Kerbala Journal for Engineering Science
https://kjes.uokerbala.edu.iq/

Effect of Changing Running Capacitor on Performance of a Single –Phase Induction Motor

Marwa A. Dawood [a]*, Amer M. Ali [a]

[a] Department of Electrical Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
* Corresponding author, Email: madsf1990@gmail.com

Received: 20 March 2022; Revised: 23 June 2022; Accepted: 30 June 2022; Published: 30 June 2022

Abstract

Single-phase induction motors are used in multiple applications in which having the correct value of the capacitor linked to auxiliary winding allows the motor to work effectively. The current study used finite element analysis based on Magnet software to investigate the effect of changing the running capacitor on the performance of a single-phase squirrel cage induction motor with non-uniform stator slots, as well as using AutoCAD to model the stator due to its asymmetrical slots. The design documentation for a 0.5 hp, 36 stator slots, and 48 rotor bars, 25 µF, four-pole tested model are used to simulate the motor. The precision of model outcomes is confirmed successfully by comparing its outcomes of rated current and torque with motor nameplate data. The effect of changing the running capacitor on the performance of a single-phase induction motor is discussed in this study. To demonstrate the simulation's versatility in motor design, the auxiliary branch capacitor was modified (increasing and decreasing) and the effect of each instance on the motor's performance was investigated.

Keywords: Single-phase induction motor, FEM, Magnet software.

1. Introduction

Permanent-split capacitor motors (PSCM) work similarly to two-phase motors, which have the main and auxiliary winding permanently connected to the power supply, This means that the auxiliary winding and capacitor are powered during both starting and running. The centrifugal switch, which disconnects the starting winding from the power supply, is therefore eliminated, making the PSCM more reliable. The auxiliary winding and capacitor could be designed in such a way that the motor operates as a two-phase motor at any desired load, with more efficiency and quieter operation than a capacitor start single-phase motor. Due to the elliptical rotating electromagnetic field, which may be described using the revolving filed polygon technique for efficient prediction of motor operating characteristics, single-phase motors are quite hard for mathematical modeling, despite their simplicity in construction[1]-[2].PSCM has a good efficiency as well as has a high power factor; however, it has weak starting characteristics. For these motors, the starting torque is typically 40% to 150% of the rated load torque.

The use of a dynamic capacitor connected in series with the auxiliary winding is to achieving maximum torque by keeping the main as well as auxiliary currents in quadrature [3]. A single phase permanent split capacitor alternating current induction motor is unsymmetrical two phase AC induction motor having main and auxiliary winding with different number of turns, wire sizes, resistances, inductances and winding distributions and it works at any desired load. As a result,backward rotating magnetic field and double stator frequency would be completely eliminated which makes the motor to run quietly without noise [4] [5]. The two windings are spaced 90° apart and fed with the displacement of two phases of current 90° in time. The capacitor is permanently connected in series with the auxiliary winding which is sometimes known as start winding and the winding is not disconnected when the motor reaches the running speed. The run capacitor is designed for continuous used and cannot provide boost of a starting capacitor. The capacitor and the starting winding, which remain in the circuit during running in order to improve the power factor[6]-[5] . The PSCM has low starting torque and starting current which make it to be used with high on and off cycle rates (intermittent cycling uses) such as adjusting mechanisms, blowers with low starting torque, fans, garage door openers and gate operators [5]. The PSCM is more reliable than other single-phase motors because it requires no starting centrifugal switch. The motor can be designed for maximum efficiency, high power factor at rated load and the design can be changed for use with speed controllers. It has a wide variety of applications depending on its design[5].

