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Dynamic Analysis of Dual Winding Induction Motor With Excitation of The Auxiliary Winding With A Capacitor

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ABSTRACT: *A dynamic analysis method is required for a better understanding of the operational behavior of a dual winding induction motor. the motor is electrically isolated, but magnetically coupled, and consists of a squirrel cage rotor with a stator having two windings known as the main winding connected to a three-phase supply and the auxiliary winding connected to a balanced capacitor for excitation. This paper primarily addresses the dynamic analysis of a dual winding induction motor, including the development of a mathematical model using Park's d-q-o transformation equations to describe the behavior of the machine. The dynamic equivalent circuit of the D-Q axis of the machine equivalent circuit of the dual winding Induction machine (DWIM) is obtained through a standard induction motor analysis method. The derived equations are used to perform a dynamic simulation in an embedded MATLAB/Simulink environment. The simulation result obtained showed that the dual winding induction motor with capacitor excitation showed a reduced inrush current and a stead torque behavior under variation of the load torque it also takes a faster time to attain a steady state behavior*

KEYWORDS: *capacitor, dual winding,induction motor, modelling,*

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I. INTRODUCTION

Various research in the field of dual winding induction motors have been one of the major interest of recent in machines analysis [1-5] and various method have been proposed on its improvement to give better overall performance, the magnetic design, practical realization and characterization of Multi-phase induction machine, in which the stator is equipped with two sets of windings of identified number of poles and standard squirrel cage rotor, Constitute the core research area addressed herein, of prime research interest is the dynamic analysis of a dual winding induction motor.

Consequently, this study focused on a dual winding induction motor with a balanced capacitor on one of the windings and no slot shifts between them. The auxiliary winding is not connected to source but s magnetically coupled to the main winding, which is connected to the source. Both windings are identical and wound for the same number of poles and the rotor is a squirrel cage rotor. This arrangement will reduce the known disadvantages of conventional induction motors by providing a system in which the magnetic flux density in the stator is maintained at a maximum level [6-7].

One set of the winding is supplied directly from the mains and the other winding is short –circuited through a balanced capacitor. The two windings are electrically isolated, but magnetically coupled like a transformer as in [8]. However, the two set of windings can interchange these roles. The machines are called induction machines because the rotor voltage that produces the rotor current and magnetic field is induced in the rotor winding rather than being connected physically by wires [9]

The dual induction motor is first written in the machine phase variables and subsequently transformed into the arbitrary reference frame. The machine in question as stated above consist of two stator windings arranged on top of each other in the same slot. This means there is no displacement between the two windings. One of the windings is considered as the main winding and it is connected to a three-phase voltage supply, while the second winding is considered as the auxiliary winding and it is connected to a balanced capacitor.

II. MATHEMATICAL MODEL OF THE INDUCTION MOTOR

The dynamic model of this dual winding motor arrangement is mathematically derived and then, analyzed in an embedded MATLAB/Simulink environment to ascertain the level of improvement, over the conventional winding configuration.In order, to distinguished between the two set of windings, the winding connected to the supply is known as the Main winding and the one short-circuited across the balanced capacitor is termed the auxiliary winding

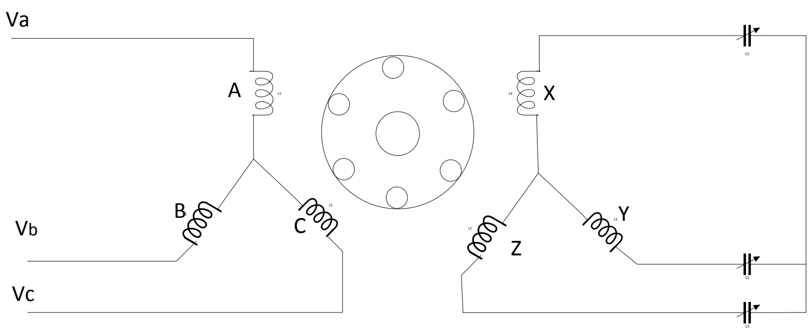

Fig 1. Winding connection of the main and auxiliary

For ease of analysis the The electrical system of this machine as described above can be represented with an equivalent circuit. Though the zero- sequence circuit diagram is omitted because the system is assumed to be balanced. Therefore, the d-q voltage equations and the flux linkage equations suggest the equivalent circuit

In order to obtain a simplified mathematical model for the analysis of the dual winding induction motor, certain assumptions are considered as follows;

- The air-gap is uniform
- Eddy- current, friction, windage losses, are neglected.
- The windings are distributed sinusoidal around the air-gap.
- The windings are identical and have same resistance.

