Effects of MATLAB and Simulink in Engineering Education: A Case Study of Transient Analysis of Direct-Current Machines

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ABSTRACT

Understanding electrical machines transient behaviors looks hazy without the aid of simulation tools like MATLAB. This is because the resulting system of differential equations is nonlinear and analytical solution is difficult and boring. In view of the above, it is very pertinent that computer softwares are employed to teach and solve most engineering problems for a better understanding of the various engineering principles.

This paper therefore models the series and separately excited motors using differential equations and invoking the powers of Simulink integrated with MATLAB®, enabling incorporation of MATLAB algorithms into models and exporting simulation results to MATLAB for further analysis of their responses. This approach gave students improved understanding of the two machines with a better student understanding rating of 85.8% from 52.8%.

Keywords: D.C machine, transient, Modeling differential equation, MATLAB)

1.0 INTRODUCTION

The rate at which the capabilities of computers increase globally necessitates computer employment in solving frequently arising challenging engineering problems. Therefore, engineering education curriculum planners must consider seriously the revision of the existing engineering curriculum to know where reasonable adjustments could be made to include comprehensive computer literacy program.

This is because commercial computer software packages addressing specific applications are sold by various vendors and are used by undergraduate engineering students, educators and engineers alike, often with no knowledge of the model limitations and the algorithms employed in developing and writing the software. This trend, if unchecked, will naturally produce future engineers and scientists who see computer results as infallible truth, rather than those who should rightly view the results as subject to the limitations of the models employed in building the software [1]. There are several computer software that could be employed in solving these challenging engineering problems of which MATLAB and simulink are among.

MATLAB is a programming language and environment that makes use of specialized data types. It is short form for **Matrix laboratory**. Certainly, you can write data evaluation programs in other programming languages such as Visual Basic, C++, or Java, but MATLAB is a language designed especially for processing, evaluating and graphical displaying of numerical data [2].On the other hand, **Simulink** provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with **MATLAB**®, enabling you to incorporate **MATLAB** algorithms into models and export simulation results to **MATLAB** for further analysis [3]. MATLAB has several advantages and disadvantages over other methods or languages. The advantages are:

☐ Its basic data element is the matrix. A simple integer is considered an matrix of one row and one column.

Several mathematical operations that work on arrays or matrices are built-in to the MATLAB environment. For example, cross-products, dot-products, determinants, inverse matrices.

 Vectorized operations. Adding two arrays together needs only one command, instead of a for or while loop.

 The graphical output is optimized for interaction. You can plot your data very easily, and then change colors, sizes, scales, etc, by using the graphical interactive tools.

 MATLAB's functionality can be greatly expanded by the addition of toolboxes. These are sets of specific functions that provided more specialized functionality. Ex: Excel link allows data to be written in a format recognized by

Excel, Statistics Toolbox allows more specialized statistical manipulation of data (Anova, Basic Fits, etc).

The disadvantages are:

 It uses a large amount of memory and on slow computers it is very hard to use.

 It sits "on top" of Windows, getting as much CPU time as Windows allows it to have. This makes real-time applications very complicated [4].

1.2 Direct Current (DC) Motors:

Direct Current (DC) motors provide propelling power to electric trains and vehicles and drive mechanisms in the manufacturing industry. The applications of DC machines are limitless and in virtually every field can be the other. They play important role in our daily life. Electric motors exist to convert electrical energy into mechanical energy. This is done by two interacting magnetic fields: one stationary and another attached to a part that can move [5]. DC motors have the potential for every high torque capabilities [6]. The greatest advantage of DC machines over other types of machines is the ease of their speed control [7].

DC series motor is very suitable for electric traction because of its electrical and mechanical characteristics. The increasing complexity of industrial processes demands greater flexibility from electrical machines in terms of special characteristics and speed control [8].

