International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 10 Issue 4 ǁ 2022 ǁ PP. 54-64

Design and Analysis of Multiphase Machine for EV

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Abstract- *Due to the dominating and potential benefits of higher-order of phases, we here show that there is a variety of advantages of multiphase machines over conventional 3-phase machines. Such various types of losses(copper loss) can be attenuated by as much as 8.5%. Efficiency is also higher, power handling capacity is increased, harmonic distortion is less, speed variation is less, and settling time is less. In Multiphase machines, we can also reduce per phase current without increasing the per phase voltage. We are targeting a compact size motor which is more reliable and can provide high power. So basically, here we show the mathematical calculations, compact design and analysis of multiphase machines which can satisfy the demand in high power applications and prove to be a good dominating alternative to conventional 3-phase induction machines.*
Index Terms- *3 phase induction machine and multiphase induction machine*

Date of Submission: 06-04-2022 Date of acceptance: 21-04-2022

I. INTRODUCTION

A three-phase induction motor is an electrochemical energy converter that converts three-phase electrical power into mechanical power [1]. And, as we all know, 3-phase induction machines are used in practically every industry. This is due to the fact that the 3-phase induction machine is simple to use and construct. However, the difficulty comes when the efficiency of conventional 3-phase induction devices is harmed due to fixed losses, lower power factor, and variable losses. However, simulations in software such as MATLAB and MOTORSOLVE reveal that multiphase machines have significant advantages over three-phase machines. The following is a description of the software:

MATLAB is a programming language that combines a desktop environmentfor iterative analysis and design processes with a programming language that can directly express matrix and array mathematics. It comes with Live Editor, which allows you to write script that integrate code, output, and formatted text into an executable notebook.

Professionally built, extensively tested, and fully documented MATLAB toolboxes. You may use MATLAB programmes to see how different algorithms interact with your data. MATLAB is a multi-paradigm programming language and numeric computing environment created by MathWorks.Matrix manipulations, functions and data visualisation, algorithm implementation, user interfaces building, and connecting with programs written in other languages are all possible with MATLAB.

MotorSolve is software for designing and analysing induction machines, synchronous machines, electronically commutated machines, and brush-commutated machines. MotorSolve uses equivalent circuit calculations to replicate the machine's performance.

The software uses finite element analysis and a user-friendly interface to produce accurate simulations of electric equipment.

The template-based interface is simple to use and adoptable enough to handle virtually any motor topology, with the unique rotors and stators available. Common FEA technique such as mesh and solver refining, winding layout, and post-processing are all automated by this tool. You can retrieve performance parameters, waveforms, and field plots with a single mouse click.

Now we know, Multiphase machines are basically induction motors in which there are more than three phases in the stator. These machines are attracted towards recent automation as they can also operate in phase open fault, higher torque density and power applications such as ship propulsion, electric cars, aircraft, hybrid vehicles, rockets etc. it is also used in improving the reliability of harmonic reduction magnetic flux [8]. It can provide high power capability by dividing power into multiphase which in turn reduces the torque pulses.

Multiphase machines can have 5,6,9, or more phases, so let's look at an example of a (SPIM) symmetrical six-phase induction machine, in which the six-phase windings are symmetrically displaced at an angle of 60 degrees around the stator circumference. This symmetrical SPIM can be used in various types such as six-phase induction motor, and six-phase self-excited generator. It can also be used as a group of two three-phase sets of windings and due to this, we can extend a variety of applications.

II. PHASE INDUCTION MACHINE

A. INTRODUCTION:-

The circuit of the 3-phase induction machine is operated in a similar fashion just like the transformer. As in a transformer, AC voltage is applied on the primary side which generates AC flux on the core. After that the generated flux will be linked to the secondary side which induces the voltage of the same frequency in turn, but with a voltage that depends on the turns ratio of the transformer.

In the case of a three-phase induction motor, on the other hand, the voltage is supplied to the stator, which produces a revoling flux wave. Voltages are generated as the wave sweeps entirely around completely the rotor bars. The motor slip, on the other hand, will influence the frequency of the provided voltage.