The voltage equations for each winding on the stator and rotor can be determined as follows in the machine variable;

$$V_{abcs\,1} = r_{s1} i_{abcs\,1} + \frac{d}{dt}\lambda_{abcs\,1} \quad (1)$$

$$V_{abcs\,2} = r_{s2} i_{abcs\,2} + \frac{d}{dt}\lambda_{abcs\,2} + V_{c_{abc}} \quad (2)$$

$$V_{abcr} = r_r i_{abcr} + \frac{d}{dt}\lambda_{abcr} \quad (3)$$

III.The voltage equations of the main winding;

$$V_{qs1} = r_{s1} i_{qs1} + \omega_1 \lambda_{ds1} + \frac{d}{dt}\lambda_{qs1} \quad (8)$$

$$V_{ds1} = r_{s1} i_{ds1} - \omega_1 \lambda_{qs1} + \frac{d}{dt}\lambda_{ds1} \quad (9)$$

IV.The voltage equation of the auxiliary winding;

$$V_{qs2} = r_{s2} i_{qs2} + \omega_2 \lambda_{ds2} + P\lambda_{qs2} + V_{Cq} \quad (10)$$

$$V_{ds2} = r_{s2} i_{ds2} - \omega_2 \lambda_{qs2} + P\lambda_{ds2} + V_{Cd} \quad (11)$$

For the auxiliary winding, the voltage equations have two additional terms V_{Cq} and V_{Cd} added to them to account for the capacitor connected across it. But in the d-q-0 reference frame, the V_{Cq} and V_{Cd} are given as;

$$\frac{dV_{Cq}}{dt} = \frac{i_{qs2}}{C} - \omega V_{Cd} \quad (12)$$

$\frac{dV_{Cd}}{dt} = \frac{i_{ds2}}{C} + \omega V_{Cq}$ (13)

Thus

$V_{Cqs2} = \frac{1}{\omega}\left[\frac{i_{ds2}}{C} - PV_{Cds2}\right]$ (14)

$V_{Cds2} = \frac{1}{\omega}\left[\frac{i_{qs2}}{C} + PV_{Cqs2}\right]$ (15)

Substituting the values of V_{Cqs2} and V_{Cds2} into the voltage equation for the auxiliary winding in equation (10) and (11) yields

$V_{qs2}=r_{s2}i_{qs2} + \omega_2\lambda_{ds2} + P\lambda_{qs2} - \frac{1}{\omega}\left[\frac{i_{ds2}}{C} - PV_{Cds2}\right]$ (16)

$V_{ds2}=r_{s2}i_{ds2} - \omega_2\lambda_{qs2} + P\lambda_{ds2} + \frac{1}{\omega}\left[\frac{i_{qs2}}{C} + PV_{Cqs2}\right]$ (17)

V. The rotor voltage equations;

$V_{qr} = r_r i_{qr} + (\omega - \omega_r)\lambda_{dr} + P\lambda_{qr}$ (18)

$V_{dr} = r_r i_{dr} + (\omega - \omega_r)\lambda_{qr} + P\lambda_{dr}$ (19)

Similarly, the flux linkage equations for the stator windings respectively and for the rotor are written in the expanded form as given;

$\lambda_{qs1} = i_{qs1}L_{l_{s1}} + L_m(i_{qs1} + i_{qs2} + i_{qr})$ (20)

$\lambda_{ds1} = i_{ds1}L_{l_{s1}} + L_m(i_{ds1} + i_{ds2} + i_{dr})$ (21)

$\lambda_{qs2} = i_{qs2}L_{l_{s2}} + L_m(i_{qs1} + i_{qs2} + i_{qr})$ (22)

$\lambda_{ds2} = i_{ds2}L_{l_{s2}} + L_m(i_{ds1} + i_{ds2} + i_{dr})$ (23)

$\lambda_{qr} = i_{qr}L_{l_r} + L_m(i_{qs1} + i_{qs2} + i_{qr})$ (24)

$\lambda_{dr} = i_{dr}L_{l_r} + L_m(i_{ds1} + i_{ds2} + i_{dr})$ (25)

VI.DYNAMIC EQUIVALENT CIRCUIT OF D-Q AXIS.

