

LabVIEW based Electrical Machines Laboratory for Engineering Education

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Abstract: - The Laboratory session in any engineering education particularly in Electrical Engineering is critical as these Labs are designed for students in accordance with theoretical course work. Software based Electrical Machines cost less and have provision of wide ranging change in parameters as compared to hardware based Lab, which results in better understanding of students in learning concepts of Electrical Machines course. Software based Laboratory experiments have become current day need due to its impacts on flexible learning of students and understanding abilities. This motivation deals with Simulation of Electrical Machines Laboratory experiments which are part of Lab session at under-graduate Electrical Engineering level using Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software. LabVIEW uses graphical language which allows a natural, vivid and user-friendly interaction.

Key-Words: - Electrical Machines, Simulation, LabVIEW, Engineering Education

1 Introduction

This research work is the up-gradation of previous research published in ICCESSE 2010 and WSEAS 2010 in which Electrical Machines-I (EE243) and Machines-II (EE350) experiments have been simulated respectively using LabVIEW software. These courses are being taught at Rachna College of Engineering & Technology (RCET), Gujranwala, Pk. in 4th and 5th term at under-graduate Electrical Engineering [1], [2].

Electrical Machines is one of the major subjects of Electrical Engineering. Electrical Machines-I course covers the basics of Transformers and DC machines and Electrical Machines-II contains Synchronous and Induction machines etc.

In this research work the complete Lab session of Electrical Machines course has been simulated using LabVIEW software. The fundamental equations of Transformer, DC machines and Induction machine using their equivalent circuits have been imparted into the LabVIEW for Simulation purpose [3], [4].

The concept for the use of LabVIEW software in Engineering education is recognized internationally but the complete Lab Experiments of Electrical Machines course has been implemented in LabVIEW based upon the exact ratings and on-ground machines parameters as a pioneer and novel research at RCET [5] – [11].

Simulation of Synchronous machines have already been implemented in LabVIEW but DC machines, Transformer and Induction machines keeping in view the Lab session requirement were not addressed potentially [12], [13].

The latest trends in education particularly in engineering education like eLearning, new models of teaching etc. have also been introduced internationally [14] – [16].

Other programming tools like MATLAB, PSCAD and SkyLab etc. are also used for Laboratory experiments

simulation purpose but due to strong graphical user interface LabVIEW is preferred on all others [17], [18]. The list of experiments for Electrical Machines-I course which has been simulated during this research work is as follows:

- Load Characteristics of a Separately Excited DC Motor
- Load Characteristics of a Shunt DC Motor
- Load Characteristics of a Series DC Motor
- Load Characteristics of a Separately Excited DC Generator
- Load Characteristics of a Shunt DC Generator
- Load Characteristics of a Series DC Generator
- Calculation of the Parameters of Transformer using Open Circuit & Short Circuit Tests
- Calculation of Voltage Regulation for a Single Phase Transformer

List of experiments related to Electrical Machines-II simulated in LabVIEW is follows:

- Equivalent circuit parameters of an Induction Motor
- Load Test of a Three Phase Induction Motor
- Load Test of a Single Phase Induction Motor
- Torque Speed relationship of an Induction Motor
- Induction Motor as an Induction Generator
- Circuit model parameters of an Induction Motor

Section 2 of this research is brief introduction to LabVIEW software. Section 3 deals with the implementation of Electrical Machines-I Lab experiments. Section 4 explains the Simulation of Electrical Machines-II experiments. Section 5 is the Conclusions of this research work. Section 6 contains the References used in this research work.

2 Introduction to LabVIEW software

LabVIEW stands for Laboratory Virtual Instrument Engineering Workbench which is a graphical programming language, based upon icons/buttons instead of lines/programming codes for application purpose. This software has the ability to build user defined interface with set of objects and graphical tools. These programs are labelled as Virtual Instruments, or VIs, owing to their operational replica of physical instruments, like oscilloscopes, multi-meters etc. A Virtual Instrument is the combination of following three components:

- a. Front panel
- b. Block diagram
- c. Icon and connector pane

Using above mentioned functions of LabVIEW, the complete course of Electric Machines at under-graduate level has been simulated [19].

3 Simulation of Electrical Machines-I Laboratory Experiments

3.1 Load Characteristics of Separately Excited DC Motor

A separately excited DC motor can be defined as a motor in which a separate constant voltage power is supplied to field circuit. The fundamental mathematical relations for above mentioned motor are [3]:

$$I_F = \frac{V_F}{R_F} \tag{1}$$

$$I_L = I_A \tag{2}$$

$$V_T = E_A + I_A R_A \tag{3}$$

Where,

I_F = Field circuit current

V_F = Field circuit voltage

R_F = Field circuit resistance

I_L = Load current

I_A = Armature current

V_T = Terminal voltage

E_A = Internally generated voltage

R_A = Armature resistance

During modeling in LabVIEW, block diagram consisting of different components related to the designing of the separately excited DC motor from the function menu have been assembled according to the requirements based upon mathematical relations given in Equ.'s 1, 2 and 3 respectively. Block Diagram of a separately excited DC motor is shown in Fig 1.

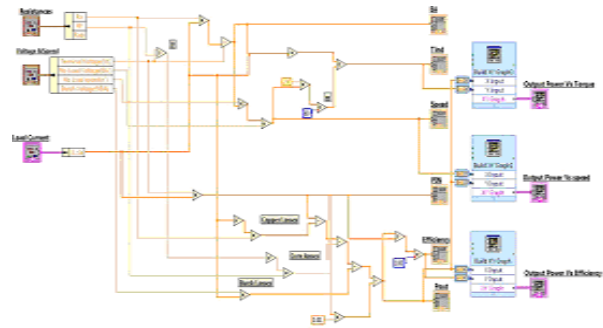


Fig. 1. Block Diagram of Separately Excited DC Motor

The specifications of different components are shown in the Front Panel as shown in Fig. 2, where different design, input parameters, voltage and speed parameters are given.

