Analysis and comparison of single-phase induction motor operation from single- and two-phase power sources using MATLAB simulation results

Mohamed Adel Esmaeel¹, Nashaat M. Hussain Hassan²

¹Department of Electrical Power and Machines Engineering, Faculty of Helwan Engineering, Helwan University, Cairo, Egypt
²Electronics and Communication Engineering, Faculty of Engineering, Fayoum University, Fayoum, Egypt

ABSTRACT

Single phase induction motor (SPIM) has zero torque, this motor has many types and the main objective is to find the starting torque of the motor. This is done by providing auxiliary coils that are mechanically separated or weakened after 75% of the engine speed. The real problem here is that these auxiliary windings occupy a third of the iron core of the motor, and when they are separated or weakened, the capacity of the iron core is not fully used and the main windings must withstand the rated load current alone which shortens the life of the motor and reduces the hours of continuous operation of the motor. In this paper, a single-phase motor is fed from a single-phase power source and again from a two-phase power source, so that the auxiliary coils are not separated after 75% of the motor's speed and have a continuous role in the motor's operation. The torque and current flow in the motor are compared in both cases. Due to the rarity of the two-phase power supply in nominal uses, it can be supplied by a full bridge inverter. This comparison was provided by steady-state analysis and the results of MATLAB Simulink. This is an open access article under the CC BY-SA license.

Keywords:
MATLAB Simulink
Single-phase induction motor
Steady-state analysis
Two-phase induction motor

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vm, Vn</td>
<td>Voltage applying on the main winding and auxiliary winding (V)</td>
</tr>
<tr>
<td>Xm</td>
<td>Magnetizing reactance(Ω)</td>
</tr>
<tr>
<td>Rm, Ra</td>
<td>Stator resistance of main winding and auxiliary winding (Ω)</td>
</tr>
<tr>
<td>Xm, Xia</td>
<td>Stator leakage reactance of main winding and auxiliary winding (Ω)</td>
</tr>
<tr>
<td>Re, Xr</td>
<td>Rotor resistance and rotor leakage reactance(Ω)</td>
</tr>
<tr>
<td>Rr', Xr'</td>
<td>Referred rotor resistance and referred rotor leakage reactance (Ω)</td>
</tr>
<tr>
<td>Zm, Za</td>
<td>Leakage impedance of the main winding and auxiliary winding (Ω)</td>
</tr>
<tr>
<td>Zf, Zb</td>
<td>The forward and backward impedances (Ω)</td>
</tr>
<tr>
<td>nM, na</td>
<td>The effective numbers of turns for main and auxiliary winding (turns)</td>
</tr>
<tr>
<td>a</td>
<td>The turns ratio of the auxiliary and main winding</td>
</tr>
</tbody>
</table>

Journal homepage: http://ijpeds.iaescore.com
Analysis and comparison of single-phase induction motor operation from ...

Mohamed Adel Esmaeel
ROTATING MAGNETIC FIELD OF SINGLE PHASE INDUCTION MOTOR

The induction motors have two stator windings in space quadrature. As a result of the unbalanced voltage applied to the two-phase motor, the currents in the two windings are unbalanced and the equation of rotating mmf is [14]-[17].

\[
F(\theta, t) = \frac{1}{\sqrt{2}} \left[ (N_m I_m - N_a I_a \sin \theta_a) \cos(\omega t + \theta) - (N_a I_a \cos \theta_a) \sin(\omega t + \theta) \right] + \\
\frac{1}{\sqrt{2}} \left[ (N_m I_m + N_a I_a \sin \theta_a) \cos(\omega t - \theta) + (N_a I_a \cos \theta_a) \sin(\omega t - \theta) \right]
\]

(1)

Where,
- \( \cos(\omega t - \theta) \) and \( \sin(\omega t - \theta) \): The Term From forward-rotating field.
- \( \cos(\omega t + \theta) \) and \( \sin(\omega t + \theta) \): The Term From backward-rotating field.

