An Improved Offline Parameter Identification Method for Electric Vehicle Asynchronous Motors (Postprint)

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Abstract

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Full Text

An Improved Off-Line Identification Method of Asynchronous Motor Parameters for Electric Vehicles

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Abstract

This paper presents an improved algorithm for off-line identification of asynchronous motor parameters. The traditional DC experiment is enhanced to obtain an equivalent control circuit for stator resistance identification. Subsequently, a single-phase AC locked-rotor experiment is employed to identify the stator leakage inductance and rotor resistance. In the V/f no-load experiment, the motor mutual inductance is identified by calculating reactive power, thereby avoiding the complex FFT computation required in conventional no-load experiments. Finally, simulation and experimental studies of parameter identification are conducted on a 3.5 kW asynchronous motor. The results demonstrate that the proposed method is simple, feasible for engineering applications, and yields motor parameters with high accuracy.

Keywords: Asynchronous motor, parameter offline identification, vector control, reactive power

1 Introduction

Asynchronous motors offer numerous advantages including simple structure, convenient manufacturing, low cost, robust durability, reliable operation, and suitability for harsh environments, making them widely employed in electric vehicle drive systems [1]. Representative control methods for asynchronous motor systems include open-loop V/f control, slip frequency control, vector control, and direct torque control. Among these, vector control technology is the most extensively used, enabling asynchronous motors to achieve wide speed ranges, large instantaneous output power, and fast torque response. However, vector control demands high precision in motor parameters for accurate estimation of rotor flux angle and automatic tuning of PI regulator parameters in both speed and current loops [2].

[Figure 1: see original paper] shows the main circuit of the asynchronous motor variable frequency control system, where the three inverter bridge arms A, B, and C are connected to the three-phase stator windings of asynchronous motor M.

2 Parameter Off-Line Identification

The main parameters of asynchronous motors include stator resistance, rotor resistance, stator leakage inductance, rotor leakage inductance, and mutual inductance between stator and rotor. Currently, parameter identification methods are primarily divided into off-line and on-line approaches [3]. On-line identification algorithms mainly comprise neural network algorithms and genetic algorithms. While these methods enable real-time parameter tuning and improved control system accuracy, they suffer from certain drawbacks. For instance, the extended Kalman filter method requires predetermined system noise and involves complex algorithms; genetic algorithms struggle with nonlinear constraints and exhibit poor stability, making on-line identification extremely difficult in practical applications [4-8].

Traditional off-line identification methods employ no-load and locked-rotor experiments [9], which can accurately measure motor parameters but are unsuitable for variable frequency drive systems due to field condition limitations. Consequently, researchers have proposed numerous off-line automatic identification methods [11-15]. Reference [11] utilizes pulse voltage and pulse current methods, but the data processing is somewhat complex. Reference [12] performs parameter identification based on indirect vector control systems with some improvements to the DC experiment, yet the total leakage inductance is obtained through estimation, introducing cumulative errors. Reference [13] proposes slip frequency control during no-load experiments to eliminate possible current oscillations in open-loop operation, but requires additional stator voltage sensors. Reference [14] employs step voltage tests to eliminate leakage inductance and remove cumulative errors in total leakage inductance, though this increases test complexity. Reference [15] compensates for inverter dead-time-induced voltage errors based on current polarity during voltage reconstruction, but involves substantial computational load.

Building upon existing methods, this paper proposes an off-line identification method for asynchronous motor stator-rotor mutual inductance parameters based on reactive power calculation, avoiding the complex FFT computation of conventional mutual inductance identification methods. Finally, both simulation and practical experiments are conducted on a 3.5 kW asynchronous motor.

2.1 DC Experiment

Stator resistance R_s identification is generally accomplished through DC experiments. The conventional structure shown in Figure 2a [Figure 2: see original paper] is improved in this paper by turning on VT1 and VT5 in Figure 1 while turning off all other switches to obtain the equivalent circuit shown in Figure 2b.

Since the inverter power supply used in this paper cannot directly apply DC voltage to the motor, PWM chopping is employed to regulate the voltage applied to the motor. The switching states of the six power transistors VT1–VT6 are controlled to achieve stator resistance identification. The PWM chopping duty ratio is the difference N between the duty ratios of the A-phase upper bridge and B-phase lower bridge. According to the set maximum allowable current, the B-phase duty ratio is adjusted accordingly to achieve the desired loop current.

To ensure accurate calculation, after the current stabilizes for a period, the motor' s line voltage and line current are accumulated, denoted as U_{ab} and I_a respectively. Finally, the stator resistance is calculated using Equation (1).

2.2 Single-Phase Experiment

Rotor resistance R_r and stator/rotor leakage inductance L_{ls} identification can be accomplished by applying single-phase AC excitation to the motor. The equivalent circuit is shown in Figure 3a [Figure 3: see original paper]. Since stator and rotor leakage inductances are typically very small and approximately equal relative to mutual inductance, the circuit can be simplified as shown in Figure 3b when the given current frequency is high.

In the two-phase stationary coordinate system, setting $U_\beta = 0$ ensures that the control signals for phases B and C in Figure 1 are identical, effectively short-circuiting phases B and C. The motor then operates in a locked-rotor condition. The phase current I_a obtained from feedback is processed through a proportional regulator K_p to obtain U_α. The control block diagram is shown in Figure 4 [Figure 4: see original paper].

The current reference is given by:

$$i^* = 2I\cos(\omega_e t)$$

where ω_e^* is the reference stator current angular frequency and I is the effective value of the motor' s rated line current.

After current stabilization, FFT is performed on the line voltage between phases A and B and the phase current of phase A to obtain their fundamental amplitudes U_{ab} and I_a, along with the phase difference θ between fundamental voltage and current.

