

IMPACT OF LOAD TORQUE VARIATIONS ON THREE PHASE INDUCTION MOTOR TO ENHANCE ITS PERFORMANCE

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ABSTRACT

This paper presents the impact of load torque variations on the three phase induction motor for improved output performance. The objective was realized with the aid of Matlab/Simulink software. The induction motor used in this work are of specifications 3-phase, 4.5 KW, 50 Hz, 2 poles, 210 V, load torque (20 – 60) Nm. The transient and steady state responses of the motors were obtained, which revealed that that increase in load torque leads to decrease in motor speed, increase in load torque resulted to corresponding rise in stator resistanc. Similarly, increase in load torque leads to an increase in rotor resistance and corresponding increase in current.

1. INTRODUCTION

Induction machine is the most widely used in industrial applications as a source of mechanical power, due to its robustness, reliability, and good self-starting capability. In an induction motor, the steady-state and transient case studies are very important and should be taken into consideration. The transient cases in an induction motor are electromagnetic transient situations that result from commutations process and mechanical transient cases as a result of fast changes of rotational speed of the motor. Speed fading of electromagnetic transient cases depends on the winding parameters of the motor, the inertia torque of mass and the value of motor loads(Barbarawi, et al., 2017). Further, electrical parameters of motor get changed in time as to temperature, current and voltage fluctuations, time varying loading conditions, driving and operating conditions. Loading changes generate fluctuations in speed of rotor (Emre Hasan Dursun, Akif Durdu 2016).

Industry automation is mainly developed around motion control systems in which controlled electric motors play a crucial role as heart of the system. Therefore, the high performance motor control systems contribute to a great extent to the desirable performance of automated manufacturing sector by enhancing the production rate and the quality of products. In fact the performance of modern automated systems defined in terms of accuracy,

smoothness and efficiency, mainly depends to the motor control strategies (Ahmed M. Shehata 2019). The steady state mathematical modelling of Induction machines is not new and has received considerable attention from researchers dated far back as the machine itself. On the other hand, the transient mathematical modelling of induction machines continues to receive enormous attention and will continue to do so because of the vital effect the transient behavior of the induction machine has on the overall performance of the system to which it forms a component part. Unlike the steady state modelling, transient modelling proves to be more difficult, both in the definition of suitable forms of equations and in the application of appropriate numerical methods needed for the solution of same. However, appropriate mathematical transient models for most machine types were found when the generalized d-q axis theory was developed and the space vector theory evolved (Okoro 2003).

Ejiofor, et al., (2019), worked on dynamic modelling and simulation of induction motor with completely reduced stator transients. The result shows that reduced model can sufficiently represent the dynamic characteristics of an induction motor such as the currents and rotor speed of the induction motor. Also, from the results the torque dynamic characteristics of the motor were not well represented by the reduced model. Similarly,

Ejiofor, et al., (2020), presented ideally the behavioral characteristics of induction motor (IM) when subjected to different loading conditions. The work was achieved using the Simulink tool of the Matlab. Dynamic model was used to study the steady state and transient behavior of induction motor. Clarke and Park's transformation of stator and rotor parameters on the synchronously rotating reference frame was used to model the induction motor. However, from the results shown there was no work done on load torque variations.

Moreover, Ejiofor, et al., (2018), highlighted the mathematical modeling of an induction motor specifically in the stationary reference frame. The induction motor parameters and the generated equations were used to form the MATLAB function which in turn was used to produce graphs that shows the performance of a 5HP motor. The torque-speed response and other characteristics were fully simulated which resulted to a sound study of the performance characteristics of a three-phase 5HP induction motor using MATLAB/Simulink. In their work, phase currents were not considered.

Further, Salleh, et al., (2012), described a step by step model of the three-phase induction motor and its computer simulation using MATLAB/SIMULINK. The model was based on two-axis theory of revolving frame transformation; power source and load torque were taken as inputs and speed, electromagnetic torque and stator current were the output. Various sub-models for the induction motor were given and their implementation in SIMULINK was outlined. The result from the simulation were similar to those obtained using the traditional simulation method involving differential equations but the rotor resistance and the stator were not considered.

