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DETERMINATION OF OPTIMUM ELECTRICAL SHIFT ANGLE OF AUXILIARY WINDING TO IMPROVE PERFORMANCE OF TWO PHASE INDUCTION MOTOR

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Abstract- In a conventional two phase induction motor stator windings are orthogonal together, electrically. In this paper, affirming results obtained from simulations and using theoretical results in this field, we discuss and analysis stator winding of two phase electric motor in orthogonal and un-orthogonal states reaching optimum angle for better performance of this motor, firstly in stationary reference frame a model for 2-phase induction motors with non-orthogonal stator windings and difference between theoretical results and practical samples of this motor are given, and then using Matlab simulation and Finite Element Analysis software, motor behavior is simulated. The results of the simulation indicate improvement in motor performance in lieu of some special angles differences between stator windings relative to orthogonal state.

Keywords: Stationary Reference Frame, Transient State Performance, Non-Orthogonal.

I. INTRODUCTION

Two phase induction motors or TPIM when three phases is not available slowly at low power applications are used frequently [1]. There are several choices for developing such machines, one of them consists of local shift of stator winding from orthogonal state to each another. Torque-slip character manipulate with shifting the secondary coils from orthogonal position. First a model for non-orthogonal TPIM presented at stationary reference frame [2], then effect of shifting stator winding on the torque and current of motor analysis with simulation with simulation software. This analysis is at steady and transient state simulations result show improvement of motor performance as some special longitudinal dihedral between stator winding to orthogonal state.

II. NON-ORTHOGONAL TPIM MODEL AT STATIONARY REFERENCE FRAME

Search method of TPIM model at stationary reference frame is offered at [2, 3]. Figure 1 shows a normal TIMP. Figure 2 is offered with help of Figure 1 for a TIMP with non-orthogonal stator winding.

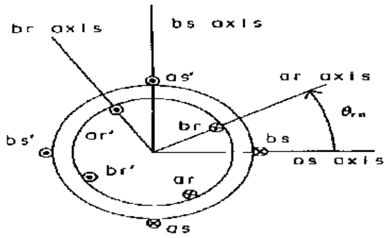

Figure 1. Two pole with orthogonal stator winding

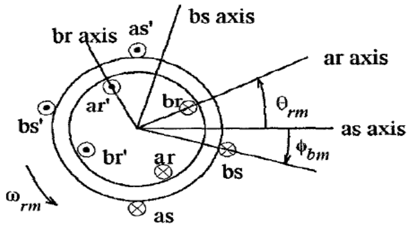

Figure 2. Two pole with non-orthogonal stator winding

In Figure 2, φ_{bm} shows shift angle, and it is positive direction is inverse to machine rotation. The mathematical relations of above machine attained like to its similar machine, but its mathematical relationships are more complex and can be used only in stationary reference frame. A TIMP mathematical model with orthogonal stator winding can be gained when electrical shift angle be zero [2]. It is assumed that stator winding are sinusoidal distributed and the machine is in term of linear magnetic. An iron loss is also overlooked. After lengthy calculations the following voltage and link charges are obtained at above relation:

$$v_{qs} = R_m i_{qs} + \frac{1}{\omega_b}\frac{d}{dt}(\psi_{qs}) \tag{1}$$

$$v_{ds} = R_a i_{ds} + \frac{1}{\omega_b}\frac{d}{dt}(\psi_{ds}) \tag{2}$$

$$R_r i'_{qr} - \frac{1}{k}\frac{\omega_r}{\omega_b}\psi' dr + \frac{1}{\omega_b}\frac{d}{dt}(\psi'_{qr}) \quad = 0 \tag{3}$$

$$k_2 R_r i'_{dr} + \frac{k\omega_r}{\omega_b}\psi'_{qr} + \frac{1}{\omega_b}\frac{d}{dt}(\psi'_{dr}) = 0 \tag{4}$$

$$\psi_{qs} = (X_{sm} + X_m) i_{qs} - kX_m \sin(\varphi_{bm}) i_{ds} + X_m i'_{qr} \tag{5}$$

$$\begin{aligned}\psi_{ds} &= -kX_m \sin(\varphi_{bm}) i_{qs} + (X_{sa} + k_2 X_m) - \\ &-kX_m \sin(\varphi_{bm}) i'_{qr} + k_2 X_m \cos(\varphi_{bm}) i'_{dr}\end{aligned} \tag{6}$$

