Research on Automatic Control Method of Motor Current in Distribution Network Based on Bionic Algorithm

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Abstract. Due to the problems of multi-parameter identification and processing in traditional approach of current-predicting, it is difficult to control PMSM in practical complex environments. In this paper, a predictive current control method based on improved extended observer is proposed, whose mathematical model based on extended state observer is also established. Because of the problem of multi-parameter setting in ESO, the flower pollination algorithm is used to adjust the parameters with the fitness function of minimum absolute error of ESO input and output. To verify the stability of PMSM system based on predicted current control with improved ESO, MATLAB/SIMULINK is used to build the simulation model. And the results show that the control strategy can predict the accurate current of $dq$, and the PMSM based on this method can output the desired current, determining the stable operation of the system.

Keywords. Predictive current control, PMSM, improved extended station observer.

1. Introduction
Permanent magnet synchronous motors have been widely used in emerging fields such as industrial robots and electric vehicles with their advantages of high precision and low loss, and correspondingly, the research on its control technology has been promoted. The traditional permanent magnet synchronous motor control strategy is mostly based on the dual closed-loop control of the PI modulator. However, the PI modulator itself has problems such as integration delay, complex parameters, and tracking speed overshoot, and it is difficult to output accurate control waveforms. In order to realize the precise control of PMSM, the model control prediction method with the advantages of fast response action, flexible configuration of parameters, easy to solve optimization problems with constraints, etc. has begun to be applied in this field [1].

In terms of electrical control, model predictive control can be divided into two forms, including continuous control set (Continuous Control Set-model Predictive Control, CCS-MPC) and limited control set model prediction (Finite Control Set-model Predictive Control, FCS-MPC) control method. The former uses online scrolling or feedback self-correction to overcome the uncertainty of the system according to the type of the predicted model. The latter optimizes the switching function through the value objective function [2]. At present, the commonly used control methods are mainly combined with the current predictive control of the two and their improvement strategies. In the literature [3], Gao Xudong [3] and others control the motor by improving the traditional current predictive control algorithm by Kautz, and use it on the DSP platform. Its stability and response speed have been verified. Aiming at the problem that traditional vector-based forecasting current requires multi-parameter control and is susceptible to internal disturbances in the system, Wang Longyang et al. [4] introduced an anti-interference observer into the model control to avoid interference caused by uncertainty and...
ensure to a certain extent The controllability of the system; Bai Jianyong et al. [5] designed a speed sensorless PMSM speed control system based on the MRAS observer, and verified the reliability of the system through simulation. However, this observer has a strong dependence on PMSM parameters, and it is difficult to be applied to the actual system well. Based on the possible uncertainty of the model and the voltage fluctuations caused by the dead zone, Yi Boyu et al. [6] designed two disturbance observers operating in parallel, and improved control by estimating multiple disturbances in the system. Considering the limitation of traditional current predictive control voltage vector control, literature [7] expands it by adding virtual state variables, which significantly improves the modulation effect of the duty cycle.

The above-mentioned control methods based on predicted current all improve the output waveform of the control motor to a certain extent, but they all need to identify and process multiple parameters in each cycle, which are difficult to apply in the actual complex environment. Therefore, this paper proposes a predictive current control method based on an improved extended observer, and verifies its feasibility on the SIMULINK platform.

2. Establishment of Model

Regardless of the permeability of the permanent magnet itself and the eddy current or hysteresis loss during the operation of the motor, the flux linkage, voltage, torque and motion equations in the rotating coordinate system dq can be represented by equations (1) to (4), respectively shown [8].

Flux linkage equation:

\[
\begin{align*}
\psi_d &= L_d i_d + \psi_f \\
\psi_q &= L_q i_q
\end{align*}
\]

Voltage equation:

\[
\begin{align*}
u_d &= R_s i_d + L_d \frac{d i_d}{dt} - L_s \omega_e i_q \\
u_q &= R_s i_q + L_q \frac{d i_q}{dt} + L_s \omega_e i_d + \omega_e \psi_f
\end{align*}
\]

Torque equation:

\[
T_e = p \left[ \psi_f i_q + (L_d - L_q) i_d i_q \right]
\]

Torqued equation of motion:

\[
T_e - T_L = J \frac{d \omega}{dt} + f \omega
\]

where, \(u_d, u_q, i_d, i_q\) are the voltage and current components on the PMSM stator dq axis; \(R_s\) is the stator equivalent resistance; \(L_d\) and \(L_q\) are the dq equivalent inductances respectively; \(\psi_f\) is the flux linkage generated by the permanent magnets on the rotor; \(\omega_e\) is the electrical angle of the rotor.

