DC Shunt Motor Speed Control Methods Using MATLAB/Simulink and Interfaced with Graphic User Interface (GUI)

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Abstract—This paper presents simulation model of DC shunt motor speed control method using MATLAB/Simulink software and interfaced with Graphical User Interface (GUI) software. In this paper, DC shunt motor speed is controlled by armature resistance, field resistance and armature voltage speed control. Its torque-speed characteristics are observed and analyzed. The simulation model will enable an easier understanding for undergraduate electric machinery courses on how the actual machine works and ease of use of the program using MATLAB/GUI designed program.

Keywords; DC shunt motor; MATLAB/Simulink; MATLAB/GUI.

I. INTRODUCTION

Computer modelling and simulation tools have been extensively used to support and enhance electric machinery courses. MATLAB with its toolboxes such as Simulink [1] and SimPowerSystems [2] is one of the most popular software packages used by educators to enhance teaching the steady-state characteristics of electric machines [4].

A graphical user interface (GUI) [3] is a type of user interface item that allows people to interact with programs in more ways than typing such as computers; hand-held devices such as MP3 Players, Portable Media Players or Gaming devices; household appliances and office equipment with images rather than text commands. A GUI offers graphical icons, and visual indicators, as opposed to text-based interfaces, typed command labels or text navigation to fully represent the information and actions available to a user. The actions are usually performed through direct manipulation of the graphical elements.

The objective of this paper is to present simulation models of DC shunt motor speed control methods. These models include Simulink models of three most common speed control methods, namely field resistance, armature voltage, and armature resistance control methods. Each Simulink model is interfaced with GUI to offer users all simulation models in a single and easy to use software package. The simulation models will help students to have better understanding on DC shunt motor speed control characteristics especially on torque – speed characteristics.
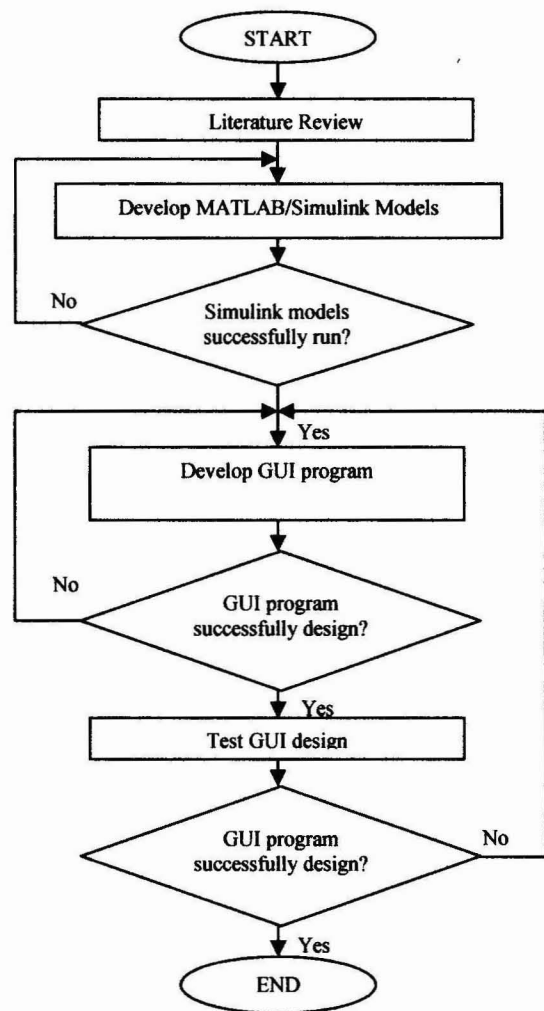
II. METHODOLOGY

A. Project Flowchart

Figure 1: Overall project flowchart

Figure1 shows the flowchart of the workflow from the initial starting to the end of the project. Literature review was done to obtain information of DC shunt motor speed control methods and information about on how to develop MATLAB/Simulink model and GUI program design. MATLAB/Simulink is used to design, simulate and evaluate the response of the speed control methods that been used. GUI offer users an easy to use simulation program.

B. MATLAB/Simulink Models of Speed Control Methods

The speed of a DC motor can be varied by controlling the field flux, the armature resistance or the terminal voltage applied to the armature circuit. The three most common speed control methods are field resistance control, armature voltage control, and armature resistance control [5]. In this section, Simulink models of these three methods for DC motor drives for steady-state analysis are presented.