The two-phase windings are unbalanced because of, the number of turns not equal i.e \( N_1 \neq N_2 \). The voltage applied to the two phases not equal and the phase shift between them is 90\(^o\).

For the above reasons, the currents flow in the two windings are not equal but the phase shift between two phases is 90\(^o\) in this case the equation for rotating mmf is [14]-[16].

\[
F(\theta, t) = \frac{1}{\sqrt{2}} \left[ (N_m I_m - N_a I_a) \cos(\omega t + \theta) + \frac{1}{\sqrt{2}} ((N_m I_m + N_a I_a) \cos(\omega t - \theta)) \right]
\]

(2)

If the two stator windings are the same and the voltage applied to the two-phase are equal and shifted from each other by 90\(^o\), the currents in the two phases are equal and the displacement between them is 90\(^o\). In this case, the two-phase are balanced and the backward rotating mmf disappears, and the equation of forward – rotating mmf is

\[
F(\theta, t) = \sqrt{2} N_m I_m \cos(\omega t - \theta)
\]

(3)

3. METHOD

The axes of the two-windings which are placed in the stator are displaced by 90\(^o\) in space. The main and auxiliary winding currents can be phase-shifted from each other by two methods. The first method, the main and auxiliary windings are completely different. The capacitor connected in series with the auxiliary winding and the voltage applied on the two windings is the same e.g. \( V_m = V_a = V \). The equivalent circuit for this case is shown in Figure 2(a). The second method, the two winding are quite similar and The voltage applied on the two-phase is shifted by angle ninety electric degrees e.g. \( V_m = V \), \( V_a = V \angle 90^\circ \), this case equivalent circuit is illustrated in Figure 2(b).

![Figure 2](image)

Figure 2. Equivalent circuit of single phase induction motor (a) SPIMCR and (b) TPIM

The currents in the main and the auxiliary windings are as follows [14]-[17].

\[
i_m = \sqrt{2} I_m \cos(\omega t)
\]

(4a)
\[ i_a = \sqrt{2} I_a \cos(\omega t + \theta_a) \] (4b)

The equivalent circuit (i) represents the main winding while (ii) represents the auxiliary winding. The main and auxiliary windings voltages for the stated equivalent circuits are,

\[ V_m = I_m(Z_{1m} + Z_f + Z_b) - j\left(\frac{E_{fa}}{a}\right) \] (5a)

\[ V_a = I_a(Z_{1a} + a^2Z_f + a^2Z_b) + jaE_{fm} - jaE_{bm} \] (5b)

\( Z_{1m}, Z_{1a}, Z_f \) and \( Z_b \) are the impedance and induced voltage of \( V_m \), and \( V_a \) respectively, and their values of both the real and imaginary parts of \( Z_f \) and \( Z_b \) are given as following:

\[ Z_f = \frac{R_f + jX_f}{2} = \frac{[R_f + jX_f(j2\pi f + 1)]}{2} \]

\[ Z_b = \frac{R_b + jX_b}{2} = \frac{[R_b + jX_b(j2\pi f + 1)]}{2} \]

\[ Z_{1m} = R_{1m} + jX_{1m} \]

\[ Z_{1a} = R_{1a} + jX_{1a} + jX_c \]

By solving the (5a) and (5b) we are to be obtain \( I_m \) and \( I_a \). The difference between the backward torque and the forward torque is known as the torque developed [14-17].

\[ T = T_f - T_b = \frac{P_{gf} - P_{gb}}{a_{syn}} \] (6)

The gap power may be written as follows:

\[ P_{gf} - P_{gb} = (|I_m|^2 + |aI_a|^2)(R_f + R_b) + 2a|I_a||I_m|(R_f + R_b)\sin(\theta_a - \theta_m) \] (7)

For the starting and operation of SPIMs this analysis is valid as both main and auxiliary windings are in operation. It can be applied for the two-phase motor. For the starting,

\[ T = \frac{2a|I_a||I_m|(R_f + R_b)}{a_{syn}}\sin(\theta_a - \theta_m) = K|I_a||I_m|\sin\alpha \] (8)