A symmetric or asymmetric 3-phase induction machine is available. Asymmetric three-phase system contains three conductors that carry the same frequency alternating current and voltage intensity relative to a common reference, but with a 120-degrees phase variation between them. The voltage on any conductor reaches its peak one-third of a cycle after one of the conductors and one-third of a cycle before the other conductor due to the phase difference. The computed amplitude of the voltage differences between two phases is 1.732 times the amplitude of the voltage between the individual phases. The 3-phase systems are also known as 3-phase symmetric systems.The reason for this is that, while asymmetric three-phase power systems can be built and operated, they lacked in the benefits and applications that are essential for feasibility.

In 3 phase induction machine, loss in the stator phase cannotbe prevented.

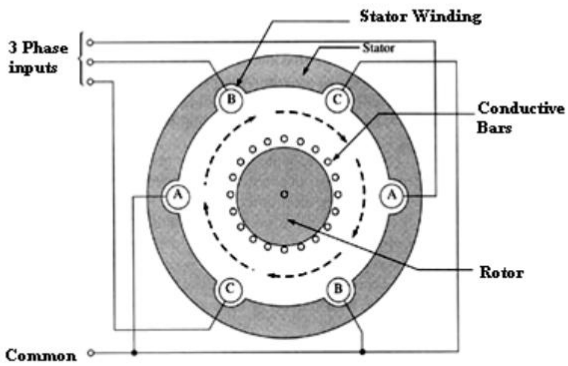

Fig. Three phase induction motor

MULTIPHASE INDUCTION MACHINE

A. INTRODUCTION:-

A Multiphase Induction machine has more benefits than a standard 3 phase induction machine. It has higher reliability, high power handling capacity and can reduce torque.

An application where multiphase induction machines are used in ship propulsion, traction in electric vehicles, and aircraft. The six-phase motor has more advantages over other types of multiphase machines.

UNDERSTANDING OF "3 & 6 PHASE" INDUCTION MACHINE

"3 & 6 PHASE" CONCEPT

In a symmetrical six-phase induction machine, the six-phase windings interest the stator at a 60-degree angle.This unique construction can be used with three-phase or six-phase electronics. It can be powered by a six-phase induction motor and fed by a sinusoidal six-phase voltage source. In the event of inverter feeding, the machine is fed with six single-phase inverters to boost reliability.

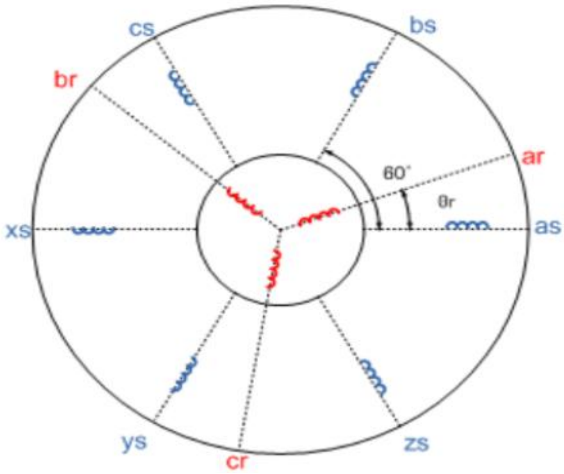

Fig. Winding of Symmetrical six phase induction machine

Because the angle of winding between each second winding is 120 degrees, the actual six-phase structure can be divided into two three-phase winding sets, boostingits work function.

1) Prototype

We can remove the three-phase stator winding of a regular 3-phase machine and replace it with a new design of six-phase winding to design a prototype of a “3 & 6 phase” induction machine.

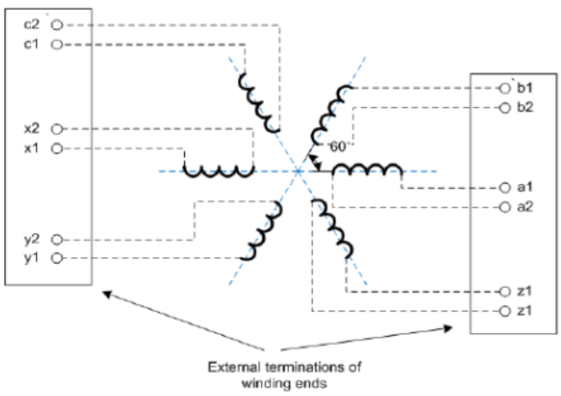

Fig. Winding distribution and termination

“3 & 6 PHASE” AS THREE PHASE MOTOR

The angle created by the six-phase machine’s second winding will be 120 degrees. This means that the symmetrical six-phase machine’s stator winding can be separated into two three-phase windings at a 60-degree angle between them.