In the field resistance control method, a series resistance is inserted in the shunt-field circuit of the motor in order to change the flux by controlling the field current. It is theoretically expected that an increase in the field resistance will result in an increase in the no-load speed of the motor and in the slope of the torque-speed curve [5]. Figure 2 shows the Simulink implementation of the field resistance control method. A DC motor block of SimPowerSystems toolbox is used. The DC motor block implements a separately excited DC motor. An access is provided to the field connections (F+, F-) so that the motor model can be used as a shunt-connected. The field circuit is represented by an RL circuit (Rf and Lf in series) and is connected between the ports (F+, F-). The armature circuit consists of an inductor (L_a) and resistor (R_a) in series with an electromotive force E_a and is connected between the ports (A+, A-). The load torque is specified by the input port TL. The electrical and mechanical parameters of the motor could be specified using its dialog box. 240 V DC source is applied to the armature and field circuits. An external resistance R_{f1} is inserted in series with the field circuit to realize the field resistance speed control. The output port (port m) allows for the measurement of several variables, such as rotor speed, armature and field currents, and electromechanical torque developed by the motor. Through the scope and display block, the waveform and steady-state value of the rotor speed can be easily measured in radian per second (rad/s), or the corresponding data can be written to MATLAB's workspace using the data box to make use of other graphical tools available in MATLAB. In this method the armature circuit resistance (R_a) and the terminal voltage (V_t) remain fixed and the speed is controlled by varying the current (I_f) of the field circuit. This is normally achieved by using a field circuit rheostat (R_{f1}) as shown in Figure 2. If magnetic linearity is assumed, the flux in the machine (Φ) will be proportional to the field current (I_f) [6]. Therefore,

$$w_m = \frac{V_t}{K_a \Phi} - \frac{R_a}{(K_a \Phi)^2} T \qquad (1)$$

$$K_a \Phi = K_f I_f \qquad (2)$$

$$I_f = \frac{V_t}{R_{ft}} \qquad (3)$$

$$R_{ft} = R_f + R_{f1} \qquad (4)$$

From equation (1) and (2),

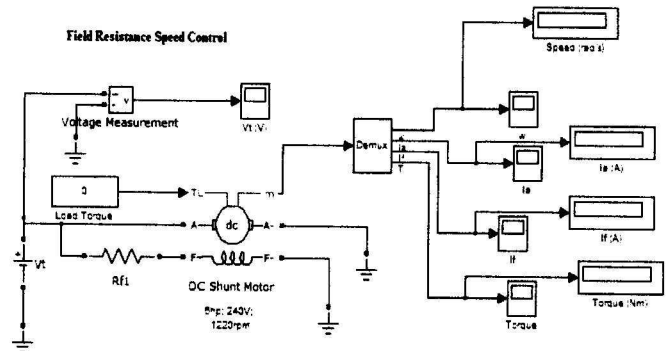$$w_m = \frac{V_t}{K_f I_f} - \frac{R_a}{(K_f I_f)^2} T \qquad (5)$$

Figure 2: Simulink model of field resistance speed control method

In the armature voltage control method, the voltage applied to the armature circuit, (V_t) is varied. When the armature voltage is increased, the no-load speed of the motor remains the same while the slope of the torque-speed curve decreases when the armature voltage is increased. Figure 3 shows the Simulink realization of the armature voltage speed control method. This simulation model is similar to that of the field resistance control method shown in Figure 2. The external resistance (R_{f1}) in Figure 2 is removed in this model. In this method of speed control the armature circuit resistance (R_a) remains unchanged, the field current (I_f) is kept constant normally at its rated value, and the armature terminal voltage (V_t) is varied as shown in Figure 3 to change the speed. If armature reaction is neglected,

From equation (1),

$$w_m = K_1 V_t - K_2 T \qquad (6)$$

where $K_1 = 1/K_a \Phi$
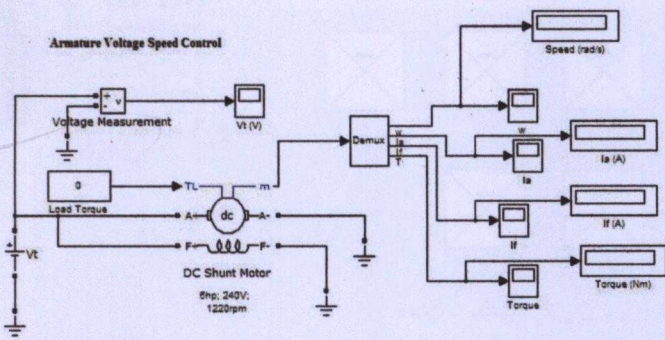$K_2 = R_a/(K_a \Phi)^2$

