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# INDUCTION MACHINES ANALYSIS USING LABVIEW SOFTWARE PACKAGE

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## ABSTRACT

*Induction machines are widely used in many industries due to their robustness, ruggedness and easy maintenance feature. Due to the addition of power electronics devices and the complexity involved in the design of induction machines, their study and analysis can be very difficult. The use of software packages has been widely adopted to analyze and study the behaviours of induction machines. This work focused on the use of an engineering software package known as Laboratory Virtual Instrument Engineering Workbench (LabVIEW). It is used in this work to study the behaviour and characteristics of induction machines. LabVIEW was utilized due to its cheap and user-friendly feature. This work shows that induction machines can be completely analyzed using related mathematical equations for performance analysis.*

**Keywords:** Induction Machines, LabVIEW and Simulations.

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## 1. INTRODUCTION

LabVIEW is a popular system design software that provides an environment for development and visual programming [1]. By creating user interfaces, LabVIEW development cycles can be created. Information and data can be passed into the program and the necessary results generated based on the inputs given. The results can be presented in graphical form, multidimensional plots or simple numerical representations. This feature has made the use of LabVIEW easy, user-friendly and it makes the simulation process simpler. When compared with the other software programs available for engineering simulations such as Matrix Laboratory (MATLAB), Finite Element Analysis (FEA), PSpice, Proteus, Electromagnetic Transient Program (EMTP), etc., LabVIEW provides an easier and cheaper alternative to be able to accomplish similar results. Adopting LabVIEW to simulate induction machines provides a better alternative to complete the analysis of induction machines.

Induction machines are generally adopted in many areas in the world today. Some of these areas include commercial, industrial and domestic applications. In fact, electric motor systems constitute the major support for industrial applications and operations [2]. The coupling of power electronics devices to induction machines have further increased its usage in recent years owing to its low cost, low weight, reliability and easy maintenance [3] [4]. Although the design of induction machines can be complex, the adoption of software packages can significantly reduce this challenge [1]. The understanding and knowledge of the operating principles, as well as governing mathematical expressions, is important in getting to know how to properly analyze induction machines [5]. Existing literature and theories provide the necessary directions in understanding the mechanisms which will be important in design and analysis procedures [3].

This study presents the use of LabVIEW to determine the characteristics and performance of induction machines. The experiments completed in this work in order to determine the characteristics and performance of induction machines includes the equivalent circuit analysis, load test, and torque-speed characteristics. This study is organized as follows: Section 2 reviews different kinds of literature for the previous work that has been done in analyzing and modelling induction machines, Section 3 discusses the methodology, Section 4 provides the results and discussions and Section 5 concludes the study.

## 2. LITERATURE REVIEW

The design process of electrical machines is a complex and multi-level task. The determination of the design parameters that will ensure that the machine operates according to specified limits is one of the important areas in electrical machine design [6]. The complexity of electrical machine design and analysis presents some pitfalls that can be significantly taken care of by the adoption of software applications. The applications can be used to evaluate the efficiency of electrical machines in terms of the electrical, mechanical and magnetic losses in a quick, easy and cheap way [6].

Different software programs have been utilized to be able to complete the design processes. One of the most common software used in electrical machine analysis includes the Finite Element Method/Finite Element Analysis software (FEM/FEA). FEM/FEA software can be used to successfully used to analyze the parameters of electrical machines. Stanislav et al. (2016) utilized this software to model an induction motor in order to obtain the operation parameters [7]. FEA technique is a powerful tool as it is capable of accurately obtaining design parameters and electrical machines characteristics. It also has the capability for optimization of electrical machines [8]. Although, the major downside of the use of FEA is that it takes a lot of time to build models and determine necessary parameters (Rosu, et al., 2017). It is also not a very user-friendly software and it is very complex in its usage, requiring special expertise. The use of MATLAB for electrical machines analysis is also widely accepted by many industries and researchers [10]. MATLAB has been utilized in many areas to analyze electrical machines. One of the powerful tools present in MATLAB known as Simulink was used to analyze an electric DC drive and the results were satisfactory [11]. The essential characteristics of a DC drive were obtained from this analysis using MATLAB software. Meenakshi and Muthu also utilized MATLAB software for the analysis of an asynchronous generator [12]. The performance characteristics of a three-phase induction machine can also be analyzed and studied effectively using MATLAB and Simulink applications [13]. MATLAB is generally acceptable and is perhaps one the best computer simulation software for electrical machines, but it is an expensive software and often requires special expertise to be able to completely model a working system. The study of the thermal conditions of electrical machines can also be done with the use of Motor-CAD. The thermal analysis of electrical motors is important in

the design process and it allows for the prediction of winding losses on temperature estimation [14].

