ANALYSIS OF A TWO-PHASE INDUCTION MOTOR USING DYNAMIC MODEL BASED ON MATLAB/SIMULINK

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ABSTRACT

This paper sets forth the development of the stationary (αβ) reference frame model of an asymmetrical two-phase induction motor. The aim of this research is to developed and designs of the asymmetrical two-phase induction motor suitable for transient and steady-state analysis. The system has been simulated to verify its capability such as input phase voltages, stator and rotor currents, electromagnetic torque and rotor speed under condition no-load and full-load test. The performance of asymmetrical two-phase induction motor under various conditions as mentioned above are simulated using Matlab/Simulink and the simulation results demonstrates the feasibility of the proposed scheme.

Keywords: two-phase induction motor, dynamic model, Matlab/Simulink.

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INTRODUCTION

In small power applications asymmetrical two-phase induction motors fed by single-phase supply have been widely used electric machines in home appliances and industrial application requiring less than 5 kW (Ojo and Omuzusi, 2001) (Ojo and Omuzusi, 2001). The single-phase induction motors with main and auxiliary windings can be viewed as two-phase machines, since these winding are displaced ninety degrees apart from each other. Therefore, the two-phase induction motors have a configuration identical to the single-phase induction motors, but the input voltage applied to the stator windings terminals are independently controlled so that a two-phase supply voltage.

In recent years, several methods that use simulation model for simulated of two-phase induction motors have been proposed. In Bala (2004) the dynamic of single/two phase induction motors have been studied and developed with Matlab software. The simulation model shown start-up transients and fault transients of the different motors are performance compared. In Gabriela (2007) Simulink implementation of two-phase induction motor model, in which Krause’s model was analyzed on a two-phase induction motor with known parameters. It was studied the saturation phenomenon for main magnetic flux and its implications on the function characteristics of a two-phase induction motor. It offers good transient and steady-state performance. However, this technique has limitation in being computationally intensive.

This paper presents the design and simulation of an asymmetrical two-phase induction motor using dynamic model with Matlab/Simulink. The proposed method is applicable to both transient and steady-state of the two-phase induction motor under condition no-load and full-load test. This method is based on the analysis of the stationary \((\alpha\beta)\) reference frame model of asymmetrical two-phase induction motor with a general two single-phase supply connected to its terminal. The rest of this paper is arranged as follows: Section 2 gives the mathematical modeling of asymmetrical two-phase induction motor, is based on stationary reference frame. In Section 3 of this paper concerns the simulation dynamic model using Matlab/Simulink programs. To evaluate the performance of the proposed approach, simulation results are presented in Section 4. Finally, Section 5 concludes this paper.

MATHEMATIC MODEL

The two-phase induction motor is composed of two asymmetrical windings. Therefore, the number of auxiliary winding usually has fewer turns than the main winding, and displaced ninety electrical degrees between these winding (Jang and Won, 2004 and Blaabjerg et al., 2002) Fig. 1 shown the schematic view of a two-phase induction motor the auxiliary \((\alpha)\) windings and main \((\beta)\) windings are not identical sinusoidal distributed windings, but are arranged in space quadrature.
The equivalent circuits represented the asymmetrical two-phase induction motor in stationary ($\alpha\beta$) reference frame are shown in Fig. 2. The dynamic model equation of asymmetrical two-phase induction motor can be written in $\alpha\beta$ reference frame variables. Components stator and rotor voltage of the two-phase induction motor can be expressed as follow:

(a) Auxiliary winding in $\alpha$ - axis.

(b) Main winding in $\beta$ - axis.

Fig. 2 Equivalent circuit of an asymmetrical two-phase induction motor in the stationary ($\alpha\beta$) reference frame.
The components of stator and rotor flux linkages equations can also be expressed as:

\[ \psi_{sa} = L_{sa} i_{sa} + L_{msa} i_{ra}, \]  
\[ \psi_{sb} = L_{sb} i_{sb} + L_{msb} i_{rb}, \]  
\[ \psi_{ra} = L_{ra} i_{ra} + L_{ras} i_{sa}, \]  
\[ \psi_{rb} = L_{rb} i_{rb} + L_{rbs} i_{sb}. \]

Using equation (5)-(8), as for the stator and rotor currents equations are given by:

\[ i_{sa} = \frac{L_{ra} \psi_{sa} - L_{msa} \psi_{ra}}{L_{sa} L_{ra} - L_{msa}^2}, \]  
\[ i_{sb} = \frac{L_{rb} \psi_{sb} - L_{msb} \psi_{rb}}{L_{sb} L_{rb} - L_{msb}^2}, \]  
\[ i_{ra} = \frac{L_{sa} \psi_{ra} - L_{msa} \psi_{sa}}{L_{ra} L_{sa} - L_{msa}^2}, \]  
\[ i_{rb} = \frac{L_{rb} \psi_{rb} - L_{msb} \psi_{rb}}{L_{rb} L_{rb} - L_{msb}^2}. \]

