The Prospects of Virtual Laboratories in Engineering Education across Africa – A Case Study in Electrical Engineering

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Abstract: A lot of African countries are underdeveloped owing to the lack of good education. In most African countries the poor economic health is responsible for the lack of proper infrastructure in the education sector. Therefore, the need for alternative means to educate the future generation arises. In Engineering a lot of laboratory work and apparatus are required, whereas only a few Universities can afford this. In Electrical Engineering for instance, “electrical machines” is a very vital topic that requires a lot of laboratory work. The analysis of induction machines is very expensive to experiment on in the lab, and this machine is the most widely used in the industry. This educational gap means that graduates are underequipped and unable to perform optimally in the industry without rigorous training exercise. This study investigates the use of a virtual laboratory (LabVIEW) to model and analyse induction motors with the aim of achieving results that closely conform to the standard characteristics of induction motors. The results obtained confirm that the use of virtual laboratories should be encouraged where finance is a problem as accurate results were obtained from the study.

1. Introduction
Contrary to popular opinion, research has proven that education is expensive, but it still remains a vital driver of a country’s socioeconomic and technological development. Developing countries, which most countries in Africa fall under are characterized by some sort of economic hardship due to lack of production [1].

Some of this can be attributed to the lack of quality education and training that encourages production and development. Engineering is one of such fields that drives a student to invent and innovate, but due to poor educational infrastructure and lack of state-of-the-art laboratories in our universities, students studying engineering have no idea of what is going on in the industry. A large percentage of engineering jobs are done by foreigners leaving our graduates with second rated jobs to handle. This is a clear indication that our education system in engineering is flawed. In this study taking electrical engineering as a case study, an attempt is made to verify the viability of using a virtual laboratory to analyze and experiment on induction motors.

Induction motors or asynchronous motors are the most commonly used motors in many industrial applications, it is the backbone of the industrial revolution due to its attribute and efficiency. And also, in view of their lower cost, weight and inertia, reliability, easy maintenance and robustness, they are mostly used [2]. An induction motor is known to be very rugged robust and reliable and is the most widely used
machine in the industry. The coupling and variable relationship between the output and input of an induction machine are complicated, therefore to model it physically is very complex and as such its simulation is not so viable in many universities.

When the secondary winding of induction motor is supplied with alternating current a revolving magnetic field is generated around the stator. This cuts the rotor and therefore induces an electromotive force. The current in rotor generates a magnetic flux rotating in the opposite direction. Torque is produced as a result of the interaction of two magnetic fields going in the opposite direction that manifest because of the voltage supplied to the stator [3].

For research work, an induction motor is normally simulated using software like PSpice and MATLAB but for the purpose of this study, LabVIEW is used.

2. Related Works
A lot of research has been done on induction motors and some of them, in line with our study, is here reviewed. In [4] a MATLAB simulation to investigate the impact of unbalanced voltage regime on the performance characteristics of a 3-phase induction motor was developed. An induction motor model for the study was obtained using MATLAB and the results that were gotten confirmed the negative impacts of the unbalanced voltage regime on the motor. In [5] the effect of broken bars on a rotor was analyzed. Circuit coupled method was made use of by using a two-dimensional Finite Element method for the modelling of a three-phase squirrel-cage induction motor. The result gotten from the experiment shows that the intended approach constitutes a useful tool for the study and diagnosis of an induction motor.

In [6] a model of a three-phase induction motor was developed it was gotten from the detailed mathematical equation in MATLAB/Simulink and it was used to study the transient execution just as the steady-state response of machine including the consistent moment of inertia and load torque for the outer system. A dynamic generalized approach of digital computer simulation of the three-phase induction machine is a generally relevant technique to propose for simulating a dynamic, non-linear, time-varying physical system. The model gave accurate results. In [7] a model that exhibits a well-ordered MATLAB/Simulink execution of an induction machine was developed utilizing dq0 axis changes of the stator and rotor factors in the arbitrary reference frame.