More so, in Al-Barbarawi, et al., (2019), a mathematical model was developed to study the dynamic behavior of a three-phase induction motor. The steady and transient states of the motor were studied for both balanced and unbalanced voltage supply. The behavior of the Torque-Speed characteristics at various conditions was studied. Matlab/Simulink models were proposed to study the dynamic behavior of the motor using d-q axis theory in the reference frame. But their work did not cover load torque variations.

Although, Dursun, et al., (2016), reported Sliding Mode Control method (SMC), which was built on

Variable Structure Control (VSC) theory, was a robust nonlinear control method creating insensibility against modeling errors, external disturbing effects and parametric change of the system. Control of a DC Motor used particularly in robots and countless industrial applications was carried out by using Sliding Mode Control (SMC) and the analysis was performed under load changes. It was desirable that motors operating under load in robotic applications must not be affected by changes depending on loading condition. In that paper, Sliding Mode Control (SMC) Method was used against this situation which was affected by stability of system and performance of motor. When comparisons between proposed method and Sliding Mode Control (SMC) method control are made in terms of performance analyses, it is seen that MatLab modelling produces more successful results.

However, Yildiz, et al.,(2017), studied speed sensor less induction motor drive, based on Unscented Kalman Filter (UKF) with the online estimations of stator stationary axis components of stator currents, rotor fluxes, rotor mechanical speed, load torque including the friction term and stator resistance were designed. The proposed speed sensor less induction motor drive was robust to load torque and stator resistance changes. The study did not cover the response of phase currents.

More so, Ustinov (2021), dealt with the method of increasing other torque of synchronous motor in the field of small slip values. It is found that the maximum torque of the synchronous motor is achievable via control by output voltage of the three phase thyristor dual converter (TDC) in the function of the load angle and phase-frequency characteristics of the excitation winding. Meanwhile, Ustinov's study was on synchronous motor.

Nevertheless, Akbaba (2009), In this work a numerical technique was presented for obtaining to a given load torque, which also in turn can be used for predicting firing angle in terms of load torque.

From the above reviews, there was no study of the effects of induction motor's parameters such as Load Torque variation on the performance of the motor. It is the interest of this research work to fill the gap.

2. MATERIALS AND METHODS

2.1 MATERIALS

In this research, the following materials were used in carrying out the simulation.

- (i) MATLAB/SIMULINK software package.

- (ii) Dell-Packard service pack 1 laptop with the following features:
 Window 7 professional
 Installed Memory (RAM): 4.00GB
 System type: 32-bit operating system
- Intel (R) core (TM) 2 Duo CPU P8700, 2.53GHz
- (iii) 4.5kW, 3-phase, 50 Hz, 2-pole, 210V induction motor.

2.2 METHODS

We implored the use of MATLAB in simulation of the Induction Motor.

The following procedures were undertaken.

- Electrical model of the machine.
- Mechanical model of the machine.
- The development of MATLAB m-file for both the electrical and mechanical models for the simulation of

The machine was considered.

A three phase voltage source is applied to the induction motor and the equations are given by.

$$V_{as} = V_m \sin(\omega t) \quad (1)$$

$$V_{bs} = V_m \sin(\omega t - \frac{2\pi}{3}) \quad (2)$$

$$V_{cs} = V_m \sin(\omega t + \frac{2\pi}{3}) \quad (3)$$

Where V_{as} , V_{bs} and V_{cs} are the three line voltages and V_m is the terminal Voltage.

These three-phase voltages are transformed to a two-phase synchronously rotating reference frame, the d-q transformation using the following equations:

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} \quad (4)$$

The direct and quadrature axis voltages are obtained during the equation below

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} \quad (5)$$

To get the instantaneous values of the stator and rotor currents in the three phase system, the following transformation is used.

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 & \frac{1}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} \quad (7)$$

Table 1: Motor parameters for Three-Phase Induction Motor.

Parameters	Values
Rated Power	4.5kW
Rated Voltages	210V
Poles	2
Rated Frequency	50Hz.
Stator resistance	0.601364Ω
Rotor resistance	0.52530Ω
Stator Inductance	1.870057e-3mH
Rotor Inductance	5.726896e-3mH
Magnetising Inductance	0.48044792mH
Moment Inertia	0.0303821kg.m ²
Load Torque	(20 – 60)Nm
Motor Inertia	0.02kg.m ²

Motor parameters gotten from the open and short-circuit tests of the induction motor under study.

