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Modelling and Simulation of a Dual Winding Induction Motor

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ABSTRACT: Dual winding induction motor in recent years have attracted more focused attention from numerous researchers due to its reliability, ruggedness, low cost and its direct connection to AC power source compared to the direct current motors. In-fact, the dual winding induction motor have several advantages compared to the conventional three-phase induction motor. The quest for high power drives in the industry brought about the study of multi-phase induction motor. This paper primary addresses the modelling and simulation of a 3Hp, 4-pole dual winding induction motor using park's transformation. Simulation results obtained using MATLAB to predict the dynamic performance of the motor is presented and discussed.

KEYWORD: Dual Winding, Auxiliary Winding, D-Q Transformation, Simulation, modelling,

I.INTRODUCTION

Multi-phase induction machines in recent times have been the focus of mainly researchers. Various researchers have studied the operations of these machines as generator as well as motors with a view to analysing their performance as compared to a conventional three-phase machine of similar rating. [1-5]. Consequently, this study focuses on the modelling and simulation of a dual winding with a balanced capacitor on one of the windings (auxiliary) and no slot shifts between them. The auxiliary winding is not connected to any sources but its magnetically coupled to main winding which is connected to a three-phase source. Both windings are identical and wound for the same number of poles and the rotor is a squirrel cage rotor. In this research work, synchronously rotating reference frame dynamic modelling of the induction motor was used. Thus, the arrangement will reduce the known disadvantages of the conventional three-phase induction motor by providing a system in which the magnetic flux density in the stator is maintained at a maximum level [6]. One set of the winding is supplied directly from the main and the other winding is short-circuited through a balanced capacitor. The machine is called induction motor because the rotor voltage that produces the rotor current magnetic field is induced in the rotor winding rather than being connected physically by wire. [7]. The dual winding induction motor is written first in the machine phase variables and subsequently transformed into the arbitrary reference frame. [8].

II. LITERATURE SURVEY

However, a comprehensive literature review from Ogunjuyigbe, A.S.O., Ayodede, T.R. & Adetokun, B.B (2018). “modeling and analysis of a dual stator winding induction machine,” Anih, L.V., 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. 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.) revealed that the machines either suffer from overheating due to excessive copper losses in the windings or incomplete utilization of the machine.

III. MATHEMATICAL MODEL OF THE MACHINE

The dynamic model of the dual winding induction 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. To distinguished between the two set of windings, the winding connected to the three-phase supply is known as the Main winding while the one short-circuited across the balanced capacitor is termed the auxiliary winding. Below is the winding connection arrangement of the main and auxiliary winding of the motor.

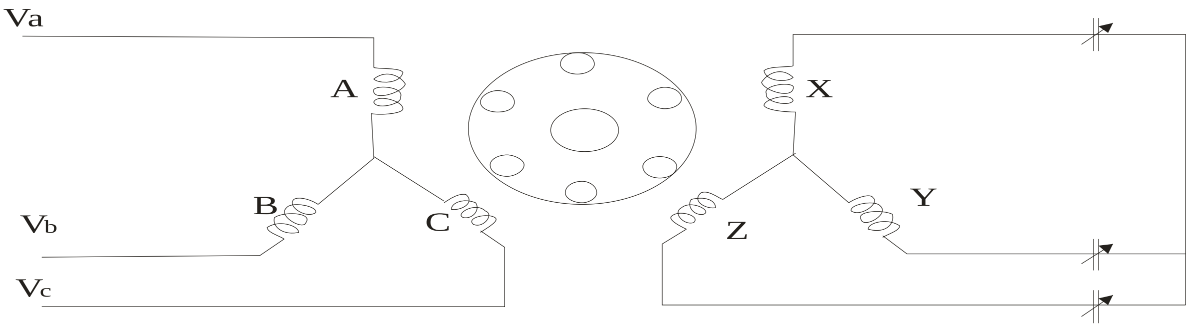

Fig:1 The winding Connection Diagram of the Main and Auxiliary Winding.