The equivalent impedance is calculated as:

$$Z_{eq} = \frac{U_{ab}}{I_a}$$

The equivalent resistance is:

$$R_{eq} = Z_{eq}\cos\theta$$

The equivalent reactance is:

$$X_{eq} = Z_{eq}\sin\theta$$

The rotor resistance is:

$$R_r = R_{eq} - R_s$$

The stator and rotor leakage inductances are:

$$L_{ls} = L_{lr} = \frac{X_{eq}}{2\omega_e}$$

2.3 No-Load Experiment

Mutual inductance L_m identification can be accomplished through no-load experiments. The experiment employs constant V/f control, where the motor speed approaches synchronous speed with slip $s \approx 0$, the stator current essentially equals the excitation current, and the rotor circuit is effectively open. The equivalent circuit is shown in Figure 5 [Figure 5: see original paper], and the control block diagram is shown in Figure 6 [Figure 6: see original paper], where f^* is the reference frequency and "ramp" is the smooth frequency conversion module.

After speed stabilization, the measured phase voltages and currents are transformed using Clarke transformation to calculate U_α, U_β, I_α, and I_β, from which the reactive power Q of the circuit can be determined. Since stator leakage inductance is small compared to mutual inductance and can be neglected in calculations, the mutual inductance can be calculated using Equation (9):

$$L_m = \frac{Q}{\omega I_s^2}$$

where $I_s^2 = I_\alpha^2 + I_\beta^2$ and ω is the synchronous angular frequency of voltage and current.

3 Simulation Research

To verify the accuracy of the proposed motor parameter off-line identification method, Matlab/Simulink is first employed for simulation studies. The selected motor in the simulation model is a 3.5 kW asynchronous motor with rated voltage of 72 V and rated frequency of 100 Hz.

3.1 DC Experiment Simulation

Figure 7 [Figure 7: see original paper] shows the DC experiment simulation waveforms. From Figure 7a, the accumulated value of U_{ab} is 45 V. In Figure 7b, I_a reaches its steady-state value after a delay due to stator leakage inductance, with the accumulated value finally stabilizing at 710 A. The simulation yields a stator resistance of 0.0302 Ω.

3.2 Single-Phase Experiment Simulation

Figure 8 [Figure 8: see original paper] shows the single-phase experiment simulation waveforms. After FFT calculation, U_{ab} has an amplitude of 5.8 V and I_a has an amplitude of 47 A. The simulation results give a rotor resistance of 0.0473 Ω and leakage inductance of 0.049 mH.

3.3 No-Load Experiment Simulation

Figure 9 [Figure 9: see original paper] shows the motor mutual inductance waveform obtained from V/f no-load experiments. After motor speed stabilization, the simulated mutual inductance between stator and rotor is 1.225 mH.

4 Experimental Research

The experimental platform employs a TMS320F28035 DSP chip from TI as its core controller. The test motor is a 3.5 kW asynchronous motor with rated voltage of 72 V and rated frequency of 100 Hz.

4.1 Stator Resistance Identification

In the stator resistance identification experiment, VT1 and VT5 in Figure 1 are turned on while all other power transistors are turned off. After current stabilization, the motor' s line voltage U_{ab} and line current I_a are sampled 514 times, and Equation (1) is used to calculate stator resistance R_s. Figure 10a [Figure 10: see original paper] shows the waveforms of the A-phase upper bridge and B-phase lower bridge during the DC experiment, while Figure 10b shows the accumulated line current waveform.

4.2 Rotor Resistance and Leakage Inductance Identification

During single-phase AC locked-rotor operation, the A-phase reference current amplitude is 180 A with a reference frequency of 78 Hz. After current stabilization, FFT transformation yields the amplitudes of U_{ab} and I_a and their phase difference θ, from which rotor resistance and leakage inductance are calculated using Equations (3)-(7). Figure 11 [Figure 11: see original paper] shows the waveforms of phase A current and line voltage between phases A and B during the single-phase experiment.

4.3 Motor Mutual Inductance Identification

In the V/f no-load experiment, the reference frequency is 100 Hz with voltage amplitude of 30 V. After frequency stabilization, three-phase voltages and currents are sampled for Clarke transformation, and the reactive power is calculated to determine motor mutual inductance using Equation (9). Figure 12 [Figure 12: see original paper] shows the current waveforms of phases A and B during the no-load experiment.

4.4 Experimental Results Analysis

The table below presents the actual values, simulation values, and experimental measurements for the tested motor. Minor errors exist between measured and actual values within acceptable tolerances, primarily due to:

1. Effects of dead time and power transistor voltage drop in voltage reconstruction calculations.
2. Approximations made to the motor model during solution processes.

Tab. Results of off-line identification test, traditional test, and simulation

Parameter	Actual Value	Simulation Value	Experimental Value
R_s (Ω)	0.0300	0.0302	0.0305
R_r (Ω)	0.0468	0.0473	0.0476
L_{ls} (mH)	0.048	0.049	0.050
L_m (mH)	1.220	1.225	1.230

5 Conclusion

This paper proposes an improved off-line identification algorithm for asynchronous motor parameters. The method employs reactive power calculation for identifying mutual inductance between motor stator and rotor, avoiding the complex FFT computation process. Both simulation and practical experiments are conducted on a 3.5 kW asynchronous motor, with the identification process completed automatically by the system and all motor parameters successfully identified. Comparison of actual, simulation, and experimental values demonstrates that the proposed method achieves high accuracy and holds significant practical value for engineering applications.

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Note: Figure translations are in progress. See original paper for figures.