3.RESULTS AND DISCUSSION

In Figure 1, at 60Nm the stator resistance attained a peak magnitude of 1.01Ω at 0.2s and as time increases the stator resistance reduces up to 0.79Ω at 1.5s. Similarly, at 50Nm the stator resistance attained a peak magnitude of 0.94Ω at 0.18s, and as time increases the resistance reduces up to 0.66Ω at 1.5s. Also, at 40Nm the stator resistance

attained a peak magnitude of 0.9Ω at 0.16s, and as time increases the resistance reduces up to 0.65Ω at 1.5s. Further, at 30Nm the stator resistance attained a peak magnitude of 0.86Ω at 0.09s, and as time increases the resistance reduces up to 0.63Ω at 1.5s. Furthermore, at 20Nm the stator resistance attained a peak magnitude of 0.83Ω at 0.08s, and as

time increases the resistance reduces up to 0.63Ω at 1.5s. Therefore, increase in load torque resulted to

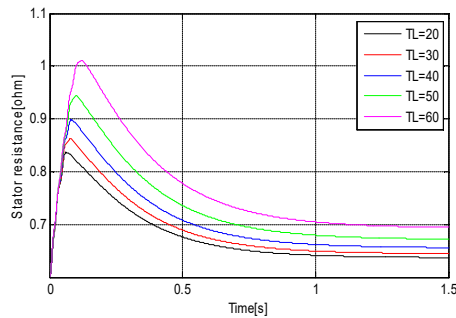


Figure 1: Graph of stator resistance against time.

Figure 2 shows that at 60Nm, the rotor resistance attained peak magnitude of 1.02Ω at 0.15s and steady state of 0.59Ω at 0.8s. Similarly, at 50Nm rotor resistance attained peak magnitude of 0.99Ω at 0.1s and steady state of 0.57Ω at 1s. Also, at 40Nm rotor resistance attained peak magnitude of 0.95Ω at 0.1s and steady state of 0.55Ω at 1s. Further, at 30Nm rotor resistance attained peak magnitude of 0.94Ω at 0.08s and steady state of 0.54Ω at 1s. Moreover, at 20Nm rotor resistance attained peak magnitude of 0.9Ω at 0.06s and steady state of 0.53Ω at 1s. Hence, increase in load torque results to increase in rotor resistance.

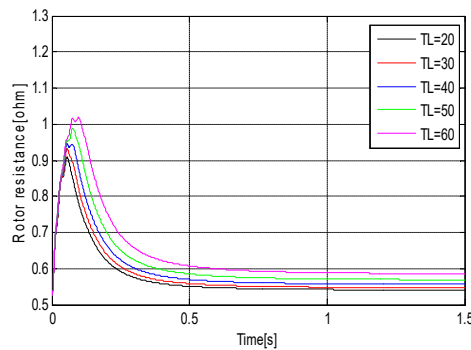


Figure 2: Graph of rotor resistance against time

In Figure 3 at 60Nm, the phase current has peak magnitude of 140A and steady state value of 35A. At 50Nm, the current magnitude is 120A while the steady state current value is 30A. Also, at 40Nm

corresponding increase in stator resistance.

the peak magnitude is 100A while the steady state value is 25A. At 30Nm, the phase current attains peak magnitude of 75A and steady state of 15A. At 20Nm the phase current attains peak magnitude of 80A and steady state of 20A. Increase in load torque leads to increase in phase current.

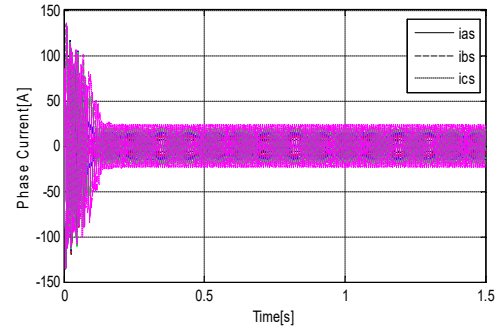


Figure 3: Graph of phase current against time.