In order to obtain a simplified mathematical model for the analysis of the dual winding induction motor, certain assumption has to be made such as;

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

The voltage equations for each winding on the stator and rotor side ca be determined as follows in the machine variables;

$$V_{abcs1} = r_{s1} i_{abcs1} + \frac{d}{dt} \lambda_{abcs1} \quad (1)$$

$$V_{abcs2} = r_{s2} i_{abcs2} + \frac{d}{dt} \lambda_{abcs2} + V_{cabc} \quad (2)$$

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

IV. VOLTAGE EQUATIONS IN THE D-Q REFERENCE FRAME

$$V_{qs1} = r_{s1} i_{qs1} + \omega_1 \lambda_{ds1} + \frac{d}{dt} \lambda_{qs1} \quad (4)$$

$$V_{ds1} = r_{s1} i_{ds1} - \omega_1 \lambda_{qs1} + \frac{d}{dt} \lambda_{ds1} \quad (5)$$

$$V_{qs2} = r_{s2} i_{qs2} + \omega_2 \lambda_{ds2} + P \lambda_{qs2} + V_{Cq} \quad (6)$$

$$V_{ds2} = r_{s2} i_{ds2} - \omega_2 \lambda_{qs2} + P \lambda_{ds2} + V_{Cd} \quad (7)$$

$$V_{qr} = r_r i_{qr} + (\omega - \omega_r) \lambda_{dr} + P \lambda_{qr} \quad (8)$$

$$V_{dr} = r_r i_{dr} + (\omega - \omega_r)\lambda_{qr} + P\lambda_{dr} \qquad (9)$$

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

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

$$\frac{dV_{Cd}}{dt} = \frac{i_{ds2}}{C} + \omega V_{Cq} \qquad (11)$$

Thus

$$V_{Cqs2} = \frac{1}{\omega}\left[\frac{i_{ds2}}{C} - PV_{Cds2}\right] \qquad (12)$$

$$V_{Cds2} = \frac{1}{\omega}\left[\frac{i_{qs2}}{C} + PV_{Cqs2}\right] \qquad (13)$$

Substituting the values of V_{Cqs2} and V_{Cds2} into the voltage equation for the auxiliary winding in equation (6) and (7) yields,

$$V_{qs2} = r_{s2} i_{qs2} + \omega_2 \lambda_{ds2} + P\lambda_{qs2} - \frac{1}{\omega}\left[\frac{i_{ds2}}{C} - PV_{Cds2}\right] \qquad (14)$$

$$V_{ds2} = r_{s2} i_{ds2} - \omega_2 \lambda_{qs2} + P\lambda_{ds2} + \frac{1}{\omega}\left[\frac{i_{qs2}}{C} + PV_{Cqs2}\right] \qquad (15)$$

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

$$\lambda_{qs1} = i_{qs1} L_{ls_1} + L_m\left(i_{qs1} + i_{qs2} + i_{qr}\right) \qquad (16)$$

$$\lambda_{ds1} = i_{ds1} L_{ls_1} + L_m\left(i_{ds1} + i_{ds2} + i_{dr}\right) \qquad (17)$$

$$\lambda_{qs2} = i_{qs2} L_{ls_2} + L_m\left(i_{qs1} + i_{qs2} + i_{qr}\right) \qquad (18)$$

$$\lambda_{ds2} = i_{ds2} L_{ls_2} + L_m\left(i_{ds1} + i_{ds2} + i_{dr}\right) \qquad (19)$$

$$\lambda_{qr} = i_{qr} L_{l_r} + L_m\left(i_{qs1} + i_{qs2} + i_{qr}\right) \qquad (20)$$

$$\lambda_{dr} = i_{dr} L_{l_r} + L_m\left(i_{ds1} + i_{ds2} + i_{dr}\right) \qquad (21)$$

V. DYNAMIC EQUIVALENT CIRCUIT OF D-Q AXIS

For ease of analysis, the electrical system of this motor 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 as shown below respectively;