The equation of electromagnetic torque produced by the machine is then given by the equation:

\[ T_e = p_p \left( L_{msb} i_{sb} i_{ra} - L_{msa} i_{sa} i_{rb} \right), \]  

and the mechanical dynamic is modeled by the equation

\[ J \frac{d}{dt} \omega_r = T_e - T_i. \]  

where \( v_{sa}, v_{sb}, v_{ra}, v_{rb} \) are the stator and rotor voltages, \( i_{sa}, i_{sb}, i_{ra}, i_{rb} \) are the stator and rotor currents, \( \psi_{sa}, \psi_{sb}, \psi_{ra}, \psi_{rb} \) are the stator and rotor flux linkages, \( R_{sa}, R_{sb}, R_{ra}, R_{rb} \) are the stator and rotor resistances, \( L_{sa}, L_{sb}, L_{ra}, L_{rb} \) are the stator and rotor inductances, \( L_{msa}, L_{msb} \) are the magnetizing
inductances, $\omega_r$ is the electrical rotor angular speed, $T_e$ is the electromagnetic torque, $T_L$ is the load torque, $J$ is the rotor moment of inertia, $\frac{d}{dt}$ is the differential operator and $\alpha$ is the main per auxiliary winding turns ratio.

MODELING USING MATLAB/SIMULINK

Matlab/Simulink models were developed to examine the asymmetrical two-phase induction motor. The equation from (1)-(4) and (9)-(14) have been implemented in Simulink using different block. In this paper the step by step modeling of the asymmetrical two-phase induction motor has been described.

![Fig. 3 Stator and rotor voltage equations.](image1)

![Fig. 4 Stator and rotor current equations.](image2)
Fig. 6 Implemented Simulink model of proposed in this paper

In Figs. 3 and 4, shows the subsystem block of stator and rotor voltages and currents, respectively. The electromagnetic torque and rotor speed determined has been shown in Fig. 5. Finally, in Fig. 6 the implement Simulink model of asymmetrical two-phase induction motor has been shown.

Simulation Results

In this section, some simulation results show excellent performances of the proposed system are presented. The simulation model has been developed in Matlab/Simulink environment. The parameters of the asymmetrical two-phase induction motor are then calculated from short circuit and no-load measurements. Through, the main and auxiliary winding resistances are measured using the DC tests when the other parameters are estimated using the stand-still and synchronous speed test (Ojo and Omozusi, 2010) The motor parameters are tabulated in Table 1 and the rated are 110 V, 60 Hz, 1/4 HP, and four-pole (Bala, 2004). In all simulated cases, the load torque is fixed at 1.0096 Nm.

**Table 1** Two-phase induction motor parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{sa}$</td>
<td>7.14 Ω</td>
</tr>
<tr>
<td>$L_{sa}$</td>
<td>0.2549 H</td>
</tr>
<tr>
<td>$L_{mr}$</td>
<td>0.2464 H</td>
</tr>
<tr>
<td>$R_{sb}$</td>
<td>2.02 Ω</td>
</tr>
<tr>
<td>$L_{sb}$</td>
<td>0.1846 H</td>
</tr>
<tr>
<td>$L_{mr}$</td>
<td>0.1772 H</td>
</tr>
<tr>
<td>$R_{ra}$</td>
<td>5.74 Ω</td>
</tr>
<tr>
<td>$L_{ra}$</td>
<td>0.2542 H</td>
</tr>
<tr>
<td>$J$</td>
<td>$2.92 \times 10^{-3}$ kg-m$^2$</td>
</tr>
<tr>
<td>$R_{rb}$</td>
<td>4.12 Ω</td>
</tr>
<tr>
<td>$L_{rb}$</td>
<td>0.1828 H</td>
</tr>
<tr>
<td>$a$</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Fig. 5 Electromagnetic torque and rotor speed equations.
The simulation result for the first method, which consists in using dynamics modeling, is shown in Fig. 7. In Fig. 7 (a), the main and auxiliary supply voltage are identical in amplitude at 60 Hz and two phase quadrature (sine and cosine wave forms) voltages were selected according to $v_{aux} = a v_{main}$ [6]. The supply voltage $v_{aux}$ was fixed at $1.18v_{main}$ since the winding turn ratio $a$ was estimated to be approximately 1.18. The simulation results of the dynamic response under no-load is show in Fig. 7 (b) and (d). It can be seen that the stator and rotor currents decreases into steady-state. At zoom pictures the stator and rotor currents. It can be seen that the stator and rotor currents is well quadrature show in Figs 7 (c) and (e). As the result, in Figs. 7 (f)-(g) it is seen that the electromagnetic torque response is generated in transient and steady-state and rotor speed is constant at 1800 rpm.