In Figure 4 at 60Nm, electromagnetic torque is 60Nm at 0.25s. Similarly, the electromagnetic torque is 50Nm at 0.25s. Also, the electromagnetic torque is 40Nm at 0.25s. Further, the electromagnetic torque is 30Nm at 0.25s. Furthermore, the electromagnetic torque is 20Nm at 0.25s. Thus, increase load torque leads to increase in electromagnetic torque.

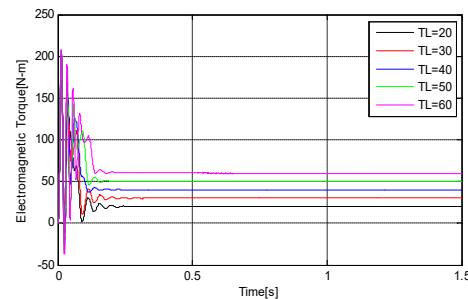


Figure 4: Graph of electromagnetic torque against time.

In Figure 5 at 60Nm, mechanical rotor speed is 1495rpm at 0.2s. Also, at 50Nm, mechanical rotor speed is 1495rpm at 0.3s. Similarly, at 40Nm, mechanical rotor speed attained a peak magnitude

of 1498rpm at 0.14s and steady state of 1496rpm at 0.3s. Further, at 30Nm, mechanical rotor speed attained a peak magnitude of 1499rpm at 0.13s and steady state of 1497rpm at 0.2s. Furthermore, at 20Nm, Mechanical rotor speed attained a peak magnitude of 1500rpm at 0.12s and steady state of 1498rpm at 0.2s. The increase in load torque is of little effect on the mechanical rotor speed.

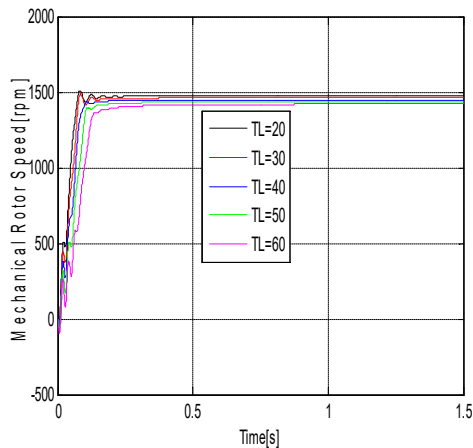


Figure 5: Graph of mechanical rotor speed against time.

Figure 6 shows that at 60Nm, shaft torque attains peak magnitude of 72rpm at 0.2s and steady of

state of 60rpm at 0.3s. Similarly, at 50Nm, shaft torque attains peak magnitude of 62rpm at 0.18s and steady of state of 50rpm at 0.3s. More so, at 40Nm, shaft torque attains peak magnitude of 54rpm at 0.16s and steady state of 40rpm at 0.3s. Moreover, at 30Nm, Shaft torque attains peak magnitude of 50rpm at 0.14s and steady state of 30rpm at 0.3s. Also at 20Nm, shaft torque attains peak magnitude of 40rpm at 0.12s and steady state of 20rpm at 0.3s. Therefore, it is observed that increase in load torque causes increase in shaft torque.

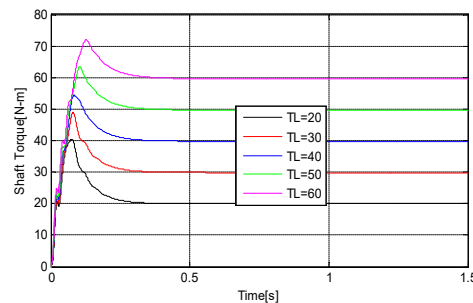


Figure 6: Graph of Shaft Torque against Time

4. CONCLUSION

The dynamic behaviors of an induction motor under varying load torque (20–60) Nm were studied. The simulations that was carried out specified motor data gotten from the open and short-circuit tests of the induction motor under study. By digital simulation of the resulting differential equations, dynamic transient responses of the motor were presented. Results revealed that increase in load torque leads to little reduction in motor speed. While increase in load torque causes increase in electromagnetic torque and also, increase in load

torque causes increase in shaft torque. Similarly, increase in load torque leads to a corresponding increase in current. The above results show that the speed of three phase induction motor can be controlled through the load torque. The simulation results presented in this paper will provide important information to the Plant Electrical Engineer over the motor performances prior to its design.

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