AN IMPROVED PARAMETER IDENTIFICATION METHOD FOR THREE PHASE INDUCTION MOTOR

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Abstract - In order to improve the control performance of vector inverter, an improved parameter identification solution for induction motor is proposed in this paper. DC or AC voltage is applied to the induction motor using the SVPWM through the inverter. Then stator resistance, stator leakage inductance, rotor resistance, rotor leakage inductance and mutual inductance are obtained according to the signal response. The discrete Fourier transform (DFT) is used to deal with the noise and harmonic. The impact on parameter identification caused by delays in the inverter switch tube, tube voltage drop and dead-time is avoided by effective compensation measures. Finally, the parameter identification experiment is conducted based on the vector inverter which using TMS320F2808 DSP as the core processor and results show that the strategy is verified.

Keywords - Vector Inverter; Parameter Identification; SVPWM; DFT; Dead-Time Compensation

I. INTRODUCTION

Due to its cheapness, excellent performance and easy maintenance, the asynchronous motor is widely used for industrial manufacturing. The high-performance frequency-conversion vector system for adjusting the speed of the asynchronous motor has been an active topic in the electric drive domain [1-2]. In the asynchronous motor vector controlling system, the accuracy of the motor is essential for magnetic flux linkage observations, rotating speed estimation and controlling parameter adjustment [3-4]. Therefore, identification of motor parameters is an important aspect of the high-performance vector speed controlling system.

Parameters needed for vector control of the asynchronous motor include the resistance and leakage inductance of the rotor and stator as well as the excitation inductance. The authors in [5] used the hybrid EKF algorithm to eliminate the impact of the structural noise. They regarded the motor’s movements as a random process and computed the system state variables and motor parameters via iterative calculations. Their method entails complex vector and matrix computations and is thus hard to be implemented on the microprocessor. A full order observer called MRAS was proposed in [6], which can identify the stator resistance through the difference between the reference value and the estimated value of the rotor’s magnetic flux. But it still needs other methods to identify other parameters. The authors in [7] proposed to identify motor parameters via the iterative least square method. But their method provides low identification accuracy due to high sensitiveness to the measurement noise and the rotating speed fluctuations. The intelligent control theory (e.g. the artificial neural network in [8-9] and the genetic algorithm in [10]) has also been applied to the identification of the motor parameters. But most of these methods are in the stage of theoretical simulations.

To achieve self-learning of the vector converter’s parameters and improve its controlling performance, we can exploit the frequency converter’s own resources, instructing the inverter to apply the AC or DC signal excitation to the asynchronous motor after the parameter is tuned via SVPWM [11-12]. Next, we can measure its response and obtain accurate motor parameters using proper computation methods. Due to the delay of the inverter’s switching tube and the existence of the tube voltage drop and the dead time, there is a discrepancy between the reference value and the actual value of the winding voltage. Failure to take compensation measures will cause errors in parameter identification. Hence, the time compensation method is used to eliminate the effect described above. Experimental results demonstrate that the proposed method for identifying asynchronous motor parameters is easy to implement, accurate and very helpful in improving the controlling performance of the vector frequency converter.

II. ANALYSIS OF THE EQUIVALENT CIRCUIT MODEL OF THE ASYNCHRONOUS MOTOR

By overlooking the harmonic interference, slot effect and iron loss, assuming the motor operates in the linear excitation zone, and converting the frequency, phase numbers and turns-in-series per-phase of the asynchronous motor’s rotor to the stator side, we can acquire the one-phase T-type equivalent circuit of the AC asynchronous motor at the stable state, as shown in Fig.1. The excitation resistance is so small that its impact on the equivalent circuit is neglected to simplify analysis.

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Fig. 1 T equivalent circuit of induction motor on steady state

The vector expression of its mathematical model is:

\[
\begin{align*}
\vec{U}_1 &= \vec{R}_s \vec{I}_s + j \omega (\vec{L}_d - \vec{L}_m) \vec{I}_s + j \omega \vec{L}_m \vec{I}_r \\
0 &= \frac{R_r}{s} \vec{I}_r + j \omega (\vec{L}_d + \vec{L}_m) \vec{I}_r + j \omega \vec{L}_m \vec{I}_s
\end{align*}
\]  

(1)

where \( R_s \) — stator resistance; \( \vec{L}_d \) — stator leakage inductance; \( \vec{I}_s \) — stator side phase current vector; \( R_r \) — rotor equivalent resistance; \( \vec{L}_r \) — rotor equivalent resistance leakage inductance; \( \vec{I}_r \) — rotor equivalent phase current vector; \( L_m \) — excitation inductance; \( \vec{U}_1 \) — stator phase voltage vector; \( s \) — slip ratio.

