Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Research on improved voltage-type rotor flux linkage observer method for engineering application

To cite this article: Gang He *et al* 2020 *J. Phys.: Conf. Ser.* **1639** 012046

Research on improved voltage-type rotor flux linkage observer method for engineering application

Gang He[1], Xingyan Dong[1], Hui Wang[1,a], Zhigang Zhao[1] and Zhiwei Luo[1]

[1] Beijing Institute of Aerospace Launch Technology, Beijing, 100076, China

[a]16121528@bjtu.edu.cn

E-mail: 18810398981@163.com

Abstract. Accurate rotor flux linkage observation is conducive to high-performance control of the motor. Among them, the voltage-type rotor flux linkage observer is widely used in engineering practice because of its simple structure and no need for speed information. However, the traditional voltage-type rotor flux linkage observer has an inherent pure integrator, which will affect the accuracy of flux linkage observation. This paper analyses the common low-pass filter instead of pure integrator, and the improved method of high-low-pass filter series compensation. Then, focus on derivation to get an improved voltage-type rotor flux linkage observer based on DC offset compensation. Finally, based on the theoretical analysis, the magnetic flux observation effects of the four observers are simulated and verified. The result proves that the method proposed in this paper can realize the accurate observation of the rotor flux linkage.

1. Introduction

With the rapid development of the automotive industry, rail transportation and other fields, the application of transmission technology has become more and more extensive. Modern transmission technology generally adopts vector control or direct torque control based on rotor magnetic field orientation, and accurate observation of flux linkage is the key to achieving control. Commonly used methods for flux observation include current model, voltage model and hybrid observation model [1]. However, the current model and the hybrid model have a strong dependence on the rotor side parameters and speed of the motor, which is easy to cause observation errors, especially when the motor is running in medium and high speed conditions [2]. In contrast, the voltage-type rotor flux observer is not sensitive to the parameters of the rotor side of the motor and does not contain speed information, so its parameter robustness is very high. At the same time, its mechanism is simple and easy to implement, and it is widely used in engineering practice.

In practical engineering applications, due to the influence of practical problems such as electromagnetic interference, sensor measurement and AD sampling error, the pure integrator of the voltage-type rotor flux observer will produce DC offset and integral saturation problems [3]. To solve this problem, this paper analyses two common improvement methods for low-pass filter instead of pure integrator, and high-low-pass filter series compensation. Then, focus on derivation to get an improved voltage-type rotor flux linkage observer based on DC offset compensation. Finally, through simulation analysis, it is concluded that the proposed method can achieve accurate observation of the rotor flux linkage.

2. Pure integral problem of voltage model and common improved methods

2.1. Traditional voltage-type rotor flux observer

Based on the flux linkage equation and voltage equation of the induction motor, the expression of the voltage-type stator flux linkage observer can be obtained after simultaneous transformation[4]:

$$\boldsymbol{\psi}_s^v = \int (\boldsymbol{u}_s - R_s \boldsymbol{i}_s) dt = \int \boldsymbol{e}_s dt \tag{1}$$

Where, $\boldsymbol{\psi}_s^v$, $\boldsymbol{u}_s$, $\boldsymbol{i}_s$, $\boldsymbol{e}_s$, are the actual value of voltage-type stator flux linkage, stator voltage, stator current and back electromotive force in static coordinate system, respectively, and R_s are stator resistance.

Based on this, the rotor flux linkage estimation value is obtained by coupling with the rotor parameters, and the implementation block diagram is as follows:

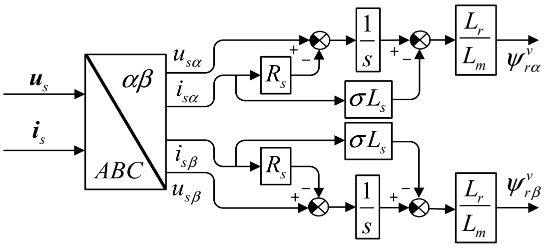

Figure1.Traditional voltage-type rotor flux observer

In the figure, $u_{s\alpha}$,$u_{s\beta}$ and $i_{s\alpha}$,$i_{s\beta}$ are the stator voltage and current components of the shaft; L_s, L_r, L_m are the stator inductance, rotor inductance and excitation inductance; $\sigma = 1 - \frac{L_m^2}{L_s L_r}$ leakage inductance coefficient; $\psi_{r\alpha}^v$, $\psi_{r\beta}^v$ are the actual value and component of the voltage-type rotor flux linkage in the static coordinate system.