From the above mathematical model of PMSM, it can be seen that as long as the current component on the rotating coordinate is effectively controlled, the motor system can be controlled, and when the \(i_d = 0\) control mode is adopted, the output torque is only determined by the q-axis component Decide. Therefore, use equations (1) and (2) to establish the predicted current model, and use the \(dq\) component current in the equation as the state variable, then the equation can be transformed into:

\[
\begin{bmatrix}
\frac{di_d}{dt} \\
\frac{di_q}{dt}
\end{bmatrix} = \begin{bmatrix}
\frac{-R_s}{L_s} & \omega_e \\
-\omega_e & \frac{R_s}{L_s}
\end{bmatrix} \begin{bmatrix}
i_d \\
i_q
\end{bmatrix} + \begin{bmatrix}
\frac{1}{L_s} & 0 \\
0 & \frac{1}{L_s}
\end{bmatrix} \begin{bmatrix}
u_d \\
u_q
\end{bmatrix} + \begin{bmatrix}
0 \\
-\frac{\psi_f \omega_e}{L_s}
\end{bmatrix}
\]
Therefore, by using the forward Euler equation to discretize the converted voltage equation, the relationship between the current value and the current current at that moment in the next cycle can be obtained. Let \( kT_s \) be the sampling value, where \( T_s \) is the sampling period, then \((k + 1)T_s\) is the estimated value, and the prediction equation is as shown in equation (6):

\[
\begin{bmatrix}
i_d(k+1) \\
i_q(k+1)
\end{bmatrix} = 
\begin{bmatrix}
1 - \frac{R_z}{L_s} & \frac{\omega_e}{L_s} & T_s \\
\frac{-\omega_e}{L_s} & 1 - \frac{R_z}{L_s}
\end{bmatrix}
\begin{bmatrix}
i_d(k) \\
i_q(k)
\end{bmatrix} + \frac{T_s}{L_s} \begin{bmatrix} u_d(k) \\ u_q(k)\end{bmatrix} + \left[ \begin{array}{c} 0 \\ \frac{-\psi_{f}\omega_e}{L_s}
\end{array} \right] T_s
\]

According to equation (4), it can be seen that as long as the current state of the current moment is accurately tracked, the accurate input of the control variables in the next cycle can be realized. Therefore, in order to ensure the effectiveness of the controller in the actual system, avoid factors To predict the problem of waveform jitter caused by prediction errors, this paper introduces an extended state observer (ESO), which uses ESO to observe internal and external disturbances that may cause system instability, and uses it as a compensation factor to adjust the output results.

Taking the current component of the vertical axis and the vertical axis as the state component, combined with equation (6), the PMSM related variables based on the observer can be expressed as:

\[
i = f(I) + D + b_0 U \\
Y = l
\]

where, \( f(Z_1) = \begin{bmatrix} -\frac{R_z}{L_s} & \frac{\omega_e}{L_s} \\ \frac{-\omega_e}{L_s} & \frac{-\psi_{f}\omega_e}{L_s} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \left[ \begin{array}{c} 0 \\ \frac{-\psi_{f}\omega_e}{L_s} \end{array} \right] \) is an internal disturbance of the system, \( b_0 = \begin{bmatrix} 0 \\ \frac{1}{L_s} \end{bmatrix} \), \( U = \begin{bmatrix} u_d \\ u_q \end{bmatrix} \) is the input of the observer, \( D \) is regarded as an external disturbance, and \( Y \) is the output variable of the observer.

According to ESO related theory [9], the original first-order system can be expanded by using disturbance components and observations, and the expanded observer structure is as follows:

\[
e = Z_1 - Y \\
\dot{Z}_1 = Z_2 - \beta e + b_0 U \\
\dot{Z}_2 = -\beta_1 f_a l(e, 0.5, \theta)
\]

where, \( f_a l(e, \alpha, \delta) = \begin{cases} |e|^{\alpha} \text{sign}(e), & |e| \geq \delta \\
bierz \frac{\delta}{|e|}, & |e| < \delta \end{cases} \), and \( e \) is the error of state variable observation; \( Z_1 \) is the estimated value of current I, and \( Z_2 \) is the estimate of the disturbance internal and external of the system, which is regarded as \( Z_2 = f(I) + D \).

