Separately Excited DC Motor Control Method Using MATLAB Software(Simulink) and Interface With Graphical User Interface(GUI)

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Abstract— **This paper investigates the characteristic of DC motor speed by using MATLAB Software. The speed of the DC motor can be controlled by Armature Voltage Control (Vt), Field Resistance Control (Rf) and Armature Resistance Control (Ra). For this study, the Separately Excited DC motor will be simulated by using MATLAB software (Simulink). Three control methods as stated above will be used in order to investigate the motor speed characteristic. Besides, MATLAB User Graphical Interface (GUI) also has been used in order to display the output from the simulation.**

Keyword – Separately Excited DC motor, MATLAB, Simulink, Graphical User Interface (GUI)

I. INTRODUCTION

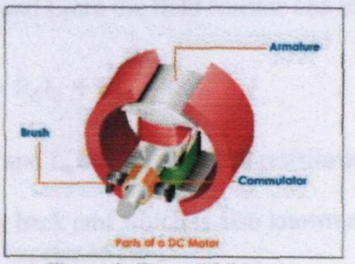

Figure 1: Parts of DC Motor

DC motors have long been widely used in many industrial applications. A DC motor can be considered a Single Input Single Output (SISO) system having torque speed characteristics compatible with most mechanical loads. This makes a dc motor controllable over a wide range of speeds by proper adjustments of its terminal voltage. Recently, DC brushless and induction motors gained a persistent effort towards making them behave like DC. Numerous discrete-time controller design methods for angular position and speed servo-systems have been presented over many years.[1]

There is a variety of techniques available ranging from classical to optimal and robust methods. Variable structure control has been used recently in speed control application such as robots where robustness is an important property in such application. Basically, the speed of the DC motor can be varied by reducing the motor voltage with a series resistor. However this is inefficient (energy wasted in resistor) and reduces torque. The current drawn by the motor increases as the load on the motor increases. More current means a larger voltage drop across the series resistor and therefore less voltage to the motor. The motor now tries to draw even more current, resulting in the motor "stalling".[1]

The DC commutator machines are built in a wide range of sizes, from small motor until up to enormous motors of 10,000hp or more used in rolling mill applications. The dc machines today are principally applied as industrial drive motors, particularly when high degrees of flexibility in controlling speed and torque are demanded. Such motors are used in steel and aluminium rolling mills, traction motors, overhead cranes, forklift trucks, electric trains and golf carts. Commutator machines are also used in portable tools supplied from batteries, in automobiles, in automobiles as starter motors, in blower motors, and in control applications as actuators and speed-sensing or position-sensing devices.[1]

II. CIRCUIT OPERATION

The equivalent circuit of a Separately excited DC motor is shown in Figure 2.

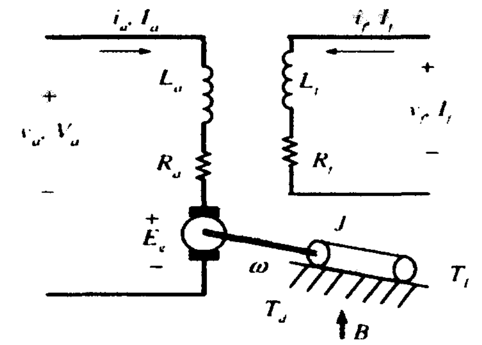

Figure 2: Equivalent circuit of Separately Excited DC motor.

When a separately excited motor is excited by a field current of I_f and an armature current of I_a flows in the circuit, the motor develops a back emf and a torque to balance the load torque at a particular speed.[2-6]

The I_f is independent of the I_a .Each winding is supplied separately. Any change in the armature current has no effect on the field current. The I_f is normally much less than the I_a. [2-6]

Field and armature equations:-

$$V_f = R_f I_f + L_f \frac{dI_f}{dt} \quad (1)$$

Where R_f and L_f are the field resistor and inductor.

$$V_a = E_g + R_a I_a + L_a \frac{dI_a}{dt} \quad (2)$$

Where R_a and L_a are the armature resistor and inductor.