### 4. RESULTS AND DISCUSSION

#### 4.1. Theoretical results

The parameters of the machine, TPIM and SPIMCSCR, used in the steady-state analysis are taken from reference [17]-[25] and a single phase 120 V, 60 Hz, four- pole two phase motor has the following equivalent circuit parameters:

\[ X_{in}=2.0 \Omega, \ R_{in}=1.5 \Omega, \ R_f=1.5 \Omega, \ X_{in}=48 \Omega, \ X_{1a}=2.0 \Omega, \ R_{1a}=1.5 \Omega, \ X_{1}'=1.5 \Omega, \ C=30 \mu F, \ a=1 \]

These data are used in the previously equivalent circuit model and the obtained steady state characteristics are plotted in the following figures. Figure 3 shows that the torque for the two phase motor is higher than the torque for the single phase motor with the capacitor run at any value of slip. Figure 4 shows that the torque is higher for TPIM than the SPIMCSCR at any value of slip. The torque of the SPIMCSCR decreases sharply due to the separation of the capacitor start when the speed reaches 75% of the rated speed.

Figure 5 shows that the current flow in the main winding is higher than current flow in the auxiliary winding. This is due to either the impedance of auxiliary coil is higher than impedance of the main coil, or the value of the capacitor run is small. This indicates that the effect of the auxiliary coil in motor operation is weak relative to the main coil.

Figure 6 shows that the current flow in the auxiliary winding is higher than current flow in the main winding because the value of the capacitor starting is great, to achieve angle 90 degree between the two coils. When the speed reaches 75% of rated speed the capacitor start disconnects from the circuit and the capacitor run remains connected in series with the auxiliary coil. So, the current of the auxiliary coil is less than the current flow in the main coil and also in this motor (SPIMCSCR) the effect of the auxiliary coil in motor operation is weak relative to the main coil.
Figure 7 the current slip curves of balance two-phase motor. The currents flow in main and auxiliary winding are equal because the two windings are equal in the number of turns, distribution of windings and the voltage applied on the two winding are equal. Comparing the curve in Figure 7, with the curves in Figures 5 and 6 the auxiliary current \( I_a \) is greater than in Figures 5 and 6 in the operation conditions and equal to the main current. So the auxiliary current \( I_a \) of TPIM affects the value of the rotating magnetic field and motor operation.

Figure 3. Torque slip curve of SPIMCR and TPIM

Figure 4. Torque slip curve of SPIMCSCR and TPIM

Figure 5. The current slip curves of SPIMCR

Figure 6. The current slip curves of SPIMCSCR

Figure 7. The current slip curves of TPIM
Analysis and comparison of single-phase induction motor operation from … (Mohamed Adel Esmaeel)

Figure 8 comparison between the torque slip characteristic of TPIM when the applied voltage is changed on one phase and SPIMCSCR. The torque slip characteristic of TPIM reduced when the voltage for any phase reduced and vice versa. If the voltage becomes zero, the torque of TPIM is almost equal to the torque of SPIMCSCR (dash line).

Figure 9 comparison between the torque slip characteristic of TPIM with control phase shift between two phases and torque slip of SPIMCSCR. The torque-speed characteristics of TPIM are reduced when the phase shift is reduced about ninety electric degrees, the highest value for the angle is 90°. If the phase shift between two-phase equal zero, the torque of TPIM is higher than the torque of SPIMCSCR during the operation speed. This is due to the impedance of the auxiliary coil for TPIM is lower than the impedance of auxiliary coil for SPIMCSCR.

Figure 8. Torque slip curve of SPIMCSCR and TPIM with the voltage control of TPIM
Figure 9. Torque slip curve of SPIMCSCR and TPIM with the phase shift control of TPIM

4-2. Simulation results

The simulation of a TPIM and SPIMCSCR using the same data is used in steady-state analysis utilize the MATLAB/SIMULINK software performs the simulation, the model block diagram is shown in Figure 10. Figure 11 and Figure 12 shows that the main current is higher than the auxiliary current during starting time and steady-state operation. The RMS value of the main current is 6 ampere and auxiliary current is 2 ampere.