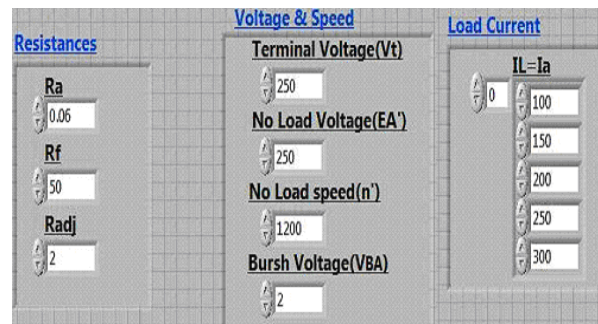


Fig. 2. Front Panel of Separately Excited DC Motor

During this experiment, the load characteristics like Internal Generated Voltage (E_A), Speed (w_o), Induced Torque (T_{ind}), Output Power and Efficiency can be evaluated. These self-explanatory results are shown in the given graphs of Fig.'s 3, 4 and 5 respectively.

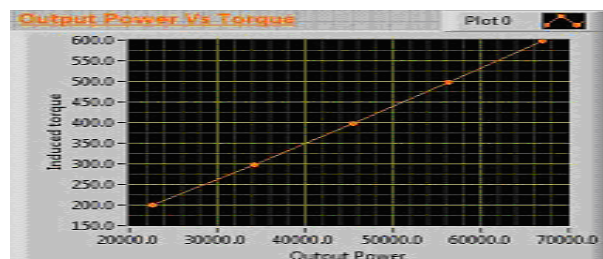


Fig. 3 Graph for Output Power vs Torque

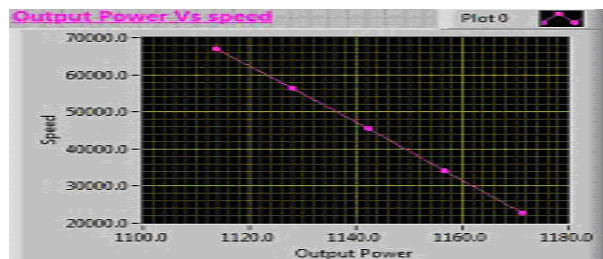


Fig. 4 Graph for Output Power vs Speed

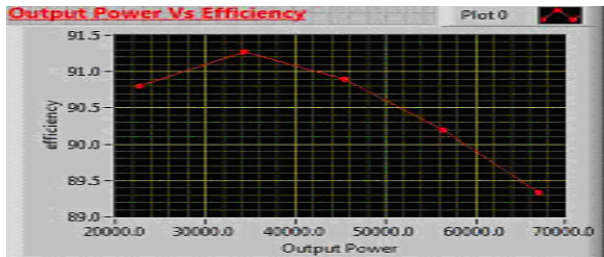


Fig. 5. Graph for Output Power vs Efficiency

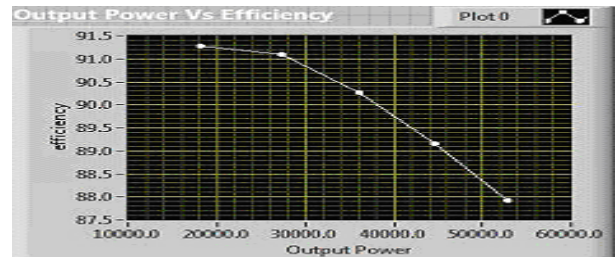


Fig. 9. Output Power vs Efficiency

3.2 Load Characteristics of a Shunt DC Motor

A motor whose field circuit is supplied directly from armature terminals is known as a Shunt DC motor. The mathematical relations related to the equivalent circuit of a DC Shunt motor are given as [3]:

$$I_F = \frac{V_T}{R_F} \quad (4)$$

$$I_L = I_A + I_F \quad (5)$$

$$V_T = E_A + I_A R_A \quad (6)$$

The design and input parameters for this experiment are given in Fig. 6.

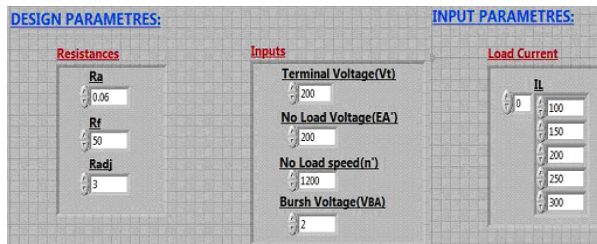


Fig. 6. Input and Design parameters of Shunt DC Motor

The different graphs obtained for the experimental values are shown in the Fig.'s 7, 8 and 9 respectively.

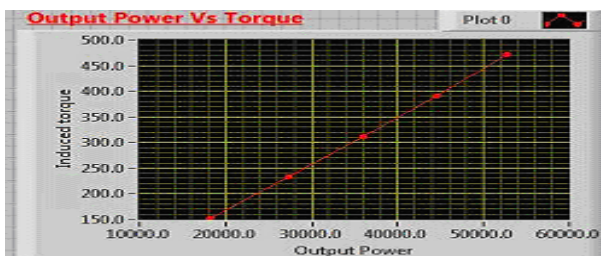


Fig. 7. Output Power vs Torque

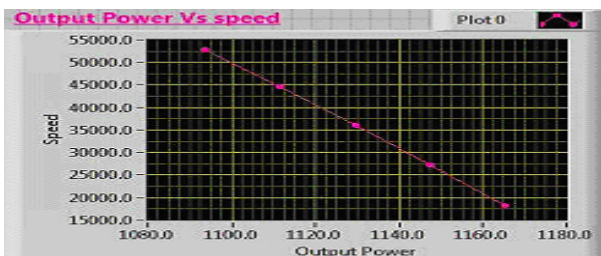


Fig. 8. Output Power vs Speed

3.3 Load Characteristics of a Series DC Motor

A Series DC motor is a motor whose field winding is connected in series with armature winding. Its mathematical relations are [3]:

$$I_L = I_A = I_S \quad (7)$$

$$V_T = E_A + I_A (R_A + R_S) \quad (8)$$

The design and input parameters for Series DC Motor are given in Fig. 10.