The motor back emf which is also known as speed voltage is expressed as:-

$$E_g = K_V \omega I_f \quad (3)$$

Kv is the motor voltage constant (in V/A-rad/s)

ω is motor speed in rad/s.

The torque develop by the motor is

$$T_d = K_t I_f I_a \quad (4)$$

Where(Kt = Kv) is the torque constant. (in V/A-rad/s)

Sometime it is written as:-

$$\tau_d = k_t \Phi I_a \quad (5)$$

For normal operation, the developed torque must be equal to the load torque plus the friction and inertia, i.e.:

$$T_d = J\frac{d\omega}{dt} + B\omega + T_L \quad (6)$$

Where

B: viscous friction constant, (N.m/rad/s)

TL: load torque (N.m)

J: inertia of the motor (kg.m^2)

Under steady state operations, a time derivative is zero. Assuming the motor is not saturated.

For field circuit from (1), it become

$$V_f = R_f I_f \quad (7)$$

The back emf is given by:

$$E_g = K_V \omega I_f$$

The armature circuit from (2) and (3), it become

$$V_a = E_g + I_a R_a = I_a R_a + K_V \omega I_f \quad (8)$$

The motor speed can be easily derived:-

$$\omega = \frac{V_a - I_a R_a}{K_V I_f} \quad (9)$$

If R_a is small value (which is usual), or when the motor is lightly loaded, i.e. Ia is small,

$$\omega = \frac{V_a}{K_V I_f} \quad (10)$$

That I_f the field current is kept constant, the motor speed depends only on the supply voltage.

$$T_d = K_t I_f I_a = B\omega + T_L \quad (11)$$

III. MATLAB/SIMULINK MODELS OF SPEED CONTROL METHODS

The speed of a DC motor can be varied by controlling the field resistance, 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.[4, 5, 7]

In this study, the Separately excited DC motors will be simulated by using the Simulink model[8, 9]. The output data from this simulation will be recorded into the table.

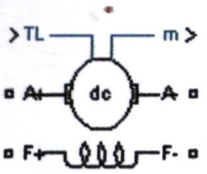

Figure 3: DC Machine block

The DC Machine block implements a separately excited DC machine. An access is provided to the field terminals (F+, F-) so that the machine model can be used as a shunt-connected or a series-connected DC machine. The torque applied to the shaft is provided at the Simulink input T_L. The armature circuit (A+, A-) consists of an inductor La and resistor Ra in series with a counter-electromotive force (CEMF) E. The CEMF is proportional to the machine speed.

$$E = K_E \omega \quad [10]$$

K_E is the voltage constant and ω is the machine speed.

In a separately excited DC machine model, the voltage constant K_E is proportional to the field current I_f.[10]

$$K_E = L_{af} I_f$$

where L_{af} is the field-armature mutual inductance.

The electromechanical torque developed by the DC machine is proportional to the armature current Ia.

$$T_e = K_T I_a$$

where K_T is the torque constant.[10]

The sign convention for T_e and T_L is

$T_e T_L > 0$: Motor mode

$T_e T_L < 0$: Generator mode

The torque constant is equal to the voltage constant.[10]

$$K_T = K_E$$

The armature circuit is connected between the A+ and A- ports of the DC Machine block. It is represented by a series Ra La branch in series with a Controlled Voltage Source and a Current Measurement block. The field circuit is represented by an RL circuit. It is connected between the F+ and F- ports of the DC Machine block. The mechanical part computes the speed of the DC machine from the net torque applied to the rotor. The speed is used to implement the CEMF voltage E of the armature circuit. The mechanical part is represented by Simulink blocks that implement the equation

$$J\frac{d\omega}{dt} = T_e - T_L - B_m\omega - T_f$$

where J = inertia, B_m = viscous friction coefficient, and T_f = Coulomb friction torque.[10]

Figure 4 shows the circuit connection for field resistance control method. An external resistance $R_{f(adj)}$ 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.

Figure 5 shows the circuit connection for armature resistance control method. An external resistance $R_{a(adj)}$ is inserted in series with the armature circuit to realize the armature resistance speed control.