The electrical system of this machine as described above can be represented with an equivalent circuit. Though the zero- sequence circuit diagram is omitted because the system is assumed to be balanced. Therefore, the d-q voltage equations and the flux linkage equations suggest the equivalent circuit diagram below;
respectively.

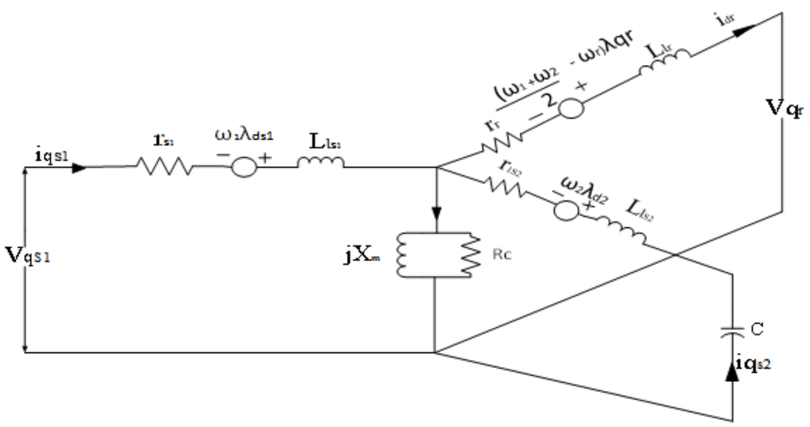

Fig .2 .Q-Axis Equivalent circuit diagram

The Voltage equation

$V_{qs1}=r_{s1}i_{qds1} + \omega_1\lambda_{qds1} + \frac{d}{dt}\lambda_{qds1}$ (8)

$V_{qs2}=r_{s2}i_{qs2} + \omega_2\lambda_{ds2} + P\lambda_{qs2} + V_{Cqs2}$ (9)

$\frac{dV_{Cq}}{dt}=\frac{i_{qs2}}{C} - \omega V_{Cd}$ (10)

Thus

$V_{Cqs2}=\frac{1}{\omega}\left[\frac{i_{ds2}}{C} - PV_{Cds2}\right]$ (11)

Substituting eqn (4) in eqn (2) gives

$$V_{qs2}=r_{s2}i_{qs2}+\omega_2\lambda_{ds2}+P\lambda_{qs2}+\frac{1}{\omega}\left[\frac{i_{ds2}}{C}-PV_{Cds2}\right] \quad (12)$$

$$V_{qr}=r_r i_{qr}+\left(\frac{\omega_1+\omega_2}{2}-\omega_r\right)\lambda_{dr}+P\lambda_{qr} \quad (13)$$

$$V_{ds1}=r_{s1}i_{ds1}-\omega_1\lambda_{qs1}+\frac{d}{dt}\lambda_{ds1} \quad (14)$$

$$V_{ds2}=r_{s2}i_{ds2}-\omega_2\lambda_{qs2}+P\lambda_{ds2}+V_{Cd} \quad (15)$$

$$\frac{dV_{Cd}}{dt}=\frac{i_{ds2}}{C}+\omega V_{Cq} \quad (16)$$

$$V_{Cds2}=\frac{1}{\omega}\left[\frac{i_{qs2}}{C}-PV_{Cqs2}\right] \quad (17)$$

Substituting the value of V_{Cds2} into the voltage equation for the auxiliary winding in eqn (9)

$$V_{ds2}=r_{s2}i_{ds2}-\omega_2\lambda_{qs2}+P\lambda_{ds2}+\frac{1}{\omega}\left[\frac{i_{qs2}}{C}-PV_{Cqs2}\right] \quad (18)$$

$$V_{dr}=r_r i_{dr}+\left(\frac{\omega_1+\omega_2}{2}-\omega_r\right)\lambda_{qr}+P\lambda_{dr} \quad (19)$$

