag{8}$$

Since the predicted and sampled currents at $(k+1)^{th}$ instant are unknown, it is necessary to shift the moments in (5), (6) forward by onecontrol period, i.e.

$$X(k)=X(k-1)-\frac{u_d(k-1)\left[i_{ds}^{p}(k)-i_d(k)\right]}{H_d} \tag{9}$$

$$Y(k)=Y(k-1)+\frac{\left[i_{qs}^{p}(k)-i_q(k)\right]\left[X(k-1)\omega_e\right]}{H_q} \tag{10}$$

Similarly, the slopes K_{q1} and K_{q2} in the time calculation can also be expressed using the estimated information as

$$\begin{cases} K_{q1}=\mathrm{d}i_{q1}/\mathrm{d}t=K_{q0}+Xu_{q1}/T \\ K_{q0}=\mathrm{d}i_{q0}/\mathrm{d}t=-Ri_q/L-\omega_e i_d-\psi_f \\ \quad =-\omega i_d-\omega_e XY/T \end{cases} \tag{11}$$

The control framework of proposed robust DV-MPCC with one-step delay compensation is shown in Fig. 1.

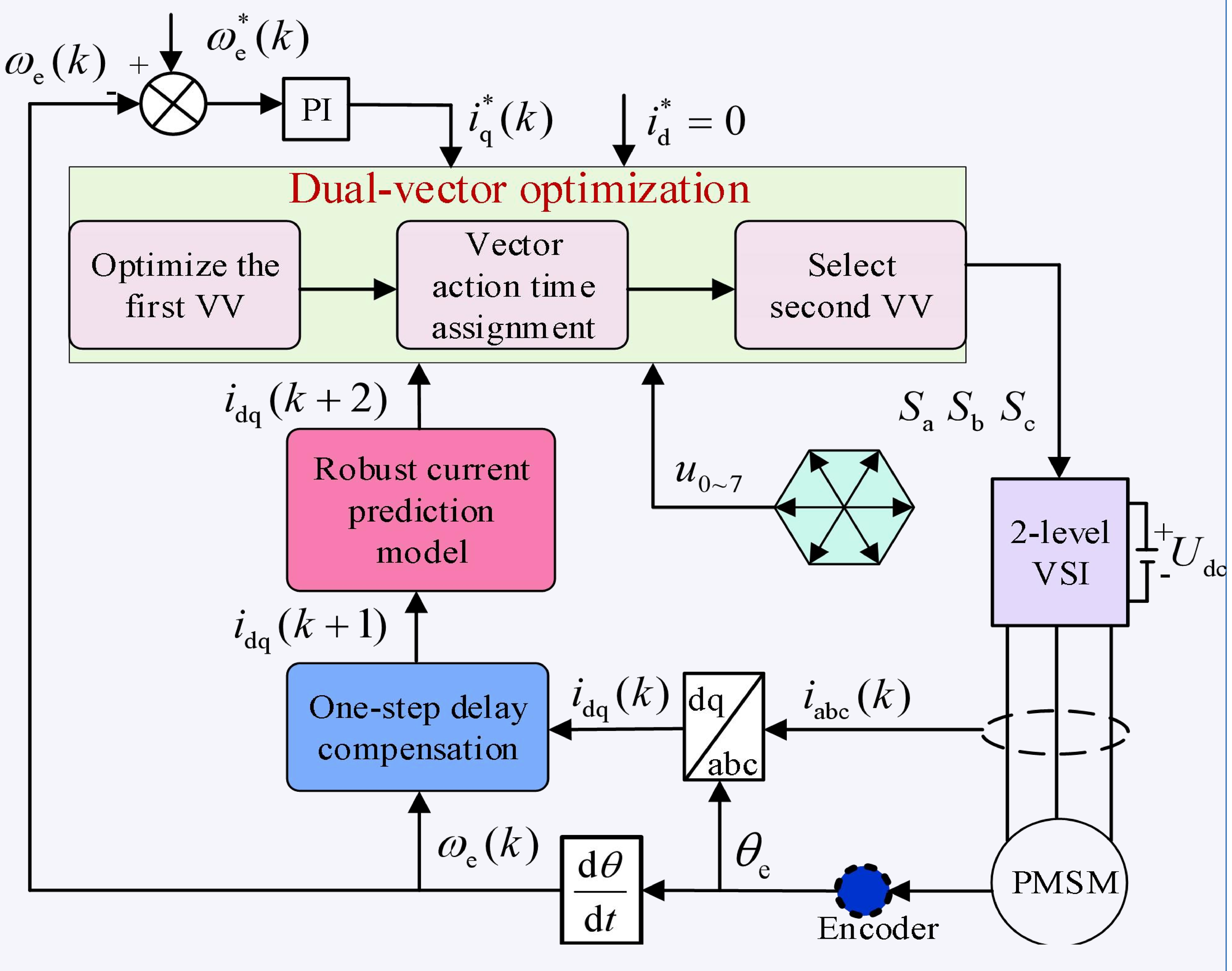

Fig. 1. Control schematic diagram of the proposed robust method.