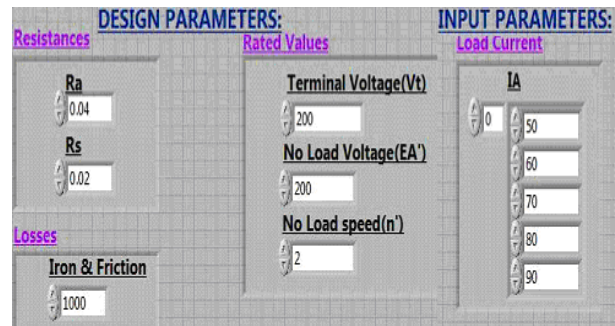


Fig. 10. Input & Design parameters of Shunt DC Motor

The different experimental results are shown graphically in the Fig.'s 11, 12 and 13 respectively.

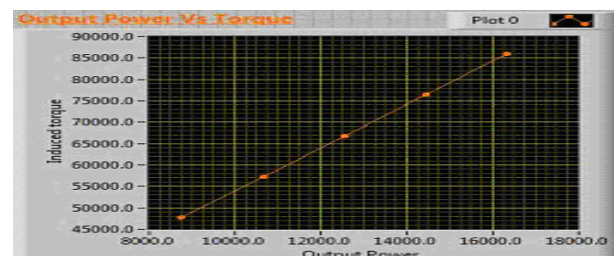


Fig. 11. Output Power vs Torque

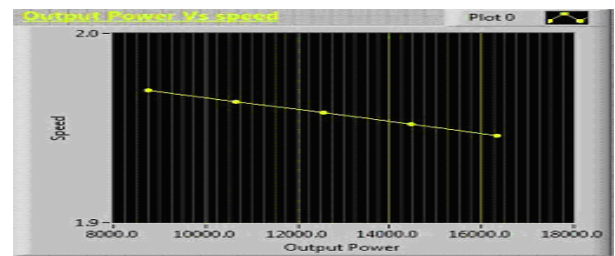


Fig. 12. Output Power vs Speed

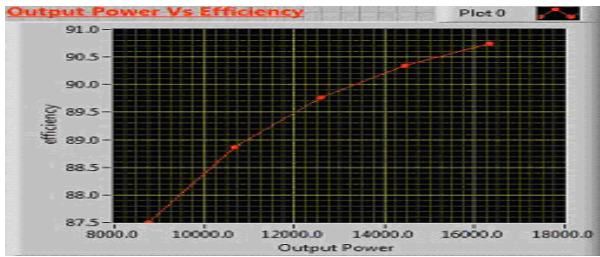


Fig. 13. Output Power vs Efficiency

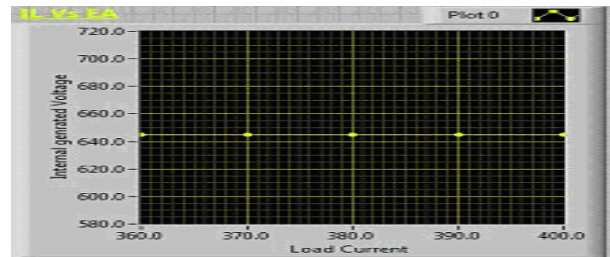


Fig. 16. Load current vs Internal Generated Voltage

3.4 Load Characteristics of a Separately Excited DC Generator

In Separately Excited DC generator, a separate DC source is used to supply the field current. The characteristics of this generator are given as [3]:

$$I_L = I_A \tag{9}$$

$$V_T = E_A - I_A R_A \tag{10}$$

$$I_F = \frac{V_F}{R_F} \tag{11}$$

Experimentally different load characteristics of a Separately Excited DC Generator have been studied by changing the input parameters which are shown in Fig 14.

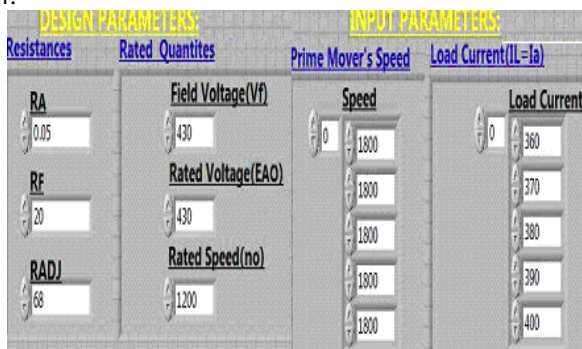


Fig. 14. Input and Design parameters of Separately Excited DC Generator

The results are obtained by maintaining the same Speed of the Prime Mover and linearly increasing the Load Current which are shown graphically in the Fig.'s 15 and 16 respectively.

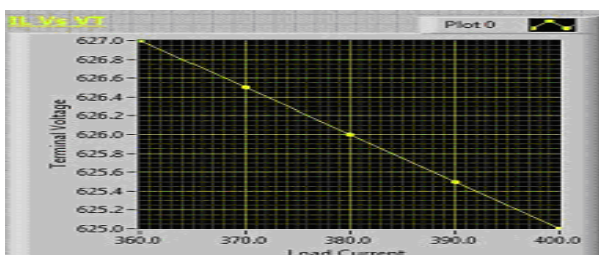


Fig. 15. Load Current vs Terminal Voltage

3.5 Load Characteristics of a Shunt DC Generator

A generator having its field connected to its own terminal to supply the field current is called a Shunt DC Generator. The equivalent circuit relations are [3]:

$$I_A = I_F + I_L \tag{12}$$

$$V_T = E_A - I_A R_A \tag{13}$$

$$I_F = \frac{V_T}{R_F} \tag{14}$$

Load characteristics of a Shunt DC Generator have been studied by changing the given input parameters which are shown in Fig 17.