The capacitors' function is to generate a leading phase current in the auxiliary winding so that the motor may start with enough torque and run as a balanced two-phase machine. The impedance of the auxiliary winding, on the other hand, varies significantly from start to run mode and is also affected by load conditions during normal operation [7]. Krikor et al., presented the effect of motor capacitor on the starting performance. The auxiliary branch capacitor changed (increasing and decreasing) and the effect of each case studied on the starting performance of the motor. The increase in capacitor value will lead to increase the value of the auxiliary current because the capacitor is connected in series with the auxiliary winding, but this increase will lead to increase in temperature, losses, and will case decrease the efficiency of the motor. In the same way, the starting torque (Tst) will increase with increased the value of the capacitor[8]. Yahaya et al., investigated the value of the capacitor of a given input parameters of a permanent split capacitor induction motor presented through MATLAB programming that will give the motor optimum efficiency. The value of that capacitor can be used to calculate the output parameters so that the electrical and mechanical characteristics of the motor can be plotted for the purpose of illustration [5].Vasilija et al., presented the effect of the size of the capacitor in the auxiliary winding on the running, and the starting characteristics of the permanent split capacitor motor. The starting torque is increased with the increase of capacitance, while the rated torque remains almost unchanged. The supply current is increased by the increase of the capacitance, while the efficiency factor is decreased at rated load operation, mainly due to increased capacitor losses. The power factor is increased by the increase of the capacitance as well [9]. Agarwal R. K proposed the analytical method of finding the value of capacitor that is suitable for split phase capacitor motors but not for the permanent split capacitor induction motor[10].

A single-phase capacitor run motor will not be able to start without capacitor, since torque is missing. Motor is not designed to give full load torque without capacitor. So even if it were to mechanically start with a force, it does not achieve full speed, and will not be able to take load. The capacitor is their just to provide the initial torque to the rotor by adding phase difference to the rotor magnetic field. If the capacitor is been removed from this kind of motor, then it will not start rotating when power will be applied to the stator winding ,as initial torque will be missing.

The present paper aims to provide a method for studying the effect of changing the capacitance value of the running capacitor on performance of a single – phase, squirrel cage induction motor having non-uniform stator slots by using finite element analysis software (Magnet) and AutoCAD to fill the research gap belonging with analyzing this special design motor.

2. Mathematical Background

The numerical analysis of the designing of the electrical machines was enhanced by the use of the finite element method based on Maxwell's equations, which are solved by partition the motor cross section area to several elements, every of which contains the magnetic vector potential (*A*) and, as a result, the magnetic flux density distribution(*B*). Because it depends on approximations, the analytical technique to calculating magnetic flux density in the various parts of the motor construction is often insufficiently accurate. As a result, the actual motor geometry, as well as all material parameters, are fed into FEM software, allowing for accurate computation of magnetic flux density distribution across whole cross section of motor. Additionally, the numerical analysis may be used to calculate a variety of motor performance, such as the motor's starting torque. FEM is used to discretize the domain of the investigated object, resulting in a group of matrix differential equations. To solve these, the temporal decomposition method is applied (TDM). The domain is divided along a time axis, as well as rather than solving each time step separately, all time steps are solved at the same time.

Below is a list of Maxwell's equations [11]:

$$\nabla \times E = \frac{-\partial B}{\partial t} \quad (1)$$

Where

E is electric field in $V.m^{-1}$

B is vector term of magnetic flux density in Tesla

$$\nabla \times H = J + \frac{\partial D}{\partial t} \quad (2)$$

D is electric displacement field in $C.m^{-1}$,

H is magnetic field in $A.m^{-1}$

J is current density in $A.m^{-2}$

$$\nabla \cdot D = \rho \quad (3)$$

$\boldsymbol{\rho}$ is resistivity of the material in Ω.m

$$\nabla \cdot B = 0 \quad (4)$$

The equations below used to calculate (input power, losses, efficiency of each case of the capacitor value) :-

$$P_{in} = V\ I\ COS\ \theta \quad (5)$$

P_{in} is the input power

$V \quad is\ \ the\ rated\ voltage$

I $is\ the\ rated\ current$

$COS\ \theta\ is\ the\ power\ factor$

$$Efficiency = \frac{P_{out}}{P_{in}} \times 100\% \tag{6}$$

P_{out} $is\ the\ output\ power$

P_{in} $is\ the\ input\ power$

$$\sum losses = P_{in} - P_{out} \tag{7}$$

3. Motor Modeling

Magnet was employed as the finite element analysis software in this study, which is a powerful electromagnetic field modeling software for engineers in the process of building and optimizing electromechanical and electromagnetic devices. Figure 1 shows the modeling flowchart with Magnet software [12].