In [8] a model of three-phase squirrel cage induction motor utilizing the MATLAB Simulink tool was designed so as to examine the performance characteristics of the induction motor. Synchronous reference frame (SRF) procedure is actualized to simplify the equivalent circuit model. In light of state space form, a flux linkage equation is produced utilizing three stages of transformation matrices. It exhibited a decent performance with quick reaction for AC start-up test, where stimulated induced torque, rotor speed, mechanical output power, efficiency, slip and stator current waveforms were created as needs are. Without a doubt, the created induced motor model can be utilized as a beginning platform for further study.

If for research work that shapes the future, the software can be trusted why then should students be deprived of benefiting? Majority of the previous work done was done using MATLAB, for advantages that would be discussed later, LabVIEW would be used.

3. Methodology
In this study LabVIEW which is an acronym for Laboratory Virtual Instrument Engineering Workbench software is used to get the performance analysis of a typical induction motor. LabVIEW is a propriety software belonging to National Instruments. When it was developed the primary goal was to have software that handles hardware control, so it was to be used to monitor and simulate a controlled instrument. Programs developed on LabVIEW are called Virtual Instruments [9], this is due to the fact that they replicate the exact operation of the hardware (instrument) that was modelled. LabVIEW is easily
used to simulate electrical machines without any form of programming, rather it uses mathematical equations and operators in form of blocks to achieve this result.

LabVIEW greatly differs from other forms of programming language has it does not require programs in the form of lines of codes, it is more of a graphical programming language. The input and output parameters on the graphical user interface (GUI) or Front panel are known as the controls and indicators respectively. Having said that LabVIEW also portrays all the strengths of a typical programming language has it comes with a fully equipped debugger and errors are easily spotted while trying to run the program [10]. A great advantage of this tool is that it operates dynamically, input and parameters can be changed on the go and the effect is seen on the output immediately.

MATLAB/Simulink has its strengths but because of the aforementioned LabVIEW is favoured when it comes to the analysis or modelling of Electrical Machines [11].

3.1 Guiding Equations for the Simulations
The equations guiding the simulation of the induction motor are gotten from the equivalent circuit. Figure 1 shows the Equivalent circuit of an induction motor.

![Fig 1: Equivalent Circuit of a three-phase induction motor](image)

An induction motor is very similar to a transformer as in works based on the principle of induction, the difference here is that one of its winding rotates. The power flow diagram of an induction machines as shown in figure 2.

![Fig 2: Power flow diagram of an induction machine](image)

The slip of the motor which is the ratio of the difference in speed between the magnetic flux and the rotor to the speed of the magnetic field (synchronous speed) and it is given by:

\[ s = \frac{n_m - n_s}{n_s} \]  \hspace{1cm} (1)

Input power is given by:

\[ P_{in} = \sqrt{3} V_L I_L \cos \theta = 3 V_{ph} I_{ph} \cos \theta \]  \hspace{1cm} (2)
3.2 Simulation and Development of Model for an Induction Motor

As stated earlier no line of code is written when using LabVIEW, here the model is developed using known standardized equations governing the operation of an induction machine. The equations are converted to some form of block diagrams using icons provided on the LabVIEW software [12]. The simulations to be carried out are:

- Speed-Torque characteristics of an induction motor.
- Induction Motor Load Test: Under this, certain relationships are examined and they are:
  - Output power vs Efficiency Characteristics
  - Output power vs Torque Characteristics
  - Power factor vs Efficiency Characteristics
  - Speed vs Efficiency Characteristics

These simulations carried out using certain motor parameters. The parameters utilized for the simulation are stated tables below: The goal here is to find out how closely the characteristics and results obtained here match that of a real-life induction motor. This would determine to what extent virtual laboratory software like LabVIEW gives accurate results. By changing the parameters and varying the load, graphical representations of the machine’s characteristics can be achieved. For the purpose of the simulation, core loss is taken to be a constant loss [13] [14].