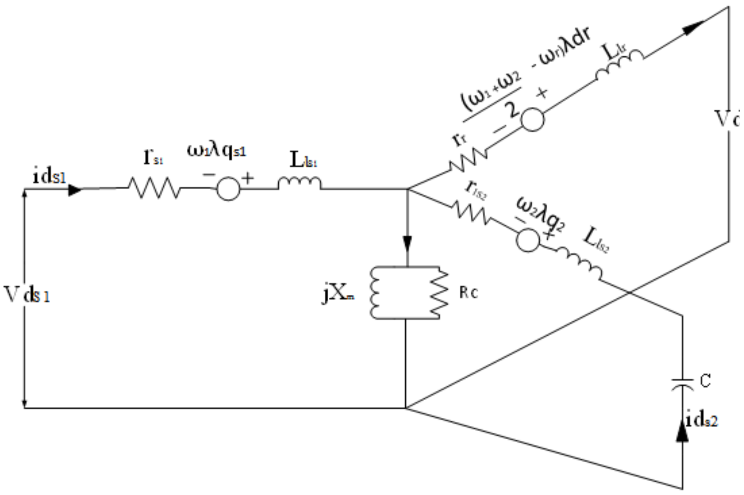

Fig. 3. D-Axis Equivalent circuit

$$V_{ds1}=r_{s1}i_{ds1}-\omega_1\lambda_{qs1}+\frac{d}{dt}\lambda_{ds1} \quad (14)$$

$$V_{ds2}=r_{s2}i_{ds2}-\omega_2\lambda_{qs2}+P\lambda_{ds2}+V_{Cd} \quad (15)$$

$$\frac{dV_{Cd}}{dt}=\frac{i_{ds2}}{C}+\omega V_{Cq} \quad (16)$$

$$V_{Cds2}=\frac{1}{\omega}\left[\frac{i_{qs2}}{C}-PV_{Cqs2}\right] \quad (17)$$

Substituting the value of V_{Cds2} into the voltage equation for the auxiliary winding in eqn (9)

$$V_{ds2}=r_{s2}i_{ds2}-\omega_2\lambda_{qs2}+P\lambda_{ds2}+\frac{1}{\omega}\left[\frac{i_{qs2}}{C}-PV_{Cqs2}\right] \quad (18)$$

$$V_{dr}=r_r i_{dr}+\left(\frac{\omega_1+\omega_2}{2}-\omega_r\right)\lambda_{qr}+P\lambda_{dr} \quad (19)$$

Similarly, the flux linkage equations for the stator windings respectively and for the rotor are written in the expanded form as given;

$$\lambda_{qs1}=i_{qs1}L_{l_{s1}}+L_m\left(i_{qs1}+i_{qs2}+i_{qr}\right) \quad (20)$$

$$\lambda_{ds1}=i_{ds1}L_{l_{s1}}+L_m\left(i_{ds1}+i_{ds2}+i_{dr}\right) \quad (21)$$

$$\lambda_{os1}=i_{os1}L_{l_{os1}} \quad (22)$$

$$\lambda_{qs2}=i_{qs2}L_{l_{s2}}+L_m\left(i_{qs1}+i_{qs2}+i_{qr}\right) \quad (23)$$

$$\lambda_{ds2}=i_{ds2}L_{l_{s2}}+L_m\left(i_{ds1}+i_{ds2}+i_{dr}\right) \quad (24)$$

$\lambda_{os2} = i_{os2} L_{l_{os2}}$ (25)
$\lambda_{qr} = i_{qr} L_{l_r} + L_m (i_{qs1} + i_{qs2} + i_{qr})$ (26)
$\lambda_{dr} = i_{dr} L_{l_r} + L_m (i_{ds1} + i_{ds2} + i_{dr})$ (27)

VII.ELECTROMAGNETIC TORQUE (T_{em}) AND SPEED

The electromagnetic torque is derived from the sum of the input power supplied to all the windings of the main (stator-1), auxiliary (stator-2), including the rotor of the dual winding induction motor in the d-q reference frame given as

$$P_{in} = \frac{3}{2}\left[V_{qs1} i_{qs1} + V_{ds1} i_{ds1} + V_{qs2} i_{qs2} + V_{ds2} i_{ds2} + V_{qr} i_{qr} + V_{dr} i_{dr}\right] \quad (28)$$

Substituting the values of the voltage equations from equation (8), (12),(13),(14),(18) and (19),will yield;

$P_{in} = \frac{3}{2}\Big[\left(r_{s1} i_{qs1} + \omega_1 \lambda_{ds1} + \frac{d}{dt}\lambda_{qs1}\right) i_{qs1} + \left(r_{s1} i_{ds1} - \omega_1 \lambda_{qs1} + \frac{d}{dt}\lambda_{ds1}\right) i_{ds1} + \left(r_{s2} i_{qs2} + \omega_2 \lambda_{ds2} + P\lambda_{qs2} +\right.$
1ωids2C−PVCds2iqs2+rs2ids2−ω2λqs2+Pλds2 +
1ωiqs2C−PVCqs2ids2+rriqr+ω1+ω22−ωrλdr+Pλqriqr+rridr+ω1+ω22−ωrλqr+Pλdridr
(29)

