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

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Article Info

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.

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NOMENCLATURE

V_m, V_a	Voltage applying on the main winding and auxiliary winding (V)
X_m	Magnetizing reactance(Ω)
R_{1m}, R_{1a}	Stator resistance of main winding and auxiliary winding (Ω)
X_{1m}, X_{1a}	Stator leakage reactance of main winding and auxiliary winding (Ω)
R_r, X_r	Rotor resistance and rotor leakage reactance(Ω)
$R_r', X_{r'}$	Referred rotor resistance and referred rotor leakage reactance (Ω)
Z_{1m}, Z_{1a}	leakage impedance of the main winding and auxiliary winding (Ω)
Z_f, Z_b:	The forward and backward impedances (Ω)
N_m, Na	The effective numbers of turns for main and auxiliary winding (turns)
a	The turns ratio of the auxiliary and main winding

jaE_{fm}, jaE_{bm}	-	The internal voltages induced in the auxiliary winding by the revoving flues Φ_{fm} and Φ_{bm} of the main winding
jE_{fa}/a, jE_{ba}/a	-	The internal voltages induced in the main winding by the revoving flues Φ_{fa} and Φ_{ba} of the auxiliary winding

1. INTRODUCTION

      Various applications use single phase induction motor (SPIM) commonly as a drive for low-power fans, pumps, and compressors. In general, a single phase induction motor has a rotating cage winding and a stator winding with an auxiliary winding with a running or running capacitor which is carried out to ensure the starting torque, the same sinusoidal voltage source supplying both windings. To model the simple and rapid determination of the characteristics of an induction motor, circuit models are applied for the assembled parameters overwhelmingly. The analysis of single-phase capacitor induction motors has been discussed in many papers. In [1], a single-phase induction motor is simulated when the two windings are completely equal, but in this paper it was not studied if the two windings were unequal and continued to operate. In [2], a high starting torque and suitable operating torque for the motor were obtained by using a control circuit with an electronic switch, which caused a cutoff in the source voltage and therefore it is possible to have some harmonics. In [3], the starting current of the motor is controlled by an AC chopper and a smooth starting is obtained, but the centrifugal switch is not dispensed with, so the auxiliary coils are disconnected after the motor is running. In [4] a mathematical model is used to show the dynamic and stable operation of the SPIMCR system for variable values of capacitor and voltage at different frequencies in the absence of load and rated load conditions. Matlab/Simulink is used to build the mathematical model for SPIMCR. Simulation results can be used to produce improved starting quality for SPIMCR. In [5], two semiconductor electrical switching from a two-phase inverter are supplied from a single-phase power supply. The static energy conditioner is used to turn the first stage of the second by 90 degrees and the circuit is not loaded with any load. This paper presents a comparison between the operation of a single-phase induction motor from a single-phase source, and this type of motor is called a capacitor start capacitor run motor (SPIMCSCR), or called a phase-split motor (SPIM), and the operation of the same motor from a two-phase power source after modification at the operating ends. The adjustment is made so that the main coils are connected to one phase and the auxiliary coils are connected to the other, and they do not need an expulsion switch or a starting capacitor. This motor is called a two-phase motor (TPIM). A two-phase power supply is provided by a full bridge inverter and studied in terms of current and torque and extracting the equation in the two different operating conditions

      Figure 1(a) shows the wiring diagram for the SPIMCS system. The single-phase motor consists of two stator windings, main windings occupying 2/3 of the iron core and auxiliary windings occupying 1/3 of the iron core. The two coils are different in the number of coils, the diameter of the wire and the distribution of the wires, and the starting capacitor comes out after 75% of the motor speed, and the current of the auxiliary coils is very little and has no real effect on the rotation of the motor. In the slotted sewers, the starting coils are completely separated after 75% of the engine speed [6]-[13].