3.2.1 Motor Parameters. Table 1, shows the internal parameters used for simulation of the induction motor and table 2, the input parameters used for simulation.

Table 1: Internal parameters used for simulation

| Parameters         | Values |
|--------------------|--------|
| Rotor Resistance   | 0.301  |
| Rotor Reactance    | 0.454  |
| Stator Resistance  | 0.71   |
| Stator Reactance   | 1.009  |
| Magnetizing Reactance | 25.3  |
| Core Loss          | 320    |
Table 2: Input parameters used for simulation

| Parameters      | Values |
|-----------------|--------|
| Phase voltage   | 239    |
| Frequency       | 50     |
| Number of poles | 4      |

As stated earlier the core loss is treated as a constant loss and does not change during the simulation. This is due to the fact that a motor’s core loss remains the same for its lifespan. Input parameters are not altered during simulation, they can cause results to differ greatly with just small changes and this would affect the experiment [15]. The operating internal parameters (excluding the core loss) can be varied during simulation with a change in the load if required. Rotor speed is varied to obtain several motor performance values so as to enable the plotting of the characteristic curve showing the relationship between these performance indices.

3.3 Simulation of Torque-Speed Characteristics of an Induction Motor

The torque-speed characteristics of an induction motor are one of the most important characteristics of an induction motor. Important conclusions and observations about an induction motor can be drawn by studying its torque-speed characteristic curve. As discussed, the motor is modelled on LabVIEW using arithmetic icons and the relevant equations. Changes in speed are used emulate variation in load. The block diagram for the modelling of the torque-speed characteristics is as shown in figure 3 and the table of the range of input speed values are shown in Table 3.

Table 3: Input (speed) values for torque-speed characteristics simulation

| Speed (Input) |
|---------------|
| 0             |
| 150           |
| 300           |
| 450           |
| 600           |
| 750           |
| 900           |
| 1050          |
| 1200          |
| 1250          |
| 1300          |
| 1350          |
| 1400          |
| 1450          |
| 1500          |
| 1550          |
| 1600          |
| 1650          |
| 1700          |
| 1750          |
| 1800          |
3.4 Induction Motor Load Test

The motor load test is used to determine various operational characteristics of an induction motor namely: Output power vs Efficiency Characteristics, Output power vs Torque Characteristics, Power factor vs Efficiency Characteristics, Speed vs Efficiency Characteristics. The induction motor is modelled using the governing equations and the arithmetic palette on the front panel of LabVIEW so as to obtain the following outputs: $P_{out}$, Efficiency, Slip, Power factor, and Induced torque. Change in speed values is used to emulate load variation. The block diagram for the modelling of the motor load test is as shown in figure 4 and the table of the range of input speed values are shown in table 4.

Table 4: Input (speed) values for motor load test simulation

| Speed (Input) |
|--------------|
| 1700         |
| 1710         |
| 1720         |
| 1730         |
| 1740         |
Fig 4: LabVIEW block diagram for Motor load test of induction motor simulation

From the block diagrams in this section, it is seen that the modelling of the motor is done without any core programming. It is done using the mathematical equations governing the operation of the induction motor. This makes it very easy for students to learn and understand as they are applying the mathematical concepts, they are already familiar with. A drawback to LabVIEW is that at $1325 pretty expensive, but compared to obtaining all the machines it can model is very economic.

4. Results and Discussion
In this section results gotten from the simulation and characteristic curves are presented and discussed.

4.1 Results from Torque-Speed Characteristics Simulation
The torque-speed characteristics curve generated from the graph plotter in LabVIEW is seen to have the normal characteristics of the theoretical torque-speed characteristic curve which are starting, pull-out and full-load torque. The graph and the table of input and output values are shown below.