Experimental Results

In order to verify the effectiveness of the methods proposed in this paper in terms of robust performance , relevant simulation experiments are designed in this section.

As demonstrated in Figs. 2-3, this section assesses and validates the steady-state performance of the proposed methods. Initially, Fig. 2 presents the steady-state results of the T-DV-MPCC and the proposed robust method at a torque of 4 N-m and a speed of 500 r/min. Under these conditions, the total harmonic distortion (THD) of the T-DV-MPCC current is 3.87%, with dq-axis current ripples of 0.70 A and 0.35 A. In comparison, the proposed robust method achieves a phase current THD of 3.80% and dq-axis current ripples of 0.70 A and 0.34 A.

Subsequently, the performance of the proposed robust method is evaluated with a constant load torque while increasing the speed to 2000 r/min. It is observed that the robust method performs comparably to the T-DV-MPCC, maintaining a similar level of control. This indicates that the proposed method exhibits robust performance and can effectively mitigate the parameter sensitivity issue associated with the T-DV-MPCC method.

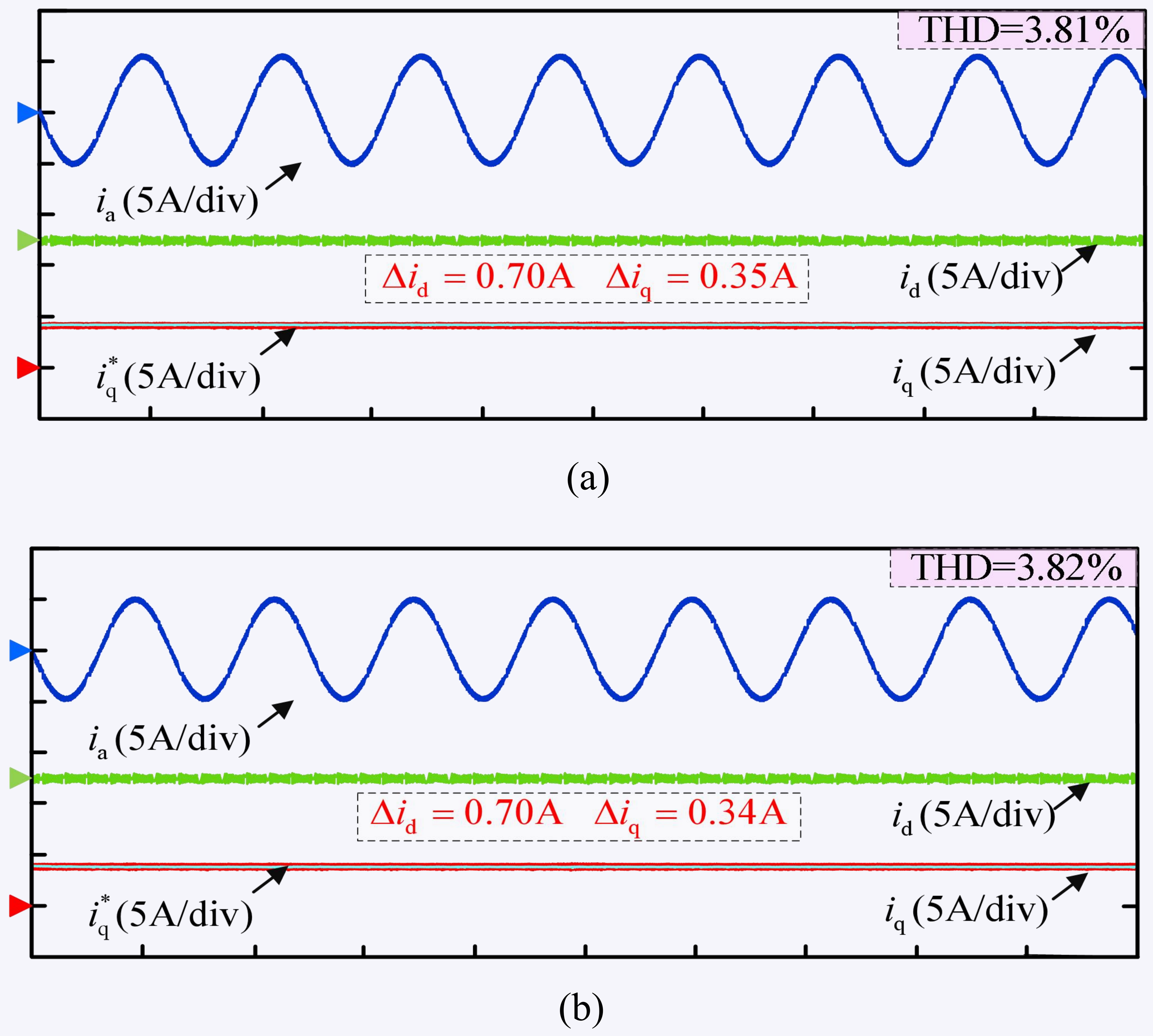

Fig. 2. Simulation results at rated load and speed of 500 r/min, (a) T-DV-MPCC method, (b) Proposed robust method.

