

# Advanced Electromagnetic Modelling of Induction Motors

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**Abstract**—Proposed paper dealt with the modelling and analysis of induction motor based on the mathematical expression using the graphical programming environment of Laboratory Virtual Instrument Engineering Workbench (LabVIEW). Induction motor modelling with the mathematical expression enables the motor to be simulated with the various required parameters. Owing to the invention of variable speed drives study about the induction motor characteristics became complex. In this simulation motor internal parameter such as stator resistance and reactance, rotor resistance and reactance, phase voltage, frequency and losses will be given as input. By varying the speed of motor corresponding parameters can be obtained they are input power, output power, efficiency, torque induced, slip and current.

**Keywords**—Induction motor, LabVIEW software, modelling and analysis, electrical and mechanical characteristics of motor.

## I. INTRODUCTION

**A**N induction motor is commonly known as the work horse of an industry owing to the robust nature, rugged construction and reliable operation. When an alternating current is provided to the secondary winding circuit of the induction motor it produces the revolving magnetic flux around the stator. Air gap acts as the dielectric medium which separates the rotor from the stator without having any physical contact. This revolving magnetic flux cuts the rotor windings axially as a result it produces an induced electromotive force in the rotor which is sinusoidal in nature. In a squirrel cage induction motor the end rings are short circuited, which provides the path for the induced current to flow across the rotor windings. The current induced in the rotor starts to circulate which produces a magnetic field in a direction opposite to the cause [1].

Production of torque is owing to the fundamental interaction between these two counterbalancing magnetic fields due to the applied voltage to the stator. The torque characteristics of an induction motor are suitable for a variety of industrial applications such as pumps, fans, prime movers, blowers etc. Induction motor is available with speed vs torque characteristics suitable for a variety of industrial applications. Squirrel cage induction motors have higher efficiency and less maintenance when compared to the wound rotor induction motor when compared to the wound rotor induction motor

because it have higher losses due to externally connected resistances in order to reduce the losses in wound rotor motor the slip power recovery technique was to reduce the losses [2].

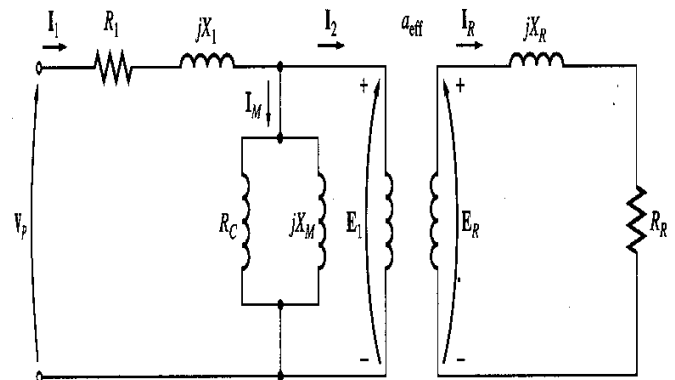


Fig. 1 Equivalent circuit parameters of an induction motor

## II. TEST FOR INDUCTION MOTOR

### A. The DC Test for Induction Motor

This test is called the dc resistance test. For this test a dc voltage is applied to the stator windings of the motor. There is no induced voltage in the rotor circuit due to dc current therefore no resulting rotor current. Even the reactance of the motor is zero at direct current. Therefore, quantity limiting of current is the motor stator resistance which can be determined.

### B. No-load Test

This test is performed to determine the no load input, no load current  $I_0$ , no load power factor, windage losses, friction losses, no load core losses, no load resistance and reactance can be found using this no-load test of the motor. This test is performed by applying different values of applied voltage which will be below and above of the rated voltage of induction motor without connecting to the external load. The test is performed at rated frequency and with balanced polyphase voltages applied to the stator terminals and will have a very small amount of slip power [3].

### C. Locked-Rotor Test

Locked rotor test is performed to determine the short circuit current of the motor ( $I_{sc}$ ) with rated voltage applied to the stator, short circuit power factor of the motor, total equivalent resistance and reactance of the motor as referred to stator. The locked rotor test on the induction motor is done by holding the shaft of the motor mechanically from turning in any direction and applying a voltage which is below the rated voltage to the stator [4].