Table 5: Input(speed) and output (torque) values for torque-speed characteristics simulation

| Speed (Input) | Torque (Output) |
|---------------|-----------------|
| 0             | 99.265          |
| 150           | 108.125         |
| 300           | 118.563         |
| 450           | 130.976         |
| 600           | 145.848         |
| 750           | 163.679         |
| 900           | 184.679         |
| Speed (rpm) | Torque (N.m) |
|------------|--------------|
| 1050       | 184.649      |
| 1200       | 207.244      |
| 1250       | 222.744      |
| 1300       | 211.595      |
| 1350       | 213.304      |
| 1400       | 193.485      |
| 1450       | 155.899      |
| 1500       | 92.8882      |
| 1550       | NaN          |
| 1600       | -128.12      |
| 1650       | -270.249     |
| 1700       | -400.248     |
| 1750       | -492.113     |
| 1800       | -537.269     |

Fig 5: LabVIEW result for torque-speed characteristics of induction motor simulation.

Fig 6: Torque-speed characteristics curve obtained from LabVIEW.
4.2 Results from Motor Load Test Simulation

The table of input and output values for the motor load test simulation is shown below.

Table 6: Input and output values for the motor load test simulation

| Speed | P<sub>out</sub> | Efficiency | Slip      | Power Factor | Induced Torque |
|-------|---------------|------------|-----------|--------------|---------------|
| 1700  | 20084.5       | 78.7348    | 0.055556  | 0.935843     | 118.998       |
| 1710  | 18690.8       | 79.8129    | 0.05      | 0.937399     | 110.519       |
| 1720  | 17153.2       | 80.8188    | 0.0444444 | 0.937826     | 101.34        |
| 1730  | 15464.3       | 81.7073    | 0.038889  | 0.936587     | 91.4322       |
| 1740  | 13617         | 82.4024    | 0.0333333 | 0.932723     | 80.7684       |

In the next section the various motor load test characteristics are shown as obtained from the graph plotter on LabVIEW.

*Output power vs Efficiency*

The relationship between efficiency and output power is shown below.

![Graph of output power vs efficiency from LabVIEW.](image)

*Output power vs Torque*

This relationship should produce a linear curve. For the sake of stability and increase in torque always yields an increase in output power. Instability would occur if a sudden breakdown of this principle occurs.

![Graph of output power vs torque from LabVIEW.](image)
Power factor vs Efficiency

Power factor and efficiency of the motor both increase as the speed is increased to attain rated speed the power factor at this point is close to 1.

![Graph of power factor vs efficiency from LabVIEW.](image)

Speed vs Efficiency

Efficiency and speed are directly proportional thereby they increase together as expected in normal operation. So, to achieve maximum efficiency the motor should be operated at rated speed if it goes higher it would affect power factor and efficiency negatively.

![Graph of speed vs efficiency from LabVIEW.](image)

The most important characteristics of induction motors are obtained from their test curves as these curves have distinct and defined shapes they are to follow if the motor is said to be functional or well modelled.

The results and characteristics curves obtained compare accurately with that of a functional motor as seen from textbooks and laboratory experimentations, and as such proves that the software is capable of accurately modelling an induction motor.

5 Conclusion

In this study, LabVIEW software was used to simulate and analyze an induction motor. The results obtained shows that LabVIEW can be used to simulate and obtain performance characteristics of an induction motor since it compares accurately to the real-time operation of an induction motor. Therefore, it is seen that a lot can be gained by exposing students to virtual laboratories where finance become a constraint in securing the state-of-the-art laboratory equipment that will place African students at par with
their counterparts in the developed countries. From this study it is recommended that further studies be carried out on other types of electrical machines and drives to further ascertain the effectiveness of the tool used, also students should be allowed to model machines using LabVIEW where the facilities are not available so as to keep them informed and at par with their peers. In addition, manufacturers of induction motors can use LabVIEW to analyze their designs and even carry out the performance characteristics of the designed motors before going on to manufacturing if they are satisfied with the performance characteristic resulting from the results of simulation. Doing this saves the manufacturer from the cost implications of a failed machine. This is very important as carrying out a real-life test and performance characteristics evaluation can be very costly and time-consuming. Therefore, the virtual laboratory (LabVIEW) saves the manufacturer time and resources.

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