The use of LabVIEW has also been adopted by many researchers to determine characteristics properties of electrical machines. Adopting the use of LabVIEW as compared to other types of software provides different advantages [3]. Some of these advantages include a user-friendly interface and easy to use features which can enable even beginners to successfully complete electrical machine models and analysis. This work utilizes LabVIEW in the study and analysis of induction motor parameters.

### 3. METHODOLOGY

In this study, three different experiments were conducted in order to be able to determine the characteristics and analyze the parameters of induction machines. These experiments include the equivalent circuit parameters, load test, and the torque-speed relationship of induction machines. Equations that represent the models that need to be studied and analyzed are first derived before the utilization of LabVIEW for necessary analysis. The mathematical expressions that represent the inputs and outputs for the analysis are directly handled with the aid of graphical representations and block diagrams in the graphical interfacing modes. The processes in the experimental design are as described in the subsections below:

#### 3.1 Equivalent Circuit Parameters of Induction Machine

The preliminary mathematical equations that are required for the model of the equivalent circuit parameters are first analyzed before replicating on LabVIEW with the use of the graphical programming interface. The speed of the magnetic field (synchronous speed) is given as:

$$n_{sync} = \frac{120f}{P} \quad (1)$$

Where  $f$  is the frequency in hertz,  $P$  is denoted as the number of poles in the induction machine. The slip speed, which is obtained by subtracting the rotor speed from the synchronous speed is given as:

$$n_{slip} = n_{sync} - n_m \quad (2)$$

Where  $n_{slip}$  is the slip speed,  $n_{sync}$  is the synchronous speed, and  $n_m$  is the rotor speed. The slip can then be expressed as a percentage of the slip speed and the synchronous speed which is given as:

$$s = \frac{n_{slip}}{n_{sync}} \times 100\% \quad (3)$$

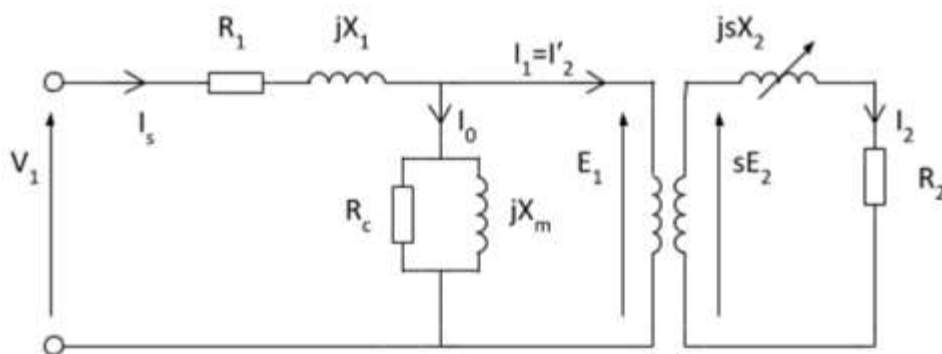
The rotor current,  $I_R$  can be expressed as:

$$I_R = \frac{E_R}{R_R + jX_R} \quad (4)$$

Where  $E_R$  is the rotor voltage,  $R_R$  is the rotor resistance and  $X_R$  is the rotor reactance. The rotor impedance,  $Z_2$  becomes:

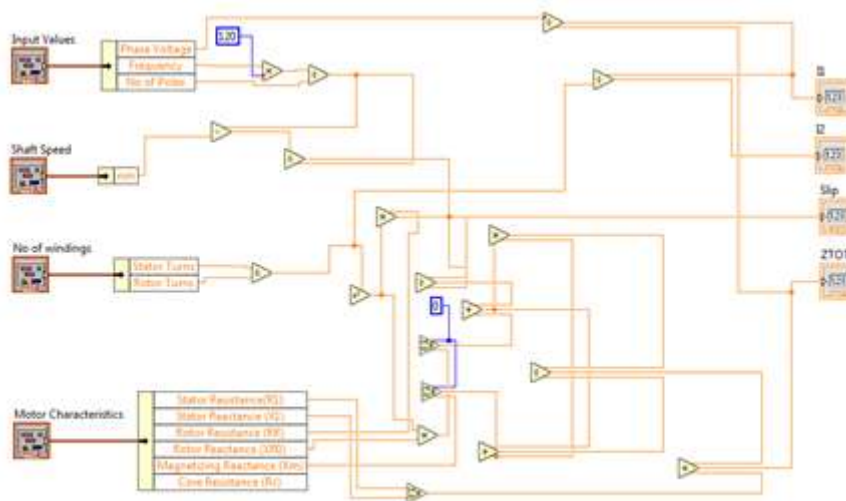
$$Z_2 = a_{eff}^2 \left( \frac{R_R}{s} + jX_R \right) \quad (5)$$

Where  $a_{eff}$  is the effective turns ratio of the induction machine. Figure 1 shows the general equivalent circuit diagram of induction machines.