Components of a series motor include the armature and the series field. The coils in the series field are made of few turns of large gauge wire, to facilitate large current flow. This provides high starting torque, approximately 2.5 times the rated load torque [9]. Series motors should never drive machines with chain or belt. If the belt or chain breaks, the load will be removed and cause the motor to over speed and destroy itself. Common uses of series motors include hoist, where large load will be raised and lowered. The series motor provides the starting torque required for moving large loads.

2.0 SERIES WOUND D.C MACHINE

The starting point for the modeling of electrical machine such as the series DC motor starts with measurements on real model because it is necessary to determine all essential parameters. The other possibility is to obtain the motor parameters from the manufacturer or determine our own parameters if motor prototype is to be built [10]. After that, the motor model can be made by using all mathematical equations describing the behavior of the motor. The armature and field current of a series motor are the same. The implication of this is that the speed of series DC motor increases as the load decreases [11]

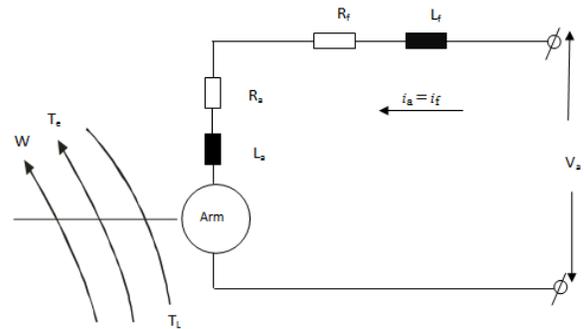The electrical circuit model of a series motor is shown in figure 1

Figure 1: Series D.C

2.1 Dynamic Equation for Series DC Motor

From circuit analysis, the differential equations of the series motor as in fig. 1 are:

$$V_a = i_a(R_a + R_f) + L_a \frac{dia}{dt} + L_f \frac{dia}{dt} + K_b i_a \omega_m \quad (1)$$

$$T_e = K_b * i_a^2 = T_L + B\omega_m \frac{Jd\omega_m}{dt} \quad (2)$$

For simulation, the equations become:

$$i_a \; dot = \frac{V_a}{L_a+L_f} - \frac{(R_a+R_f)}{L_a+L_f} i_a - \frac{K_b \omega_m}{L_a+L_f} \qquad (3)$$

$$T_e = K_b * i_a^2 \qquad (4)$$

$$\acute{\omega}_m = \frac{1}{J}(T_e - B\omega_m - T_L) \qquad (5)$$

2.2 Separately Excited DC Motor

In this motor, the fielding is connected to its own dc source. The armature circuit is also connected to another source. The interaction between the magnetic fields of the two windings exerts torque on the shaft causing it to rotate. Therefore separate and shunt excited D.C motor are better connected to the source via voltage regulators such as choppers or rectifiers [7].

A circuit model of a separately Excited D.C motor is shown in figure 2:

The dynamic equations describing the behavior of the separately excited DC machine as in fig. 2 are:

$$V_a = R_a i_a + L_a \frac{dia}{dt} + K_b i_f \omega_m \qquad (6)$$

$$V_f = R_f i_f + L_f \frac{dif}{dt} \qquad (7)$$

The torque developed by the machine in motor operation is:

$$T_e = T_L + B\omega_m \frac{Jd\omega_m}{dt} \qquad (8)$$

also the machine torque is related to armature and field current as:

$$T_e = K_a * \varnothing * i_a \qquad (9)$$

Representation of DC machines in state-space form is a modern method of system analysis.

$$T_e = K_b * i_a * i_f = T_L + B\omega_m + \frac{Jd\omega_m}{dt} \qquad (10)$$

DC motor transient analysis is complex and requires numerical methods to analyze. The adoption of state space concept makes the work simple. The state of a system is defined as the minimum amount of information required to determine its present future response, for any present or future input [12].

Therefore, the state space concept is the mathematical representation of a system in order to determine the systems response in steady or transient state.