The machine operates as 3 phase induction motor, by connecting two winding in series or parallel.

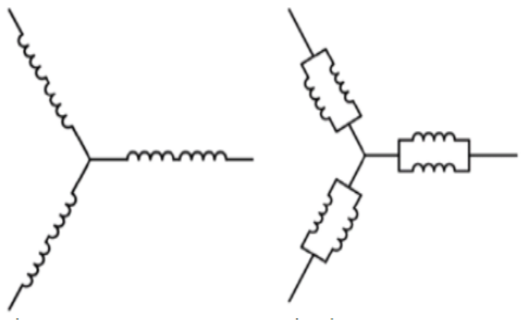
(A) (B)

Fig. Connection in three phase motor

A. Mathematical Model

[2], [3] provide documentation for this model. This model's reference frame was altered to omega,which is equivalent to thedesired reference frame's rotational speed.

2) Voltage Equations

$$v_q^s = r^s i_q^s + \omega\lambda_d^s + p\lambda_q^s \quad (1)$$

$$v_d^s = r^s i_d^s - \omega\lambda_q^s + p\lambda_d^s \quad (2)$$

$$v_0^s = r^s i_0^s + p\lambda_0^s \quad (3)$$

$$v_q^r = r^r i_q^r + (\omega - \omega_r)\lambda_d^r + p\lambda_q^r \quad (4)$$

$$v_d^r = r^r i_d^r - (\omega - \omega_r)\lambda_q^r + p\lambda_d^r \quad (5)$$

$$v_0^r = r^r i_0^r + p\lambda_0^r \quad (6)$$

3) Flux Linkage Equations

$$\lambda_q^s = i_q^s(L_l^s + L_m) + L_m i_q^r \quad (7)$$

$$\lambda_d^s = i_d^s(L_l^s + L_m) + L_m i_d^r \quad (8)$$

$$\lambda_q^s = i_q^s L_l^s \quad (9)$$

$$\lambda_q^r = i_q^r(L_l^r + L_m) + L_m i_q^s \quad (10)$$

$$\lambda_d^r = i_d^r(L_l^r + L_m) + L_m i_d^s \quad (11)$$

$$\lambda_0^r = i_0^r L_l^r \quad (12)$$

4) Torque Equation

$$T_{em} = \frac{3}{2}\frac{p}{2} L_m\left(i_d^r i_q^s - i_d^s i_q^r\right) \quad (13)$$

Where,d = d-axis
q = q-axis
r = rotor parameters
s = stator parameters

B. EQUIVALENT CIRCUIT

In this case, the three-phase motor will be designed through this mathematical model.

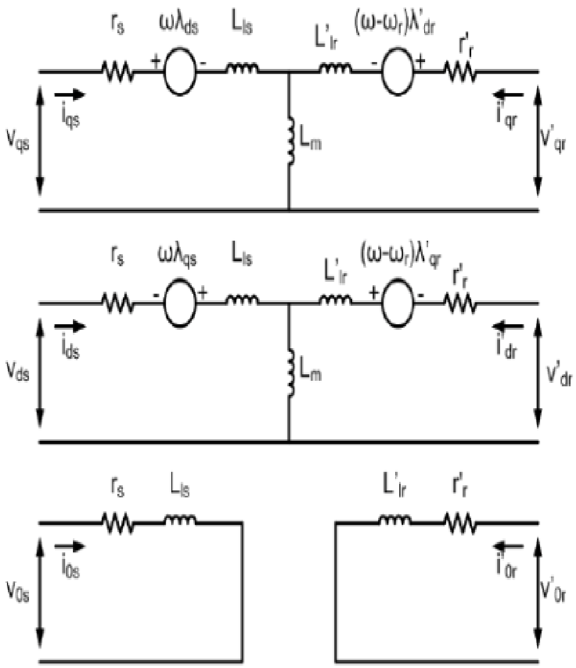

Fig. Equivalent circuit of a three-phase "3 & 6 phase" induction motor

C. SIMULATION RESULT IN MATLAB

In MATLAB, a mathematical model was constructed, and Simulink was used to create results.