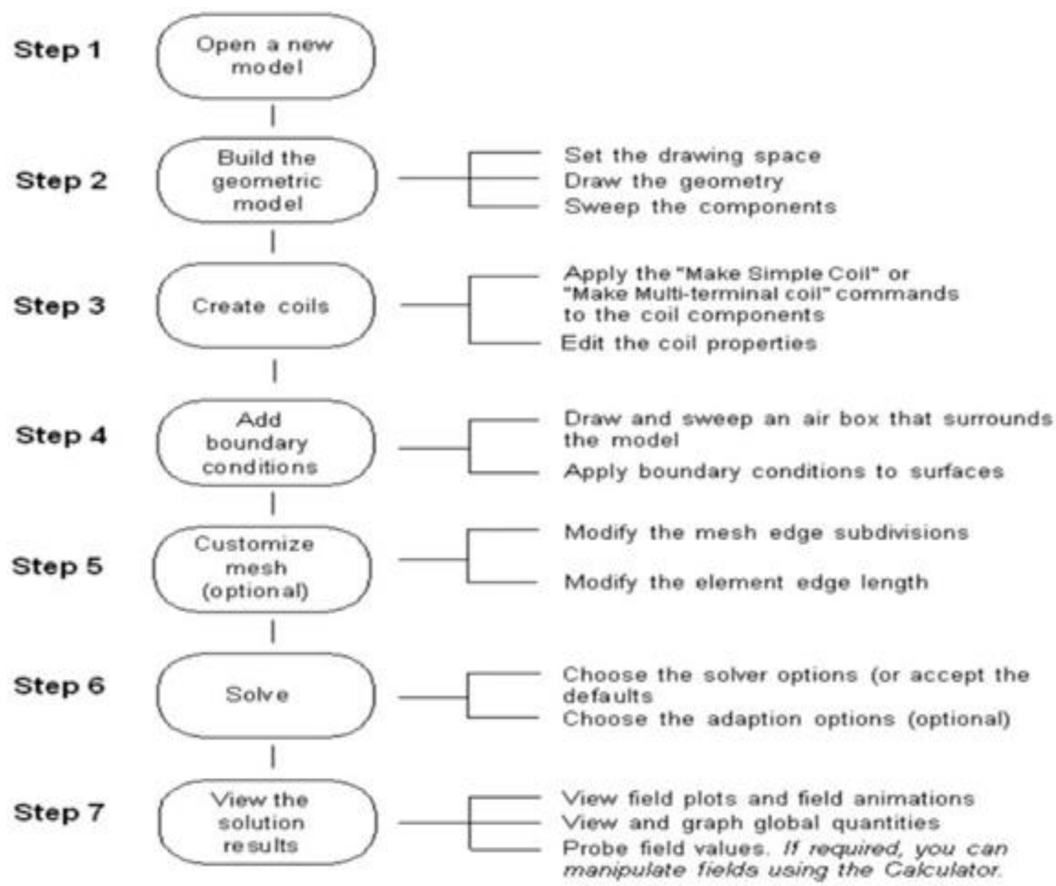

Figure 1 Modeling steps by Magnet Software.

The initial stage in defining the FEM model for motors is to enter the specific motor shape and attributes of the motor materials. The auxiliary as well as main stator windings are made of copper wire and installed in auxiliary and main stator slots, respectively, while rotor winding is squirrel cage with an aluminum rotor cage. The core is made from silicon steel type M800-65A, according to its BH curve. A 25 µF capacitor is permanently attached to the auxiliary winding during motor start-up and continuous operation. The resistance for each phase is defined, and stranded conductors define the two stator windings (main and auxiliary); a voltage source component is defined using the standard sinusoidal signal formulation. Two resistances and inductances are utilized for the front and rear parts of the stator windings, which cannot be represented using two-dimensional finite elements, and must be calculated using stator slot, turn per slot, and poles per phase, as well as the number of parallel coils [13]. Figure 2 depicts the electrical circuit connection of the test motor by Magnet.