III. METHOD FOR IDENTIFYING MOTOR PARAMETERS

3.1 Method for identifying stator resistance

Fig. 2 shows the way of connecting the three-phase voltage inverter to the asynchronous motor. The desired AC or DC voltage actuating signal can be generated by controlling the states of each switching tube in the inverter. The equivalent circuit of the motor can be simplified in the presence of the actuating signal. We can obtain motor parameters in the presence of different actuating signals by detecting and processing the corresponding signals as well as using the proper computation methods.

DC is chosen to experiment on the identification of the stator resistance. The basic theory is to instruct the inverter to inject the low DC voltage into the motor’s stator winding and then compute the resistance via the Ohm’s law. In practice, the rectified AC voltage \( U_{dc} \) is chopped via SVPWM to generate the high-frequency voltage impulse, adjust the duty ratio of the voltage impulse and acquire the desired equivalent DC. The inputs to SVPWM for given \( U_\alpha \) and \( U_\beta \) are adjusted to connect VT2 and VT6, disconnect VT3 and VT5, and make the trigger of VT1 the PWM wave with a certain duty ratio. In this way, the voltage applied to the asynchronous motor is the DC voltage of the ripple. For the asynchronous motor, it is equivalent to b and c being shorted and then connected in series with a. Therefore, what the inverter outputs directly into the motor is the line voltage \( U_{ab} \), and the equivalent circuit is shown in Fig. 3.

![Fig.3 Equivalent circuit of DC experiment](image)

According to the Ohm’s law, the stator resistance of the motor is:

\[
R_s = \frac{U_{ab}}{1.5I_a} = U_a / I_a
\]

(2)

In the presence of the DC voltage, the relation between the three-phase voltage and current in the winding loop is:

\[
\begin{align*}
I_b &= I_r = -0.5 I_a \\
U_b - U_c &= 0.5 U_a
\end{align*}
\]

(3)

For coordinate conversion of vector control, the voltage and current in the \( \alpha-\beta \) coordinate system is related to the voltage and current described above in the following way:

\[
\begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{1}{\sqrt{3}} & \frac{2}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} U_a \\ U_b \end{bmatrix}
\]

(4)

Substituting Equation (3) into (4) yields the input to SVPWM:

\[
\begin{align*}
U_\alpha &= U_a \\
U_\beta &= (U_a + 2U_b) / \sqrt{3}
\end{align*}
\]

(5)

The controlling structure of the DC experiment is...
given in Fig.4. The given signal is the given value $I_{a}^{*}$ of the current along the $\alpha$ axis in the $\alpha$-\$\beta$ coordinate system, and the feedback signal is the effective value of the current along the $\alpha$ axis after the stator current goes through the coordinate conversion. The $\alpha$-axis voltage $U_{\alpha}$ can be output via the PI regulator. $U_{\beta}$ is directly set to 0 to ensure that the signal for controlling the switching tube of the bridge arm of the phases b and c is the same. The operating condition of the inverter can be controlled through SVPWM and the use of $U_{\alpha}$ and $U_{\beta}$. A high frequency of the pulse means that the voltage applied to the motor approximates to DC more closely and that the ripple of the current is low. Because the voltage applied to the stator resistance cannot be too large, the current closed-loop control mode is chosen so that the output current can reach the specified value through the adjustment of the pulse duty cycle. And $U_{\alpha}$ can be adjusted using the current PI regulator with amplitude limited output. The $a$-phase voltage $U_a$ can be computed using the inverter DC voltage $U_{dc}$, the duty ratio of the output pulse and the voltage reconstruction technique. Then, the stator resistance of the asynchronous motor can be computed via Equation (2) above.

\begin{equation}
\frac{U_{a}(k) - U_{a}(k-1)}{I_{a}(k) - I_{a}(k-1)}
\end{equation}

where $U_{a}(k)$ and $U_{a}(k-1)$ refer to the reference values of the phase voltages with varying duty ratios applied to the motor winding at different time, $I_{a}(k)$ and $I_{a}(k-1)$ refer to the values of the phase current in the two experiments. Several experiments can be performed to compute the finally identified value of the stator resistance in an offline manner using the least square method.