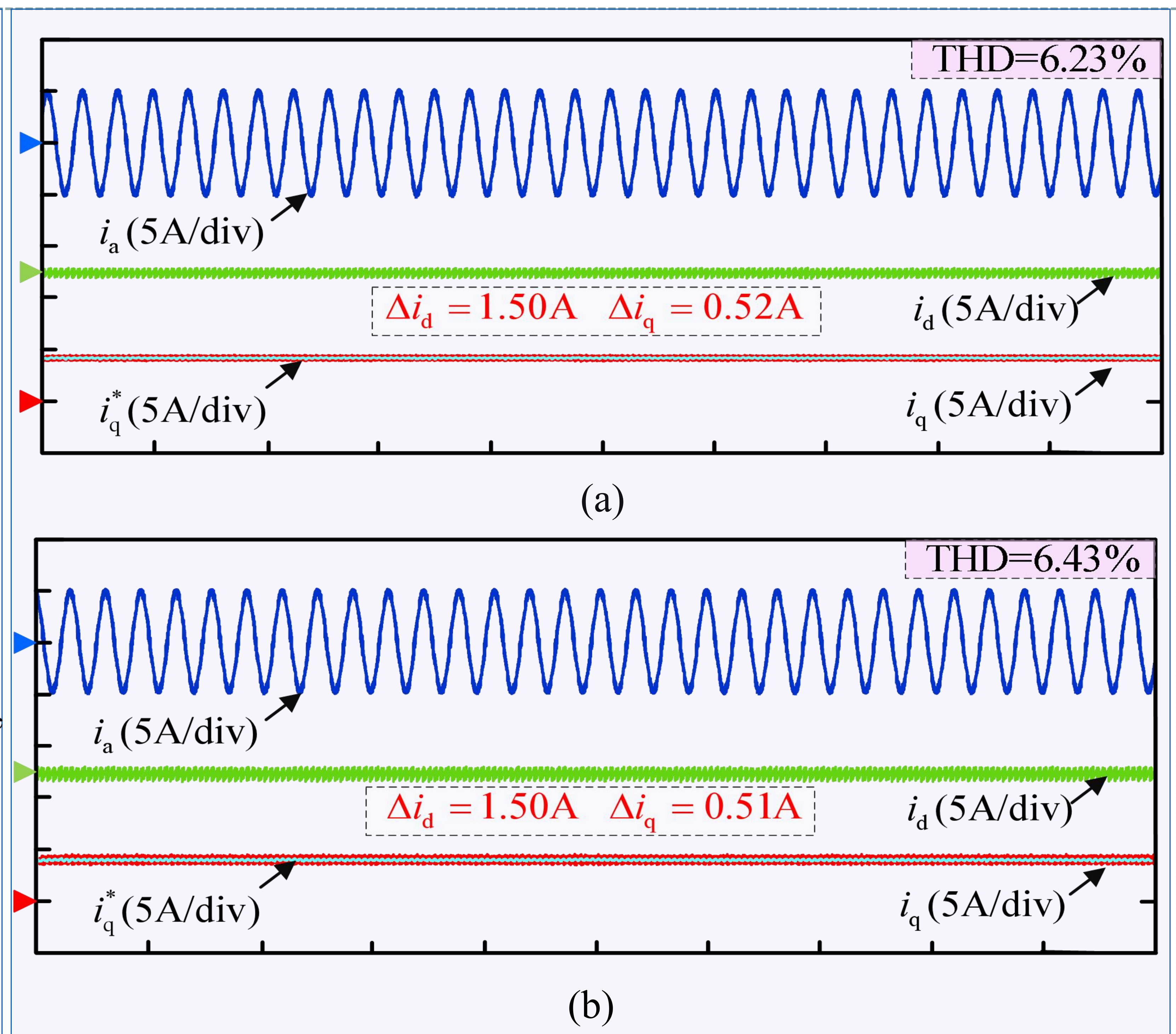

Fig. 3. Simulation results at rated load and speed of 2000 r/min, (a) T-DV-MPCC method, (b) Proposed robust method.

The above experimental results show that the proposed robust method can maintain a control performance comparable to that of the T-DV-MPCC at both low and high speeds. This highlights the ability of the proposed method to effectively reduce the parameter sensitivity of the T-DV-MPCC method.