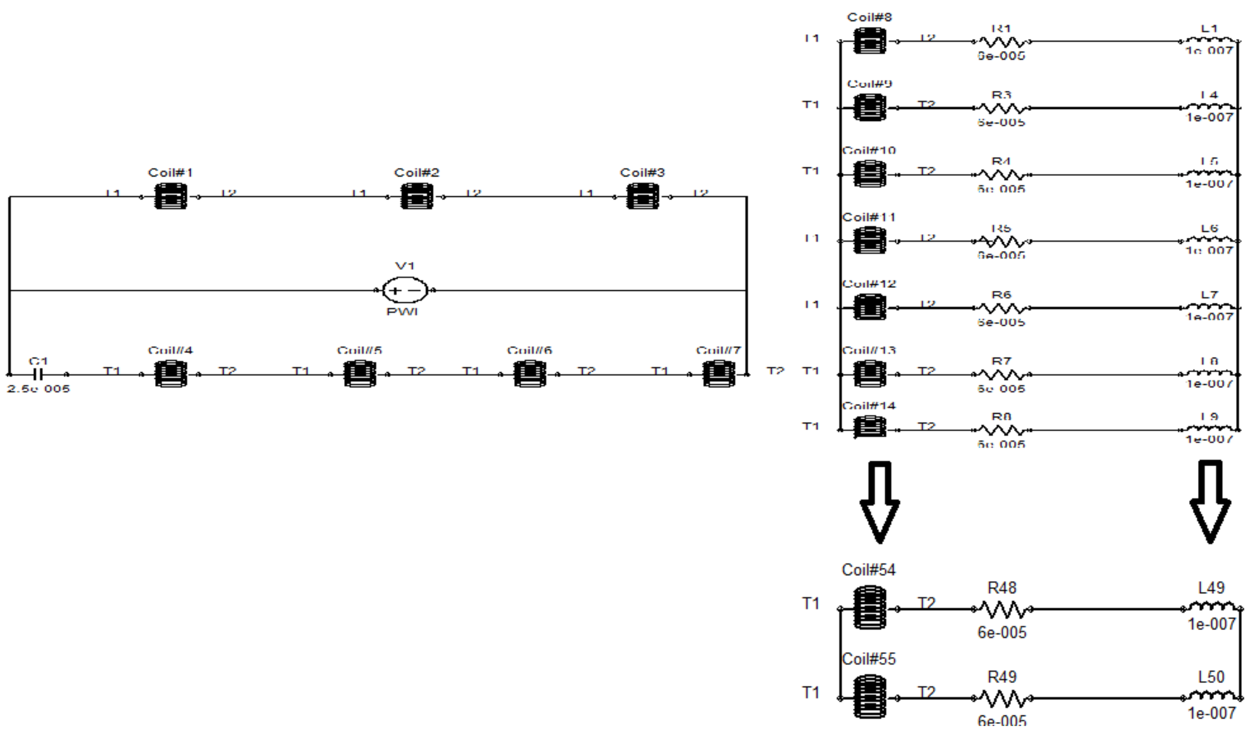

Figure 2 The electric circuit of the test motor by Magnet.

The stator model was drawn by AutoCAD software because of non-uniform stator slots. After that we transfer it to the Magnet software.

Table 1 shows the test motor nameplate data, and figure 3 shows its winding diagram, while figures 4 and 5 show the dimensions of rotor and stator lamination.

Table 1 Test motor nameplate data.

Rated output power(hp)	Rated current (A)	Rated voltage (V)
½	2.8	220
Rated torque (N.m)	**Rated speed (r.p.m)**	**Efficiency**
2.5	1425	65 %