\section{Method for Identifying Rotor Resistance and Leakage Inductance}

The one-phase AC experiments are carried out for the identification of the rotor resistance and leakage inductance. The theory of the one-phase experiment is to apply the one-phase sinusoidal voltage to the motor winding. Then, instead of generating electromagnetic torque, the motor is stationary. When the frequency is high, the excitation inductance is so high that the current flowing through the excitation circuit can be neglected. The rotor resistance and the leakage inductance can be computed using the simplified motor circuit and the voltage/current information. The SVPWM method is still used in the one-phase experiment: apply the sinusoidal voltage to the asynchronous motor by controlling $U_a$ and $U_{\beta}$ in the $\alpha$-\$\beta$ coordinate system in order to connect VT1, VT6, and VT2 or connect VT4, VT3, and VT5. The equivalent circuit of the one-phase AC motor experiment is given in Fig.5.

\begin{equation}
Z_{eq} = \frac{U_{ab}}{I_{a}}
\end{equation}

The sum of the stator and rotor resistances is:

\begin{equation}
Z_{eq} \cos \theta = \left( \frac{U_{ab}}{I_{a}} \right) \cos \theta = 1.5(R_{s} + R_{r})
\end{equation}

where $\theta$ is the power factor angle. So the rotor resistance is:

\begin{equation}
R_{r} = \frac{2}{3} \left( \frac{U_{ab}}{I_{a}} \right) \cos \theta \cdot R_{s}
\end{equation}

The sum of the stator and rotor reactance is:

\begin{equation}
Z_{eq} \sin \theta = \left( \frac{U_{ab}}{I_{a}} \right) \sin \theta = 1.5(L_{s} + L_{r})\omega_{1}
\end{equation}

where $\omega_{1}$ is the angular frequency of the voltage fundamental wave. Generally, the stator leakage inductance is equal to the rotor leakage inductance. So the stator and rotor leakage inductance is:
Equation (5) holds true for the relation between the current/voltage in the α-β coordinate system and the motor’s three-phase current/voltage. The controlling structure of the one-phase experiment is similar to that in Fig.3. The SVPWM inputs are given as:

\[
\begin{align*}
\Omega_a &= U_a \cos \alpha_T \\
\Omega_f &= 0
\end{align*}
\] (12)

After the motor produces the stable outputs in the presence of the one-phase sinusoidal voltage, we compute the effective value of the asynchronous motor’s a-phase current, the effective value of the line voltage, and the power factor. The rotator resistance as well as the stator and rotator leakage inductance can be computed using Equations (9) and (11).

Due to the existence of the noise and harmonics in the current and voltage signals, the filtered response signals are processed via DFT while computing the magnitudes of voltage and current as well as the power factor angle in the one-phase experiment. Details are given below.

Let \( x(t) \) denote the continuous voltage or current signal. By obtaining \( N \) sets of uniform and synchronous samples from the signal during each period of the fundamental wave, we get the sequence \( x(n) \). Let \( M \) denote the signal’s highest harmonic number. If the sampling theorem holds, then the sequence \( x(n) \) can go through the Fourier transform. So the discrete sequence can be expressed as:

\[
X(k) = DFT[x(n)] = \sum_{n=0}^{N-1} x(n) e^{-2\pi j n k / N}, \quad k = 0, 1, 2, \ldots, N-1
\] (13)

where \( k \) is the harmonic number. According to the Euler’s formula, we have:

\[
e^{-j\frac{2\pi n}{N}} = \cos\left(\frac{2\pi n}{N}\right) - j \sin\left(\frac{2\pi n}{N}\right)
\] (14)

By substituting Equation (15) into (14), can be transformed into:

\[
X(k) = \sum_{n=0}^{N-1} x(n) e^{2\pi j n k / N} = \sum_{n=0}^{N-1} x(n) \left[ \cos\left(\frac{2\pi n k}{N}\right) - j \sin\left(\frac{2\pi n k}{N}\right) \right]
\]

\[
= \sum_{n=0}^{N-1} x(n) \cos\left(\frac{2\pi n k}{N}\right) - j \sum_{n=0}^{N-1} x(n) \sin\left(\frac{2\pi n k}{N}\right)
\] (15)