## III. BUILDING INDUCTION MOTOR MODEL

National Instruments developed LabVIEW software for the first time in the year 1986 for the Apple Macintosh Company. It was conceptualized as a programming environment for hardware control. The introduction of an interface between the personnel Computer and the instrument which is to be controlled by software was the main aim. The graphical user interface, which is used to simulate the controlled instrument on the computer, monitors itself with the help of LabVIEW software [5].

Nowadays LabVIEW software is also compatible with other operating system such as Windows and Linux, etc. The word LabVIEW is an acronym for Laboratory Virtual Instrument Engineering Workbench which is a graphical programming language based on graphical icons instead of number of programming codes for simulation purpose. LabVIEW software allows the user to build their own set of virtual instruments easily. These programs are known as Virtual Instruments, due to their operational replica of physical instruments, like temperature monitor, spectral scopes, pressure gauges, cathode ray oscilloscopes, and multi-meters [6].

The inputs are known as controls and the outputs are known as indicators are placed on the graphic user interface (GUI) called Front Panel (FP). They communicate with each block diagram through terminals of the icons. In LabVIEW the data flow of the program will be from left to write, but in C/C++ programming codes will be executed in order of top to bottom, errors in the LabVIEW will be easily identified during the execution of the program itself [7].

#### IV. SIMULATION AND ANALYSIS OF INDUCTION MACHINE

Machine’s modelling developed in LabVIEW software is based on the mathematical expressions. Mathematical equations are first derived then converted into models using icons from the arithmetic board for further implementation in LabVIEW for graphical analysis [8]– [14].

Simulation of induction motor load test needs certain parameters that are described in Table I. To analyses the parameters are an important factor.

S.No	Parameter	Input Values
	Phase voltage	$V_{ph}$
	Number of poles	P
	Frequency	F
	Stator Resistance	$R_1$
	Stator Reactance	$X_1$
	Rotor Resistance	$R_2$
	Rotor Reactance	$X_2$
	Magnetizing Reactance	$X_m$

The above said parameters are used to model the induction motor. By changing the above input parameters corresponding values can be obtained in the form of graphical representation.

TABLE II  
MOTOR INTERNAL PARAMETER

Symbols	Parameter	Input Values
$R_1$	Rotor Resistance	
$R_2$	Rotor Reactance	0.500
$S_1$	Stator Resistance	1.110
$S_2$	Stator Reactance	0.500
$X_m$	Magnetizing Reactance	

Motor internal parameters are taken from the best operating conditions of induction motor these values are made constant for the simulations of motor. For a particular operating load condition these values are made constant. Parameters can be changed before simulating for different load condition. They are corresponding characteristics curve can be drawn.

TABLE III  
MOTOR INPUT TERMINAL

Symbols	Parameter	Input Values
$V_{ph}$	Phase voltage	
Hz	Frequency	
P	Number of poles	

Values are made constant throughout the simulation because small changes in these input values will deviate simulation result.

TABLE IV  
MOTOR CORE LOSS

Symbols	Parameter	Input Values
L	Core losses	

Core loss is made constantly throughout the simulation because they won’t change for a motor throughout its lifetime. So it’s made as constant in this simulation.