Figure 6 shows the circuit connection for the armature voltage control method. Armature voltage will be varied and while the field voltage will be remain constant during this investigate done.

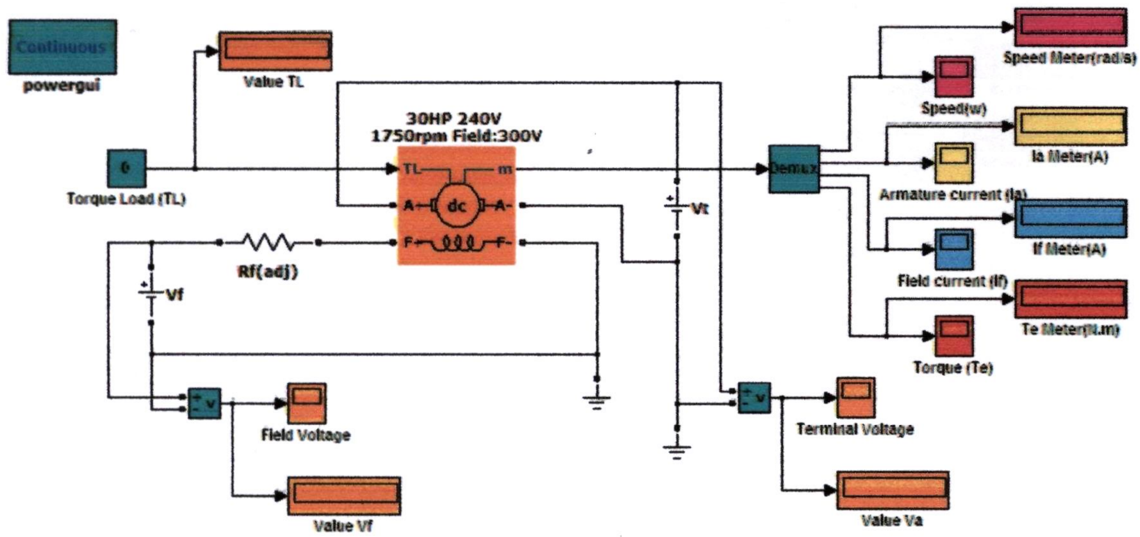

Figure 4: Circuit connection for field resistance control method

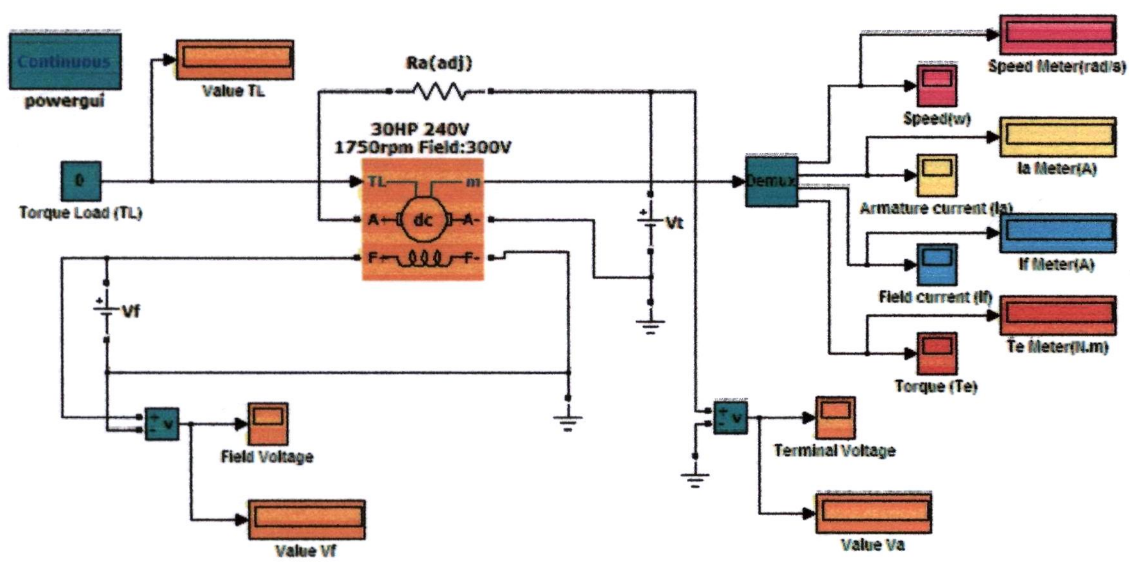

Figure 5: Circuit connection for armature resistance control method

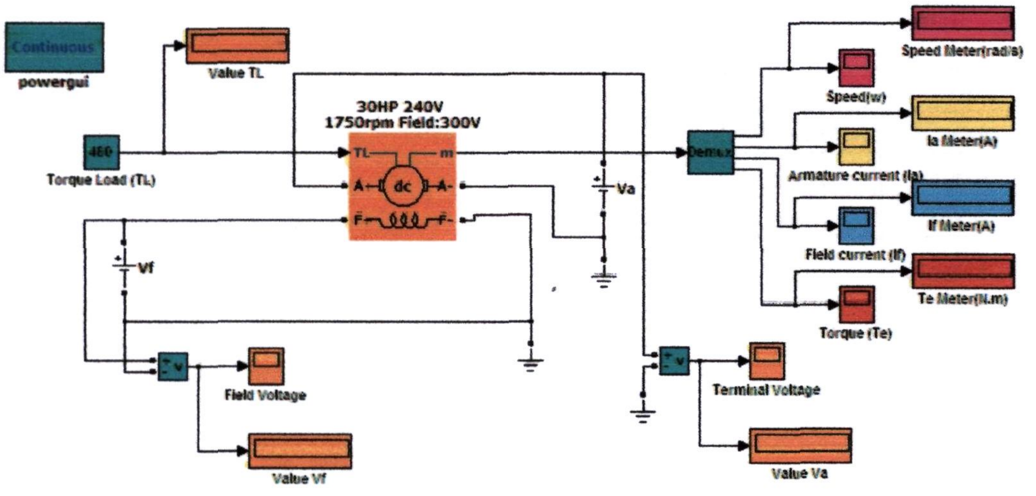

Figure 6: Circuit connection for armature voltage control method

IV. SIMULATION RESULTS

This section presents simulation results for the speed control methods of Separately Excited DC motor. The torque-speed curves for the speed control methods are determined using the Simulink models. For this purpose, a 30-Horse Power (HP) DC motor of 240 V rating 1750 rpm is used in the simulation models. The equivalent circuit of the motor are R_f=0.2275Ω, L_f=0.002866H, R_a=102.3Ω and L_a=20.82H.

First, the external field resistance $R_{f(adj)}$=0Ω is inserted in series with the field circuit and simulations are run for several values of load torque in the range of T_L 0-480 N.m 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, the value of external field resistance is increased to 50Ω and then to 100Ω.[11] The same steps of simulations are repeated for the same load level. All the data needed to plot the torque-speed curve have been recorded into the table. TABLE 1 show the speed of the three field resistance varied according to the changes in load torque. From the data in the TABLE 1, the torque-speed curves have been plotted and showed in the Figure 7. This figure clearly shows that when $R_{f(adj)}$ is increased, the speed motor also increase. However at full load condition, an increase in $R_{f(adj)}$ will decrease the speed of the motor.[4]

TABLE 1: SPEED OF THREE FIELD RESISTANCE FOR THE SEPARATELY EXCITED DC MOTOR.