Figure 3: Simulink model of armature voltage speed control method

The armature resistance control is a method for speed control in which an external resistance is inserted in series with the armature circuit. An increase in the armature resistance results in a significant increase in the slope of the torque-speed characteristic of the motor while the no load speed remains constant [5]. Simulink model of this method is almost the same as that of the field resistance control method shown in Figure 2. The only difference is that R_{f1} resistance in Figure 2 is removed and an external resistance R_{a1} is inserted in series with the armature circuit between the ports (A+, A-) to vary the armature resistance. In this method, the armature terminal voltage (V_t) and the field current If (hence Φ) are kept constant at their rated values [6]. The speed is controlled by changing resistance in the armature circuit. An armature circuit rheostat (R_{a1}), as shown in Figure 4, is used for this purpose.

From equation (1),

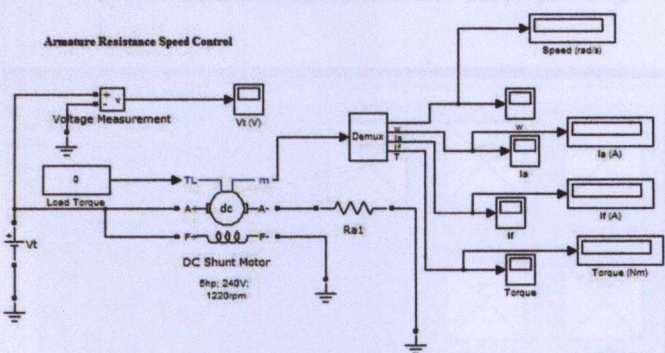$$w_m = \frac{V_t}{K_a \Phi} - \frac{R_a + R_{a1}}{(K_a \Phi)^2} T$$

(7)

Figure 4: Simulink model of armature resistance speed control method

C. MATLAB/GUI Interface Program Design

After the Simulink models development work finished, this project continues with the MATLAB/GUI program design. This work is done by using MATLAB/GUIDE software. This work involved with working more on designing windows to become a complete program that can be easily used by users.

The works started with designing a 'Main Window' which consists of five 'push button'. One 'push button' represent about the information of DC Shunt Motor and program exit respectively. The other three 'push button' represent about the selection of speed control methods which are 'Armature Resistance Control', 'Armature Voltage Control' and 'Field Resistance Control'. Figure 5 shows the design of 'Main Window' GUI program.
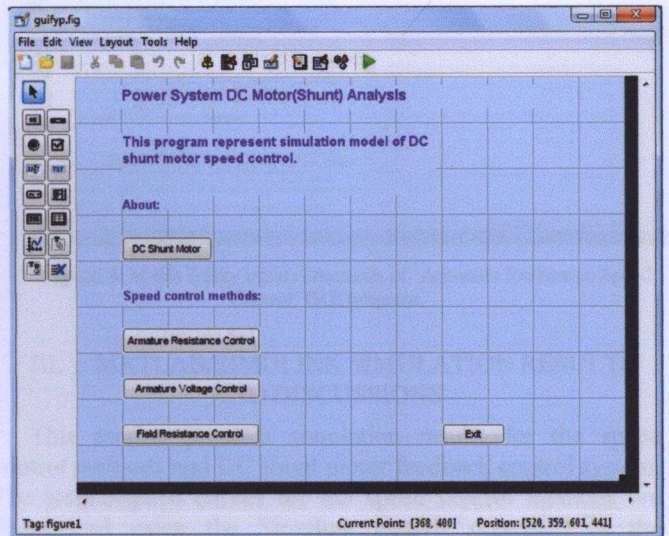

Figure 5: 'Main Window' GUI program design

The works then continued by designing the 'Armature Resistance Speed Control', 'Armature Voltage Speed Control' and 'Field Resistance Speed Control' GUI programs. Each program consists two 'slider bar', two 'edit value box', five 'axes' and four 'push button'.