A parameter of 1.5kW will be used during the simulation of a three-phase induction motor to generate the results.

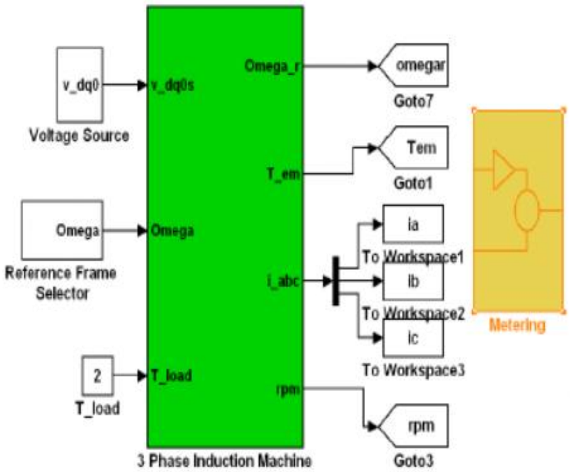

Fig. Simulink model of “3 & 6 phase” induction machine as three phase motor

GRAPHS:-

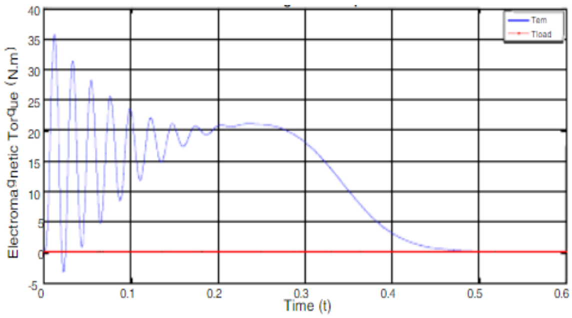

Fig.(a) Torque vs Time

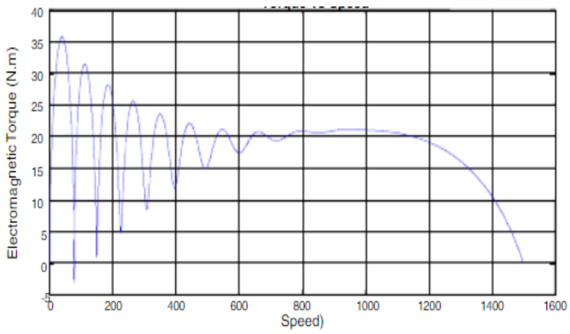

Fig.(b) Torque vs Speed

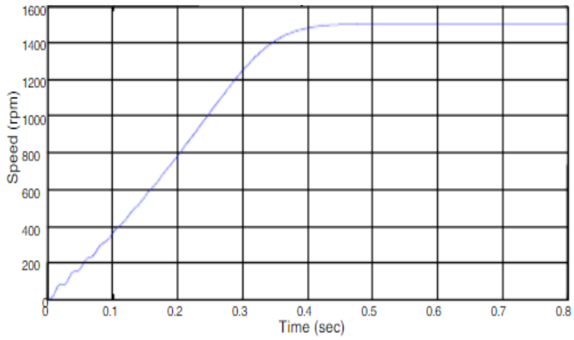

Fig.(c) Speed vs Time

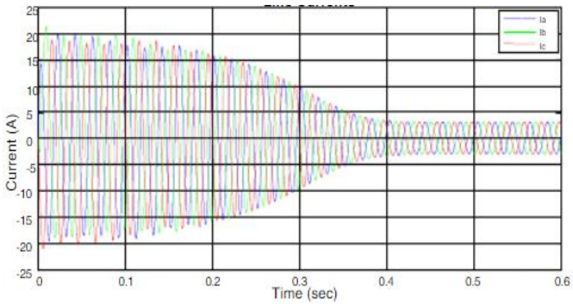

Fig.(d) Line Current vs Time

The graphs of free acceleration characteristics are created.