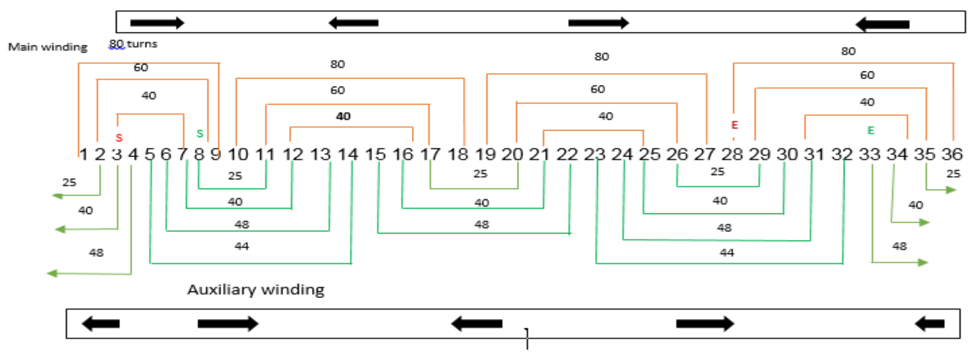

Figure 3 Winding diagram of the test motor (arrows point to current direction).

Figures 4 and 5 show the schematics of stator and rotor lamination of SPIM which manufactured in state company of electrical and electronic Industries in Baghdad-Waziriya

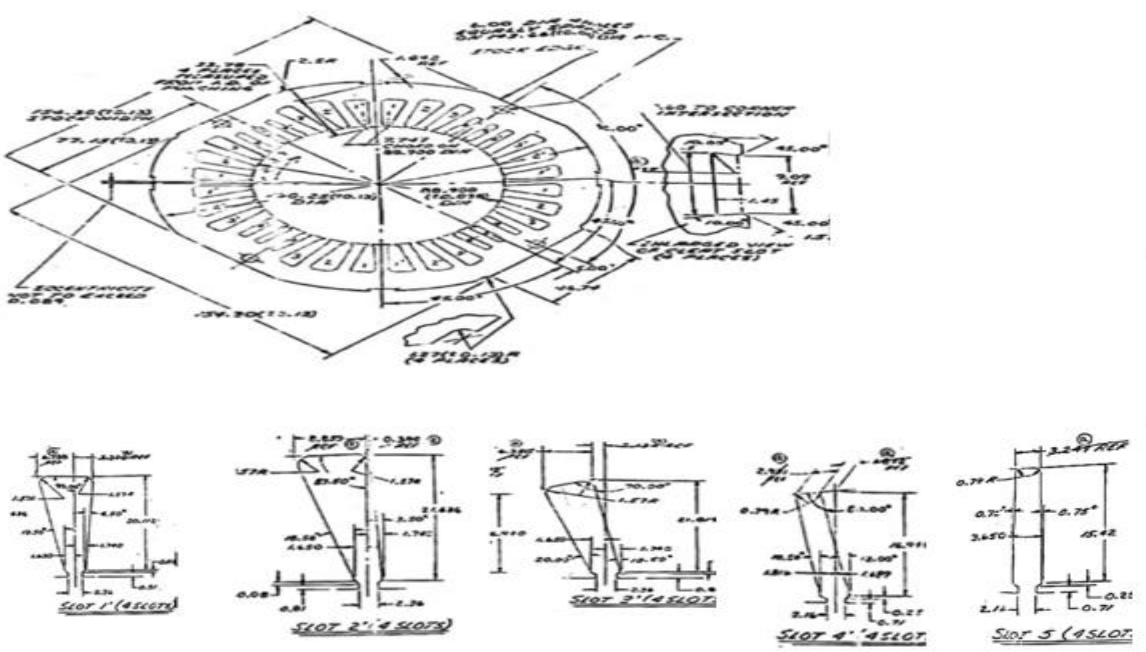

Figure 4 Stator lamination of the test motor.