**Figure 1** shows the equivalent circuit of an induction machine

The mathematical expressions are modelled in LabVIEW where the components are arranged appropriately and assembled based on the appropriate requirements. The block diagram that can be used to obtain the equivalent circuit parameters of induction machines is as shown in Figure 2.



**Figure 2** shows the block diagram of the equivalent circuit parameters of induction machines

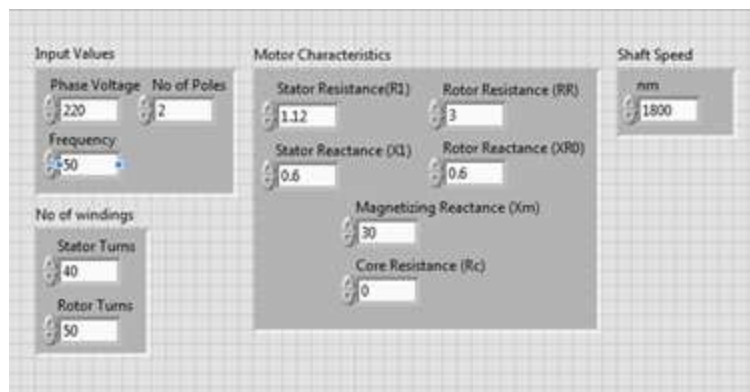
The input parameters that are used in the analysis of the equivalent circuit is as shown in Table 1 below:

**Table 1** Design and input parameters of an induction machine

Parameter	Value
Phase Voltage ( $V_{ph}$ )	220
Number of Poles	2
Frequency	50
Stator Turns	40
Rotor Turns	50
Stator Resistance ( $R_1$ )	1.12
Stator Reactance ( $X_1$ )	0.6
Rotor Resistance ( $R_R$ )	3
Rotor Reactance ( $X_{R0}$ )	0.6

Magnetizing Reactance ( $X_m$ )	30
Core Resistance ( $R_c$ )	0
Input: Rotor mechanical shaft speed ( $n_m$ )	1800

It is important to note that the shaft speed must be less than the synchronous speed, else no voltage will be induced. Figure 3 shows the design and input parameters of an induction machine from the front panel of the LabVIEW.



**Figure 3** shows the design and input parameters of an induction machine from LabVIEW

### 3.2 Load test of Induction machine (3 phase)

In order to determine the efficiency of the induction machine, the following analysis is considered. The stator copper losses, core losses and the rotor losses can be found can be obtained by using the mathematical expression below:

$$P_{SCL} = 3I_1^2 R_1 \quad (6)$$

The above expression represents the stator copper losses where  $I_1$  represents the input current that is obtained from the division of the input voltage with the equivalent impedance. The core losses are expressed as:

$$P_{core} = 3E_1^2 G_C \quad (7)$$

The rotor losses can be expressed as:

$$P_{RCL} = 3I_2^2 R_2 \quad (8)$$

Where  $I_2$  represents the rotor current and  $R_2$  represents the rotor resistance. If the losses expressed above are subtracted from the input power, the remaining power can be converted to mechanical power, which provides the developed electrical power for the induction machine. This can be expressed mathematically as follows:

$$P_{conv} = 3I_2^2 R_2 \left( \frac{1-s}{s} \right) \quad (9)$$

The induced torque is given by the equation:

$$\tau_{and} = \frac{P_{conv}}{\omega_m} \quad (10)$$

By mathematical manipulations, it can be shown that the induced torque is also given as:

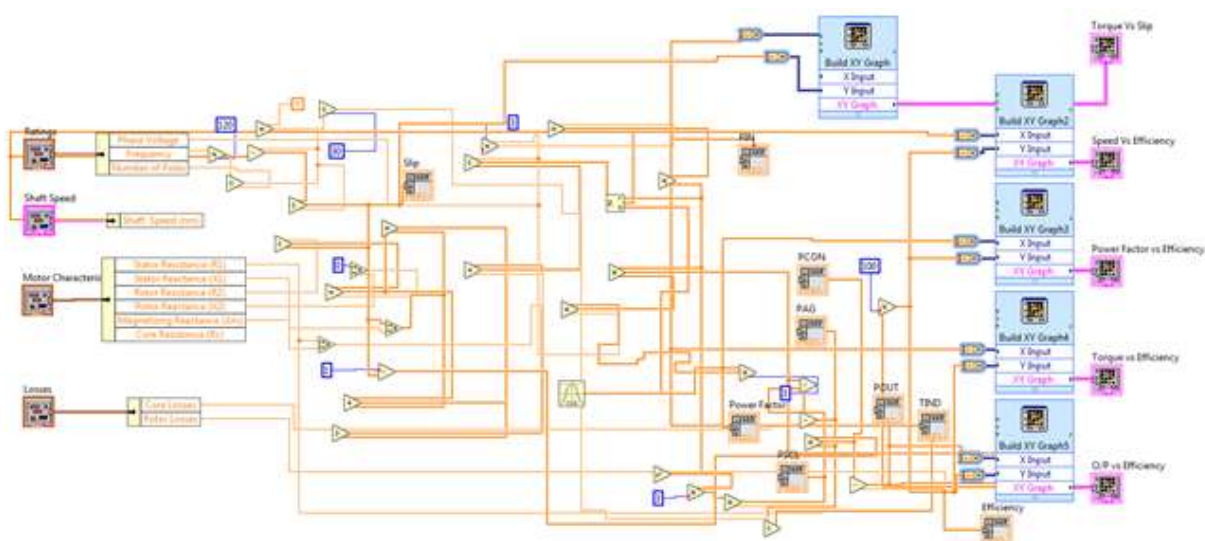
$$\tau_{\text{and}} = \frac{3V_{\text{TH}}^2 R_2/s}{\omega_{\text{sync}}[(R_{\text{TH}} + \frac{R_2}{s})^2 + (X_{\text{TH}} + X_2)^2]} \quad (11)$$

Computing the ratio of the output power to the input power provides the efficiency of the induction machine. Figure 4 shows the block diagram for the load test of an induction machine. Table 2 presents the design parameters which is used to determine the necessary output parameters.

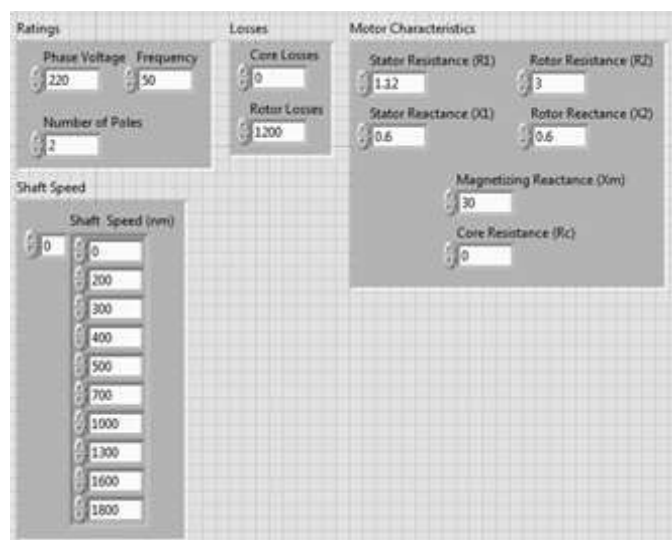
**Table 2** Design parameters of an induction machine

Parameter	Value
Phase Voltage ( $V_{ph}$ )	220
Number of Poles	2
Frequency	50
Rotational losses	1200
Core losses	0
Stator Resistance ( $R_1$ )	1.12
Stator Reactance ( $X_1$ )	0.6
Rotor Resistance ( $R_R$ )	3
Rotor Reactance ( $X_{RO}$ )	0.6
Magnetizing Reactance ( $X_m$ )	30
Core Resistance ( $R_C$ )	0
Input range: Rotor mechanical shaft speed ( $n_m$ )	[0 200 300 400 500 700 1000 1300 1600 1800]

It is important to note that the shaft speed must be less than the synchronous speed, else no voltage will be induced. Varying the value of the shaft speed also causes a corresponding change in the output values. Figure 5 shows the design and input parameters of an induction machine from the front panel of the LabVIEW.