"3 & 6 PHASE" AS SIX PHASE MOTOR

This six-phase motor has the same diagram as a six-phase induction machine. The rotor model chosen will have a direct impact on all of the machine's mathematical models since the flux linkage equations will be different, resulting in the torque produced by the machine being different.

A. MATHEMATICAL MODEL

[4], [5] describe this model. A symmetrical six-phase induction machine has a mathematical model that has already been documented. Because we're working with a six-phase this time, Park's transform should produce two sets of dq axes in the arbitrary reference frame.

As a result, it is mathematically shown that these two axes are perpendicular to each other, implying that torque cannot be produced.

Equations (24) & (25) show that no coupling will be there between stator and rotor and then no torque is produced in these subspaces.

1) Voltage Equations

$$v_{q1}^{s} = r^{s} i_{q1}^{s} + \omega\lambda_{d1}^{s} + \frac{d}{dt}\lambda_{q1}^{s} \quad (14)$$

$$v_{d1}^{s} = r^{s} i_{d1}^{s} - \omega\lambda_{q1}^{s} + \frac{d}{dt}\lambda_{d1}^{s} \quad (15)$$

$$v_{q2}^{s} = r^{s} i_{q2}^{s} + \frac{d}{dt}\lambda_{q2}^{s} \quad (16)$$

$$v_{d2}^{s} = r^{s} i_{d2}^{s} + \frac{d}{dt}\lambda_{d2}^{s} \quad (17)$$

$$v_{01}^{s} = r^{s} i_{01}^{s} + \frac{d}{dt}\lambda_{01}^{s} \quad (18)$$

$$v_{02}^{s} = r^{s} i_{02}^{s} + \frac{d}{dt}\lambda_{02}^{s} \quad (19)$$

$$v_{q}^{r} = 0 = r^{r} i_{q}^{r} + (\omega - \omega_{r})\lambda_{d}^{r} + \frac{d}{dt}\lambda_{q}^{r} \quad (20)$$

$$v_{d}^{r} = 0 = r^{r} i_{d}^{r} - (\omega - \omega_{r})\lambda_{q}^{r} + \frac{d}{dt}\lambda_{d}^{r} \quad (21)$$

2) Flux Linkage Equations

$$\lambda_{q1}^{s} = i_{q1}^{s}(L_{l}^{s} + L_{m}) + L_{m} i_{q}^{r} \quad (22)$$

$$\lambda_{d1}^{s} = i_{d1}^{s}(L_{l}^{s} + L_{m}) + L_{m} i_{d}^{r} \quad (23)$$

$$\lambda_{q2}^{s} = i_{q2}^{s} L_{l}^{s} \quad (24)$$

$$\lambda_{d2}^{s} = i_{d2}^{s} L_{l}^{s} \quad (25)$$

$$\lambda_{01}^{s} = i_{01}^{s} L_{l}^{s} \quad (26)$$

$$\lambda_{02}^{s} = i_{02}^{s} L_{l}^{s} \quad (27)$$

$$\lambda_{q}^{r} = i_{q}^{r}(L_{l}^{r} + L_{m}) + L_{m} i_{q1}^{s} \quad (28)$$

$$\lambda_{d}^{r} = i_{d}^{r}(L_{l}^{r} + L_{m}) + L_{m} i_{d1}^{s} \quad (29)$$

3) Torque Equation

$$T_{em} = \frac{6}{2}\frac{p}{2} L_{m}\left(i_{d}^{r} i_{q}^{s} - i_{d}^{s} i_{q}^{r}\right) \quad (30)$$

B. SIMULATION RESULTS IN MATLAB

In MATLAB, a mathematical model was constructed, and Simulink was used to create results.
To get the results, a 1.5kW parameter will be employed during the simulation of a three-phase induction motor.
The graphs of free acceleration characteristics are created.