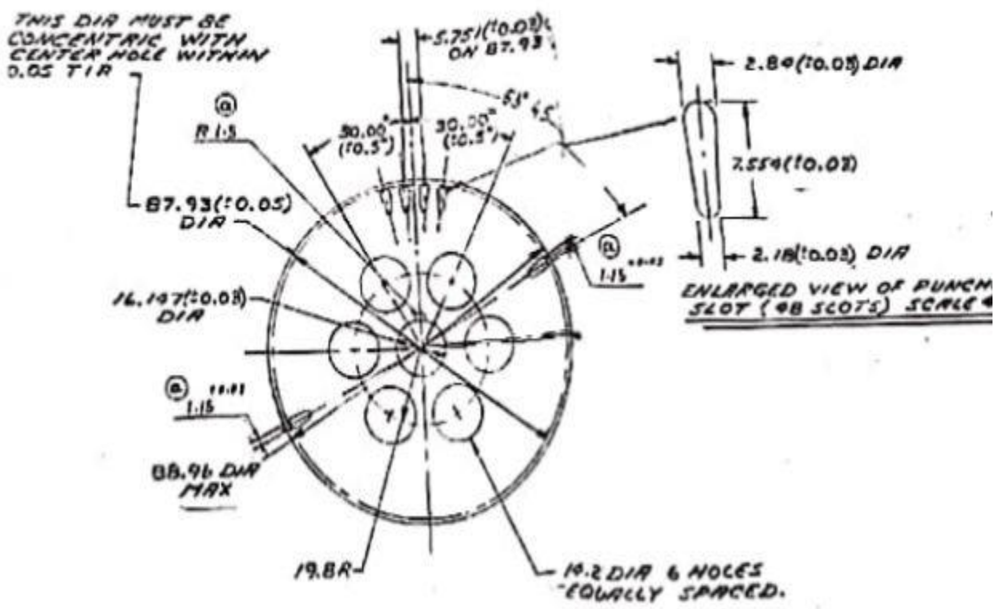

Figure 5 rotor lamination of the test motor.

The finite element mesh of the model is shown in figure 6

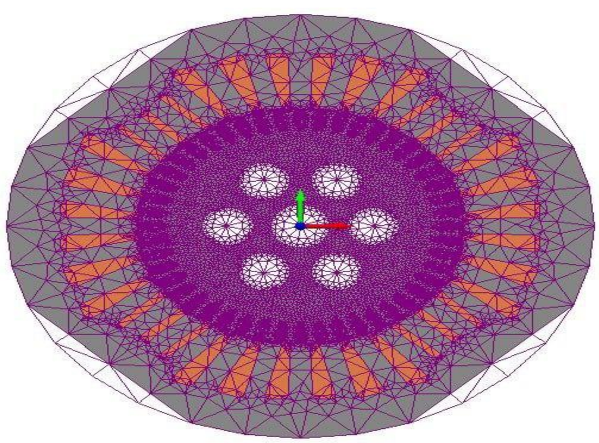

Figure 6 Test motor model meshing by Magnet .

4. Results and Discussion

After the first step of accurate proving of the FEA results received from Magnet software is completed by comparison calculating motor torque as well as current from it at the full load condition together with motor nameplate data. The comparison appear a good agreement of (FEA) outcomes with the motor nameplate data as shown in table 2.

Table 2 Comparison between FEM results and test motor nameplate data.

	FEM results	Nameplate	Error
Rated current	2.812 A	2.8A	0.426%
Rated torque	2.7 N.m	2.5 N.m	7.407%

The auxiliary branch capacitor was modified in steps of 5μF to demonstrate the flexibility of the simulation on motor design (increasing and decreasing). As a result, the values for the auxiliary winding capacitor were set at (20μF, 25μF, 30μF, 35μF, 40 μF, 45 μF) and the effect of each instance on the motor's performance was investigated.

Table (3) shows the correlation between capacitor values and Magnet software findings for stator currents (main and auxiliary), rated current, starting torque, starting current, losses, efficiency, and rated torque at full load conditions.

Table 3 The correlation between capacitor values and Magnet software findings

Capacitor Value	I_{main} (rms)A	I_{aux} (rms) A	Rated current (rms)A	Rated torque N.m	Starting torque N.m	Starting current (rms) A	Losses (W)	Efficiency %
20 μF	3.656	1.667	3.250	2.709	1.059	16.529	205.435	64.484
25 μF	3.523	2.123	2.812	2.778	1.350	16.302	215.326	63.400
30 μF	3.396	2.521	2.848	2.845	1.655	16.088	222.893	62.595
35 μF	3.282	2.955	2.886	2.903	1.970	15.878	230.844	61.77
40 μF	3.184	3.414	2.915	2.961	2.292	15.675	236.912	61.156
45 μF	3.105	3.875	3.010	3.017	2.620	15.481	256.789	59.226

As shown in figure 7, the power factor was calculated from the rated voltage and current waveforms.