Figure 10. Simulink simulation model for TPIM, SPIMCR and SPIMCSCR

Figure 13 and Figure 14 show the main and auxiliary currents are equal during starting time and steady state operation. The RMS value of this current is 2 ampere. Figure 15 shows that the TPIM motor’s rotor reaches its rated speed more stably than SPIMCR. Thus if the load increases by the same value on the two motors, TPIM keeps the speed almost constant without any vibrations in the speed value.
Figure 11. The main and auxiliary currents for SPIMCS during start time and steady state operation

Figure 12. The main and auxiliary current for SPIMCS steady state operation

Figure 13. The main and auxiliary current for TPIM during start time and steady state operation

Figure 16 shows the electromagnetic torque of TPIM and SPIM during start time and steady-state operation. The electromagnetic torque of TPIM is constant at about 1 N.M but SPIMCR oscillates at 0.05 N.M. Table 1 shows a comparison between two phase induction motor and single phase induction motor with capacitor start capacitor run. Table 1 shows a comparison of the previous results, and it was not compared with other researches due to the difference in the data of electric motors, but the results match with other research with the different method of comparison.
Analysis and comparison of single-phase induction motor operation from ... (Mohamed Adel Esmaeel)
5. CONCLUSION

In this paper, a comparison between TPIM and SPIMCSCR is presented, in terms of torque value and current flow in the coils of all motors. This comparison was carried out using MATLAB simulations that show, From the previous comparison of the results, using TPIM for loads that require high starting torque and speed stability is the best in use and the longest in the operating life of the motor because the current is distributed on the two coils equally. The starting torque and the maximum torque of the TPIM motor are much greater than that of the SPIMCSCR motor. Also, motor control methods can be used to make the maximum torque the same as the starting torque and thus produce high torque with low current distributed over two windings compared to a single phase motor.

REFERENCES


10.1109/IAS.2005.1518298


BIOGRAPHIES AUTHORS

Mohamed Adel Esmaeel Salama was born in Cairo, Egypt, in 1980. He received the B.Sc. M.Sc. and Ph.D. in 2004, 2009, and 2012 respectively from Helwan University and AL-Azhar University. He works as a lecturer for the Faculty of Engineering and Technology, Helwan University. His research interests include renewable energy, electrical machines, power electronic, photovoltaic, energy-storage applications, and space power applications. He can be contacted at email: Mohamed.adel121980@yahoo.com, Mohamed.adel.80@h-eng.helwan.edu.eg

Nashaat M. Hussien Hassan was born in Quena, Egypt, in 1977. He received his B.Sc. in communication and electronics engineering from Al-Azhar University – Egypt in 2002. In 2005, he received his M.Sc. degree in communication and electronics engineering from (C.N.M.) National Center of Microelectronics, Seville University – Spain. In 2009, he received his Ph.D. in Digital Integrated Circuit Design for the Applications of Image processing from (C.N.M.) National Center of Microelectronics, Seville University – Spain. In October 2019 he was promoted to the position of an Associate Professor position. Currently, he is working as an associate professor in the department of Electronics & Electrical communication, Faculty of Engineering, Fayoum University – Egypt. His research interest includes algorithms development (analysis, design and improvement) and full-cycle software & Hardware product development (Matlab, C, C++, VHDL, FPGA, and Xilinx) in the following Applications: digital Image processing, Biomedical Image Processing, Computer Vision, Artificial Intelligence. He authored and co-authored more than 30 publications, in international journals and conference proceedings of Image Processing & Bio-Medical Image processing and Computer Vision Technologies. He is a reviewer in many international journals and conferences. He can be contacted at email: nmh01@fayoum.edu.eg.