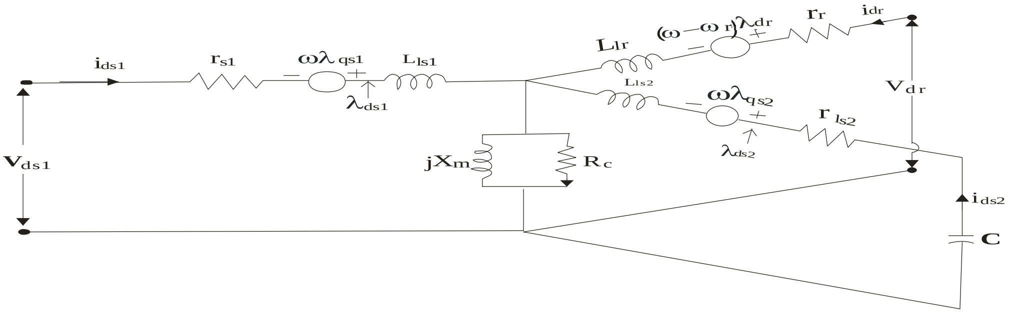

Fig: 2 D-axis Equivalent Circuit Representation

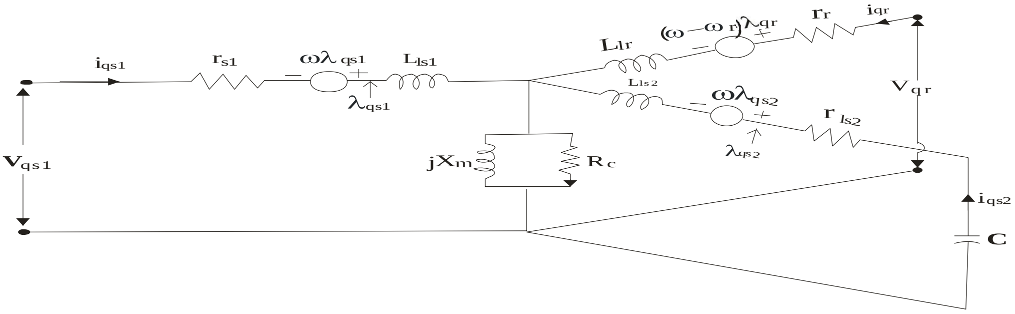

Fig:3 Q-axis Equivalent Circuit Representation.

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

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

$$P_{in}=\frac{3}{2}\left[V_{qs1}i_{qs1}+V_{ds1}i_{ds1}+V_{qs2}i_{qs2}+V_{ds2}i_{ds2}+V_{qr}i_{qr}+V_{dr}i_{dr}\right] \qquad (22)$$

Substituting the values of the voltage equations from equation (4), (5), (8), (9) (14) and (15) into equation (22) will yield;

$$T_{em}=\frac{3}{2}\frac{P}{2\omega_r}\left[\left[\omega_1\left(\lambda_{ds1}i_{qs1}-\lambda_{qs1}i_{ds1}\right)+\omega_2\left(\lambda_{ds2}i_{qs2}-\lambda_{qs2}i_{ds2}\right)+\frac{1}{\omega}\left[\frac{i_{ds2}}{C}-\frac{d}{dt}V_{Cds2}\right]i_{qs2}+\left[\frac{i_{qs2}}{C}+\frac{d}{dt}V_{Cqs2}\right]i_{ds2}\right]\right] \qquad (23)$$

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;

$$\omega_r=\frac{P}{2j}\int\left(T_{em}-T_L\right)dt \qquad (24)$$

Voltage conditions for the main winding supply

$$V_a = v_m \cos(\omega t) \tag{25}$$

$$V_a = v_m \cos(\omega t + 2\pi f) \tag{26}$$

$$V_a = v_m \cos(\omega t - 2\pi f) \tag{27}$$

Table:1: Induction motor Parameter

Parameter	Value
Main stator resistance	3.72 Ω
Auxiliary stator resistance	3.72Ω
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

VII. SIMULATION RESULTS AND DISCUSSION

The following graphs shows the main winding and auxiliary winding current, rotor speed, electromagnetic torque, and torque -Speed curve of the motor.