Therefore, the electrical and mechanical models appropriate for simulation are obtainable from Equations 6, 7, 8 and 9 as;
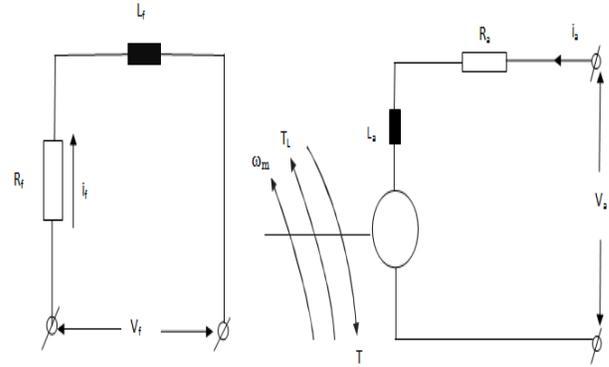

Fig. 2: A Separately Excited D.C Motor

$$\begin{bmatrix} i_a \; dot \\ \\ i_f \; dot \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} - & \frac{K_b \omega_m}{L_a} \\ \\ 0 - & \frac{R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_a \\ \\ i_f \end{bmatrix} + \begin{bmatrix} \frac{V_a}{L_a} \\ \\ \frac{R_f}{L_f} \end{bmatrix}$$
$$(11)$$

$$T_e = K_b * i_a * i_f$$
$$(12)$$

$$\acute{\omega}_m = \frac{1}{J}(T_e - B\omega_m - T_L)$$
$$(13)$$

2.3 DC Motor Parameters and Transient Performances

The following parameters were taken from the motor data sheet. Armature Resistance (Ra), Field Resistance (Rf),

Armature inductance (La) and Field Inductance (Lf), loading Torque (TL), Moment of Inertia (J), Frictional Losses (Bm)

and Torque Constant (Kb) were used for the simulation.

The parameters are in table 1 for Series and Separately Excited Motors

Table 1: Series/Separately excited D.C Motor parameters

	SWDM/SEDM
R_a	0.026Ω
L_a	0.030H
R_f	2.35 Ω
L_f	0.167H
J	4kg-m^2
B	1.054 e-6 Nms^2
T_L	6.490Nm
V_a	220V
V_f	160V

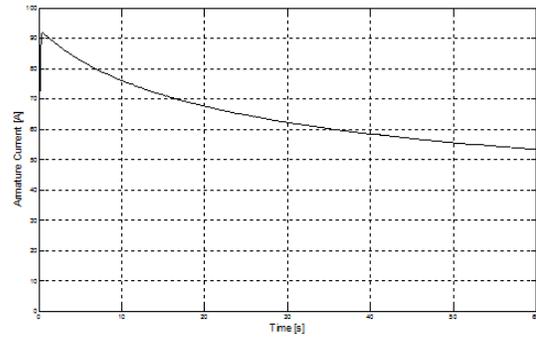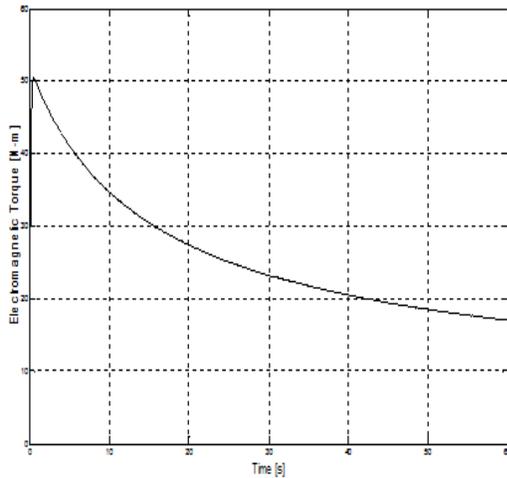Where: SEDM- Separately Excited D.C Motor, SWDM – Series Wound D.C Motor