GRAPHS:-

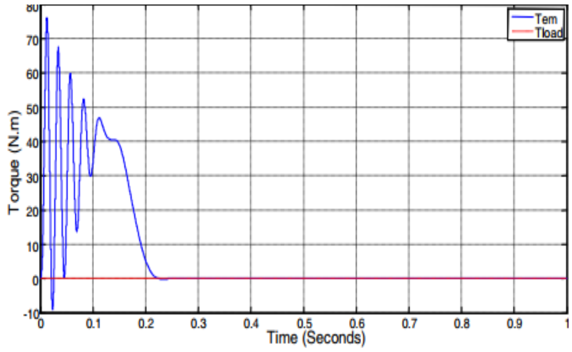

Fig.(a) Torque vs Time

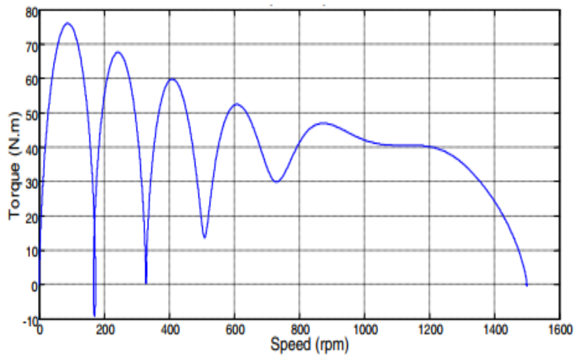

Fig.(b) Torque vs Speed

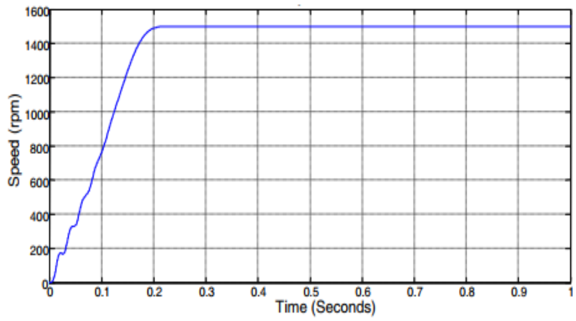

Fig.(c) Speed vs Time

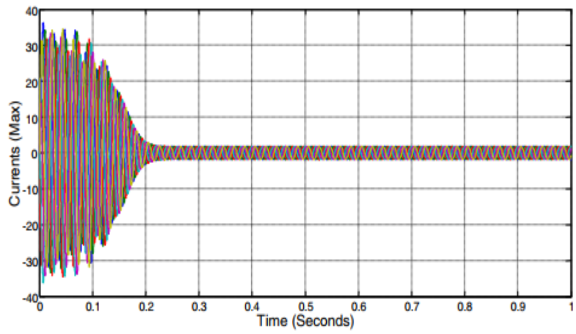

Fig.(d) LineCurrent vs Time

If a load is attached, the machine will produce torque, as shown in Figure (a). The stability of the machine is depicted in Fig. (b). The machineinFigure (c) is unloaded and running at synchronous speed for a four-pole motor. Because the induction motor has a strong inrush current, it possesses the characteristics shown in Fig. (d).

"3 & 6 PHASE" AS THREE PHASE MOTOR WITH REACTIVE POWER INJECTION

It consist of two three-phase windings displaced at a 60-degree angle. The primary winding is coupled to a three-phase supply, while the auxiliary winding is connected to a series of static capacitors [6] [7].

To increase the motor's power factor, reactive power will be supplied. The angle formed by the main and auxiliary winds is 0 degrees [6] [7].