$$\psi'_{qr} = X_m i_q - kX_m \sin(\varphi_{bm}) i_{ds} + (X_{sr} + X_m) i'_{qr} \tag{7}$$

$$\psi'_{dr} = k_2 X_m \cos(\varphi_{bm}) i_{ds} + k_2 (X_{sr} + X_m) i'_{dr} \tag{8}$$

$$\begin{aligned}T_e &= P / [2(\frac{X_m}{\omega_b}).k(i_{qs} i'_{dr} - i_{ds} i'_{qr} \cos(\varphi_{bm}) - \\ &-k i_{ds} i'_{qr} \sin(\varphi_{bm}))]\end{aligned} \tag{9}$$

$$T_e - T_L = J \frac{d}{dt}(\omega_r) \tag{10}$$

where V_q and V_d are voltages, d_s and q_s stator axes, R_m, X_{sm} and R_a, X_{sa} are resistors and leakage reactance of d_s and q_s axes, X_m is magnet charger reactance, φ_{bm} is electrical shift angle, ω_b and ω_r are angular speed.

$$\psi_{qs} = \omega_b \left(\int \left(v_{qs} - R_m \, i_{qs} \right) dt \right) \tag{11}$$

$$i_{qs} = \frac{1}{X_{sm} + X_m} \left(\psi_{qs} + kX_m \sin\left(\varphi_{bm}\right) i_{ds} - X_m i'_{qr} \right) \tag{12}$$

Block diagram at Figure 3 is offered for simulation Equations (11) and (12):

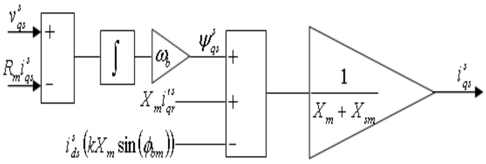

Figure 3. Block diagram for calculate i'_{qs}

So other equation are simulated Equations (9) and (10) are used for calculating system speed. As mentioned, above equations are correct at stationary reference frame, for shifting the stator variables to abs system inverse of K_{2s} change matrix is used.

$$\left(K_{2s}\right)^{-1} = \begin{bmatrix} \cos\left(0\right) & \sin(0) \\ \sin(0) & -\cos\left(0\right) \end{bmatrix}^{-1} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \tag{13}$$

For shifting the rotor variables to abr system inverse of K_{2r} change matrix is used:

$$\begin{aligned}\left(K_{2r}\right)^{-1} &= \begin{bmatrix} \cos\left(0-\theta_r\right) & \sin(0-\theta_r) \\ \sin(0-\theta_r) & -\cos\left(0-\theta_r\right) \end{bmatrix}^{-1} = \\ &= \begin{bmatrix} \cos\left(\theta_r\right) & -\sin(\theta_r) \\ -\sin(\theta_r) & -\cos\left(\theta_r\right) \end{bmatrix}\end{aligned} \tag{14}$$

III. SIMULATION RESULTS

After TPIM simulation at uncharged state, following results are obtained.

a) $\varphi_{bm} = 0$, the state is normal two phase induction motor with orthogonal stator winding simulation result are shown at Figure 4.

b) $\varphi_{bm} = 0.393$ rad, simulation results is shown in Figure 5.

c) $\varphi_{bm} = -0.393$ rad, simulation result is shown in Figure 6.