      Figure 1(b) it shows the operation of the same previous motors as TPIM by making the voltages applied to the phases equal in amplitude and the phase shift between them is 90 electric degrees. This is so that the current in the two coils has a role in operating the motor, and an internal adjustment can be made in the motor's coils by making the coils equal in terms of the number of coils and wire diameter, and thus we get an equal current in the coils and between them an angle of 90 degrees. The mmfs generated by the currents of the two coils are balanced and the rotor mmf disappears backwards [6]-[13].
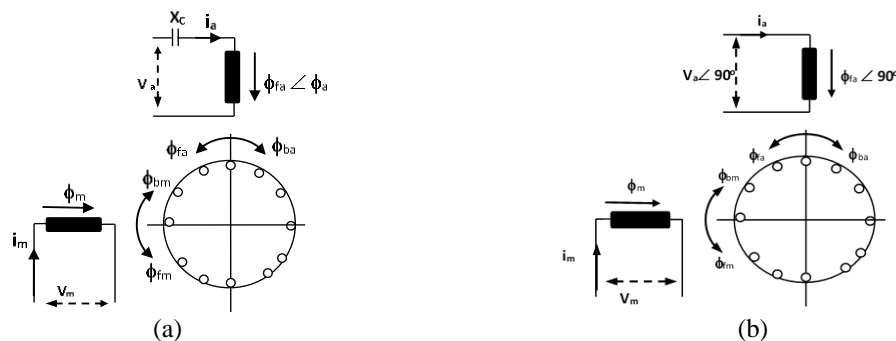

Figure 1. Wiring diagram of the single phase induction motor (a) SPIMCSCR and (b) TPIM

2.   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].

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

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 $N1 \neq N2$. The voltage applied to the two phases not equal and the phase shift between them is 90°

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

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

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°, the currents in the two phases are equal and the displacement between them is 90°. In this case, the two-phase are balanced and the backward rotating mmf disappears, and the equation of forward – rotating mmf is

$$F(\theta,t) = \sqrt{2}N_m I_m \cos(\omega t - \theta) \tag{3}$$

3.   METHOD

The axes of the two-windings which are placed in the stator are displaced by 90° 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. $Vm = V$, $Va = V\angle 90°$, this case equivalent circuit is illustrated in Figure 2(b).

(a)   (b)

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].

$$i_m = \sqrt{2} I_m \cos(\omega t) \tag{4a}$$

$$i_a = \sqrt{2}\, I_a \cos(\omega t + \theta_a) \qquad (4b)$$

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,
The voltages of the main and Auxiliary winding for both equivalent circuits are,

$$V_m = I_m(Z_{1m} + Z_f + Z_b) - j(\frac{E_{fa}}{a}) + j(\frac{E_{ba}}{a}) \qquad (5a)$$

$$V_a = I_a(Z_{1a} + a^2 Z_f + a^2 Z_b) + ja E_{fm} - ja E_{bm} \qquad (5b)$$

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:

$$Z_f = \frac{[j\frac{X_m}{2}(j\frac{X'_r}{2} + \frac{R'_r}{2s})]}{[\frac{R_r}{2s} + j(\frac{X_m}{2} + \frac{X'_r}{2})]} = R_f + jX_f \qquad , \qquad Z_b = \frac{[j\frac{X_m}{2}(j\frac{X'_r}{2} + \frac{R'_r}{2(2-s)})]}{[\frac{R'_r}{2(2-s)} + j(\frac{X_m}{2} + \frac{X'_r}{2})]} = R_b + jX_b$$

$$Z_{1m} = R_{1m} + jX_{1m} \qquad , \qquad Z_{1a} = R_{1a} + jX_{1a} + jX_c$$

By solving the (5a) and (5b) we can be to obtain Im and Ia . the difference between the backward torque and the forward torque is known as the torque developed [14]-[17].

$$T = T_f - T_b = \frac{P_{gf} - P_{gb}}{\omega_{syn}} \qquad (6)$$

The gap power may be written as follows:

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

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,

$$T = \frac{2a|I_a||I_m|(R_f + R_b)}{\omega_{syn}}\sin(\theta_a - \theta_m) = KI_a I_m \sin\alpha \qquad (8)$$