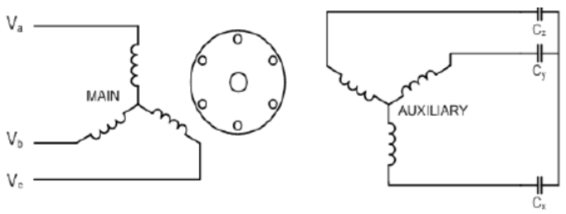

Fig. Reactive power injection as three phase motor

A. Equivalent Circuits

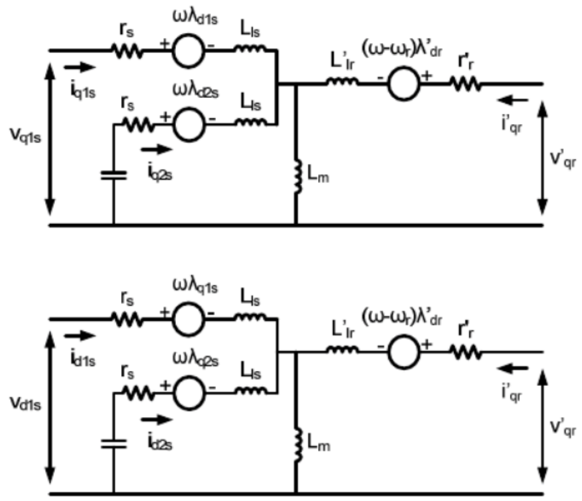

Fig. Equivalent circuits of 3 phase machine with reactive power injection

B. Simulation Results

A mathematical model was built in MATLAB, and Simulink was utilised to generate the findings. Results will be achieved in both the steady-state and dynamic modes.

1) Steady-state Results

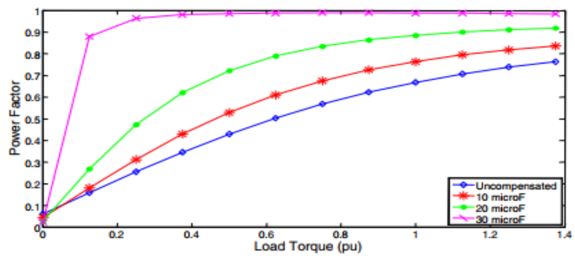

Fig (a)

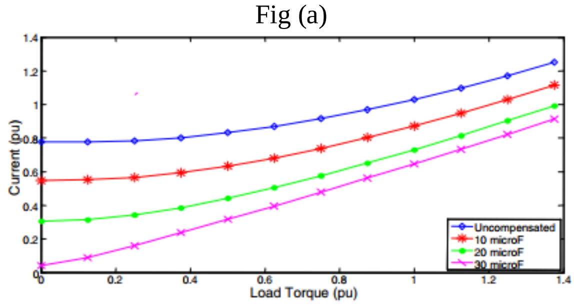

Fig (b)

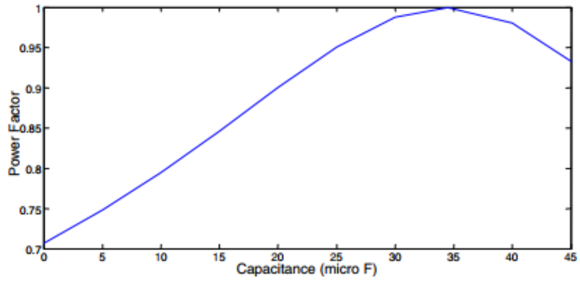

Fig (c)

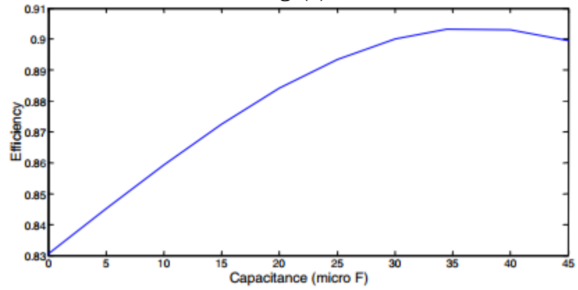

Fig (d)

Figures (a) and (b) show power and current as a function of capacitor size. Figure (c) depicts power factor vs capacitance as capacitance size increases. Figure (d) shows that as reactive power rises, the motor's efficiency rises as well.

2) Dynamic Results

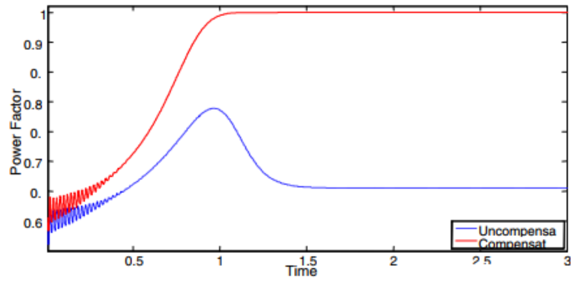

Fig (a)