Let \( k=1 \). Then, the real and imaginary parts of the signal’s fundamental wave are:

\[
a_1 = \frac{2}{N} \sum_{n=0}^{N-1} x(n) \cos\left(\frac{2\pi n}{N}\right)
\]

\[
b_1 = \frac{2}{N} \sum_{n=0}^{N-1} x(n) \sin\left(\frac{2\pi n}{N}\right)
\] (16)

In practical applications, the continuous voltage and current signals should be processed in the way above, and the magnitudes and phases of their respective fundamental waves can be then computed. Let \( a_{il} \) and \( b_{il} \) represent the real and imaginary parts of the voltage’s fundamental wave, \( \theta_{il} \) denote the phase, and \( U_l \) denote the magnitude. So, we have:

\[
U_l = \sqrt{a_{il}^2 + b_{il}^2}, \quad \theta_{il} = \arctg\left(\frac{b_{il}}{a_{il}}\right)
\] (17)

Let \( a_{il1} \) and \( b_{il1} \) represent the real and imaginary parts of the current’s fundamental wave, \( \theta_{il1} \) denote the phase, and \( I_l \) denote the magnitude. So, we have:

\[
I_l = \sqrt{a_{il1}^2 + b_{il1}^2}, \quad \theta_{il1} = \arctg\left(\frac{b_{il1}}{a_{il1}}\right)
\] (18)

Hence, the power factor is:

\[
\cos \theta = \cos(\theta_{il} - \theta_{il1}) = \frac{a_{il} a_{il1} + b_{il} b_{il1}}{\sqrt{a_{il}^2 + b_{il}^2} \sqrt{a_{il1}^2 + b_{il1}^2}}
\] (19)

### 3.3 Method for Identifying Excitation Inductance

The no-load experiments are carried out for the identification of the excitation inductance. When it is in the no-load operation, the rotating speed of the motor approximates to the synchronous speed, the slip ratio \( s \) is almost zero, and the motor rotator circuit can be regarded as an open circuit approximately. Meanwhile, the voltage falls into the stator resistance, stator leakage inductance and excitation inductance, the stator current is almost equal to the excitation current, and the one-phase equivalent circuit of the motor is given in Fig.6. The excitation inductance can be obtained using the phase voltage and current. The operation of the motor can be controlled via the SVPWM-based constant proportion of voltage to frequency method (V/F) [10].
\[ Z_{eq} = \frac{U_a}{I_a} \]

Then, the equivalent reactance of the winding circuit is:

\[ X_{eq} = Z_{eq} \sin \theta = \left( \frac{U_a}{I_a} \right) \sin \theta \]

So, the excitation inductance is:

\[ L_{ex} = \frac{X_{eq}}{2 \pi f_1} = \frac{U_a}{I_a} \sin \theta / 2 \pi f_1 - L_{dc} \]

(22)

where \( f_1 \) denotes the fundamental frequency of the AC voltage applied to the stator’s three-phase winding.

The controlling structure of the no-load experiment is given in Fig.7. For the given frequency, the specified synthesized voltage space vector can be computed via the V/F controlling algorithm. The approximate three-phase AC voltage needed for the motor to run in the no-load mode can be computed via SVPWM and the voltage vector angle. After the motor’s rotating speed stabilizes, we can compute the effective value \( I_a \) of the motor’s phase current, effective value \( U_a \) of the phase voltage and the power factor \( \cos \theta \). Then, the formulas described above can be used to compute the excitation inductance. While computing \( U_a \), \( I_a \), and \( \cos \theta \), the signal processing procedures still use the same DFT transform as in the one-phase experiment.

![Fig.7 The control structure diagram of no-load experiment](image)

The switching delay of the inverter and the dead time has impact on the identification of parameters in above three motor parameter identifying experiments. The dead zone effect caused by the switching delay of the switching tube and the dead time is analyzed briefly below [11].

Consider phase a of the three-phase voltage inverter in Fig.2. The direction in which the current flows into the motor is defined as the positive direction, and the outbound direction is defined as the negative direction. Let \( t_d \) denote the dead time inserted before each switching tube turns on the signal. During the dead time, the output voltage is independent of the switching tube and only relies on the direction of the phase current. Within a switching period, when the phase current is positive, the actual positive pulse time of the output voltage is shorter than that of the ideal voltage by \( t_d + t_{on} - t_{off} \), where \( t_{on} \) denotes the turn-on time of IGBT, and \( t_{off} \) denotes the turn-off time of IGBT.