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, foure- pole two phase motor has the following equivalent circuit parameters:

X_{1m}=2.0 Ω, R_{1m}=1.5 Ω , R_r'=1.5 Ω, X_m=48 Ω , X_{1a}=2.0 Ω, R_{1a}=1.5 Ω, X_r'=1.5 Ω, C=30 μF, 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 Ia is greater than in Figures 5 and 6 in the operation conditions and equal to the main current. So the auxiliary current Ia of TPIM affects the value of the rotating magnetic field and motor operation.
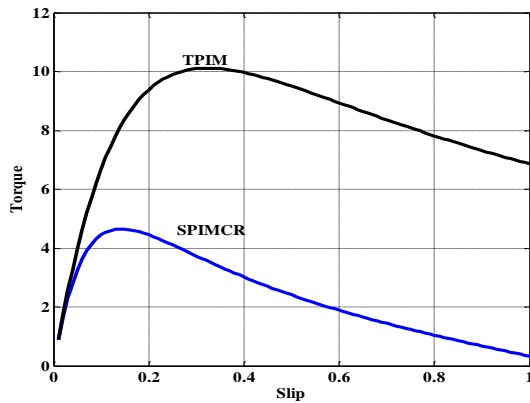
Figure 3. Torque slip curve of SPIMCR and TPIM
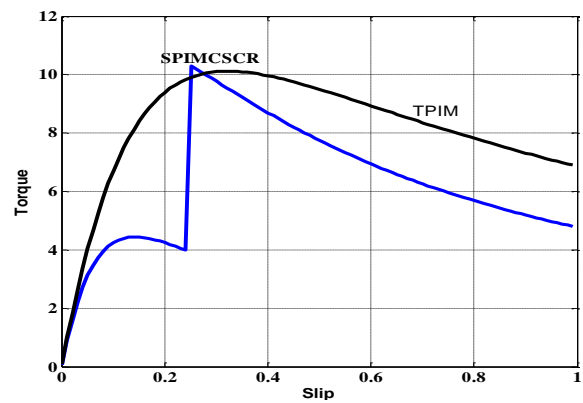
Figure 4. Torque slip curve of SPIMCSCR and TPIM
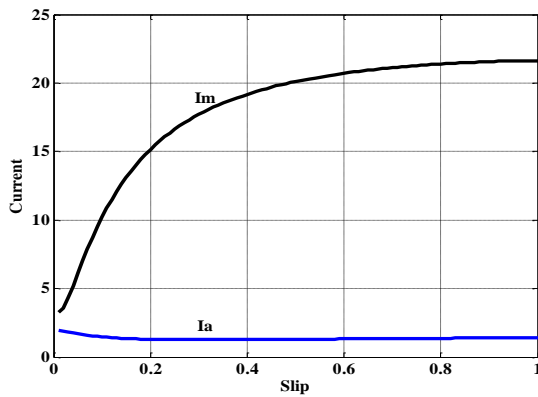
Figure 5. The current slip curves of SPIMCR
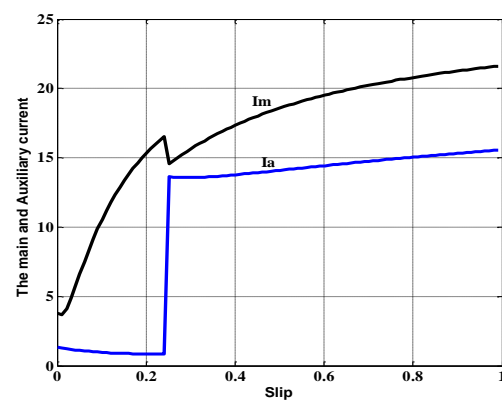
Figure 6. The current slip curves of SPIMCSCR
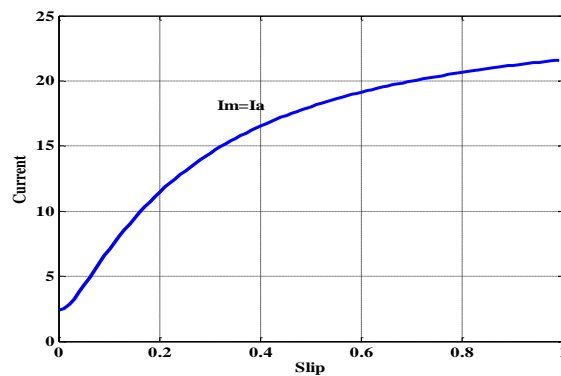
Figure 7. The current slip curves of TPIM