The 'Armature Resistance Speed Control' GUI program consists 'slider bar' and 'edit value box' that can be used to vary the load torque value and the armature resistance (R_{a1}) value. The five axes provide spaces to display all the desired outcomes which are motor speed (w_m), armature current (I_a), field current (I_f), motor torque (T_m) and motor torque (T_m) vs motor speed (w_m) curve characteristics as shown in Figure 6. The four 'push button' represent the selection of 'Simulate, 'Simulink Model', 'Back' and 'Exit'. 'Simulate' button used to run the program. 'Simulink Model' button used to call the Simulink model. 'Back' button used to return the program back to the 'Main Window' and 'Exit' button used to close the program.
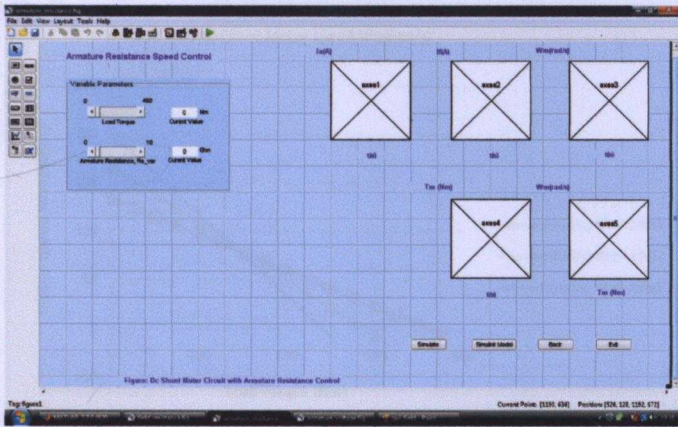
Figure 6: 'Armature Resistance Speed Control' GUI program design

The 'Armature Voltage Speed Control' and 'Field Resistance Speed Control' GUI programs also apply the same design as 'Armature Resistance Speed Control' GUI program. The only difference is that the 'slider bar' and 'edit value box' of armature resistance (R_{a1}) is changed to armature voltage (V_t) and field resistance (R_{f1}) respectively as shown in Figure 7 and Figure 8.
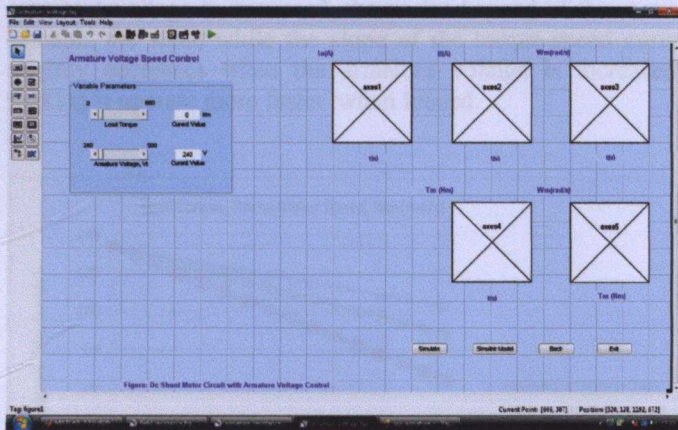

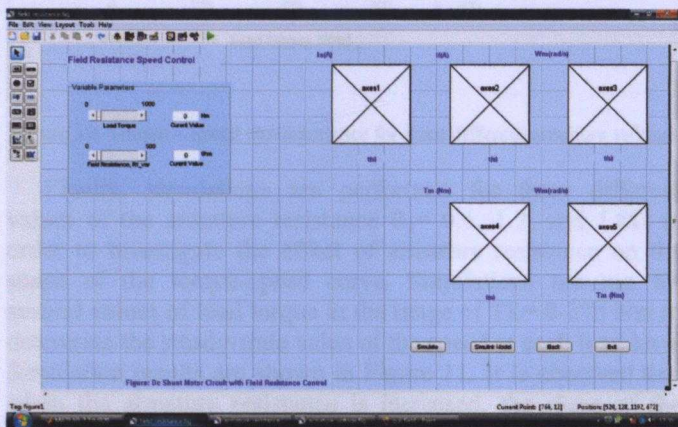Figure 7: 'Armature Voltage Speed Control' GUI program design