Fig 3: Graph of Electromagnetic Torque against Time

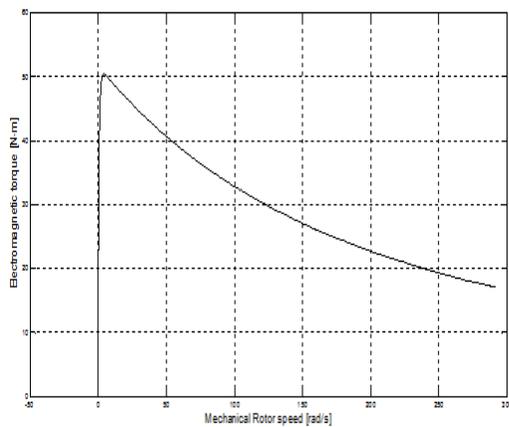Fig 4 Graph of Electromagnetic Torque against Mechanical rotor Speed

Fig 5: Graph of Mechanical rotor Speed against Time

3.0 APPLICATION OF MATLAB

Presently the mode of teaching in our Engineering Faculties is via lectures, assignment/tutorials and conduct of practical where applicable. Teaching engineering course without practical exposition is full of drudgery. Simulation using MATLAB code offers one of the best methods of teaching as engineering colleges are faced with equipment unavailability and obsolesce. It offers capabilities beyond what the classroom only can offer. Ordinarily, MATLAB provides a better teaching and learning experience for students and lecturers [13].

S/N	ACADEMIC SESSION	NO OF STUDENT	AVERAGE PERFORMANCE WITHOUT MATLBAB	AVERAGE PERFORMANCE WITH MATLAB
1	2007/2008	48	52	75
2	2008/2009	70	48	75
3	2009/2010	85	60	76
4	2010/2011	150	70	85
5	2011/2012	180	60	90
6	2012/2013	220	45	95
7	2013/2014	250	40	95
8	2014/2015	264	48	95

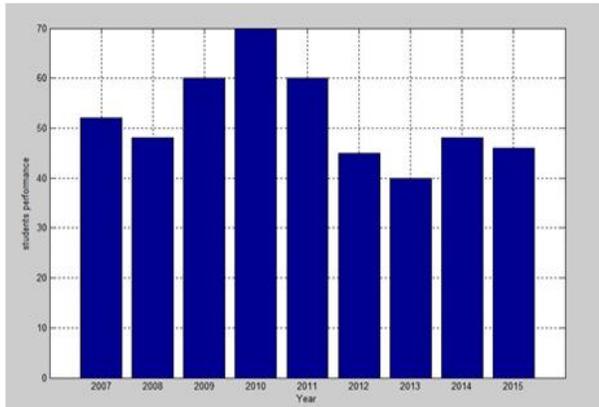Table 2 Summarizes the performance of students exposed to this mode of teaching

Fig. 7: The performance of students in Electrical machine laboratory experiment without MATLAB.
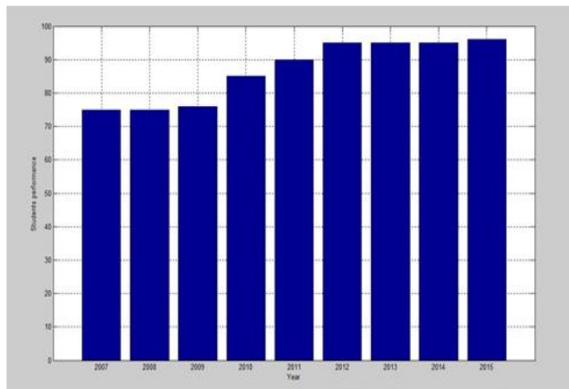

Fig.8: The performance of students in Electrical machine laboratory experiment with MATLAB

4. CONCLUSION

Modeling and simulation offer a short learning curve for students, engineering lecturers and technologists. They provide an exciting platform for learning and experimentation because actual experimentation on real systems is costly. In this work, the state space models of series and separately excited dc motors were developed and using MATLAB codes, the models were simulated with the response curves shownfigs.3 - 6. The application of MATLAB/Simulink Software in electrical machines Laboratory class over a period of eight academic sessions showed better student understanding of the subject with improved performance from 52.8% to 85.8% as shown bar charts in figs. 7 and 8. It is therefore recommended that more computer software and programs be provided for improvement in engineering education.

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