#### A. Simulation of Induction Motor

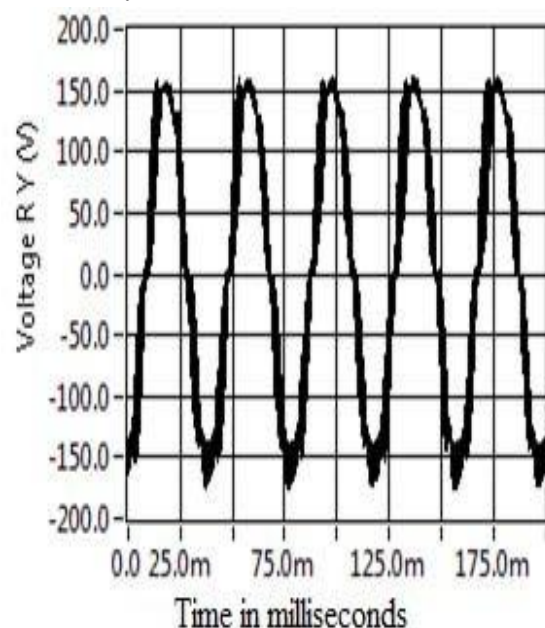


Fig. 2 Voltage waveform of induction motor

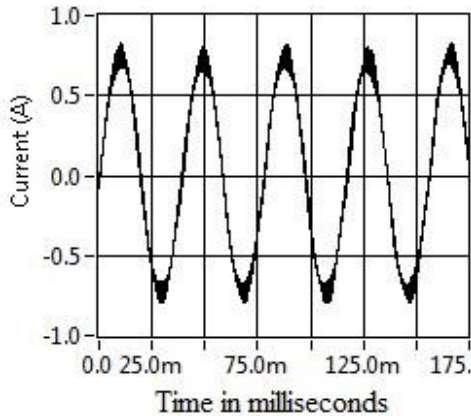


Fig. 3 Current Waveform of Induction Motor

Current consumed by the motor here is 0.8 amperes. They measured in the milliseconds. Maximum current absorbed by the motor is 0.8 amperes. There are ripples due to the harmonics present.

$$\frac{n_s}{sE_2^2 R_2}$$

(1)

$$*$$

(2)

There are two main characteristics explained or concerned in the field of machine design they are classified into electrical characteristics and the other one is mechanical characteristics. Normally torque vs. speed characteristics is also known as mechanical characteristics. Electrical characteristics are further classified into the torque vs. Current characteristics and speed vs. current characteristics.

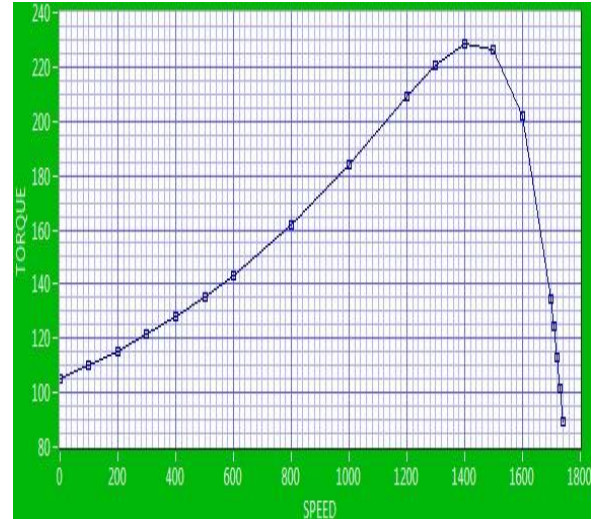


Fig. 4 Torque vs speed characteristics of induction motor

Torque vs. speed characteristics are drawn but is a single quadrant operation where the motoring region is only shown. Plugging and generating regions are avoided to reduce the complexity is modeling of the induction motor.

TABLE V  
SPEED VS TORQUE CHARACTERISTICS

S.No	Speed	Torque
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Mechanical characteristics of induction motor are to be analysed in that torque vs speed characteristics plays a major role in analyses of induction motor. In this simulation the torque vs speed characteristics are analysed for the study of an induction motor which are modelled by the mathematical calculation.



Fig. 5 Torque vs current characteristics of induction motor

Torque and current increases in a straight line due to the fact torque is directly proportional to the current. The maximum torque is directly proportional to square of rotor induced emf at the standstill.



Fig. 6 Speed vs current of induction motor

Speed vs current characteristics shows that whenever there is an increased in speed there will be decreased current. In Fig. 6 there relation between the speed and current is shown in an opposite direction when the speed tends to decrease automatically current starts to increase this shown in the graph where the modeled induction motor graph drawn during decreasing the speed.