Figure 8: 'Field Resistance Speed Control' GUI program design

When designing all the windows is completed, the input commands for each element in the workspace need to be written. All the input commands are written in the M-file Editor. The input commands are used to interface the GUI program and Simulink model, used to interface between different GUI programs and also to run the 'Simulate' button. It was also used to set up the range of the load torque value and controller elements value (R_{a1}, R_{f1}, V_t) and also used to insert picture. Example of M-file Editor input commands are show in Figure 8.
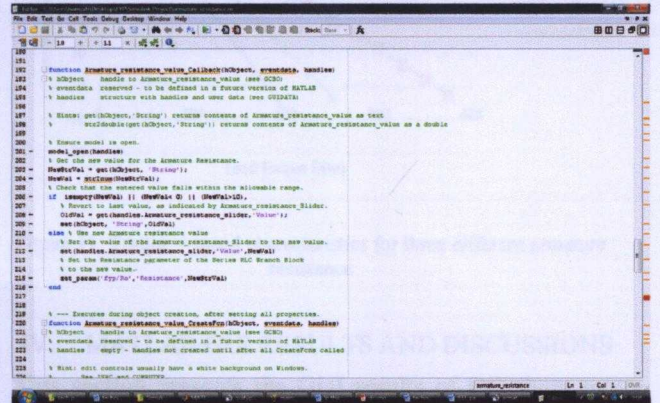

Figure 8: M-file Editor input commands of 'Armature Resistance Speed Control' GUI program.

III. MATLAB/SIMULINK SIMULATION RESULTS AND DISCUSSIONS

This section presents simulation results for the speed control methods and DC shunt motor feedback control system. The torque-speed curves for the speed control methods are determined using the Simulink models presented in the previous section. For this purpose, a 5-Horse Power (HP) DC motor of 240 V rating 1,220 r/min is used in the simulation models. The equivalent circuit parameters of the motor are: $R_f= 240 \ \Omega$, $L_f= 120H$, $R_a= 0.6\Omega$.

For the field resistance control, first, the nominal value of the field resistance $R_f= 240\Omega$ is selected and simulations are run for several values of load torque in the range of TL= 0-750 Nm to determine the steady-state value of the speed at each load level. In order to investigate the effect of an increase in the field resistance on the torque-speed characteristic, $R_{f1}= 60\Omega$ and 120Ω external resistance is then inserted in series with the field circuit as illustrated in Figure 2 and simulations are repeated for the same load levels. The torque-speed curves for the three resistance values are shown in Figure 9. This figure clearly shows an increase in the slope of the curve as well as in the no load speed of the motor with respect to an increase in the field resistance. It must also be noted that over the range from no-load to full-load conditions (TL= 0-300 Nm), an increase in R_f causes an increase in the motor speed. On the other hand, at very slow speed (TL>300 Nm), an increase in R_f will decrease the speed of the motor [5].
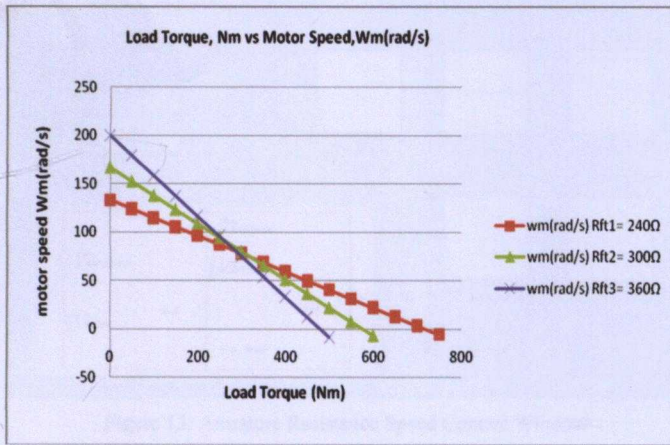
Figure 9: Torque – speed characteristics for three different field resistance

For the armature voltage control, simulations are performed using the model shown in Figure 3 for three different armature voltages, V_t= 240, 300, and 360V. Simulations are run for several values of load torque in the range of TL= 0-375 Nm to determine the steady-state value of the speed at each load level. Figure 10 compares the torque-speed characteristics. Figure 10 clearly illustrates when the armature voltage is increased, the no-load speed of the motor remains the same while the slope of the torque-speed curve slightly decreases when the armature voltage is increased, making it operate more faster when loaded.
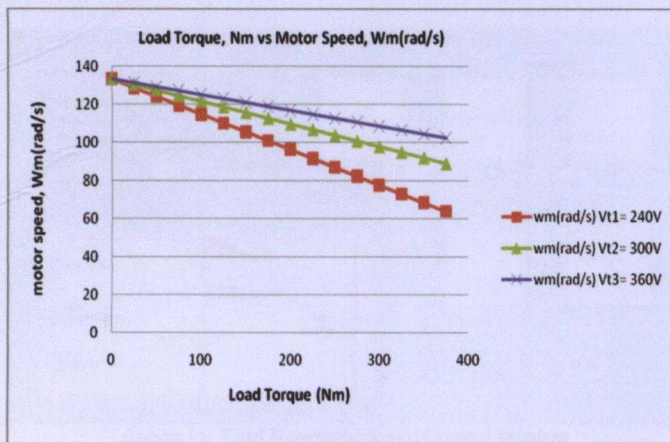