Fig. 8 (a) show the simulation supply voltage for 60 Hz two phase quadrature voltages with equal magnitude of $110V_{rms}$ at no-load. Under these conditions the auxiliary winding current is no longer in quadrature, and has small magnitude. This is because the larger back-emf. developed in the auxiliary winding prevents a useful winding current flowing when the applied phase voltage magnitude is too low as show in Figs 8 (b)-(c). Figs 8 (d)-(e) shows transient and steady-state rotor current, respectively. In Figs. 8 (f)-(g) shows the transient responses of the electromagnetic torque and rotor speed is 1800 rpm at no-load.
Fig. 7 Simulation results of the main and auxiliary two-phase induction motor \( (v_{\text{main}} = 110V_{\text{rms}} \) and \( v_{\text{aux}} = \alpha \times 110V_{\text{rms}} \)) at no-load condition: (a) supply voltage (b) stator current (c) stator current at zoom (d) rotor current (e) rotor current at zoom (f) electromagnetic torque and (g) rotor speed.
Fig. 8 Simulation results of the main and auxiliary two-phase induction motor ($v_{\text{main}} = v_{\text{aux}} = 110 \, \text{Vrms}$) at no-load condition: (a) supply voltage (b) stator current (c) stator current at zoom (d) rotor current (e) rotor current at zoom (f) electromagnetic torque and (g) rotor speed.
Fig. 9 Simulation results of the main and auxiliary two-phase induction motor ($v_{\text{main}} = 110V_{\text{rms}}$ and $v_{\text{aux}} = a*110V_{\text{rms}}$) at full-load condition: (a) supply voltage (b) stator current (c) stator current at zoom (d) rotor current (e) rotor current at zoom (f) electromagnetic torque and (g) rotor speed.
Fig. 10 Simulation results of the main and auxiliary two-phase induction motor ($v_{main} = v_{aux} = 110\,\text{Vrms}$) at full-load condition: (a) supply voltage (b) stator current (c) stator current at zoom (d) rotor current (e) rotor current at zoom (f) electromagnetic torque and (g) rotor speed.

The transient and dynamic response are presented in Fig 9, when applied supply voltage ($v_{aux} = av_{main}$) is changed values of the load torque at 1.0096 Nm (full-load) as shown in Fig. 9 (a). In Figs 9 (b)-(e), shows the transient and dynamic response of the stator and rotor winding currents. Fig. 9
(f)-(g) shows the transient responses of the rotor speed and the electromagnetic torque when the electromagnetic torque is change. It is noted here that the smooth and stable of speed at 1765 rpm.

The supply voltage, the stator and rotor currents waveform, the electromagnetic torque, and rotor speed obtained with scheme are shown in Fig 10 (a)-(g), respectively. The rotor speed is 1765 rpm as show in Fig. 10 (e) and the reference load torque is 1.0096 Nm. Fig. 10 (a) shows the steady-state response of the motor when it is supplied with a two-phase balanced sinusoidal supply. The simulation results of the dynamic response under full-load is show in Fig. 10 (b) and (d). It can be seen that the high ripple stator and rotor currents. Zoom on pictures the stator and rotor currents, it can be seen that the stator and rotor currents is well quadrature show in Figs 10 (c) and (e). The electromagnetic torque responses of the two-phase induction motor when it has two asymmetrical winding are shown in Fig 10 (f). In this case, the torque ripple under full-load is 1 Nm (rate torque).

Although the supply input voltage \( v_{aux} = av_{motor} \) has better performance than the two phase quadrature supply voltages with equal magnitude \( v_{aux} = v_{max} \), in this research work using asymmetrical two-phase induction motors since they are commercially available over the counter.

**CONCLUSION**

This paper has presented developed and design dynamic modeling of the asymmetrical two-phase induction motor using Matlab/Simulink. The paper has proposed model analyses the transient and steady state characteristics with variable two phase quadrature supply voltages. The simulation results have shown that the transient and steady-state of the supply voltage, the stator and rotor winding currents, the electromagnetic torque and rotor speed under no-load and full-load. The model gives good dynamic and steady-state response performance of the asymmetrical two-phase induction motor.

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**REFERENCES**