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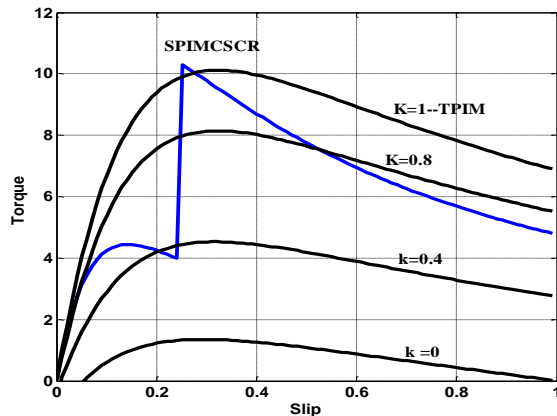
Figure 8. Torque slip curve of SPIMCSCR and TPIM with the voltage control of TPIM
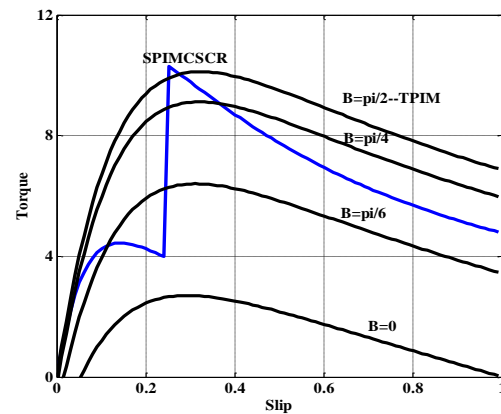
Figure 9. Torque slip curve of SPIMCSCR and TPIM with the phase shift control of TPIM

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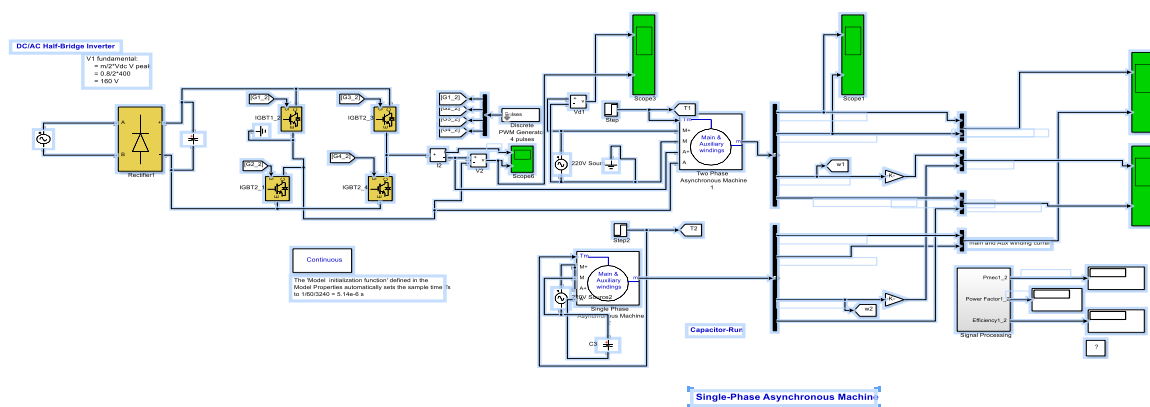
Figure 10. Simulink simulation model for TPIM, SPIMCR and SPIMCSCR