Taking into account the effect of the turn-on and turn-off delay as well as the dead time, let \( t_{ed} \) denote the equivalent time, then we have:

\[ t_{ed} = \text{sign}(i)(t_d + t_{on} - t_{off}) \]

(23)

where \( \text{sign}(i) = \begin{cases} 1, & i > 0 \\ -1, & i < 0 \end{cases} \) denotes the current.

It can be seen from above analysis that the root cause of the time error is that the actual turn-on time of the switching tube is longer or shorter than the ideal turn-on time. To address this problem, a SVPWM-based dead zone compensation method is proposed, which determines the polarity of the three-phase current within each carrier period \( T_{pwm} \) via the region of the synthesized stator current vector. Then, the proposed method can determine the compensation for the acting time of the corresponding basic voltage space vector. Consider the voltage SVPWM-based first sector where the polarities of the phases abc are positive-negative-negative. Due to the dead zone effect, the actual positive pulse time of phase a is shorter than that of the ideal positive pulse time, while the actual positive pulse time of phases b and c is longer than that of the ideal positive pulse time. To provide the compensation, the a-phase bridge arm (i.e. \( S_a \), high level) should be lengthened by \( t_{ed} \), and the b- and c-phase bridge arms (i.e. \( S_b \) and \( S_c \), high levels) should be shortened by \( t_{ed} \). The voltage vector acting time before and after the compensation is shown in Fig.8, where the dotted line indicates the acting time of different voltage vectors before the compensation. After the compensation, the acting time of the vector voltage \( u_0 \) is increased by \( 2t_{ed} \), the acting time of \( u_b \) is intact, the acting time of \( u_c \) is decreased by \( t_{ed} \).

![Fig.8 Action time of basic voltage space vector before and after compensation](image)

IV. EXPERIMENT RESULTS AND ANALYSIS

To prove the effectiveness of the proposed method for identifying motor parameters, an experimental platform for asynchronous motor vector controlling...
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The motor parameter identifying algorithm is shown in Fig.10. Digital implementation of the algorithm is completely done via DSP. And the software development platform is CCS3.3. The entire identifying process in practice consumes 8s approximately.

Fig. 11 shows the waveform in the motor parameter identifying experiment. The winding current waveform and PWM pulse waveform in the DC experiment with a voltage duty ratio of 5% is given in Fig. 11(1), the winding current waveform in the 45Hz one-phase experiment is given in Fig. 11(2), and the winding current waveform in the 50Hz no-load experiment is given in Fig.11(3). Table (3) compares the motor parameter identifying results with the motor’s actual parameters. The comparison indicates that the experimental values are close to the actual values, demonstrating the accuracy of the proposed compensation method.

### Table 1 Result of motor parameter identification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(\alpha_1)</th>
<th>(\alpha_2)</th>
<th>(\theta_{stator_leakage}) mH</th>
<th>(\theta_{rotor_leakage}) mH</th>
<th>(\theta_{mutual}) mH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>1.07</td>
<td>1.27</td>
<td>6.33</td>
<td>6.33</td>
<td>175.1</td>
</tr>
<tr>
<td>True value</td>
<td>1.06</td>
<td>1.29</td>
<td>6.40</td>
<td>6.40</td>
<td>177.7</td>
</tr>
<tr>
<td>Error/%</td>
<td>1.03</td>
<td>1.08</td>
<td>1.09</td>
<td>1.09</td>
<td>0.571</td>
</tr>
</tbody>
</table>

Fig. 11 Experiment waveforms of motor parameter identification

**CONCLUSION**

Accuracy of the motor parameters is essential for the high-performance vector frequency conversion and speed governing system. In this paper, the traditional offline experiments are improved using SVPWM as well as effective optimization and compensation measures. In the DC experiments, the stator resistance is computed more accurately through the use of the current PI regulation and the increment calculation method. The errors caused by the switching delay of the switching tube and the dead time are offset in the experiments. Experimental results demonstrate that the proposed method for identifying asynchronous parameters is very practical and accurate and can be used effectively for vector converters.

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