ω is known as the speed voltage, in the above equations any term that does not have ω in it does not contribute to torque, therefore will turn to zero for a balanced system. This implies that the electromagnetic torque (T_{em}) developed is given by the sum of the terms that contains the speed voltageω, divided by the mechanical speed.ω_m
Therefore,

$T_{em} = \frac{3}{2}\frac{1}{\omega_m}\Big[\omega_1 \lambda_{ds1} i_{qs1} - \omega_1 \lambda_{qs1} i_{ds1} + \omega_2 \lambda_{ds2} i_{qs2} + \frac{1}{\omega}\left[\frac{i_{ds2}}{C} - \frac{d}{dt} V_{Cds2}\right] i_{qs2} - \omega_2 \lambda_{qs2} i_{ds2} + \frac{1}{\omega}\Big[\frac{i_{qs2}}{C} -$
ddtVCqs2ids2+ω1+ω22−ωrλdriqr−ω1+ω22−ωrλdriqr (30)

Factorizing equation,

$T_{em} = \frac{3}{2}\frac{1}{\omega_m}\Big[\omega_1 (\lambda_{ds1} i_{qs1} - \lambda_{qs1} i_{ds1}) + \omega_2 (\lambda_{ds2} i_{qs2} - \lambda_{qs2} i_{ds2}) + \frac{1}{\omega}\left[\frac{i_{ds2}}{C} - \frac{d}{dt} V_{Cds2}\right] i_{qs2} +$
iqs2C−ddtVCqs2ids2]+ω1+ω22−ωrλdriqr−λdriqr. (31)

Note, $\frac{P}{2}\omega_m = \omega_r$. And $\omega_m = \frac{2}{P}\omega_r$.

$T_{em} = \frac{3}{2}\frac{P}{2\omega_r}\Big[\Big[\omega_1 (\lambda_{ds1} i_{qs1} - \lambda_{qs1} i_{ds1}) + \omega_2 (\lambda_{ds2} i_{qs2} - \lambda_{qs2} i_{ds2}) + \frac{1}{\omega}\left[\frac{i_{ds2}}{C} - \frac{d}{dt} V_{Cds2}\right] i_{qs2} + \Big[\frac{i_{qs2}}{C} -$
ddtVCqs2ids2]. (32)

Note that ω can take any arbitrary value such that if it is stationary, ω=0; if it is referred to the rotor , $\omega = \omega_r$ and for synchronously rotating reference frame, $\omega = \omega_s$
And the speed is given as

$$\omega_r = \frac{P}{2J}\int (T_{em} - TL)\, dt \quad (33)$$

Voltage conditions for the main winding supply

$V_a = V_m \cos(wt)$ (34)
$V_b = V_m \cos(wt + 2\pi f)$ (35)
$V_c = V_m \cos(wt - 2\pi f)$ (36)

VIII. ANALYSIS AND RESULT

Table 1.1 Induction Motor Parameters

Parameter	Value
Main stator resistance	3.72 Ω
Auxiliary stator resistance	3.72

	Ω
Rotor resistance	2.12 Ω
Mutual inductance	0.022 H
Stator inductance	0.022 H
Rotor inductance	0.006 H
Inertia load	0.0662 Kgm^2
Voltage	415 V
No of poles	4
Capacitance	10-100uf
Load Torque	2--15 Nm
Frequency	50Hz