Load Torque (T_L)(N.m)	Speed (rad/s)		
	$R_{f(adj)}$=0Ω	$R_{f(adj)}$=50Ω	$R_{f(adj)}$=100Ω
0	254.0	376.9	498.7
20	248.8	365.5	478.7
40	243.7	354.2	458.7
180	207.8	274.6	318.7
200	202.6	263.3	298.7
220	197.5	251.9	278.7
300	176.9	206.5	198.7
320	171.8	195.1	178.7
340	166.7	183.7	158.7
360	161.5	172.4	138.7
460	135.9	115.6	38.7
480	130.7	104.2	18.7

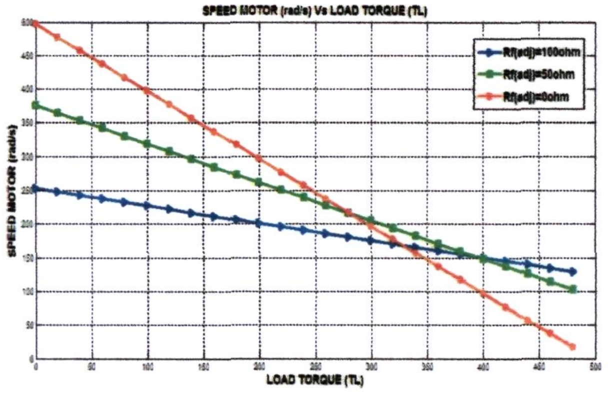

Figure 7: Torque-speed characteristics for three different fields resistances for the Separately Excited DC motor

For the armature resistance control, simulations are performed using the model shown in Figure 5. The external armature resistance $R_{a(adj)}$=0.5Ω is inserted in series with the armature circuit and simulations are run for several values of load torque in the range of T_L (0-120 N.m) to determine the steady-state value of the speed at each load level. In order to investigate the effect of an increase in the armature resistance on the torque-speed characteristic, the value of external armature resistance is increases to 1Ω and then to 1.5Ω.[11] The same steps of simulations are repeated for the same load level. All the data needed to plot the torque-speed curve have been recorded into the table. TABLE 2 shows the speed of the three armature resistance varied according to the changes in load torque. From the data in the TABLE 2, the torque-speed curves have been plotted and shows in the Figure 8. This figure clearly shows that when $R_{a(adj)}$ is increased, the speed of motor will decrease.

For the armature voltage control, simulations are performed using the model shown in Figure 6 for three different armature voltages, V_a=240V, V_a=300V, and V_a=360V while the voltage applied to the field circuit is kept constant at its nominal value 240 V. All the data needed to plot the torque-speed curve have been recorded into TABLE 3. From the data in the TABLE 3, the torque-speed curves have been plotted and shows in Figure 9. Figure 9 clearly illustrates that the torque-speed curve is shifted upward by increasing the armature voltage while the slope of the curve remains unchanged, as it is theoretically expected.[2, 12]

TABLE 2: SPEED OF THREE ARMATURE RESISTANCE FOR THE SEPARATELY EXCITED DC MOTOR

Load Torque (T_L)(N.m)	Speed (rad/s)		
	$R_{a(adj)}$=0.5Ω	$R_{a(adj)}$=1Ω	$R_{a(adj)}$=1.5Ω
0	251.4	248.9	246.40
10	243.2	235.2	227.10
20	235.1	221.4	207.80
30	226.9	207.6	188.50
90	177.8	125.0	72.53
100	169.6	111.2	53.20
110	161.4	97.45	33.88
120	153.2	83.68	14.56

TABLE 3: SPEED OF THREE ARMATURE VOLTAGE FOR THE SEPARATELY EXCITED DC MOTOR

Load Torque (T_L)(N.m)	Speed (rad/s)		
	V_a =240V	V_a =300V	V_a =360V
0	254.00	317.70	381.3
50	241.10	304.80	368.5
100	228.30	292.00	355.7
150	215.50	279.10	342.8
200	202.60	266.30	330.0
800	48.59	112.30	176.0
850	35.76	99.45	163.1

Figure 8: Torque-speed characteristics for three different armature resistance for Separately Excited DC motor

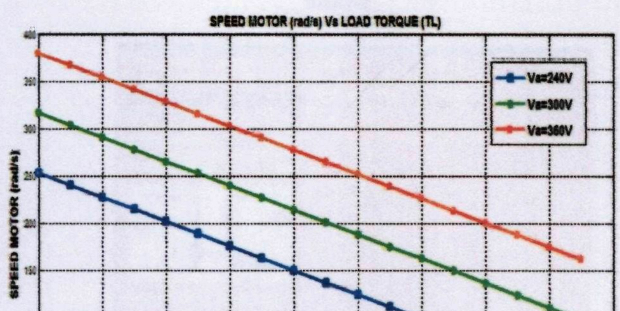

Figure 9: Torque-speed characteristics for three different armature voltage for Separately Excited DC motor