Although replacing the pure integral link by the first-order low-pass filtering link can eliminate the integral saturation phenomenon to a certain extent, it will bring extra errors in the phase and amplitude. At the same time, due to the low frequency of DC bias, the use of low-pass filtering can not solve the problem of DC bias caused by sensor measurement in actual projects .

2.2. Improved voltage model based on first-order low-pass filter(FO-LPF)

A commonly used improvement method is to replace the pure integrator in the voltage model with a first-order low-pass filter. The improved rotor flux linkage implementation block diagram is:

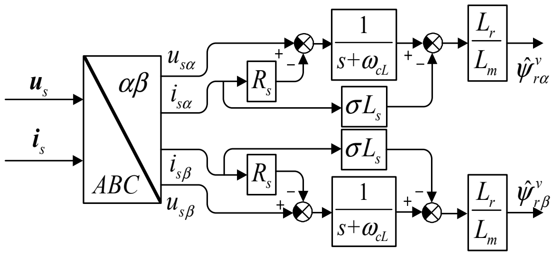

Figure2. Improved voltage model based on first-order low-pass filter

Although replacing the pure integral link by the first-order low-pass filtering link can eliminate the integral saturation phenomenon to a certain extent, it will bring extra errors in the phase and amplitude. At the same time, due to the low frequency of DC bias, the use of low-pass filtering can’t solve the problem of DC bias caused by sensor measurement in actual projects [5].

2.3. Improved voltage model based on high and low pass filter series compensation(H-LPF-C)

In response to the above problems, some scholars have further proposed an improved method through high and low pass filters connected in series to improve the accuracy of flux linkage observation. The expression is [6]:

$$\boldsymbol{\psi}_s^v = \frac{s}{s+\omega_{cH}} \frac{1}{s+\omega_{cL}} (\boldsymbol{u}_s - R_s \boldsymbol{i}_s) \tag{2}$$

The overall phase and amplitude compensation values are:

$$\varphi = \arctan(\frac{\omega_e}{\omega_{cL}}) - \arctan(\frac{\omega_{cH}}{\omega_e}) - \frac{\pi}{2} \tag{3}$$

$$M = \frac{\sqrt{(\omega_e^2 + \omega_{cH}^2)}\sqrt{(\omega_e^2 + \omega_{cL}^2)}}{|\omega_e|^2} \tag{4}$$

The integrated model (2), (3), (4) and coupled rotor side parameters can be obtained based on the improved model of the low-pass filter compensation block diagram is as follows:

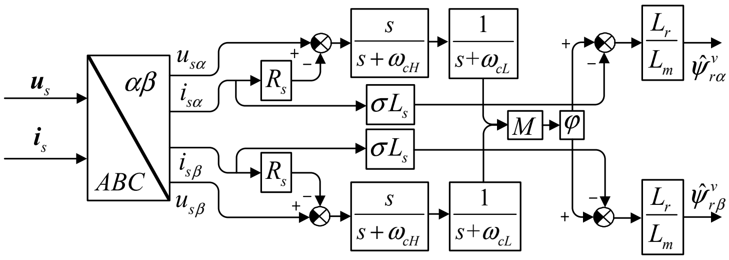

Figure3. Improved voltage model based on high and low pass filter series compensation

After the series of high-pass filter links are connected, the errors generated by the single low-pass filter links can be compensated, and the influence of DC offset can be reduced. The subsequent phase and amplitude compensation can appropriately compensate the errors in phase and amplitude.

