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ROBUST SENSORLESS CONTROL OF PMSM AT LOW SPEEDS THROUGH HIGH-FREQUENCY SIGNAL INJECTION

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Abstract: Permanent Magnet Synchronous Motors (PMSM) are highly favored by major electric vehicle manufacturers due to their simple construction, compact size, lightweight, and superior efficiency. However, traditional sensor less control methods based on fundamental excitation mathematical models encounter limitations, especially at low motor speeds, where extracting reference signals becomes challenging. This obstacle can lead to difficulties in accurately determining the rotor position, resulting in detection failures.
To overcome these issues, a sensorless control strategy based on high-frequency signal injection has emerged. This innovative approach relies less on mathematical parameters and motor models, offering enhanced robustness and stability. In particular, it effectively compensates for the shortcomings of fundamental excitation mathematical models when PMSMs operate at low speeds.
Keywords: PMSM, electric vehicles, sensorless control, low-speed operation, high-frequency signal injection

Introduction

PMSM for electric vehicles is widely used by major vehicle manufacturers because of its simple construction, small size, low weight, power losses and high efficiency.[1][2][3] Because the sensorless control method based on the fundamental excitation mathematical model relies on the generated back electromotive force and other factors, it is difficult to extract the reference signal when the motor is running at low speed, which affects the rotor position extraction when the motor is running at low speed, resulting in detection failure.[4][5][6] The sensorless control method based on high frequency Signal[[7][8]injection does not depend on the mathematical parameters and model of the motor, and has good robustness and stability, which makes up for the failure of the mathematical model of fundamental excitation under low speed operation of the motor.[9][10]

1. Mathematical model of PMSM under high-frequency excitation

It is assumed that the magnetic field is sinusoidally distributed in spatial, regardless of hysteresis and rotor eddy current losses. The mathematical model of PMSM is established:

$$\begin{bmatrix} \frac{di\hat{}^{r}_{din}}{dt} \\ \frac{di\hat{}^{r}_{qin}}{dt} \end{bmatrix} = \begin{bmatrix} \cos\theta_c & -\sin\theta_c \\ \sin\theta_c & \cos\theta_c \end{bmatrix} \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{l_d} \end{bmatrix} \begin{bmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{bmatrix} \begin{bmatrix} \hat{u}^r_{din} \\ \hat{u}^r_{qin} \end{bmatrix} \quad (1)$$

The high-frequency voltage signal can be obtained as follows:

$$\begin{bmatrix} \hat{u}^r_{din} \\ \hat{u}^r_{qin} \end{bmatrix} = \begin{bmatrix} 0 \\ u_{in}\cos\omega_{in}t \end{bmatrix} \quad (2)$$

The high-frequency current signal follows:

$$\begin{bmatrix} \hat{\imath}_{din} \\ \hat{\imath}_{qin} \end{bmatrix} = \begin{bmatrix} -L_2\sin\hat{\theta}_c \\ L_1 - L_2\cos2\hat{\theta}_c \end{bmatrix} \frac{u_{in}\sin\omega_h t}{\omega_h(L_1^2-L_2^2)} \quad (3)$$

2. Design of rotor position observer

2.1. Rotor position estimation method based on following observation

This article designed the rotor position tracking observer is designed. As shown in figure 1. After modulating the current amplitude, the input signal expression of the rotor position is obtained after the low-pass filter (LPF):

$$f(\tilde{\theta}_c) = LPF(\hat{\imath}^r_{qin}\sin\omega_{in}t) = \frac{u_{in}\Delta L}{2\omega_{in}(L^2-\Delta L^2)}\sin2\tilde{\theta}_c \quad (4)$$

Linear error signal:

$$f(\tilde{\theta}_c) = \frac{u_{in}(L_d - L_q)}{4\omega_{in} L_d L_q} \sin 2\tilde{\theta}_c \quad (5)$$

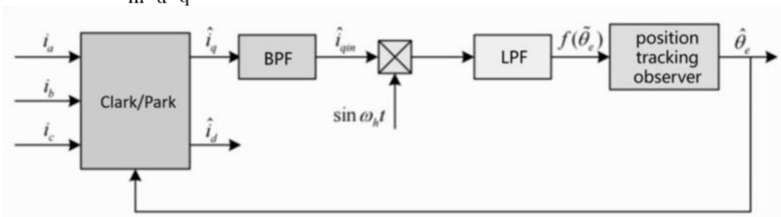

Figure 1: Block diagram of rotor position tracking observer

2.2. Design of improved rotor position observer based on second-order generalized integral phase locked loop

The second-order generalized integrator (SOGI) is optimized according to the generalized integrator, which is generally widely used in the field of power and electrical control and has a strong suppression effect on harmonics and noise. As shown in figure 2.