From the simulation it can be shown that the very high armature current needed to start up the motor. As the motor (rotor) continues to speed up, the armature current continues to fall and the torque induced also goes down until the speed motor is stable. Figure 10 shows the characteristic of the armature current, rotor speed and torque induced change according to the time.

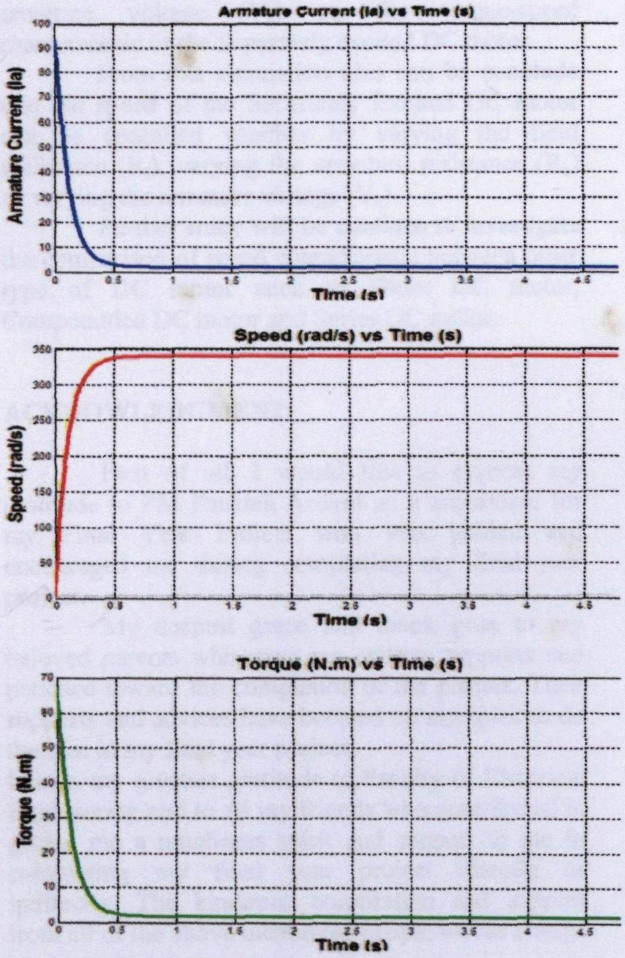

Figure 10: Simulink output for the Separately Excited DC motor

V. RESULTS FROM GUI

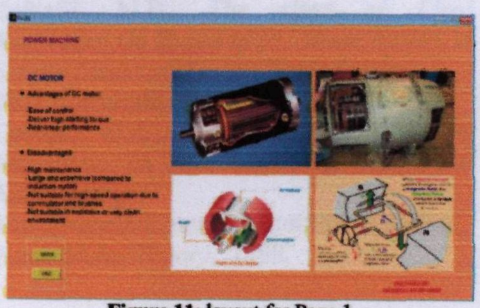

Figure 11: layout for Page 1

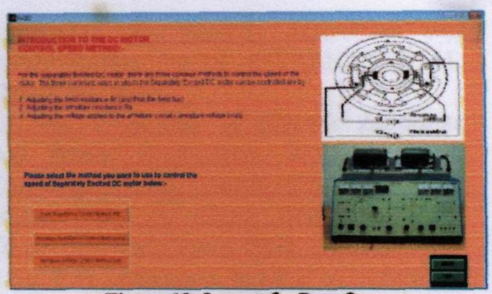

Figure 12: Layout for Page 2

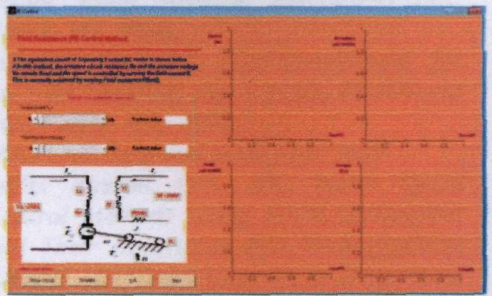

Figure 13: Page for field resistance (R_f) control method

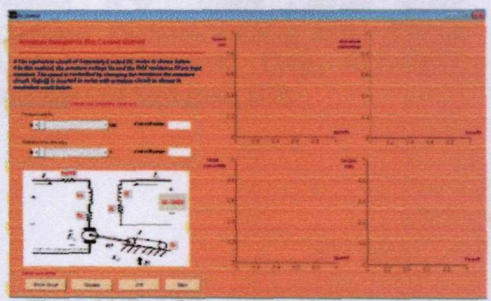

Figure 14: Page for armature resistance control method

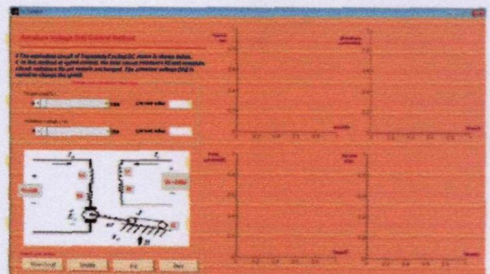

Figure 15: Page for armature voltage control method

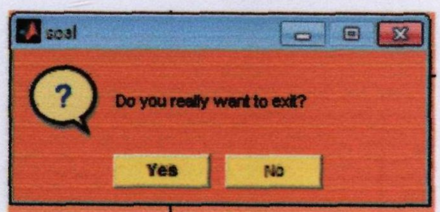

Figure 16: Page for user confirmation action

VI. CONCLUSION

Simulation models of DC 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 (R_f), armature resistance (R_a), and the armature voltage (V_a) on the torque-speed characteristic of the Separately excited DC motor.

From this simulation also can be conclude that the speed of the Separately Excited DC motor can be contolled whether by varying the field resistance (R_f), varying the armature resistance (R_a) or varying the armature voltage (V_a).