3. Improved voltage model based on DC offset compensation (DCOC)

First, the expression of the voltage-type stator flux linkage observer in equation (1) in the s-domain:

$$\boldsymbol{\psi}_s^v = \frac{1}{s}(\boldsymbol{u}_s - R_s \boldsymbol{i}_s) = \frac{1}{s}\boldsymbol{e}_s \tag{5}$$

The DC offset detection function based on the steady state integrator is defined as:

$$\frac{\boldsymbol{\psi}_s^v}{\boldsymbol{e}_s} = \frac{1}{j\omega_e} \tag{6}$$

On this basis, in order to avoid complex calculations caused by changes in the stator frequency, the above formula is transformed and the pure integrator DC deviation variable is defined as:

$$D = \omega_e \boldsymbol{\psi}_s^v - \frac{\boldsymbol{e}_s}{j} = \omega_e \frac{(\boldsymbol{u}_s - R_s \boldsymbol{i}_s)}{s} - \frac{(\boldsymbol{u}_s - R_s \boldsymbol{i}_s)}{j} \tag{7}$$

Then, the stator flux linkage expression including DC offset compensation is obtained:

$$\boldsymbol{\psi}_s^v = \frac{(\boldsymbol{u}_s - R_s \boldsymbol{i}_s) - K_d D}{s} \tag{8}$$

Where, K_d is the DC offset compensation coefficient.

Because the stator angular frequency changes between positive and negative in the actual stator flux estimation process, it is necessary to introduce the stator frequency sign $\mathrm{sgn}(\omega_e)$ and absolute value $|\omega_e|$ to correct the stator flux expression. Combining equations (7) and (8), the modified stator flux linkage is derived:

$$\boldsymbol{\psi}_s^v = \frac{1}{s}\left[\left(\boldsymbol{u}_s - R_s\boldsymbol{i}_s\right) - K_d\left(\boldsymbol{\psi}_s^v\left|\omega_e\right| - \frac{\mathrm{sgn}(\omega_e)}{j}\left(\boldsymbol{u}_s - R_s\boldsymbol{i}_s\right)\right)\right] \tag{9}$$

In order to avoid harmonic interference and high-frequency components while ensuring the response speed of the flux linkage observer, the following design is made for the DC offset compensation coefficient:

$$K_d = \begin{cases} C & ,\left|\omega_e\right| < \dfrac{\omega_c}{C} \\ \dfrac{\omega_c}{\left|\omega_e\right|} & ,\left|\omega_e\right| \geq \dfrac{\omega_c}{C} \end{cases} \tag{10}$$

Where, C is the DC offset gain coefficient, ω_c is the cut-off frequency.

Combining equations (9) and (10) with the coupled rotor-side parameters, an improved voltage-based rotor flux linkage observer implementation block diagram based on DC offset compensation can be obtained:

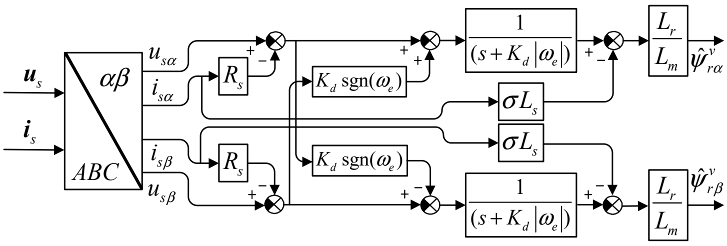

Figure4. Improved voltage model based on DC offset compensation

Considering that the actual engineering applications are all discrete digital systems, this paper uses the bilinear transformation method to discretize the above methods [7]. The relationship between the *s* and *z* domain of the bilinear transformation method (TT) [8] is:

$$s = \frac{2}{T}\frac{z-1}{z+1} \tag{11}$$

Where, *T* is the calculation step.