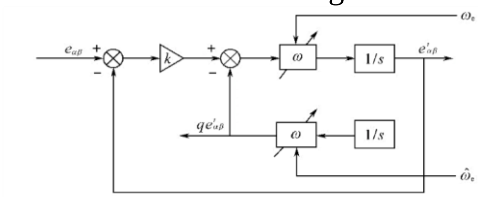

Figure 2: Principle Diagram of Second Order Generalized Integrator

The article, according to the theory of second-order generalized integrator optimized its characteristics in Matlab/Simulink make simulation. The input signal is Sine Wave curve and high-frequency Random signal Random Number, which are superimposed to obtain the waveform image as shown in the following figure 3 after filtering high-frequency vibration signal by second-order generalized integrator.

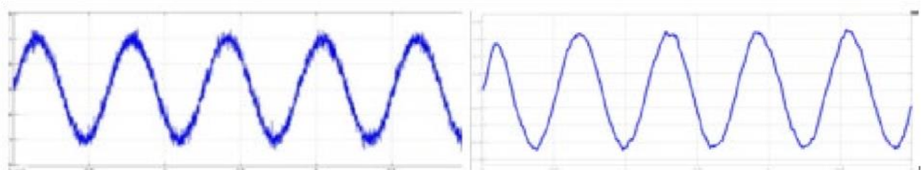

Figure 3: Filtered high frequency random signal waveform

The SOGI still has defects in the simulation, so this paper proposes a SOGI PLL to optimize the rotor position observer. The basic principle model is shown in the following figure 4:

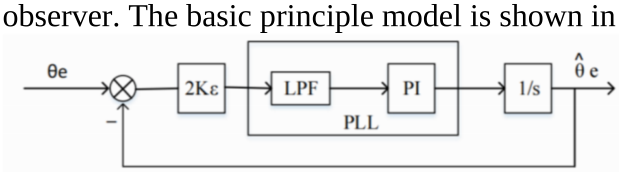

Figure 4: Second-order generalized integral PLL filtering system

-41-

In this paper, the second-order generalized integrator is improved on this basis. The improved SOGI PLL Simulink simulation block diagram is shown figure 5 below:

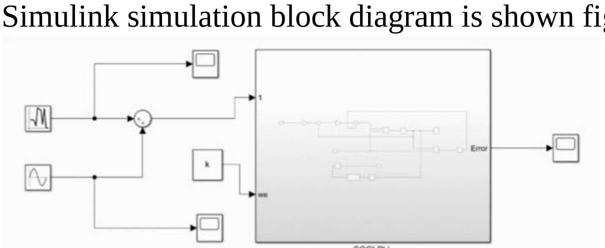

Figure 5: Second-order generalized integral PLL

The disturbance signal is injected into the SOGI PLL to gained a complete and glossy sine curve. As shown in figure 6. The optimization results is markedly, which enhance the feasibility of this method to improve the accuracy of PMSM rotor position estimation.

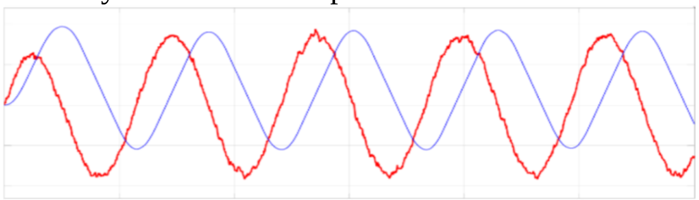

Figure 6: Improved before and after curve waveform

4. Analysis of simulation and experimental results

In order to validate the effectiveness of the proposed method for rotor position identification after filtering the disturbance when the PMSM drive system starts and runs at low speed, a simulation control system model. As shown in figure 7.