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.
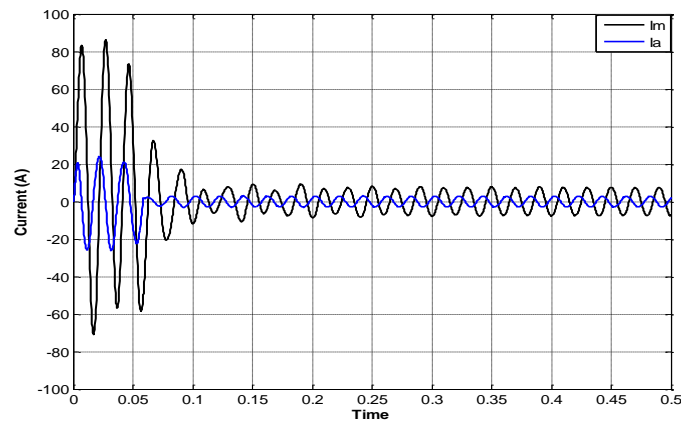
Figure 11. The main and auxiliary currents for SPIMCS during start time and steady state operation
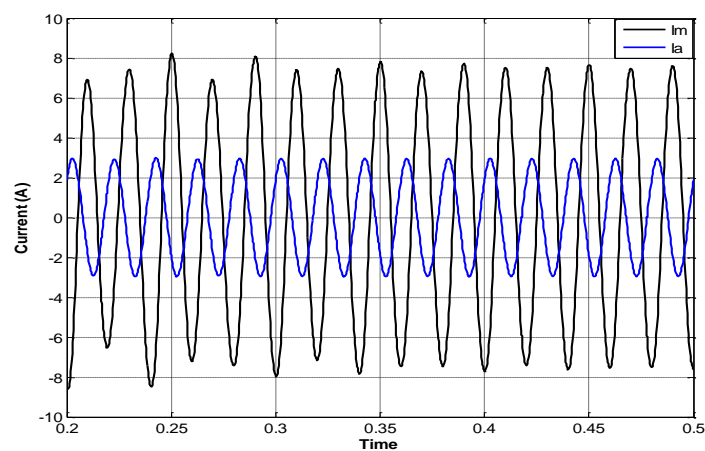

Figure 12. The main and auxiliary current for SPIMCS steady state operation
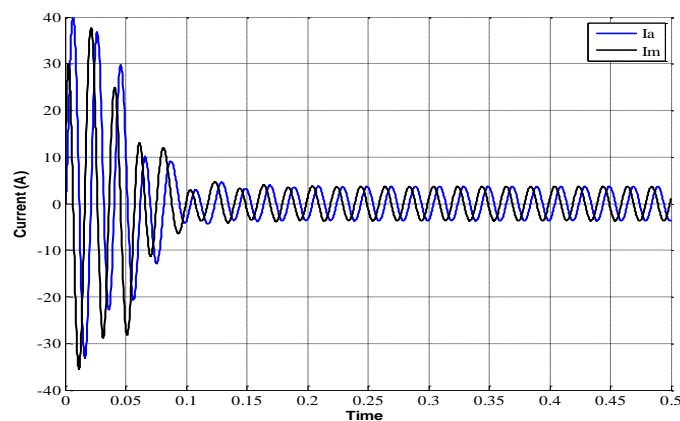

Figure 13. The main and auxiliary current for TPIM during start time and steady state operation