It is further deduced that the expression of DC voltage compensation flux rotor flux linkage after discretization based on bilinear transformation method is obtained:

$$\begin{cases} \hat{\psi}_{r\alpha}^v(k+1) = \dfrac{L_r}{L_m}\left[\hat{\psi}_{s\alpha}(k+1) - \sigma L_s i_{s\alpha}(k)\right] \\ \hat{\psi}_{r\beta}^v(k+1) = \dfrac{L_r}{L_m}\left[\hat{\psi}_{s\beta}(k+1) - \sigma L_s i_{s\beta}(k)\right] \end{cases} \tag{12}$$

Based on the discretization of bilinear transformation method DC offset compensation improved voltage-type stator flux linkage expression:

$$\begin{cases} \hat{\psi}_{s\alpha}^v(k+1) = \dfrac{\hat{\psi}_{s\alpha}^v(k)(2-K_{TT}) + T(K_{s\alpha} + K_{s\beta}K_{\mathrm{sgn}})}{2+K_{TT}} \\ \hat{\psi}_{s\beta}^v(k+1) = \dfrac{\hat{\psi}_{s\beta}^v(k)(2-K_{TT}) + T(K_{s\beta} - K_{s\alpha}K_{\mathrm{sgn}})}{2+K_{TT}} \end{cases} \tag{13}$$

Where, $K_{TT} = TK_d\left|\omega_e\right|$, $K_{s\alpha} = e_{s\alpha}(k+1) + e_{s\alpha}(k)$, $K_{s\beta} = e_{s\beta}(k+1) + e_{s\beta}(k)$, $K_{\mathrm{sgn}} = K_d\,\mathrm{sgn}(\omega_e)$.

4. Experimental testing and verification

As shown in Figure 5, add 2A DC bias before sampling the A-phase current, and use the output value of the rotor flux linkage of the induction motor module in the simulink library as the actual value to compare the effect of flux estimation. The flux estimation effect of the improved voltage-type rotor flux linkage observer based on DC offset compensation in a wide speed range is shown in Figure 6.

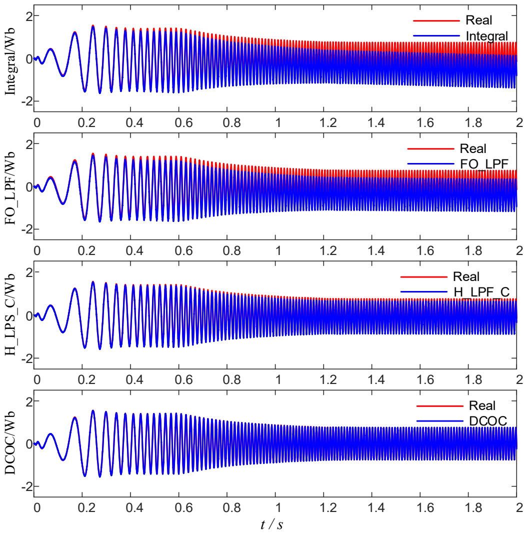

Figure5. Comparison graph of α component of estimated effect of four voltage-type rotor flux linkages.

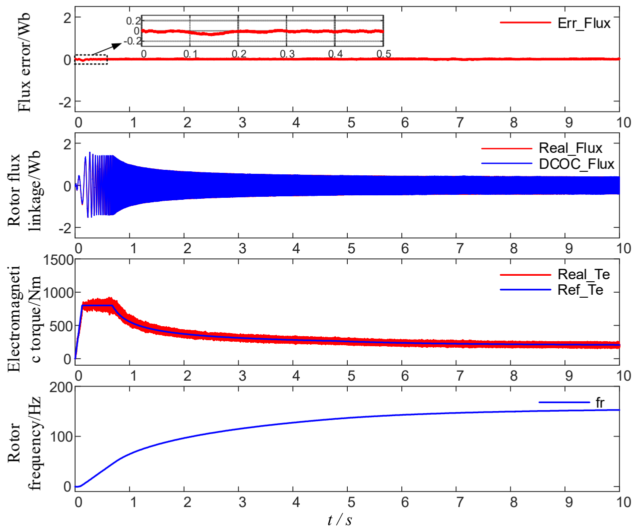

Figure6. Estimation effect of improved voltage-type rotor flux linkage observer in wide speed range based on DC offset compensation