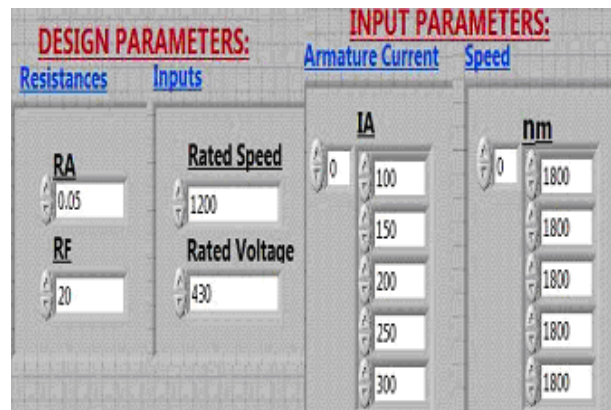


Fig. 17. Input and Design parameters

Graphical results obtained during this experiment are shown in Fig,'s 18 and 19.

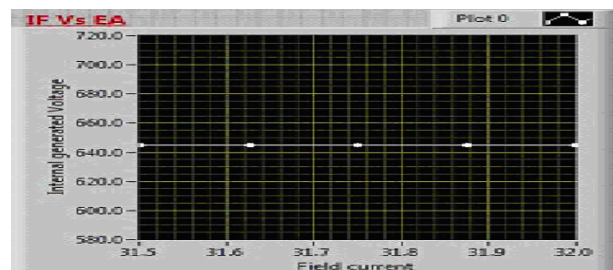


Fig. 18. Load current vs Terminal Voltage

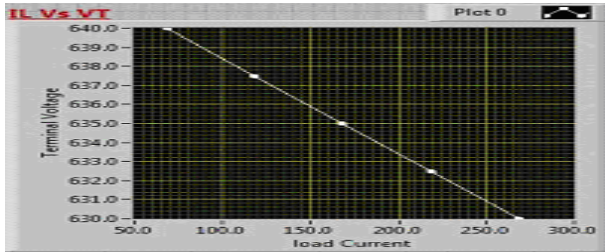


Fig. 19. Field Current vs Internal Generated Voltage

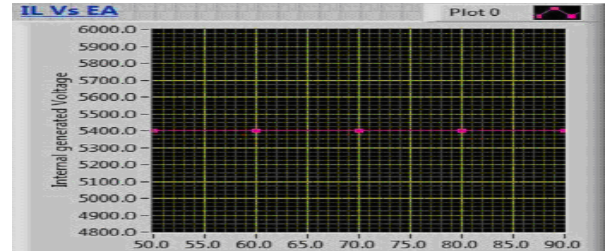


Fig. 22. Field Current vs Internal Generated Voltage

3.6 Load Characteristics of a Series DC Generator

In a Series DC generator field winding is connected in series with armature winding. The fundamental mathematical relations for this generator are given as [3]:

$$I_A = I_L = I_s \tag{15}$$

$$V_T = E_A - I_A (R_A + R_S) \tag{16}$$

The Input and design parameters are given in Fig. 20.

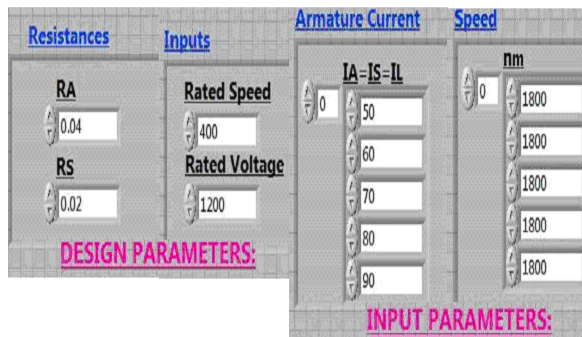


Fig. 20. Input and Design parameters

By changing the Speed of the Prime Mover, the Internal Generated voltage changed. The same Speed of the Prime Mover is maintained and the Load Current is increased resulting in increase in the Armature Voltage Drop and Series Voltage Drop and decreased in the Terminal Voltage as graphically shown in Fig.'s 21 and 22 respectively.

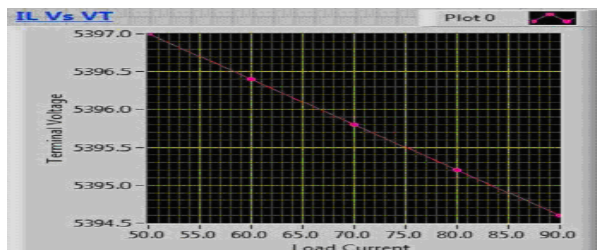


Fig. 21. Load current vs Terminal Voltage

3.7 Calculations for the Parameters of Transformer using Open Circuit Test and Short Circuit Test

A transformer is a device that transforms the electric power from one voltage level to another. The relationship between primary/ secondary voltages and currents are given as [20]:

$$\frac{V_p(t)}{V_s(t)} = \frac{N_p}{N_s} = a \tag{17}$$

$$\frac{I_p(t)}{I_s(t)} = \frac{N_s}{N_p} = \frac{1}{a} \tag{18}$$

Where,

$V_p(t)$ = Primary side voltage

$V_s(t)$ = Secondary side voltage

$I_p(t)$ = Primary side current

$I_s(t)$ = Secondary side current

N_s = No. of Secondary turns

N_p = No. of Primary turns

Design of a Single Phase Transformer is taken experimentally by Open Circuit Test Data (V_{oc} , I_{oc} , P_{oc}) and Short Circuit Test Data (V_{sc} , I_{sc} , P_{sc}).