**Figure 4** shows the block diagram for the load test of an induction machine.



**Figure 5** shows design and input parameters from the front panel of LabVIEW

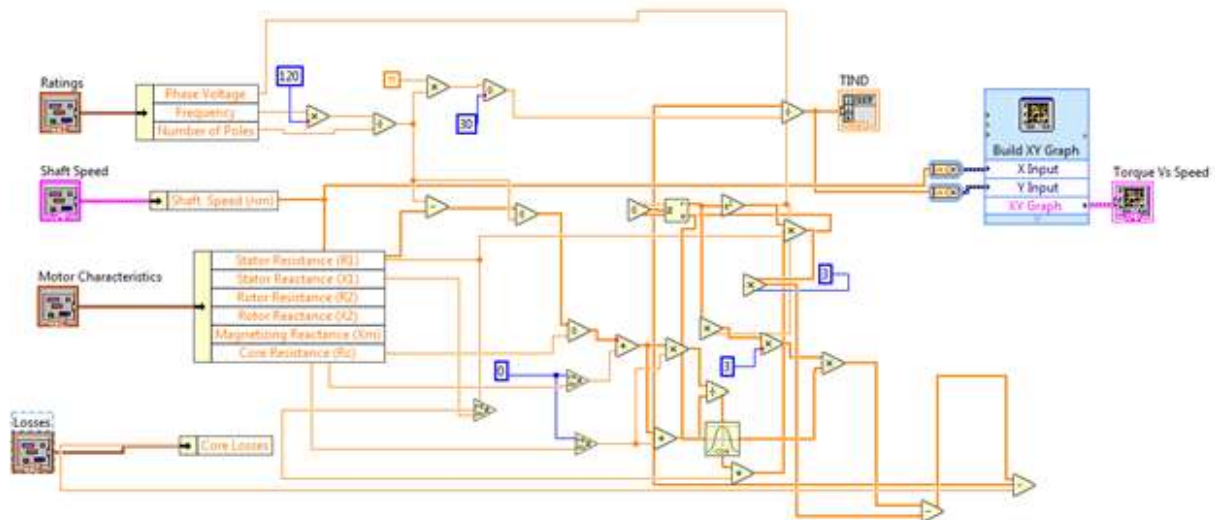
### 3.3. Torque-Speed Relationship of Induction Machine

This is one of the most important relationships that can describe the behaviour of an induction machine. When the speed and induced torque of an induction machine are plotted against each other, some certain characteristics of the induction machine can be studied. The block diagram that was utilized in LabVIEW for the torque-speed characteristic is as shown in Figure 6. Table 3 shows the design parameters that were used in the torque-speed relationship experiment in LabVIEW.

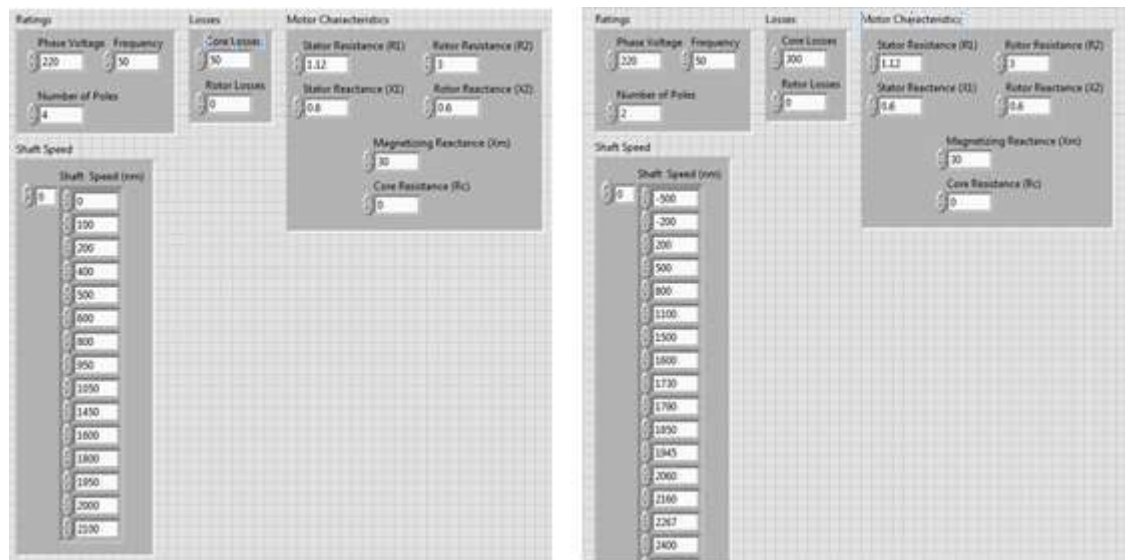
**Table 3** Design parameters for torque-speed relationship of an induction motor

Parameter	Value
Phase Voltage ( $V_{ph}$ )	220
Number of Poles	2
Frequency	50
Core losses	300
Stator Resistance ( $R_1$ )	1.12
Stator Reactance ( $X_1$ )	0.6
Rotor Resistance ( $R_R$ )	3
Rotor Reactance ( $X_{RO}$ )	0.6
Magnetizing Reactance ( $X_m$ )	30
Core Resistance ( $R_C$ )	0
Input: Rotor mechanical shaft speed ( $n_m$ )	[-500 -200 0 100 200 400 500 600 800 950 1050 1100 1450 1500 1600 1730 1800 1850 1945 1950 2000 2100 2160 2267 2400]





**Figure 6** shows the block diagram in LabVIEW for the torque-speed characteristic.



**Figure 7** shows design parameters in the front panel of the LabVIEW application

The values of the rotor speed used in this analysis must be less than the synchronous speed. Figure 7 shows the design parameters in the front panel of the LabVIEW application.