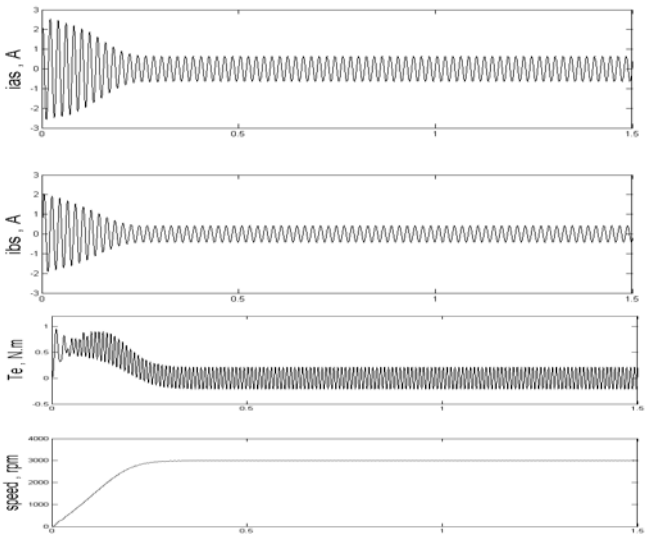

Figure 4. Input currents, torque and speed at $\varphi_{bm} = 0$ state

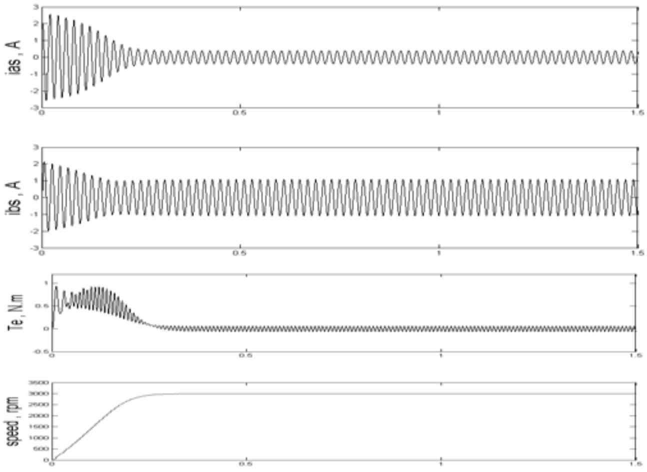

Figure 5. Input currents, torque and speed at $\varphi_{bm} = 0.393$ rad state

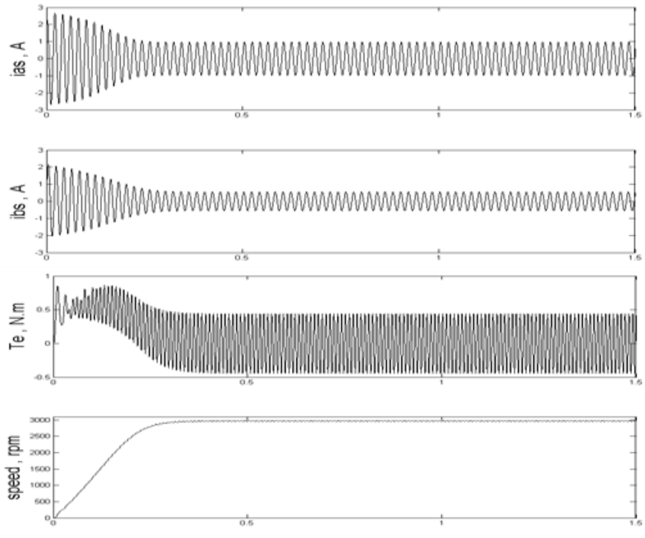

Figure 6. Input currents, torque and speed at $\varphi_{bm} = -0.393$ rad state

Figures 4, 5 and 6 show important result, which most important of these is as follow:

- nominal torque increase for some positive values of electrical angular displacement.

- nominal torque decrease for some negative values of electrical angular displacement.
- torque ripple increases for some negative values of electrical angular displacement.
- torque ripple decreases for some positive values of electrical angular displacement.
- start-up torque increases for some negative values of electrical angular displacement.
- start-up torque decreases for some positive values of electrical angular displacement.
- machine speed ripple decreases for some positive values of electrical angular displacement.
- machine speed ripple increases for some negative values of electrical angular displacement.
- no-load losses decreases for some positive values of electrical angular displacement.
- no-load losses increases for some negative values of electrical angular displacement.
- start-up current decreases for some positive values of electrical angular displacement.
- start-up current increases for some negative values of electrical angular displacement.
- break-down torque increases for some positive values of electrical angular displacement.
- break-down torque decreases for some negative values of electrical angular displacement.

All the angles are not checked. It is effort that more information gets below. We get torque-slip moment and continue slip torque for some different value of electrical angular displacement (Figures 7, 8, 9 and 10).

The torque diagram almost equals to average value of torque moment, because motors power is low sometimes negative values increases start-up torque (Figures 9 and 10) and positive values decrease start-up torque but increase the break-down nominal torque. So less pulsation torque with use of some positive values of electrical angular displacement is gained with negative value amount of this pulsation torque increases.

The very important point in practical sample of this motor is finding out factors affecting differences between simulation and practical findings. One of available ways for affirming design practical is finite element analysis. Figures 11-14 are related to a 2-polor and 2-phase stator winding design in orthogonal state.