Figure 10: Torque – speed characteristics for three different armature voltage

Finally, simulations are performed for three different values of the armature resistance R_a= 0.6, 1.2, and 1.8Ω in order to investigate the effect of armature resistance on the shape of the torque-speed curve. Simulations are run for several values of load torque in the range of TL= 0-375 Nm to determine the steady-state value of the speed at each load level Simulation results are shown in Figure 11. It is observed that when the armature resistance is increased, the slope of the motor's torque-speed characteristic increases drastically, making it operate more slowly if loaded. The no-load speed of

the motor remains the same even though the armature resistance R_a value is changed.
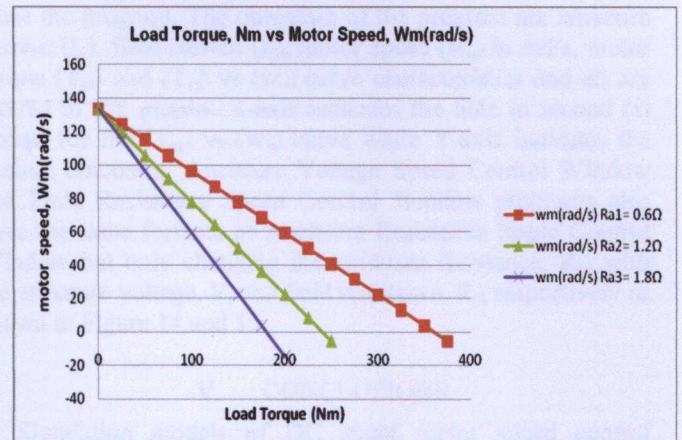

Figure 11: Torque – speed characteristics for three different armature resistance

IV. MATLAB/GUI RESULTS AND DISCUSSIONS

This section presents the GUI results of DC shunt motor speed control methods program. Figure 12, 13, 14 and 15 showed the example output of the program.
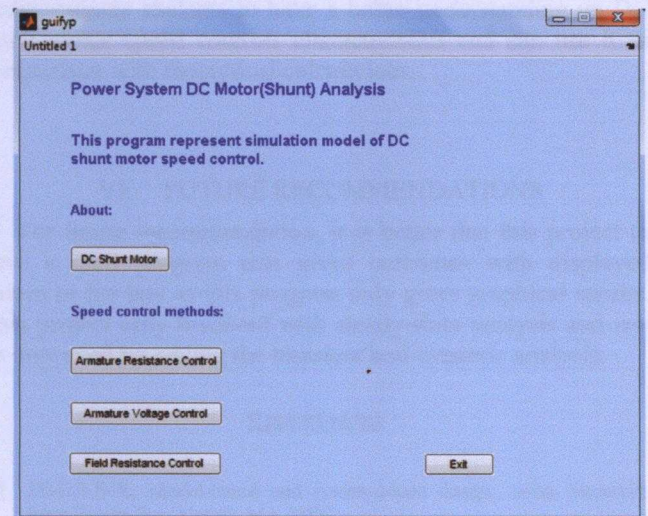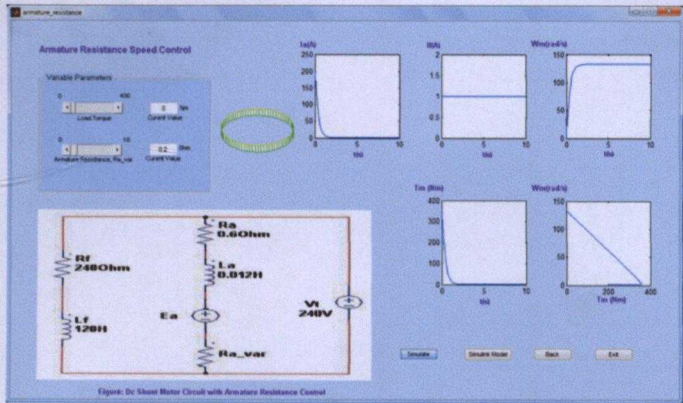