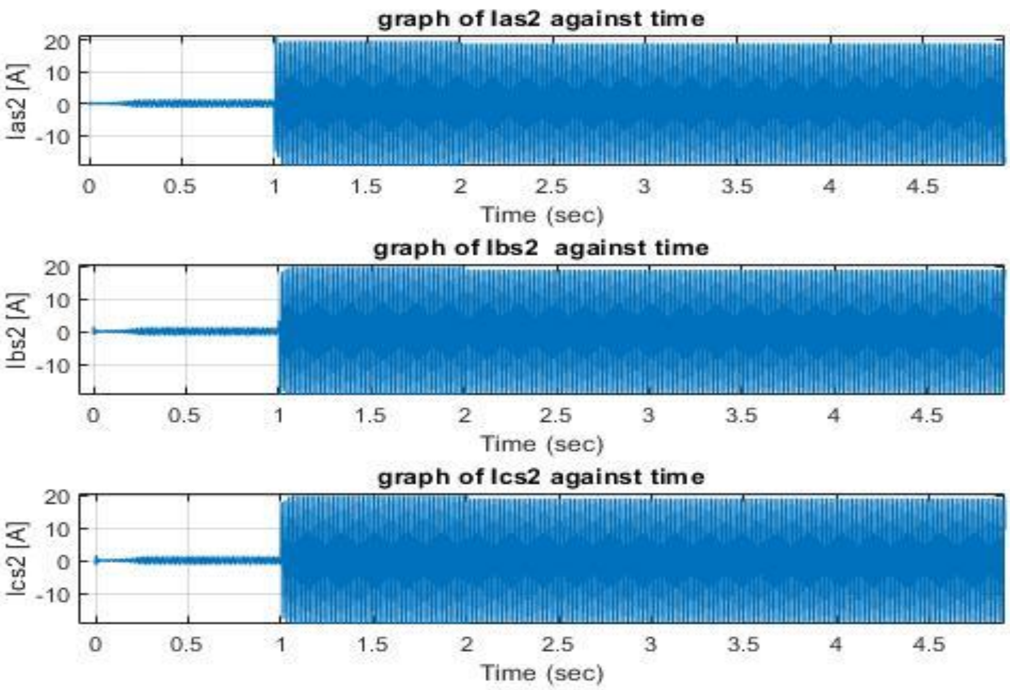

Fig 4 Main Stator Current

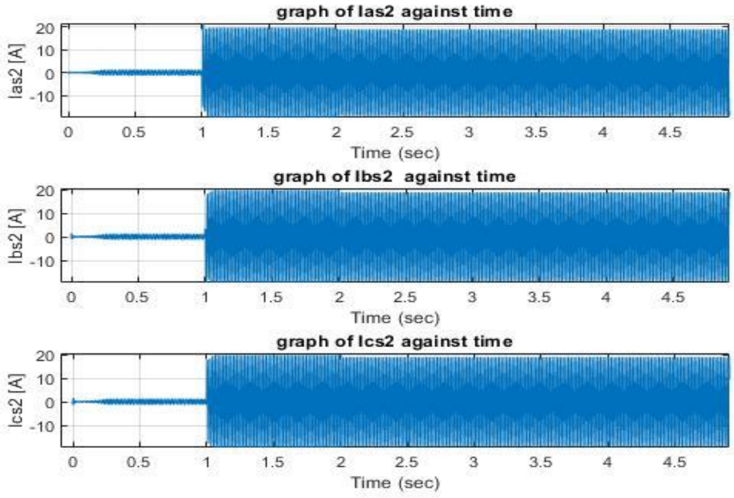

Fig .5. Auxiliary Stator Current

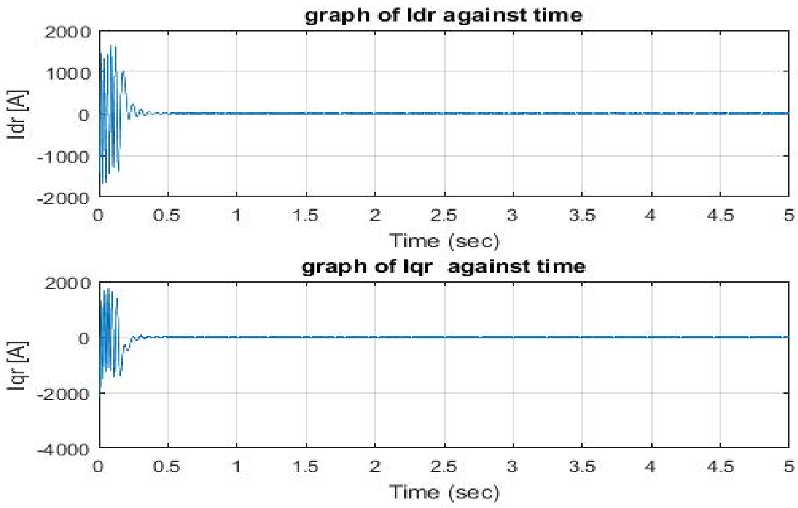

Fig .6. Rotor Current

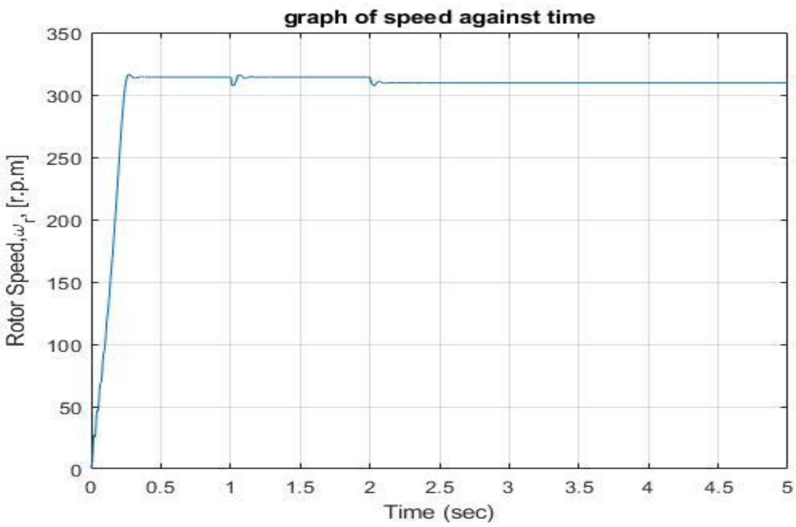

Fig 7 Speed of the Motor

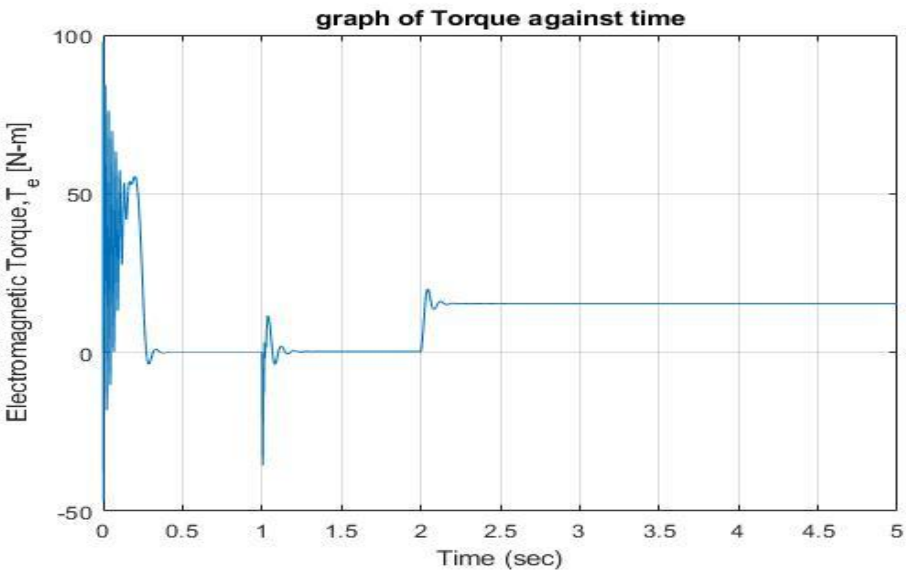

Fig .8. Electromagnetic Torque against Time

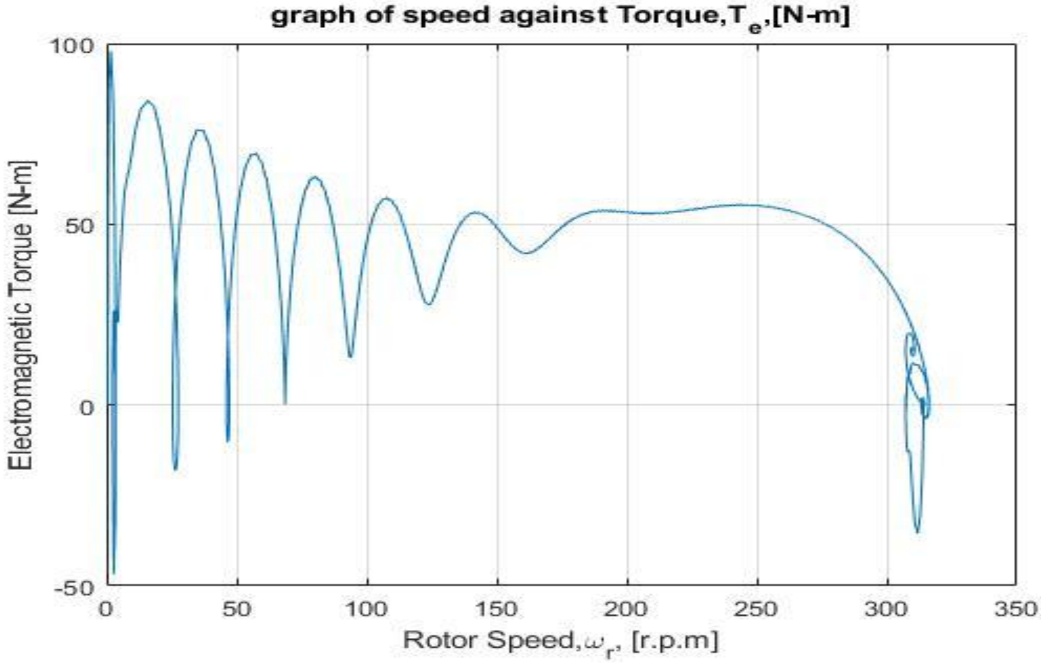

Fig .9. Speed Torque Characteristics

The introduction of a phase shift capacitor at the auxiliary end of the second stator reduces the inrush current taken by the capacitor during starting, the introduction of the capacitor also enable the machine to attain steady state fast which can be seen in Fig 4. to Fig 7.as it takes seconds for the machine which is modelled in the rotating reference frame to attain dynamic stability, the capacitor inclusion in the torque equation also enables the torque the machine reaches a steady torque as shown in Fig 8.and increase the speed of the machine, the capacitor enable the machine to maintain a balanced condition under varying load which was varied from no load to 30NM the diagrams from Fig .9. ,fig 7 also shows the reduction of current in the rotor end

The capacitor in the auxiliary winding is used to limit current flow which helps prevent high inrush current which can be seen by the current flow in different direction between the main and the auxiliary stator winding

d-q transformation was used to simplifying the analysis in this study to simplify the analysis form the arbitrary reference frame.