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.
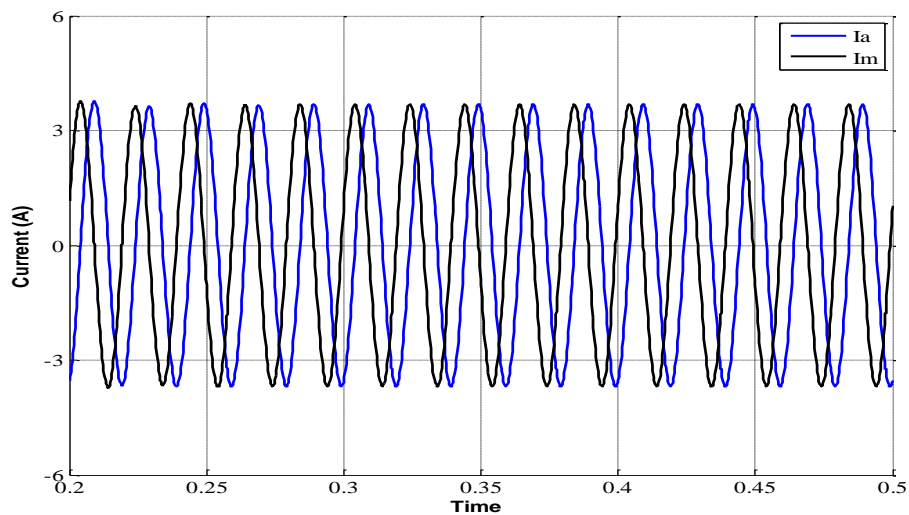
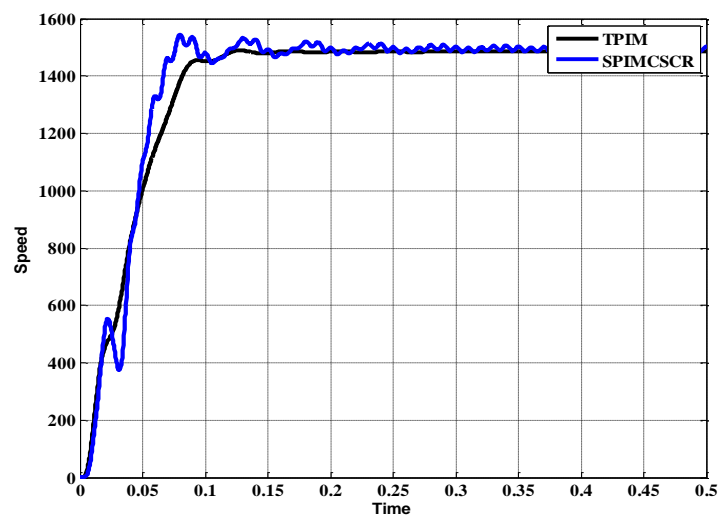Figure 14. The main and auxiliary current for TPIM during stert time and steady state operation

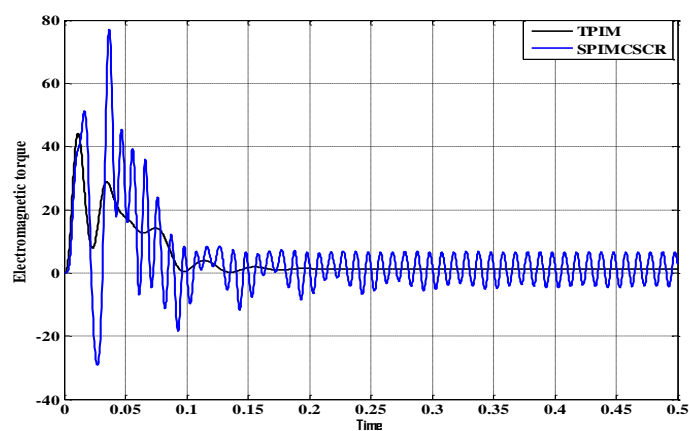Figure 15. The speed of TPIM and SPIMCSCR during start time and steady state operation

Figure16. The electromagnetic torque of TPIM and SPIM during start time and steady state operation

Table 1. Shows a comparison of previous results

Type of motor		TPIM		SPIMCSCR	
Slip		1	0.05	1	0.05
Current value from Theoretical results (A)	I_m	21	2.5	20	4.5
	I_a	21	2.5	15	1
Current value from matlab simulation (A)	I_m	30	2.5	60	7
	I_a	30	2.5	20	2
Torque	(N.M)	7	1	4	0.05
Maximum Torque	(N.M)	10 at s=0.3		4 at s=0.1	

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.

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