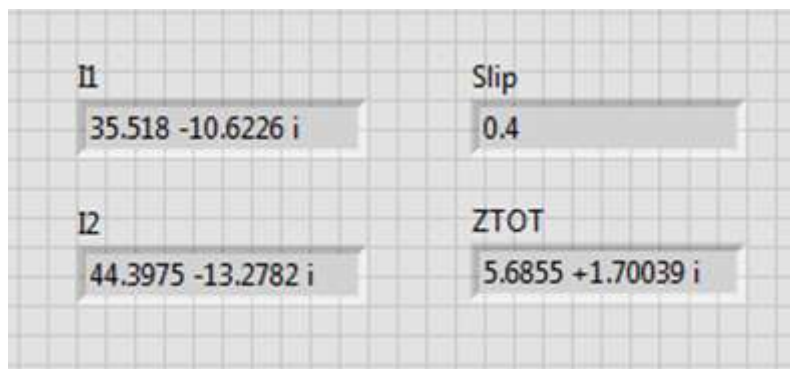
## 4. RESULTS AND DISCUSSIONS

The results obtained from the experiments and analysis done are discussed in this section.

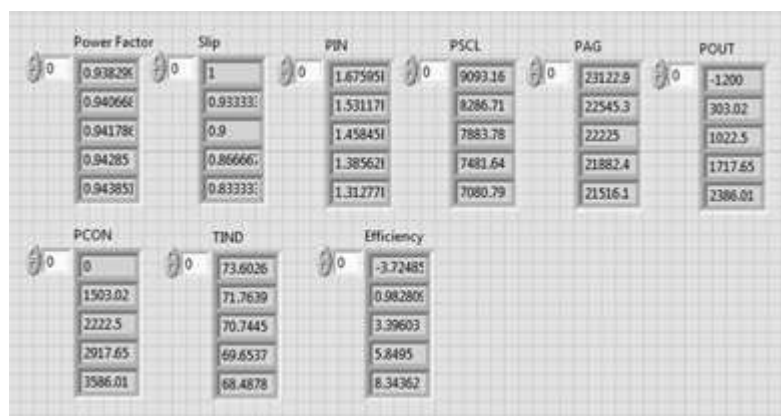
Table 4 shows the result for the equivalent circuit parameters of an induction machine. The slip, stator current, rotor current and the equivalent impedance are accurately obtained. It can be observed that by increasing the rotor shaft speed, there is a corresponding increase in the values of the slip, stator current, rotor current and a decrease in the impedance. Figure 8 shows the front panel results as obtained from LabVIEW.

**Table 4** Design parameters for torque-speed relationship of an induction motor

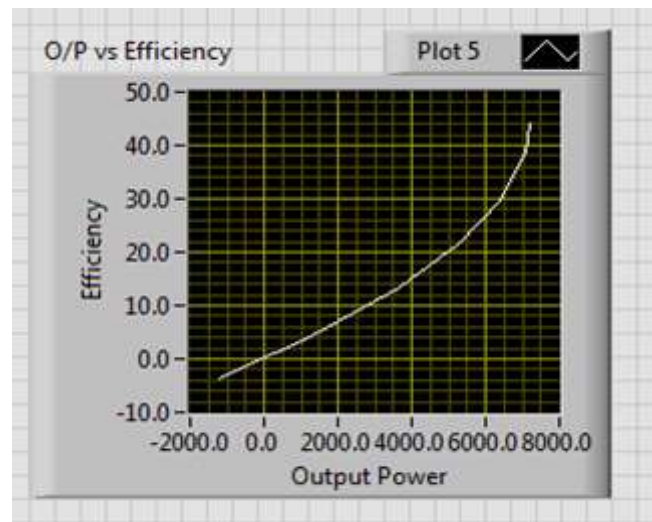
Parameter	Value
Slip	0.4
$I_1$	$35.518 - j10.6226$
$I_2$	$44.3975 - j13.2782$
$Z_{tot}$	$5.6855 + j1.70039$