IX. CONCLUSION

From the MATLAB simulation of dynamic transient analysis, it can be seen that the capacitor excitation in the auxiliary winding gave a significant reduction effect of the high in-rush current drawn by the induction machine. Also from the torque speed characteristic it can be seen that the high starting torque which is produced by the dual winding reaches a steady state condition in a very short time internal hence, the speed of the motor showed relative stability from the transient to steady state. Hence the dual winding induction motor gives a better performance and overall efficiency as compared to a single winding induction motor.

This arrangement will reduce the known disadvantages of conventional induction motors by providing a system in which the magnetic flux density in the stator is maintained at a maximum level, the stability of the machine under variation of no load-to-load conditions is the main advantage of the model and auxiliary excitation of the capacitor.

REFERENCE

[1] .Tarek, N. & Dusan, M. (2018). *Comparative study of frequency converters for doubly-fed induction machine,* Czech Technical University in Prague.

[2]. Ogunjuyigbe, A.S.O., Ayodede, T.R. & Adetokun, B.B (2018). "modeling and analysis of a dual stator winding induction machine" Power, energy, machine and drive research group, electrical and Electronic Engineering Department, Faculty of Technology, University of Ibadan, Nigeria.

[3] . Priya, D.B., Ranjit, M. & Babu, R.V. (2018). *Performance of dual inverter fed open and winding induction motor drive using carrier shift PWM techniques* UNR Vignana Jyothi Institute of Engineering and Technology Hyderabad, India.

[4] .Canakglu, A. Murat, T., Asim, G.Y. & Mustafa, T. (2017). *Locus diagrams of net magnetic fed vector of dual winding induction motor.* Dumlupur University Kutahya, Turkey and Sakarya University, Sakarya, Turkey.

[5]. Jussi, K. (2017). *Current Harmonic Compensation in dual three-phase PMSM,* Visedo OY, Lappeenvanta, Finland.

[6]. Anih, L.U., Obe, E.S. & Abonyi, S.E. (2015). *Modeling and performance of a hybrid synchronous reluctance machine with adjustable* $X_d 1 X_q$ *ratio, IET Electric Power Applications*, 9(2), 171-182.

[7]. Tshibain (2015). *Modeling and field-oriented control of a dual stator winding motor in the EMTP-type environment*. Department of Electrical Engineering, Polytechnique Montreal QC, Canada.

[8]. Olarinoye, G.A. & Oricha, J.Y. (2013). *A method for solving the voltage and torque equations of the split-phase induction machines*. Department Electrical Engineering, Ahmadu Bello University, Zaira, Kaduna State, Nigeria.

[9]. Ogunjuyigbe, A.S.O, Jimoh, A.A. Nicolae, D.V. & Obe, E.S. (2010). Department of Electrical Engineering Tshwame of Technology, Pretoria, South Africa and Department of Electrical Engineering, University of Nigeria, Nsukka, Nigeria.

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