Figures 15 and 16 show mentioned winding in non-orthogonal state with +15° and -15°, respectively. In this motor reaching only angles are correct multiples from 15°, is possible. So, this point is one of the differences between theoretical and practical results, because, reaching every angle is impossible, practically. Figures 14, 15 and 16 show flux lines in orthogonal and non-orthogonal designs with +15° and -15° angles.

From these figures, it is clear that penetrating electromagnetic waves in non-orthogonal winding with angle difference +15° is better than other (Figure 16). So, reduction in nuclear losses in mentioned angle is expected.

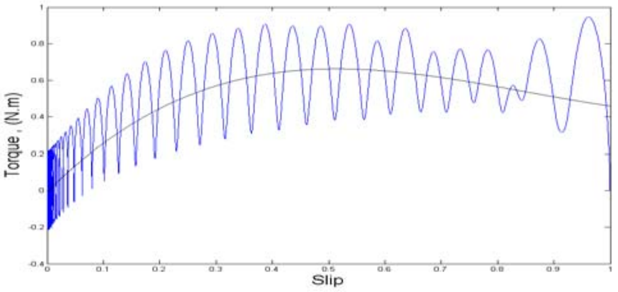

Figure 7. Torque-slip characteristic steady and transient state $\varphi_{bm} = 0$

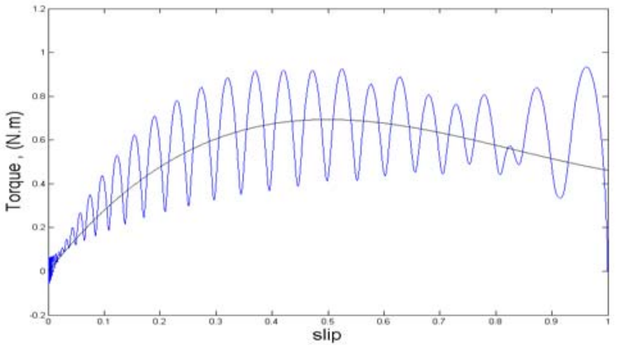

Figure 8. Torque-slip characteristic steady and transient state $\varphi_{bm} = 0.393$ rad

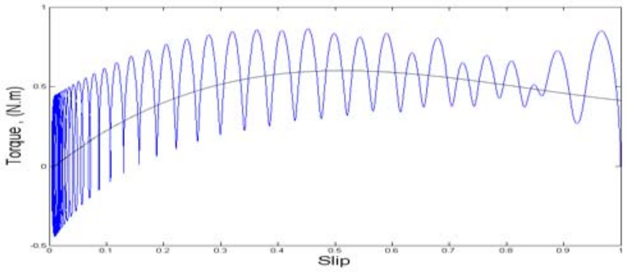

Figure 9. Torque-slip characteristic steady and transient state $\varphi_{bm} = -0.393$ rad

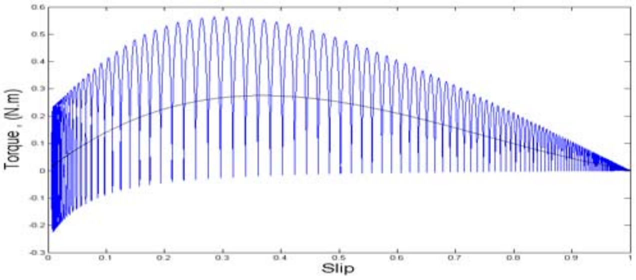

Figure 10. Torque-slip characteristic steady and transient state $\varphi_{bm} = -1.57$ rad

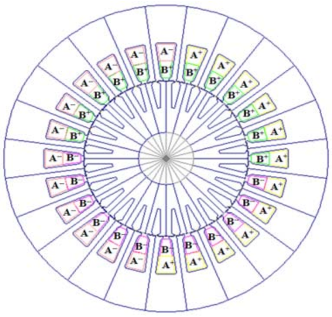

Figure 11. 2-polor, 2-phase stator windings design in orthogonal state

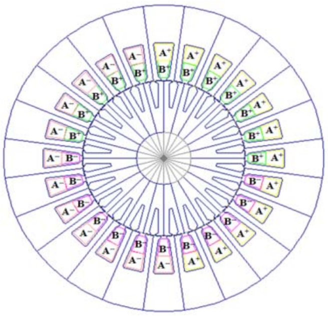

Figure 12. 2-polor, 2-phase stator windings design in un-orthogonal state with relocation angle +15°