Meanwhile, in order to further demonstrate the robustness of the proposed robust method in the full speed range, Fig. 4 shows the current THD of the above two methods in the full speed range, and it can be seen that the phase current THD of the two methods remain similar under the same operating conditions, which again strongly proves the strong robustness of the proposed method.

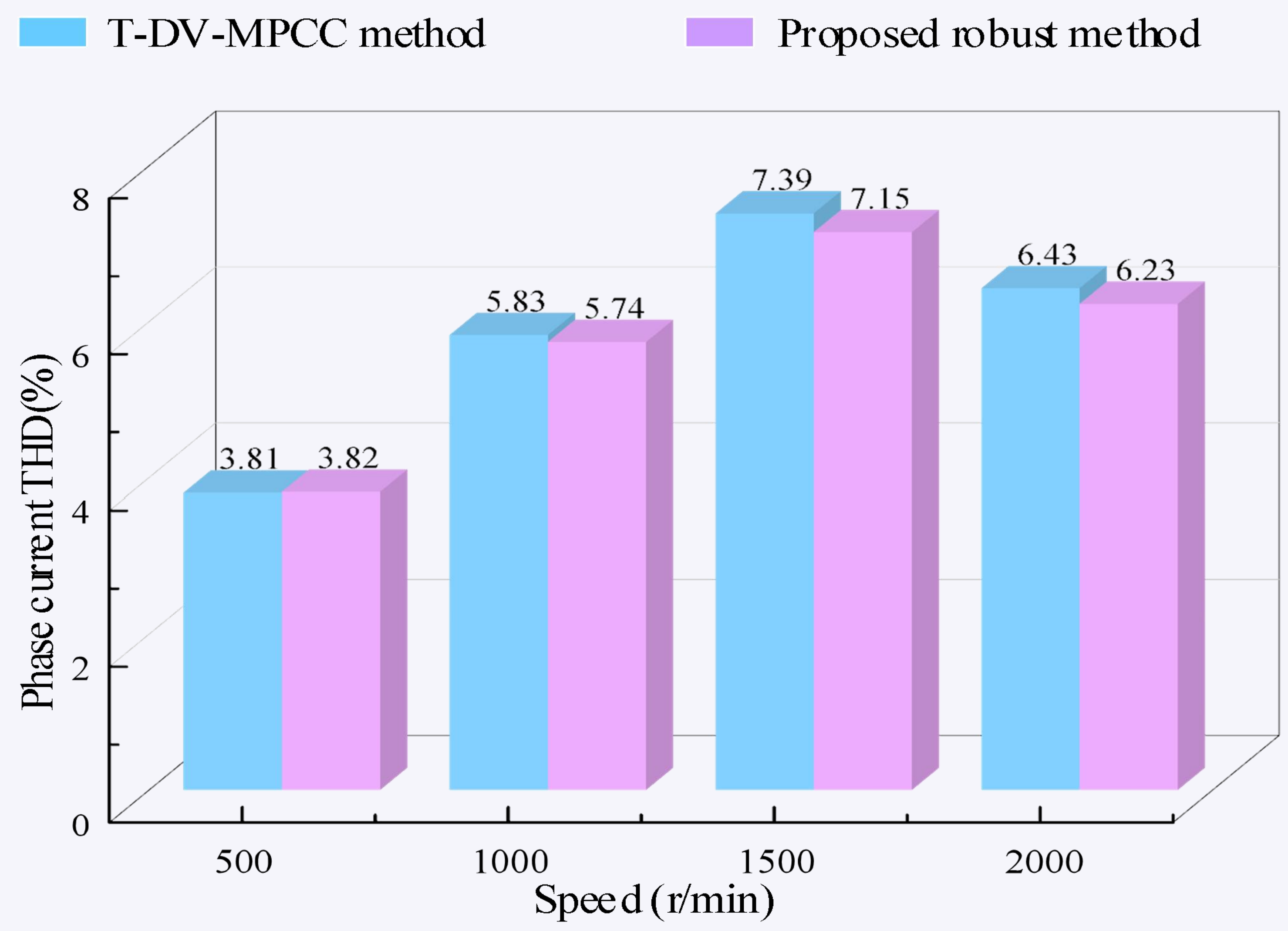

Fig. 4. Comparison of current THD in full speed range between the two methods.

CONCLUSION

In order to reduce the dependence of the DV-MPCC method on the motor parameters in the mathematical model, a simple two-vector robust model prediction method is proposed in this paper. The method calculates the set total parameters containing the motor parameter information in real time by constructing the d-axis and q-axis value functions. Then the calculated set total parameter information is used to update and correct the prediction model in real time, and the prediction model can be made infinitely close to the real mathematical model of the motor when it is running, so as to control the motor to run stably and well. Finally, the simulation results verify that the proposed method has good parameter robustness.