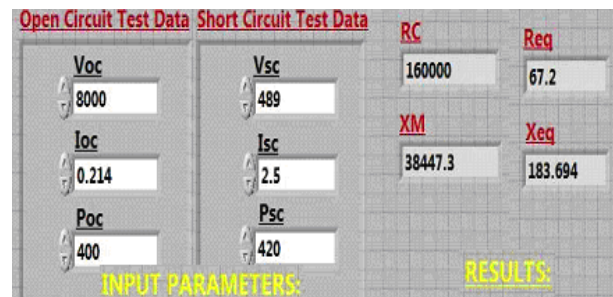


Fig. 23 Input parameters and Results of Transformer

The Unknown Parameters which are Core Resistance (R_c), Magnetizing Reactance (X_m), Equivalent Resistance (R_{eq}) and Equivalent Reactance (X_{eq}) have been calculated.

3.8 Calculation of Voltage Regulation for a Single Phase Transformer

The Input Parameter is the Resistive and Inductive Load which is connected to the secondary of the Single Phase Transformer as shown in Fig.'s 24 and 25.

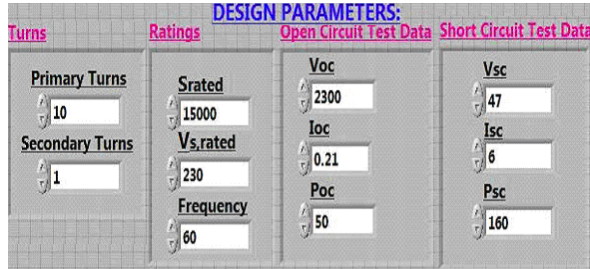


Fig. 24. Design parameters of Single Phase Transformer

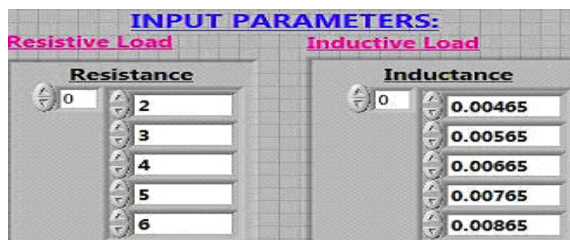


Fig. 25. Input parameters of Single Phase Transformer

Unknown parameters of transformer and Power Factor of given load is calculated here. With the increase in the Resistive and Inductive Load, the power factor decreases. It is also observed experimentally that the voltage regulation becomes poor with the increase in the Load which is shown in the Fig. 26.

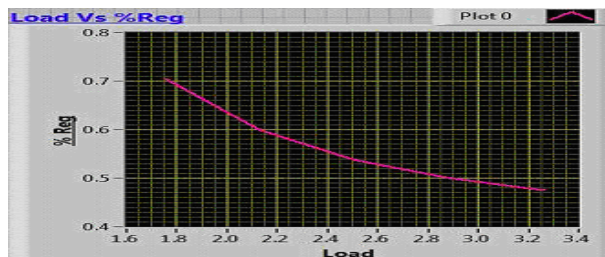


Fig. 26. Load vs % Regulation

4 Simulation of Electrical Machines-II Laboratory Experiments

4.1 Equivalent Circuit Parameters of an Induction Motor

An induction motor is an AC motor in which power is supplied to rotor with electromagnetic induction. The fundamental relations associated with Induction motor are given below [21].

The speed of magnetic field's rotation can be calculated as:

$$n_{sync} = \frac{120 f_e}{P} \tag{19}$$

Where,

f_e = System frequency

P = No. of poles

Induced voltage in rotor is given as:

$$e_{ind} = (v.B).I \tag{20}$$

Where,

v = velocity of rotor

B = magnetic flux density vector

I = length of conductor in the magnetic field

Induced torque in induction motor is:

$$\tau_{ind} = k B_R \times B_S \tag{21}$$

Where,

B_R = Rotor magnetic field

B_S = Stator magnetic field

The slip of the rotor is defined as:

$$s = \frac{n_{sync} - n_m}{n_{sync}} \tag{22}$$

Where,

n_{slip} = slip speed of machine

n_{sync} = speed of magnetic fields

n_m = mechanical shaft speed of motor

The rotor frequency can be stated as:

$$f_r = s f_e \tag{23}$$

Or,

$$f_r = \frac{P}{120} (n_{sync} - n_m) \tag{24}$$

In block diagram different components are arranged related to the designing of an induction motor from the function menu and assembled according to the requirements during modeling in LabVIEW. These block units helped to make a general layout of an induction motor as shown in Fig. 27.

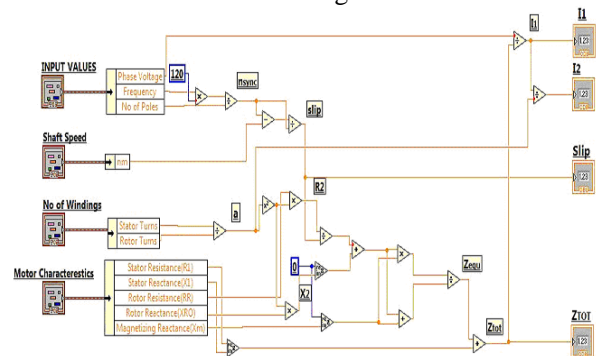


Fig. 27. Block diagram of an induction motor

Front Panel diagram for equivalent circuit model parameters of an Induction Motor is shown in Fig. 28,

where different design parameters and the input parameters are shown.