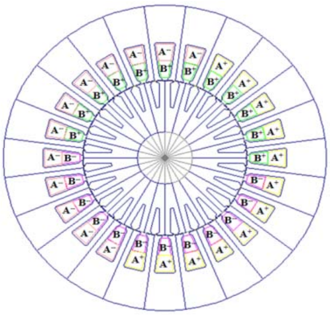

Figure 13. 2-polor, 2-phase stator windings design in un-orthogonal state with relocation angle -15°

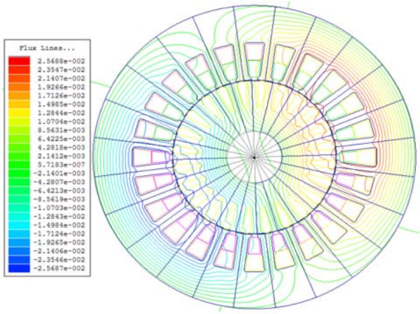

Figure 14. Magnetic flux lines in orthogonal windings in *t*=1sec

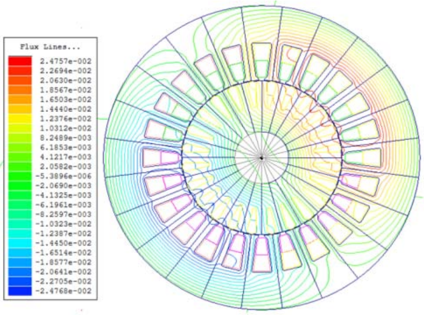

Figure 15. Magnetic flux lines in un-orthogonal windings with -15° in *t*=1sec

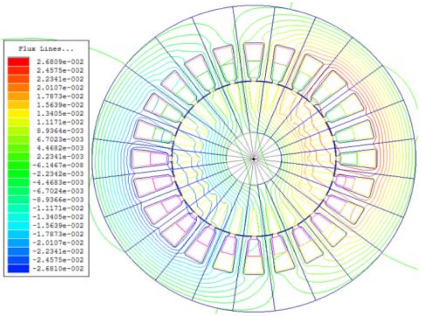

Figure 16. Magnetic flux lines in un-orthogonal windings with +15° in *t*=1sec

Figure 14 shows the motor speed characteristic during free accelerating in orthogonal and non-orthogonal designs with +15° and -15° angles. From Figure 14, it is known that motor performance with orthogonal winding is inappropriate and maximum motor speed is reached 2500 rpm. But by using non-orthogonal windings, speed characteristic is improved and reaching higher speeds than 2800 rpm is possible.

The reason for this as mention before is increasing in torque advance component and start-up torque value in non-orthogonal designing. Figure 17 shows that two un-orthogonal have the same accelerating characteristic, but +15° angle take precedence over -15° angle due to penetrating electromagnetic waves (Figures 14, 15 and 16). Thus, the goal is that by using positive relocation angle, motor performance improves considerably, that simulation and practical results affirm this point, too.

Improving performance includes increases in start-up torque and permanent torque and increasing final speed of motor. In addition, because of change in electromagnetic waves penetration in stator and rotor nucleus reduction in nucleus losses is possible. Decreasing in nucleus losses provide increasing temperature of motor performance.

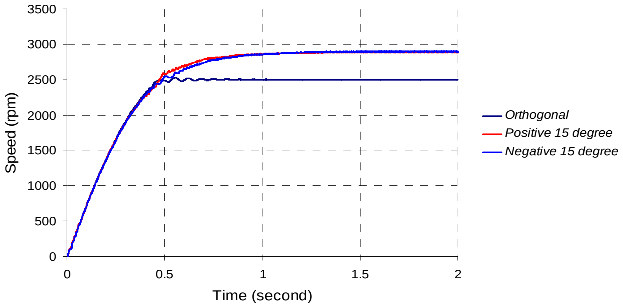

Figure 17. Speeding out motor in accelerating in orthogonal and non-orthogonal windings, freely with +15° and -15° angles differences

In practice providing positive relocation angle is not difficult. But the main point is that accessing each angle is impossible practically. For example in motor under simulation the best relocation angle $\varphi_{bm} = 0.393 \text{ rad} = 22.5\ °$ was calculated. But as Figures 11, 12 and 13 show it is only possible to reach angles are correct multiple from +15°.