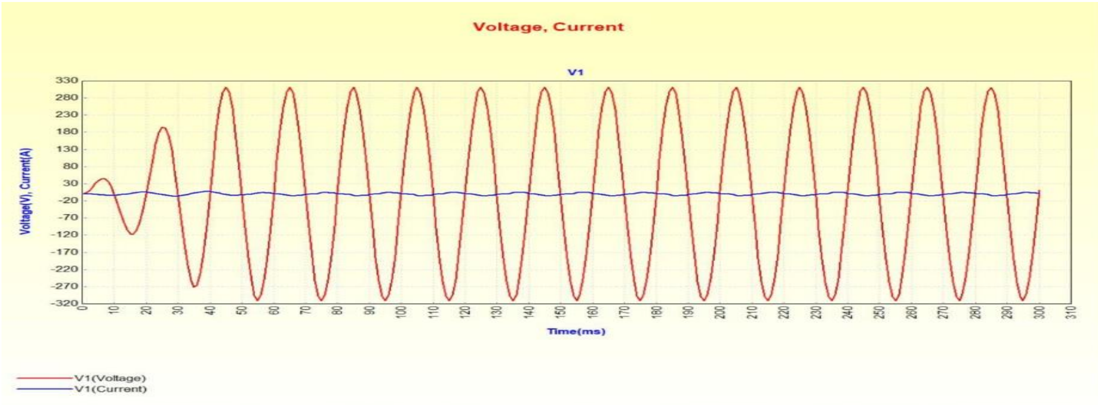

Figure 7 Test motor rated voltage and current waveforms.

Where the angle ***P*** is the phase angle difference between peak value of current as well as voltage waveforms.

225-217=8ms (phase shift in time)

$$\frac{\theta}{360} = \frac{8ms}{20ms}$$

$$\therefore \theta = 144^{\circ} (phase\ shift\ in\ degree)$$

$$cos\ \boldsymbol{P} = 0.809\ lagging\ power\ factor$$

$$\because\ P_{in} = V\ I\ COS\ \theta\ \Rightarrow\ P_{in} = 220 \times 3.250\ \times 0.809 = 578.435\ W\ (FEM)$$

$$\because\ P_{out}\ = 0.5\ hp\ , Efficiency = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\because \sum losses = P_{in} - P_{out} = 578.435W - 373\ W$$

$$\therefore \sum losses = 205.435\ W$$

$$\therefore\ Efficiency = 64.484\ \%$$

These results show the increasing of the capacitance of capacitor in auxiliary winding of tested motor is followed by the increasing of current in auxiliary stator winding (due to decreasing in the capacitance reactance which is linked in series with auxiliary winding), increase in starting torque, decrease in main stator winding, decrease in the starting current, increase in the rated torque. Based on that, total losses of motor are increased, as well as the efficiency factor is reduced. As output power in test motor model must be kept constant, the input power is gradually increased as a result of the increase of total losses in model ,so the efficiency is decreased.

These results confirm the ability of the simulation on finding the performance of the machine when its elements changed.

5. Conclusion

A single-phase capacitor motor with non-uniform stator slots has been successfully modeled and analyzed by Magnet software with assist of AutoCAD. The effect of changing the running capacitor on the performance of a single-phase induction motor is discussed in this study. Because the capacitor is linked in series with the auxiliary stator winding, an increase in current in auxiliary stator winding, an increase in starting torque, a decrease in main stator winding, a decrease in the starting current, and an increase in the rated torque can be observed from the presented results. As a result, total motor losses increase, and the efficiency factor decreases. The adopted methodology for this research will assist the designer of this type of motor in studying the effect of changing motor design like the value of running capacitor on the motor performance like a virtual laboratory.