#### V. CONCLUSION

The analysis of this experimental result shows that induction motor model was built with the LabVIEW software. It can be used to model and simulate the working process of induction motor by which motor performance calculated, is set to compare with the real time operating consideration of the induction motor for the optimal operation of machines.

#### REFERENCES

- [1] R. K. Rajput, "Electrical Machines," first edition, New York: McGraw-Hill, 1993, pp. 352-353.
- [2] R. Krishnan, "Electric Motor Drives Modelling, Analysis and Control", first edition, Prentice-Hall International, Inc. Upper Saddle River, New Jersey 07458, 2001, pp 400 - 415.
- [3] R. Gunabalan, S. Immanuel Prabakaran, J. Reegan, and S. Ganesh "Simulation of inverter fed induction motor drive with LabVIEW" *International Journal of Electrical, Robotics Electronics and Communications Engineering* vol:8, no:1, pp:91-95, 2014.
- [4] Gentian dume "Synchronous generator model based on LabVIEW software", *WSEAS Transactions on Advances in Engineering Education* vol:10 pp: 101-112, 2013.
- [5] R. A. Jabbar, Azah Mohamed, M.A. Hannan, Muhammad Junaid, M. Mansoor, A. Latif and H. Noor, Simulation of electrical machines laboratory using LabVIEW", *International Conference on Computer, Electrical, and Systems Science, and Engineering*, World Academy of Science Engineering and Technology pp:29-31, 2010.
- [6] Abdenour Soualhi, Guy Clerc, and Hubert Razik, "Detection and diagnosis of faults in induction motor using an improved artificial ANT clustering technique" *IEEE Transactions on Industrial Electronics*, Vol. 60, pp: 4053 – 4062, 2013.
- [7] M. Aderiano da Silva, J. Richard Povinelli, and A.O Nabeel Demerdash "Rotor bar fault monitoring method based on analysis of air-gap torques of induction motors" *IEEE Transactions on Industrial Informatics*, Vol. 9, pp: 2274 – 2283, 2013.
- [8] Bogdan Virlan, Seifeddine Benelghali, Alecsandru Simion, Leonard Livadaru, Rachid Outbib, and Adrian Munteanu, "Induction motor with outer rotor and ring stator winding for multispeed applications" *IEEE Transactions on Energy Conversion*, Vol. 28, pp: 999 – 1007, 2013.
- [9] L. Daniel Ransom and Randy Hamilton, "Extending motor life with updated thermal model overload protection" *IEEE Transactions on Industry Applications*, Vol. 49, pp: 2471 – 2477, 2013.
- [10] Gianmario Pellegrino, Alfredo Vagati, Barbara Boazzo, and Paolo Guglielmi, "Comparison of induction and pm synchronous motor drives for ev application including design examples", *IEEE Transactions on Industry Applications*, vol. 48, pp: 2322 – 2332, 2012.
- [11] N. Konstantinos Gyftakis, V. Dionysios Spyropoulos, C. Joya Kappatou and D. Epaminondas Mitronikas, "A novel approach for broken bar fault diagnosis in induction motors through torque monitoring" *IEEE Transactions on Energy Conversion*, vol. 28, pp: 267 – 277, 2013.
- [12] Lu'is Alberto Pereira, C'esar Cataldo Scharlau, Lu'is Fernando Alves Pereira, and S'ergio Haffner, "Influence of saturation on the airgap induction waveform of five-phase induction machines" *IEEE*
- [13] Pinjia Zhang, Yi Du, G. Thomas Habetler, and Bin Lu, "A nonintrusive winding heating method for induction motor using soft starter for preventing moisture condensation " *IEEE Transactions on Industry Applications*, vol. 48, pp: 117 – 123, 2012.
- [14] E.Ramprasath, P.Manojkumar, Modelling and Analysis of Induction Motor using LabVIEW, *International Journal of Power Electronics and Drive System (IJPEDS)* Vol. 5, No. 3, February 2015, pp. 344~354.