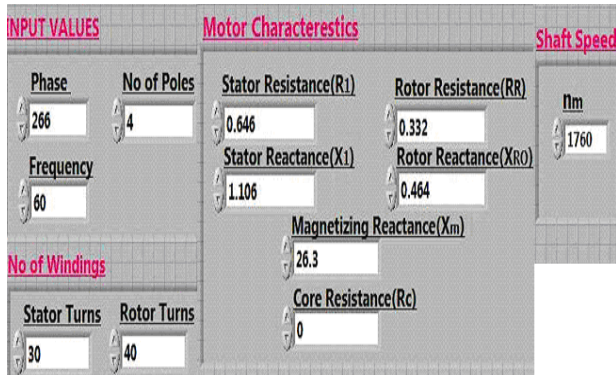


Fig. 28. Design and input parameters

It is observed experimentally that by increasing the Rotor’s mechanical shaft speed, the values of Slip, Stator Current and Rotor Current increases and the value of Equivalent Impedance decreases. These results are shown in the Table 1.

Table 1
Results for Equivalent Circuit parameters

Slip	0.0222222
I_1	27.0063-12.3954j
I_2	36.0084-16.5272j
Z_{tot}	8.13565+3.73412j

4.2 Load Test of a Three Phase Induction Motor

For load test of a Three Phase Induction motor, the design parameters are shown in Fig. 29.

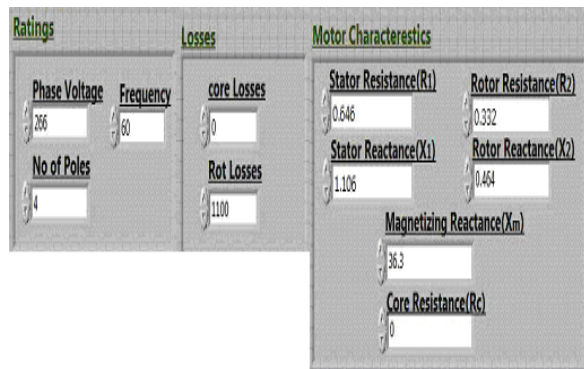


Fig. 29. Design parameters of 3/P induction motor

The variable parameter is only the rotor’s mechanical shaft speed (n_m). The value of the rotor’s mechanical shaft speed must be less than the synchronous speed. By changing this value results will also be changed.

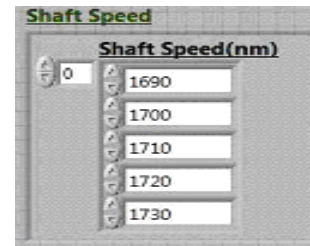


Fig. 30. Variation in shaft speed of 3/P induction motor

Graphs in Fig.’s 31, 32, 33, 34 and 35 show the behavior of three phase induction motor during this experiment.

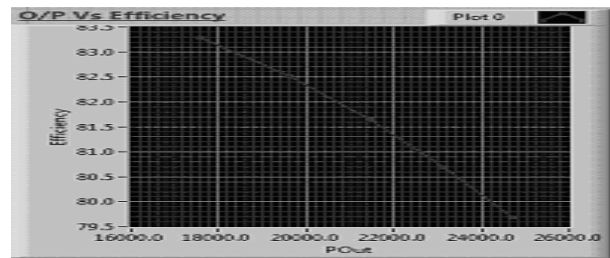


Fig. 31. Output Power vs. Efficiency

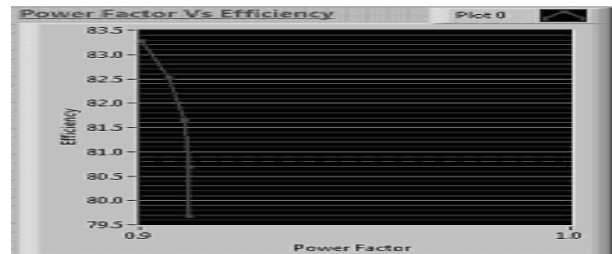


Fig. 32. Power Factor vs. Efficiency

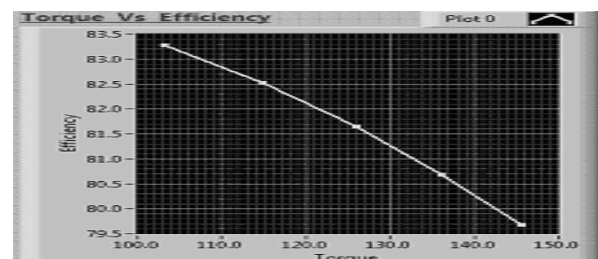


Fig. 33. Torque vs. Efficiency

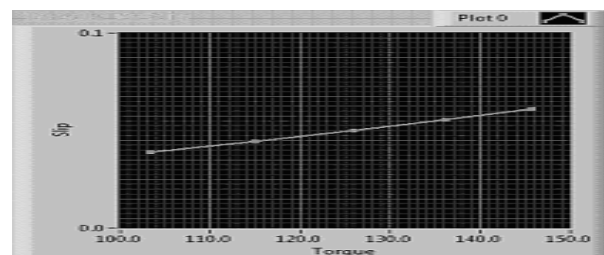


Fig. 34. Torque vs. Slip

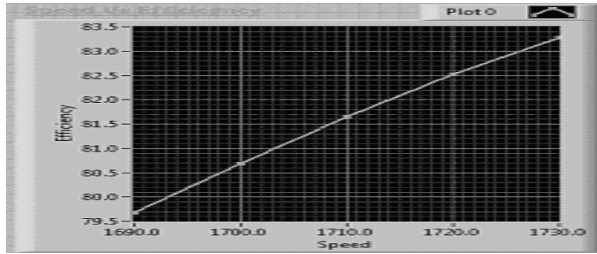


Fig. 35. Speed vs. Efficiency

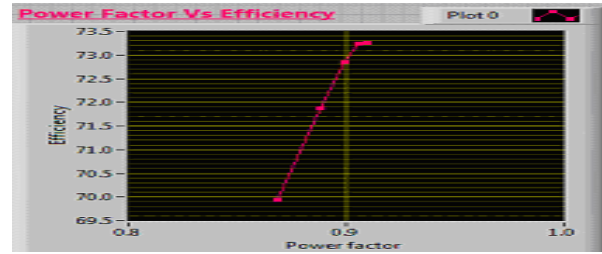


Fig. 39. Power Factor vs. Efficiency

4.3 Load Test of a Single Phase Induction Motor

The design and input parameters for a single phase induction motor are given in the Fig 36.