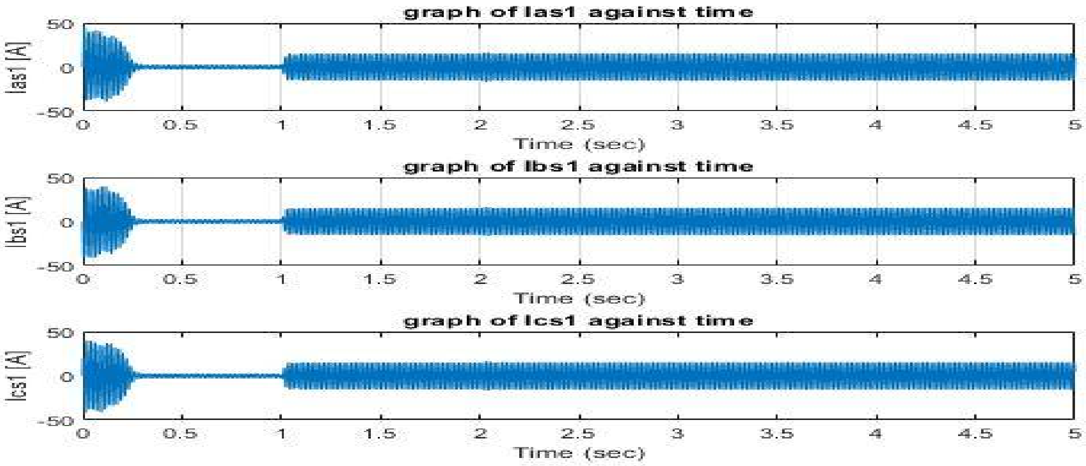

Fig: 4 Main Winding Current against Time

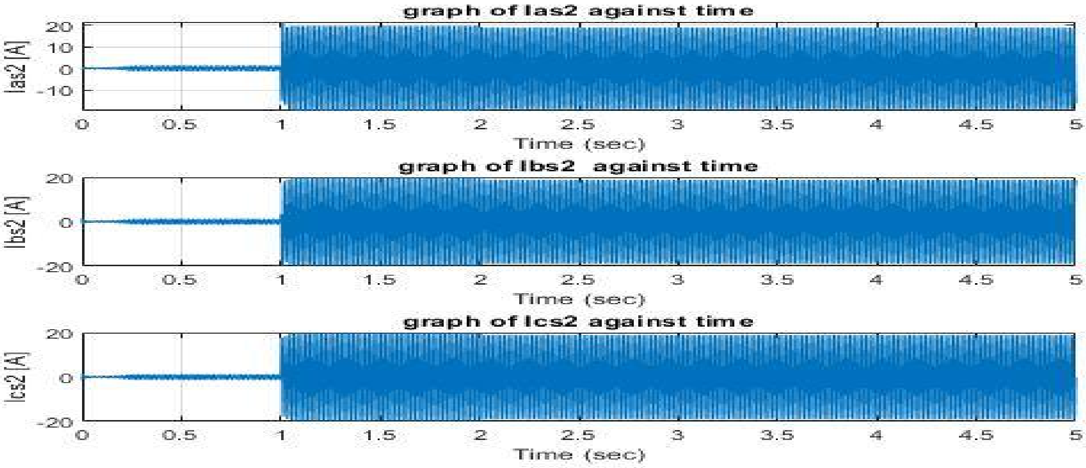

Fig: 5 Auxiliary Winding Current against Time

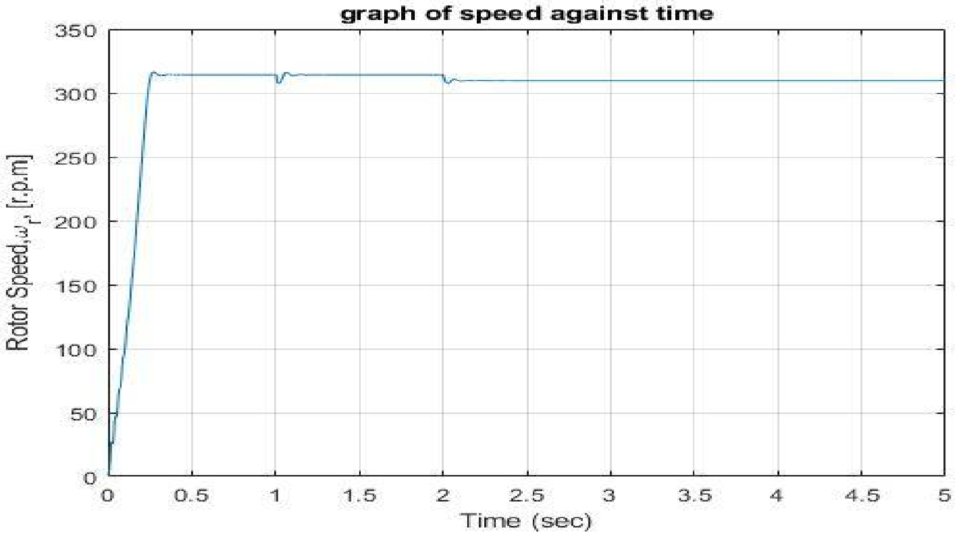

Fig:6 Mechanical Torque against Time

The introduction of the capacitor at the auxiliary end of the second winding reduces the in-rush current taken by the capacitor during starting, the introduction of the capacitor also enables the machine to attain steady state fast which can be seen in Fig 4. to Fig 5. as it takes 1.2 secs 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 electromagnetic torque and mechanical rotor speed reaches synchronism at 0.3 secs. as shown in Fig:6 and Fig: 7.