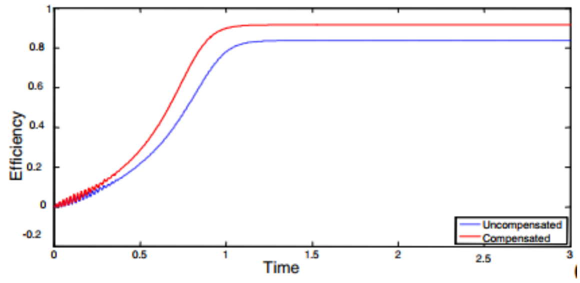

Fig (b)

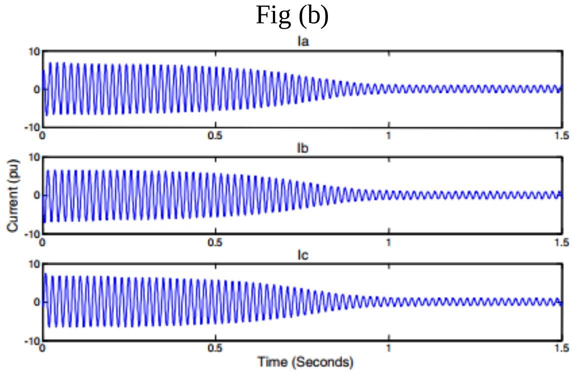

Fig (c)

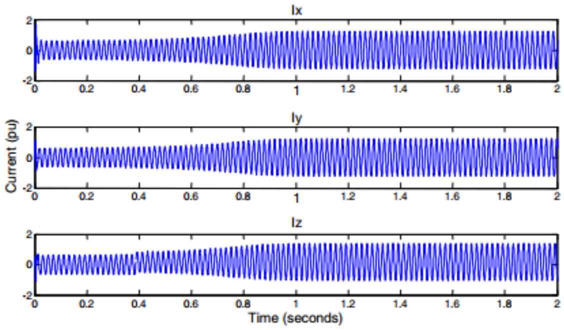

Fig (d)

The power factor in the injected machine will improve, as shown in Fig (a). Figure (b) shows that efficiency will improve. The main winding in Fig. (c) has a significant inrush current. Auxiliary winding current is depicted in Figure (d).

III. CONCLUSION

We may predict from data that a multiphase induction machine is superior than a three-phase induction machine by understanding the "3 & 9 phase" induction machine, which is used in both three and six-phase induction motors.

A six-phase induction machine is superior to other multiphase induction machines in terms of performance. Compared to other multiphase machines, the six-phase motor offers additional benefits.

The reliability of the harmonic reduction magnetic flux will be improved, and torque pulses will be reduced, with a six-phase induction machine. It's capable of producing a lot of power.

Electric and hybrid electric vehicles, rockets, and aeroplanes, among other things, use six-phase induction machines.

REFERENCES

[1]. Shaikh MohammedSuhel and Rakesh Maurya, "Modelling, design and analysis of multiphase induction motor"International Journal of Power and Energy Conversion 2017 Vol.8 No.2.

[2]. P. C. Krause, Analysis of Electric Machinery. New York: Mcgraw-Hill, 1986.

[3]. C. M. Ong, Dynamic Simulation of Electric Machinery Using Matlab/Simulink. New Jersey: Prentice Hall PTR, 1997.

[4]. E. Levi, "Recent Development in High Performance Variable Speed Multiphase Induction Motor Drives" in Sixth International Symposium Nikola Tesla, Serbia, 2006.

[5]. E. Lesi, R. Bojoi, F. Profumo, H. A. Toliyat and S. Williamson, "Multiphase induction motor drives – a technology status review", Electric Power Applications, IET, vol. 1, pp. 489-516, 2007.

[6]. E. Muljadi, T. A. Lipo and D. W. Novotny, "Power Factor enhancement of induction machines by means of solid-state excitation" Power Electronics, IEEE Transactions on, vol. 4, pp. 409-418, 1989.

[7]. Tamrakar and O. P. Malik, "Power factor correction of induction motors using PWM inverter fed auxiliary stator winding", Energy Conversion, IEEE Transactions on, vol. 14, pp. 426-432, 1999.

[8]. Iqbal, S. M. Ahmed, M. A. Khan, M. R. Khan and H. AbuRub, "Modeling, simulation and implementation of a five phase induction motor drive system", in Power Electronics, Drives and Energy System & 2010 Power India, 2010 Joint International Conference on, pp. 1-6.