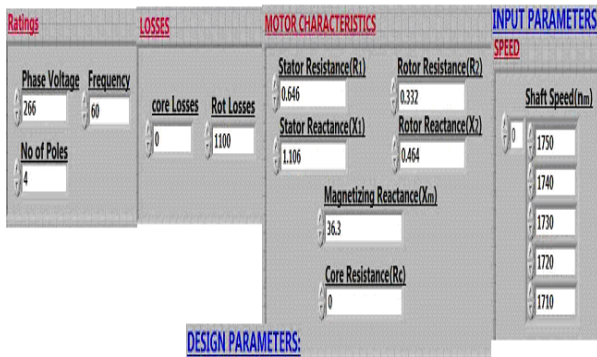


Fig. 36. Design and input parameters of single phase induction motor

Fig.'s 37, 38 and 39 respectively show the linear relation between (Output Power, Power Factor and Torque) vs. Efficiency.

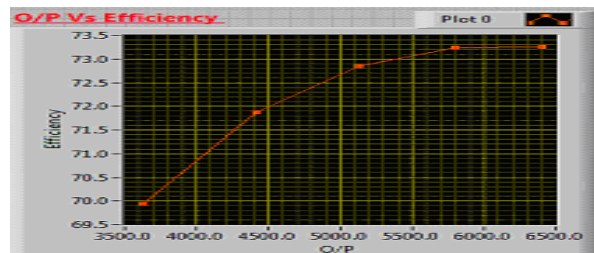


Fig. 37. Output Power vs. Efficiency

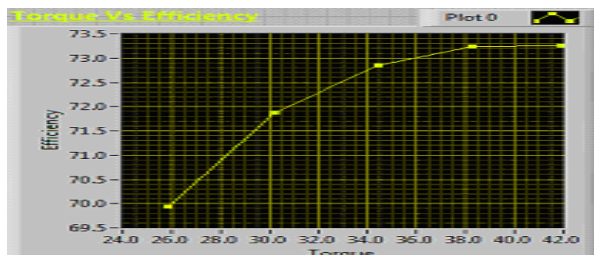


Fig. 38. Torque vs. Efficiency

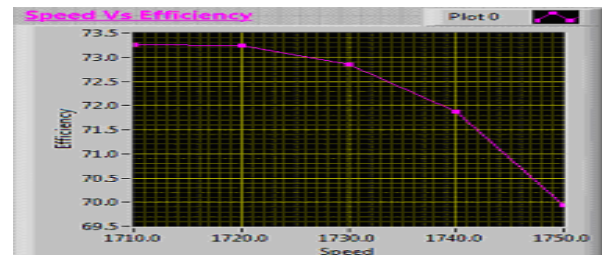


Fig. 40. Speed vs. Efficiency

Fig. 41 shows that with the increase in Torque, the value of Slip also increases for the single phase induction motor.

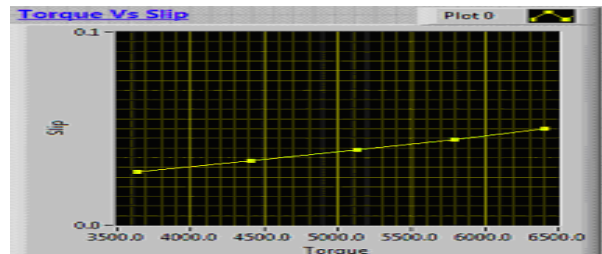


Fig. 41. Torque vs. Slip

4.4 Torque Speed Relationship of an Induction Motor

The design parameters for torque speed relationship of an induction motor experiment are given in the Fig. 42.

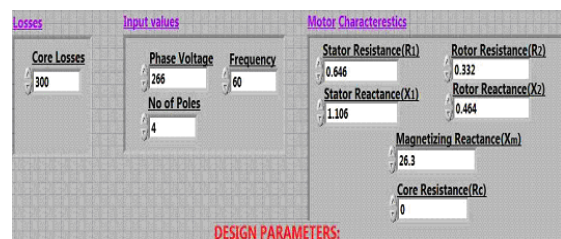


Fig. 42. Design parameters for torque speed relationship of an induction motor

It is observed that with the increase in the rotor's mechanical shaft speed, the value of Induced Torque decreases.

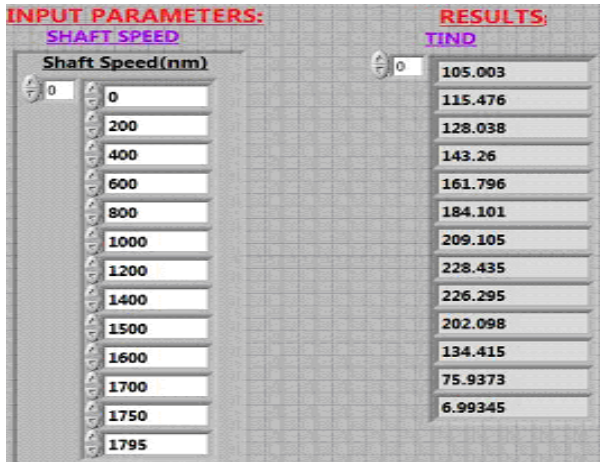


Fig. 43. Input parameters and Results for torque speed relationship of an induction motor

The graph shown in Fig. 44 describes the torque-speed characteristics of an induction motor.