Further study will be continue to investigate the comparison of speed characteristic between other type of DC motor such as Shunt DC motor, Compounded DC motor and Series DC motor.

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REFFERENCES

1. Zulkafli, M.B., *The effect of Field Resistance On Speed of DC Shunt Motor*, in *School Electrical System Engineering* 2007, Universiti Malaysia Perlis: Arau.
2. Cruden, D.A., *Introduction to Electric Machines*, in *Electronic & Electrical Engineering*.
3. http://www.reliance.com/mtr/mtrthrmn.htm. *Basic Motor Theory*. 1998.
4. J.Chapman, S., *Electric Machinery and Power System*. 1st ed. INTERNATIONAL EDITION. 2002.
5. P.C.Sen, *Principles of Electric Machines and Power Electronics*. 2nd ed. 1996, Kingston, Ontario, Canada. 615.
6. Salam, D.Z., *DC Motor Drive*, in *Power Electronics and Drives*. 2003, UtmJB.
7. Arya, P.H., *Actuators*, in *Dept. of Aerospace Engineering*: Bombay.
8. SIMULINK, *Model-based and system-based design, using Simulink, MathWorks Inc., Natick, MA*. 2000.
9. Simulink, M.f.u.w., *SimPowerSystems for use with Simulink, user's guide, MathWorks Inc., Natick, MA,*. 2002.
10. MATLAB, *help and demo files*. 2009.
11. Saffet Ayasun, G.K., *DC Motor Speed Control Methods Using MATLAB/Simulink and Their Integration into Undergraduate Electric Machinery Courses*, in *Department of Electrical and Electronics Engineering*. 2007, Nigde University: Nigde.
12. Penrose, H.W., *Direct Current Motor Electrical Evaluation Using Motor Circuit Analysis*. (Ph.D BJM Corp, ALL-TEST Division Old Saybrook, CT).