Abbreviations

E	Electric field intensity
D	Electric flux density
H	Magnetic field intensity
J	Electric current density
B	Vector term of magnetic flux density
ρ	Resistivity of the material in **Ω**.m
P_{in}	input power
P_{out}	Output power
V	Rated voltage
I	Rated current
cos**P**	Power factor

References:

[1] C. B. Rasmussen and T. J. E. Miller, "Revolving-field polygon technique for performance prediction of single-phase induction motors," *IEEE Trans. Ind. Appl.*, vol. 39, no. 5, pp. 1300–1306, 2003.

[2] A. Leicht and K. Makowski, "Analysis of a single-phase capacitor induction motor operating at two power line frequencies," *Arch. Electr. Eng.*, vol. 61, no. 2, pp. 251–266, 2012.

[3] V. Verma, P. Pant, and B. Singh, "Simulation of a single-phase induction motor with dynamic capacitor for maximum torque operation," in *2008 Joint International Conference on Power*

System Technology and IEEE Power India Conference, 2008, pp. 1–6.

[4] B. L. Theraja, *A textbook of electrical technology*. S. Chand Publishing, 2008.

[5] Y. A. ENESI, T. J. OMOKHAFE, J. G. Ambafi, and E. O. AGBACHI, “Permanent Split Capacitor (PSC) alternating current induction motor,” 2015.

[6] L. K. Irving, “Electric machinery and transformer.” Delhi, PHI Learning Private Limited India, 2008.

[7] C. Mademlis, I. Kioskeridis, and T. Theodoulidis, “Optimization of single-phase induction Motors-part I: maximum energy efficiency control,” *IEEE Trans. Energy Convers.*, vol. 20, no. 1, pp. 187–195, 2005.

[8] S. K. Krikor, Y. M. Dhari, and K. Y. Maha, “Starting performance analysis of single-phase capacitor motor using finite element method,” *Eng. Tech.*, vol. 26, no. 8, 2008.

[9] V. Sarac and N. TRAJCHEVSKI, “Impact of capacitor on operating characteristics of single-phase motor,” in *2019 16th Conference on Electrical Machines, Drives and Power Systems (ELMA)*, 2019, pp. 1–5.

[10] R. K. Agarwal, *Principles of electrical machine design*. SK Kataria and Sons, 2009.

[11] O. J. Tola, E. A. Umoh, E. A. Yahaya, C. Idoko, and A. Imoru, “Electromagnetic Field analysis of a Single-phase Induction Motor based on Finite Element Method.”

[12] “Magnet Getting Started Guide,” no. May. pp. 1–30, 2014.

[13] S. A. Nasar, *The induction machines design handbook*. CRC press, 2010.

تأثير تغيير متسعة التشغيل على اداء المحرك الحثي احادي الطور

الخلاصة: *تُستخدم المحركات الحثية أحادية الطور في تطبيقات متعددة حيث تسمح القيمة الصحيحة للمتسعة المرتبطة بالملف المساعد للمحرك بالعمل بفعالية. استخدمت الدراسة الحالية تحليل العناصر المحدودة بناءً على برنامج Magnet لاستقصاء تأثير تغيير متسعة التشغيل على أداء محرك الحثي نوع القفص السنجابي أحادي الطور بفتحات الجزء الثابت غير المنتظمة ، وكذلك استخدام AutoCAD لنمذجة الجزء الثابت بسبب فتحاته غير المتماثلة. تستخدم وثائق التصميم لمحرك اختبار رباعي الأقطاب بقوة 0.5 حصان و 36 فتحة ثابتة و 48 قضيبًا دوارًا و 25 مايكروفاراد لنمذجة المحرك. تم تأكيد دقة نتائج النموذج بنجاح من خلال مقارنة نتائجها للتيار المقدروعزم الدوران مع بيانات لوحة المحرك. تمت مناقشة تأثير تغيير متسعة التشغيل على أداء المحرك الحثي أحادي الطور في هذه الدراسة. لإثبات تنوع المحاكاة في تصميم المحرك ، تم تعديل متسعة الملف المساعد (زيادة ونقصان) وتم التحقيق في تأثير كل حالة على أداء المحرك.*