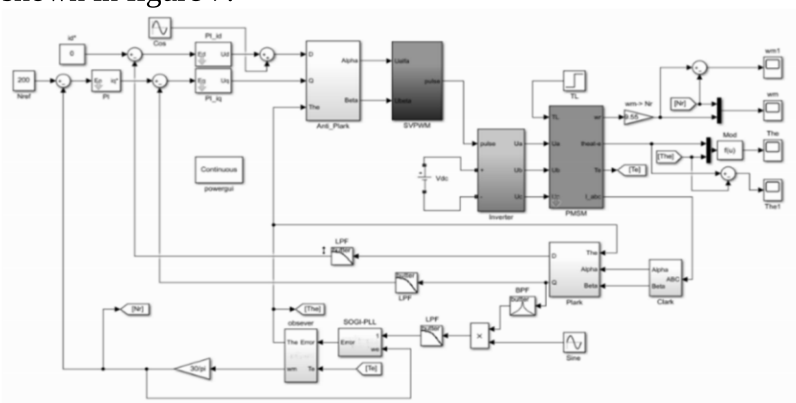

Figure 7: Optimized system simulation model diagram System simulation with PMSM parameters as follows:

Phase voltage 310V, rated speed 2500r /min, stator resistance R=2.8 Ω , stator inductance L=0.008 H, the rotor flux linkage ψ = 0.175 Wb, the rated torque 3.2N·m , the moment of inertia J=0.008 kg·m2.

The figure 8 shows that the estimated value of rotor angle overlaps with the actual value after the improvement, and the phase error tends to 0 after a short time of 0.02s, which can assure the tracking of rotor situational.

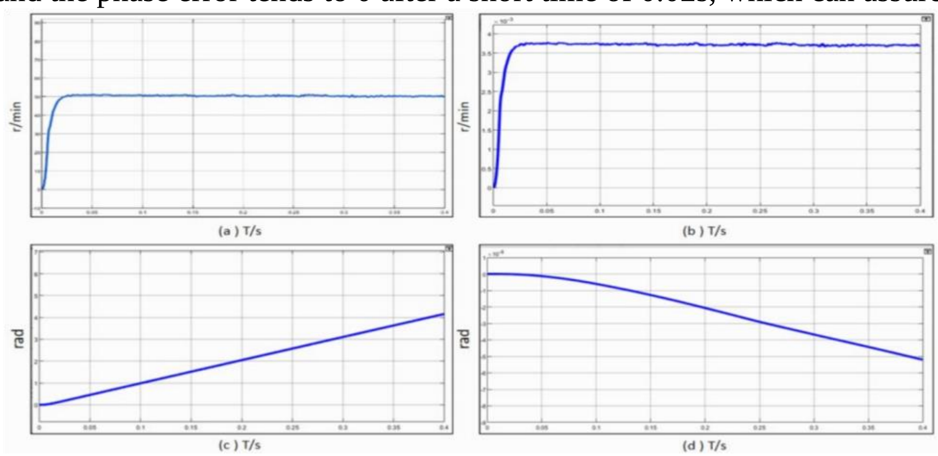

Figure 8: Shows the improved waveform

The motor rising from 50r/min to 100r/min at 0.2 seconds and running at 100r/min are respectively set. Figure 9, (a) shows the simulation result curve when the speed changes to 100r/min, and Figure (b) shows the simulation result curve when the speed is stable at 100r/min:

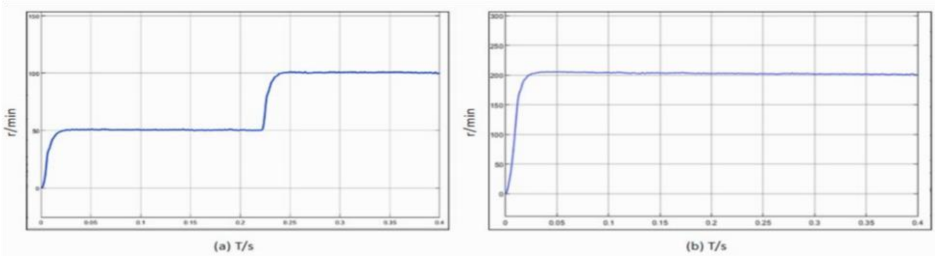

Figure 9: Curve of the speed change

As can be seen from Figure 9, that the motor runs stably at 50r/min after starting, and the speed responds quickly to the given mutation at 0.2 seconds, and quickly reaches the stable state. The dynamic performance of the system is excellent without overshoot.

5. Conclusion

This paper has designed by the rotor position state observer based on the improved second order generalized integral phase-locked loop is designed, and the simulation experiment is carried out for the designed filter, and the high frequency vibration signal is injected and the obvious filtration performance is achieved. After fusion with the rotating position observer, the errors between the estimating rotor position angle value and the actual rotor position value obtained after simulation verification on the MATLAB/Simulink platform approaches zero after 0.02 seconds, which can keep the stable tracking of rotor position angle at low speed. The adaptability and practicability of this method are obviously improved compared with the control method before improvement.

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