**Figure 8** shows the front panel results for equivalent circuit

Furthermore, as obtained from the induction machine load test, it can be observed experimentally that an increase in the shaft speed or rotor speed which is greater than the synchronous speed will cause the induction machine to act as a generator and the torque is reversed. Further observations can be made from the induction machine load test. While constantly varying the values of the design parameters, the behaviour and characteristics of the induction machine can be determined. The values of the slip, torque, power factor and the output power decrease with an increase in the rotor speed, however, this leads to higher efficiency. The output of the motor load test is as displayed in Figure 9 below:


**Figure 9** shows the output of the motor load test

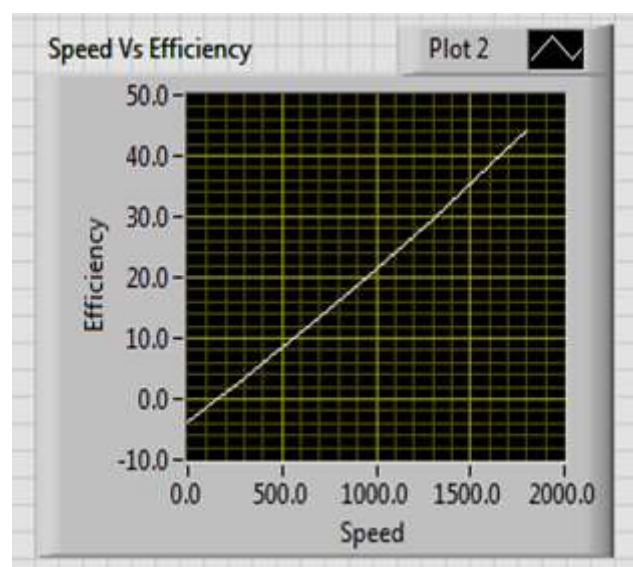
The graphical representations in Figures 10-16 describe the behaviour of the induction machine with varying rotor speed. Increase in the output power, induced torque and power factor causes the efficiency of the induction machine to reduce as seen in the graphical representations. Furthermore, it can also be observed that the torque is in a way, directly proportional to the slip. An increase in torque leads to a corresponding increase in the slip. Increasing the rotor speed also causes the efficiency of the induction machine to increase as seen in the graph of the efficiency versus speed relationship.



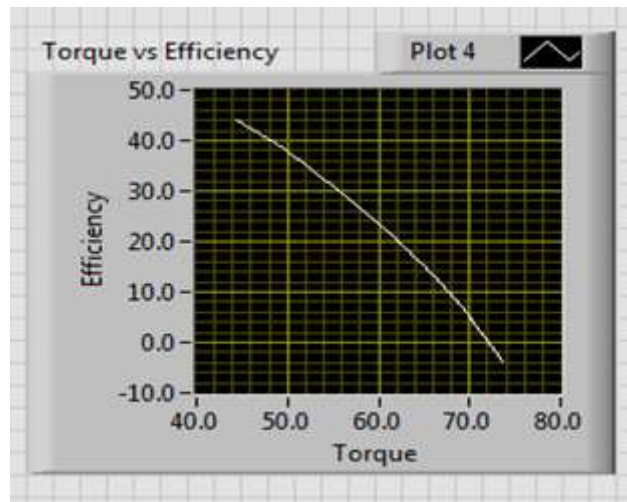
**Figure 10** shows Efficiency Vs Output



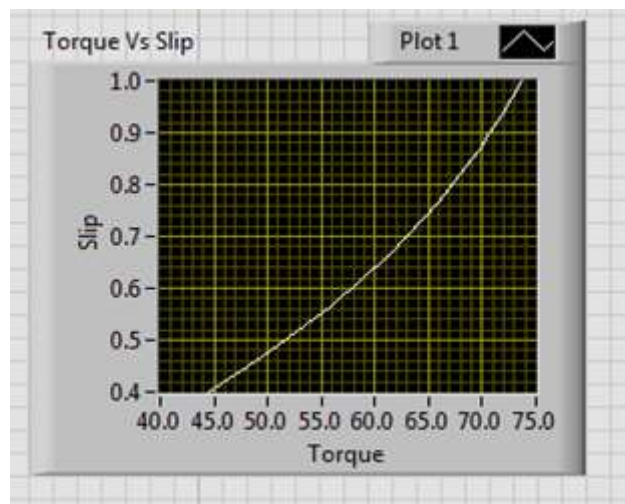
**Figure 11** shows the Efficiency Vs Power Factor