The theoretical results of a motor 1 kW in two states with zero relocation angle and positive relocation angle are given are shown in Table 1. The practical values are also shown in Table 2. As it was mentioned, difference between theoretical values in Table 1 and practical values in Table 2 indicates that accessing angle difference $\varphi_{bm} = 0.393 \text{ rad}$ is practically impossible.

Table 1. Theoretical results

Current	Ripple torque	Nominal torque	φ_{bm} relocation angle
5.5 A	9%	3.41N.m	$\varphi_{bm} = 0$
5A	5%	3.62 N.m	$\varphi_{bm} = 0.393 \text{ rad} = 22.5\ °$

Table 2. Experimental results

Current	Ripple torque	Nominal torque	φ_{bm} relocation angle
5.8 A	9.5%	3.3 N.m	$\varphi_{bm} = 0$
5.4A	7%	3.42 N.m	$\varphi_{bm} = 0.393$ rad = 22.5 °

To reduce difference between theoretical and practical results designing primary stator winding (initial orthogonal winding) should provide reaching optimal relocation angle practically.

IV. SIMULATION ANALYSIS

Dynamic behavior and the steady state of a TPIM with non-orthogonal stator windings were obtained by analysis and simulation. Also in variable source voltage state and variable frequency the analysis can be performed in the same way. Similar results below are valid in all states:

1- Higher break-down in slip torque curve and higher nominal torque reduction in pulsation torque and start-up torque for some positive electrical angle relocation values are obtained. Also lower unload losses (because to low current amplitude in the same power) reduction in initial start-up current and decreasing instant speed ripple can be added to above cases.

2- Start-up torque and higher pulsation torque, lower nominal torque and break-down in slip-torque curve for some negative electrical angle relocation are obtained. Therefore considering characteristic such as nominal torque value pulsation torque, start-up torque and current losses and appropriate electrical relocation angle can be found. This angle depends on motor characteristic.

V. EXPERIMENTAL ANALYSIS

1- Non-reaching angle differences $\varphi_{bm} = 0.393$ rad were proved practically.

2- nominal torque value current and torque ripple in theory and simulation and obtained practical results in $\varphi_{bm} = 0$ or the same relocation angle have quantitative difference which is resulted from limitation in reaching angles are correct multiples from +15°.

3- Another reason is practical and theoretical values unsteady is resulted from oscillations in penetrating electromagnetic waves in stator and rotor nucleus and nucleus losses because penetrating electromagnetic waves in non-orthogonal winding with angle difference +15° is better than other designs.

4- To reduce difference between practical and theoretical results and also to decrease losses and control motor temperature it is very critical to select optimal angle which is only reaching angles are correct multiples from +15°.

VI. CONCLUSIONS

Trough the conducted studies on the theoretical and practical results of two-phase and two-pole electrical machines in the orthogonal and non-orthogonal stator winding modes and also the simulation results of the Finite Element Analysis software, it was cleared that the best structural displacement angle of the stator winding of these machines is when the angle is the coefficient of 15° electrical. Of course, by the conducted studies and income results it was cleared that the best mode of the displacement is on the non-orthogonal mode and having 15° electrical of the angle difference of the stator windings, because in the mode:

1- The most electromagnetic waves penetration is occurred on the machine rotor nuclear.

2- The internal losses of these machines is minimized in the so-called mode.

REFERENCES

[1] A.E. Fitzgerald, C. Kingesly, "Electric Machinery", McGraw-Hill, Tokyo, 1983.

[2] P.C. Kraus, O. Wasynczuk, S.D. Sudhoff, "Analysis of Electric Machinery and Drive System", IEEE Press, 2002.

[3] T.A. Walls, S.D. Sudhoff, "Analysis of a Single Phase Induction Machine with a Shifted Auxiliary Winding", IEEE Trans. on Energy Conversion, Issue 4, Vol. 11, pp. 681-686, Dec. 1996.

[4] S.D. Sudhoff, "Multiple Reference Frame Analysis of an Unsymmetrical Induction Machine", IEEE Trans. on Energy Conversion, Vol. 8, No. 3, pp. 425-423, Sep. 1993.

[5] A. Shiri, H.P. Nabi, A. Shoulaie, "Experiment and Analytical Parameter Sensitivity Analysis of Indirect Field Oriented Control of Induction Motor", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 11, Vol. 4, No. 2, pp. 1-6, June 2012.

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