Therefore, by collecting the AC-DC axis voltage of the previous cycle, the state current can be estimated by equation (6), and the estimated value can be corrected through the above-mentioned observer model. After the current based on the expanded state observer, the predictive discrete model can be expressed as:

\[
e = Z_1(k-1) - Y(k-1)
\]

\[
Z_1(k) = T_s[Z_2(K-1) - \beta e + b_0 U(K-1)] + Z_1(k-1)
\]

\[
Z_2(k) = Z_2(k-1) - T_s\beta_1 f_a l(e, 0.5, \theta)
\]

Considering that the selection of \( \beta \) and \( \beta_2 \) parameters of ESO itself will have an impact on the effect of error correction, \( \delta \) as a filter factor affects the filtering effect of the system. At the same time, this part is also related to the speed of system adjustment. If the adjustment speed is very large, it will cause the system to jitter or overshoot. Therefore, the setting of this parameter is more important. However, when setting the parameters in the traditional way, trial and error method is often used for the setting. This method takes a large proportion of artificial participation, and the result of the setting
is accidental. In order to ensure that the ESO parameters can be adjusted adaptively, this paper introduces the flower pollination algorithm [10] into the parameter tuning link to determine the three parameters $\beta$, $\beta_2$ and $\delta$. The specific method is as follows: first, define a pollen search space as $(\beta, \beta_2, \delta)$, and each parameter is searched in one dimension, and its range is set to $[0, \beta_{\text{min}}], [0, \beta_{2\text{min}}], [0, \delta_{\text{min}}]$. For the convenience of calculation, the conversion probability is 0.8, the number of iterations is 50, and the evaluation function of the global search is set to the minimum absolute error of the current value observed by the observer and the standard value at each moment, as shown in equation (10):

$$J_{\text{min}} = \sum_{i=0}^{m} T_s(i)|e(i)|\Delta T_s$$

where $i$ represents the $i$th sampling point. As a result, the observer parameters are adjusted to correct the predicted current value to obtain the optimal voltage vector, which is used as the input of the inverter to achieve effective control of the PMSM.

3. Analysis of Simulation Results

In order to verify the control effect of the PMSM system based on the improved ESO, this paper builds the control block diagram based on equations (1)-(6) in SIMULINK. The parameters of the controlled motor are set as follows: stator internal resistance is 0.835Ω, direct axis inductance is 0.835 mH, the quadrature axis inductance is 0.835 mH, the main flux linkage of the motor is 0.27 Wb, the moment of inertia is 0.0004725 kg·m², the number of pole pairs is 4, and the damping coefficient is 0.0081. Set the system cycle to 10^{-3} s, the input speed to 260 r/s, and the load torque to 3 N·m. The simulation results are shown in figure 1 and figure 2 respectively. Among them, figure 1 is the current prediction value under the $dq$ coordinate system, and figure 2 is the three-phase current output by the PMSM based on the improved current prediction control strategy.

![Stator current iq (A)](image)

(a) $i_q$ prediction results

![Stator current id (A)](image)

(b) $i_d$ prediction results

**Figure 1.** $dq$ current component prediction results.

It can be seen from figure 1 that when $i_d^* = 0$ A and $i_q^* = 3$ A, although the system still has the influence of certain higher harmonics, the relative error between the current prediction value and the
reference value is basically not large, and the results output by the prediction model fluctuate up and down the reference value, which meets the requirements of improving the predictive current control strategy. The minimum requirement of the value function can realize the optimal voltage vector of the inverter input and ensure the sinusoidal distribution of the three-phase current driving the PMSM.

![Figure 2. Three phase current output of PMSM based on improved predictive current control.](image)

According to the three-phase current output by the PMSM shown in figure 2, it can be seen that the PMSM controlled by the improved strategy essentially only observes and compensates for the system state. Although the suppression of higher harmonics is not obvious, it is not affect the stable operation of the system, as shown in the figure: from 0.02s, the system begins to stabilize, and each phase presents a sinusoidal distribution law.

4. Conclusion
This article first analyzes the mathematical model of the permanent magnet synchronous motor based on the traditional method, and builds the block diagram of the predictive current control based on the extended state observer on this basis. Taking into account the multi-parameter setting problem of ESO itself, this paper proposes to use the flower pollination algorithm to adjust the parameters with the minimum absolute error of ESO input and output as the fitness function, and use MATLAB/SIMULINK to control the stability of PMSM system based on improved ESO. After verification, it can be found that although the system is still affected by higher harmonics, the system can output the desired current waveform, can effectively control PMSM in the actual environment, and has a certain practicability.

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