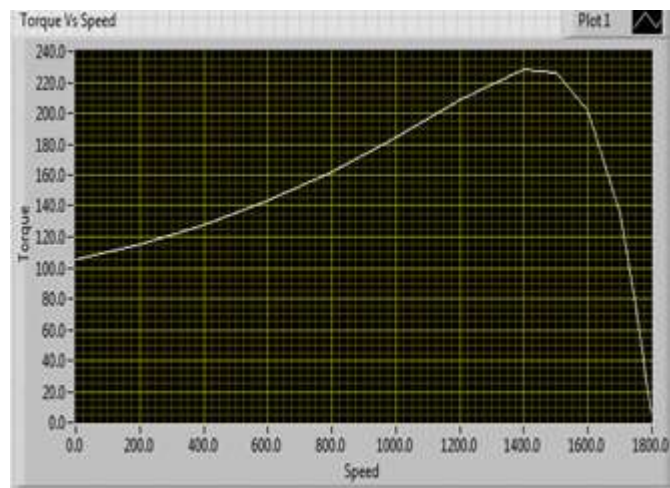
**Figure 12** shows Efficiency Vs Speed



**Figure 13** shows Efficiency Vs Torque

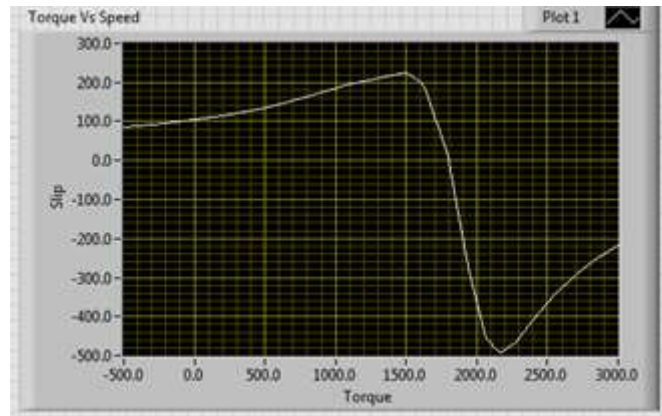


**Figure 14** shows Slip Vs Torque



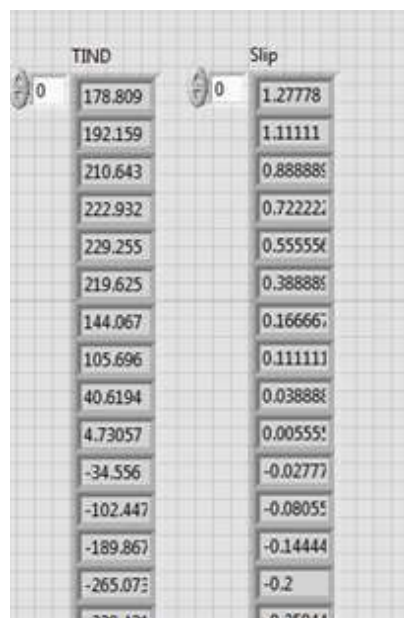
**Figure 15** shows Speed Vs Torque





**Figure 16** shows Speed Vs Torque (2)

The result of the torque-speed characteristic of from the LabVIEW analysis can be observed from the graph in Figure 15. It can be seen that an increase in the rotor speed leads to a decrease in the induced torque. If the rotor speed is allowed to run less than the synchronous speed, the induction machine runs as a motor which is the normal operation. However, if the rotor speed is allowed to run greater than the synchronous speed, the machine acts as an induction generator. It can be observed from Figure 16 that the speed-torque characteristic accommodates both the positive and negative section of the graph. When it runs in the positive section, this is the region where the induction machine acts a motor, otherwise, it acts as a generator. It can also be observed that the induced torque in an induction machine is zero at synchronous speed. The results of the speed-torque characteristics as obtained from LabVIEW is shown in Figure 17 below:



**Figure 17** shows induced torque and slip values of the torque-speed characteristics

## 5. CONCLUSION

LabVIEW has been successfully used to analyze and observe the characteristics of induction machines. The working principles and processes of an induction machine can be simulated and analyzed with the full knowledge of the mathematical models and equations that governs the operating characteristics of the induction machines. The work can be improved further and

applied to different machines such as synchronous machines, DC machines and some special machines. The LabVIEW software is capable of providing a platform in which electrical machines problems can be settled and solved. Proper modelling and analysis of induction machines can significantly reduce design and production time, as well as determine the best operations scenario for maximum efficiency. Finally, the adoption of the software in analyzing and modelling induction machines can save cost, recover the financial loss and also provide a platform to investigate the performance characteristics of an induction machine.

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