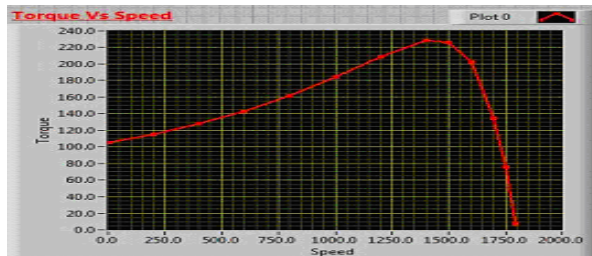


Fig. 44. Torque vs. Speed of an induction motor

4.5 Induction Motor as an Induction Generator

The design parameters for this experiment are given in the Fig. 45.

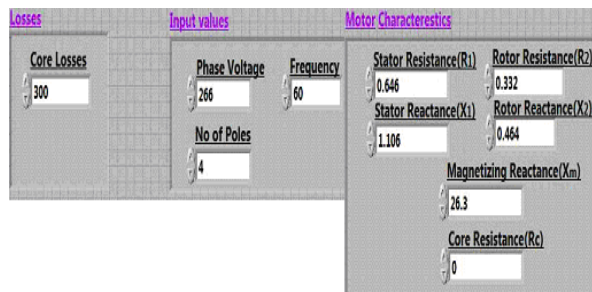


Fig. 45. Design parameters of an induction motor when run as induction generator

The Input parameter the results are shown in the Fig. 46.

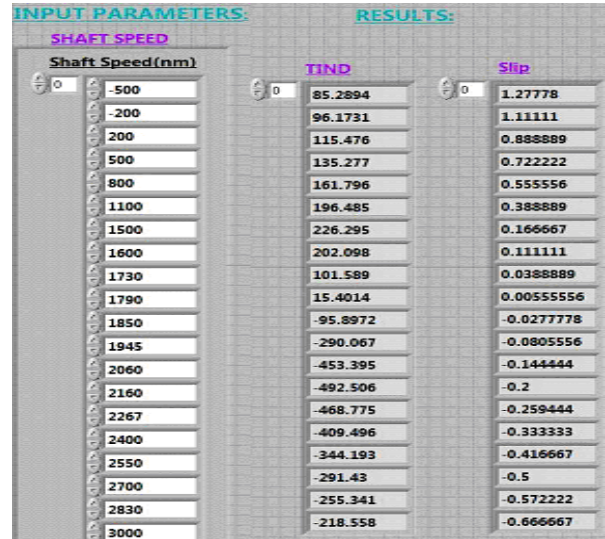


Fig. 46. Input parameters & Results

Graph in Fig. 47 shows the Torque vs Speed relation. The portion of the graph showing the positive value of Induced Torque above the zero-axis is the motor region. The portion of the graph showing the negative value of Induced Torque below the zero-axis is the generator region.

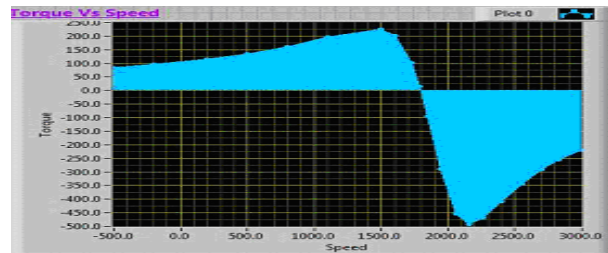


Fig. 47. Torque vs. Speed

4.6 Circuit Model Parameters of an Induction Motor

The input parameters for this experiment are Frequency, DC Test data values (V_{DC}, I_{DC}), No Load Test Data Values (V_T, I_A, I_B, I_C, P_{IN}, and F) and Locked Rotor Test data values (V_T, I_A, I_B, I_C, P_{IN}, and F) which are given in the Fig. 48.

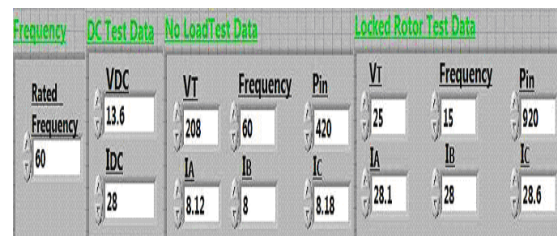


Fig. 48. Input parameters for circuit parameters of an induction motor

Experimental results of these three Tests are verified one by one. It is worth mentioning here that:

- DC Test is used to calculate the value of Stator Resistance (R_1)
- No Load Test is used to calculate the Rotational Losses (P_{rot}) and No Load Impedance (Z_{nl})
- Locked rotor Test is used to calculate Locked Rotor Resistance (R_{LR}) and Locked Rotor Reactance (X_{LR}).

These circuit parameter results are shown in the Fig. 49.

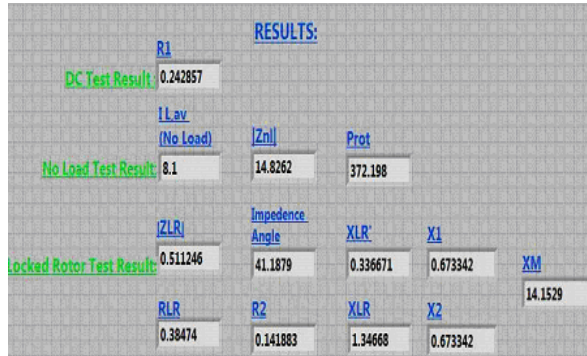


Fig. 49. Circuit parameters results of an Induction Motor

5 Conclusions

The idea of Electrical Machines Lab experiments Simulation using LabVIEW software is being successfully put into operation at RCET Electrical Engineering Department (EE Deptt.) which results in outstanding feedback of students Lab work evaluation. The same idea can also be extended for other courses Lab sessions in parallel with hardware based Labs. The Simulation performed during this research work can also utilized as on-line experiments performance not only at Campus level but also at National and International levels using latest information technology tools.

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