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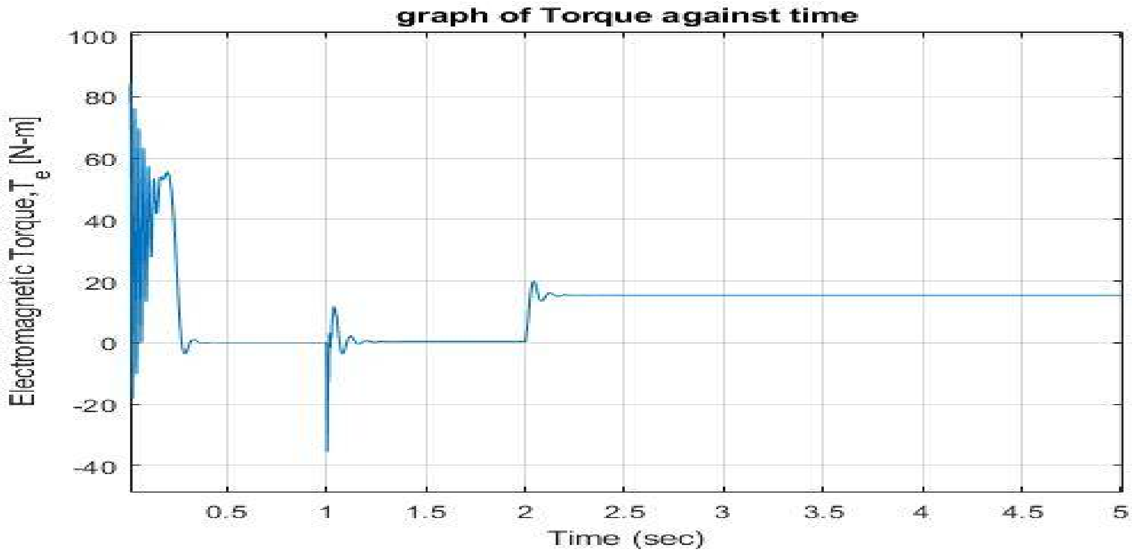

Fig:7 Electromagnetic Torque against Time

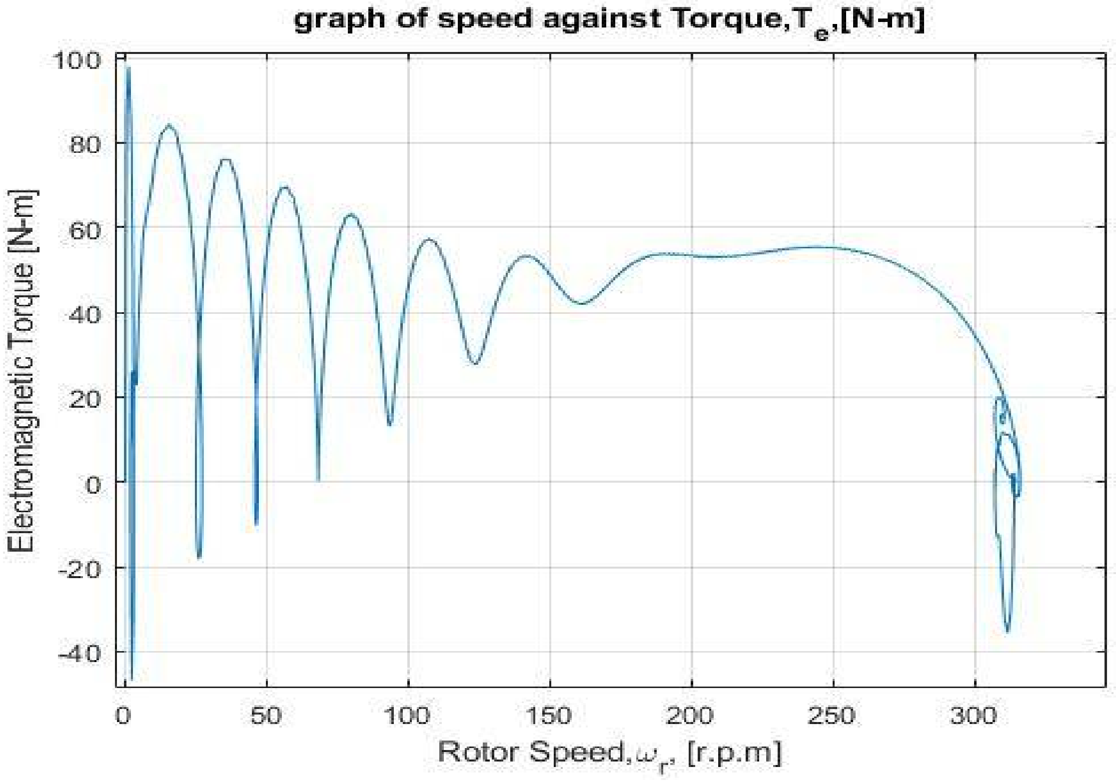

Fig: 8 Electromagnetic Torque against Mechanical Rotor Speed.

VI.CONCLUSION

From the MATLAB simulation of dynamic analysis, it can be seen that the capacitor excitation in the auxiliary winding gave a significant reduction effect of the high inrush 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 induction motor reaches a steady state condition in a very short time interval. Hence the speed of the motor show relative stability from 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 the auxiliary excitation of the capacitor.

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