Figure 12: Main Window

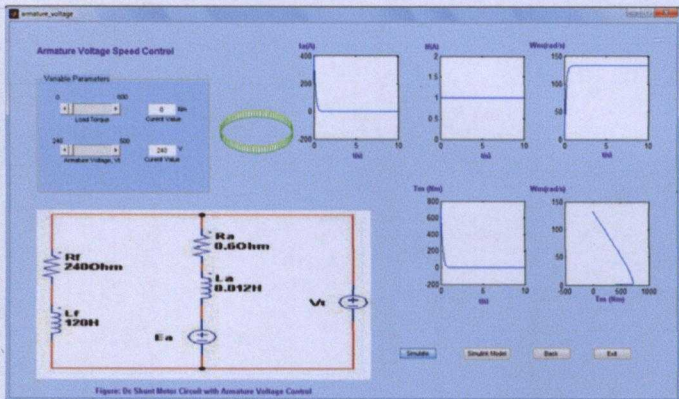Figure 13: Armature Resistance Speed Control Window
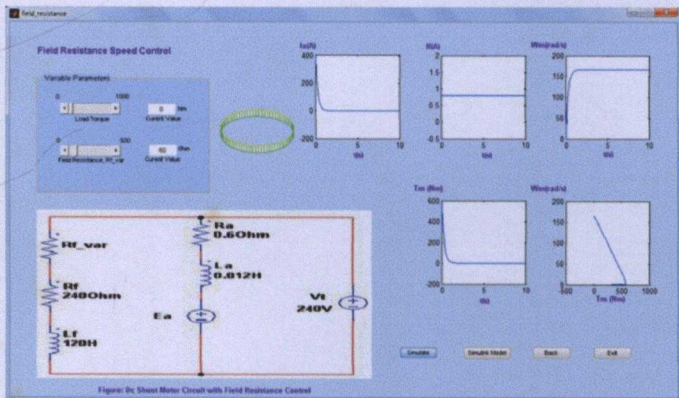

Figure 14: Armature Voltage Speed Control Window

Figure 15: Field Resistance Speed Control Window

Figure 12 shows the Main Window of the program. It consists five pushbutton optains for users to choose. Users can push the DC Shunt Motor 'pushbutton' if they want to know about brief information of DC shunt motor. If they want to observe the speed control characteristics, they can push either Armature Resistance Control, Armature Voltage Control or Field Resistance Control 'pushbutton'. 'Exit' button used to close the program.

Figure 13 shows Armature Resistance Speed Control Window program. This window allows users to change the load torque, TL and armature resistance, R_a value through the

'slider bar' or 'edit value box'. It's also consists 'Simulate' button used to run the program. 'Simulink Model' button used to call the Simulink model. 'Back' button used to return the program back to the 'Main Window' and 'Exit' button used to close the program. The outcomes of the program are armature current (I_a), field current (I_f), motor speed (w_m) in rad/s, motor torque (T_m) and (T_m) vs (w_m) curve characteristics and all are plotted in XY graphs. X-axis indicates the time in second (s) except for the (T_m) vs (w_m) curve while Y-axis indicates the desired outcomes. Armature Voltage Speed Control Window and Field Resistance Speed Control Window programs also have the same features as Armature Resistance Speed Control Window but only changing the armature resistance, R_{a1} with the armature voltage, V_t and field resistance, R_{f1} respectively as shown in Figure 14 and 15.

V.   CONCLUSIONS

Simulation models of DC shunt motor speed control methods have been developed using MATLAB/Simulink. It has been shown that proposed simulation models correctly predict the effect of field resistance, armature voltage, and armature resistance on the torque-speed characteristic of the DC shunt motor. Furthermore, Simulink models have been successfully interfaced with MATLAB Graphical User Interface (GUI) program. Through GUI, this project offer users an attractive and easy way to use DC shunt motor speed control methods simulation software. It can help undergraduate students to have a better understanding on DC shunt motor speed controls characteristics and can use it as comparison with theoretical calculations.

VI.   FUTURE RECOMMENDATIONS

For future recommendation, it is better that this project to have a GUI program that gives outcomes with displayed values or list box as this program only gives graphical results. This project only involved with steady-state analysis and can be improved by adding the transient and dynamic analysis.

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