It can be seen from Fig. 5 that DCOC can ensure the accuracy of the flux estimation value in the presence of DC bias at the input. The structure is simple and easy to implement in engineering applications. It can be seen from Fig. 6 that the maximum error of the flux estimation amplitude of the improved method proposed in this paper is about 0.05Wb, and the maximum relative error is about 0.03. In other states, the estimated error is almost zero. Therefore, the observer can always maintain a high estimation accuracy in a wide speed range.

Finally, the effect of the discretized flux linkage observation is as follows:

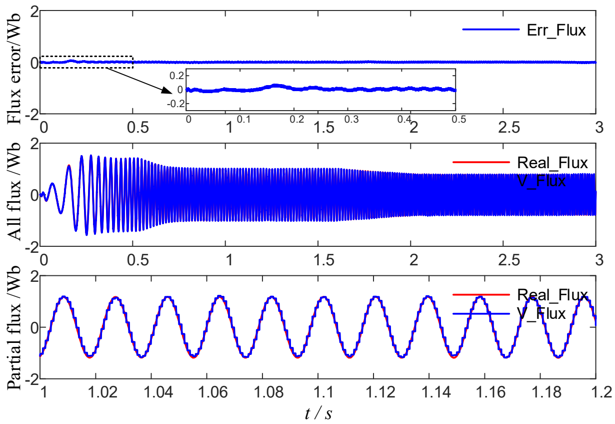

Figure7. Improved voltage model based on DC offset compensation

It can be seen from the result of the above figure that although the absolute error jitters during the low-speed acceleration, the error value does not exceed 0.06Wb. And under the following variable working conditions, the absolute error of the flux linkage is estimated to remain stable and almost zero, and the accuracy is high, which further proves the feasibility of its practical application in engineering.

Journal of Physics: Conference Series **1639** (2020) 012046 doi:10.1088/1742-6596/1639/1/012046

5. Conclusion

In this paper, two common voltage model rotor flux linkage improvement methods are introduced. Then, an improved model based on DC offset compensation was introduced in detail, and the bilinear variation method was used for discretization. Finally, by comparing and analyzing the effect of four kinds of observers on flux linkage observation, it is concluded that the improved method proposed in this paper has higher accuracy of flux linkage observation. At the same time, it can maintain a good flux linkage observation effect under the wide speed range and the realization of discretization.

References

[1] Lu Wenbing. Research on Sensorless Control of Induction Machine Based on Voltage and Current Model Flux Observer [D]. 2013.
[2] Liao Xiaozhong. Multivariable control of induction motor[M]. Science Press, 2014.
[3] Mitronikas E D, Safacas A N. An Improved Sensorless Vector-control Method for An Induction Motor Drive[J]. IEEE Transactions on Industrial Electronics, 2005, 52(6):1660-1668.
[4] Yongdong Li. Digital control system of AC motor. Beijing: Mechanical Industry Press, 2003.
[5] Wen-Xiang S , Zhi-Yong R , Yun Y . Modified rotor flux observer based on statically compensated voltage model[J]. advanced technology of electrical engineering and energy, 2012.
[6] Ma Huixian, Improved Flux Observation Method Based on Rotor-Field Oriented Vector Control of Induction Motor, Electric Machines & Control Application, 2017(8):65-68.
[7] Comanescu M. Influence of the Discretization Method on the Integration Accuracy of Observers with Continuous Feedback[C]//2011 IEEE International Symposium on Industrial Electronics. IEEE, Gdansk, 2011:625-630.
[8] Oppenheim, Alan V, Schafer, Ronald W, Buck, John R. Discrete-time signal processing (2nd ed.)[M]. Prentice-Hall, Inc. 1999.