Shunt DC Motor Speed Control Methods Using MATLAB

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Abstract - **This paper describes the simulation of DC motor speed control using Matlab Simulink. The three most common speed control methods are field resistance control, armature voltage control, and armature resistance control. The interface program is designed so that the user can vary all the parameters of the circuits using the program and display the various characteristics.**

Keywords-Shunt DC motor; Speed control; MATLAB Simulink; Graphical user interface;

I. INTRODUCTION

Computer modeling 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 characteristics of electric machines. The objective of this paper is to present simulation models of DC motor speed control methods. These models include Simulink models of three most common speed control methods, field resistance, armature voltage, and armature resistance control methods.

MATLAB's graphical user interface programming is used to offer students all simulation models in a single and easy-to-use software package. The simulation models of DC motors are integrated into a control-oriented senior level electric machinery course to enhance the understanding the dynamic analysis of DC motors. It has been observed that with the help of simulation results obtained, students increase their understanding of DC motor characteristics and dynamic behaviour beyond the understanding they gain from classroom lectures and textbooks.

In any electrical machine, operation is based on simple electromagnetism. A current carrying conductor generates a magnetic field which when placed in an external magnetic field; it will experience a force proportional to the current in the conductor and to the strength of the external magnetic field. The internal configuration of a DC motor is designed to harness the magnetic interaction between current-carrying conductors and an external magnetic field to generate rotational motion [3]. The geometry of the brushes, commutator contacts, and rotor windings are such that when power is applied, the polarities of the energized winding and the stator magnet(s) are misaligned, and the rotor will rotate until it is almost aligned with the stator's field magnets. As the rotor reaches alignment, the brushes move to the next commutator contacts, and energize the next winding [3].

In field resistance 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_{fc}). The flux in the machine (Φ) will be proportional to the field current (I_f) [4]. Therefore:

$$K_a \Phi = K_f I_f \qquad (1)$$

$$\omega_m = V_t / K_f I_f - (R_a/(K_f I_f)^2)T \qquad (2)$$

$$\omega_m = K_1 - K_2 T \qquad (3)$$
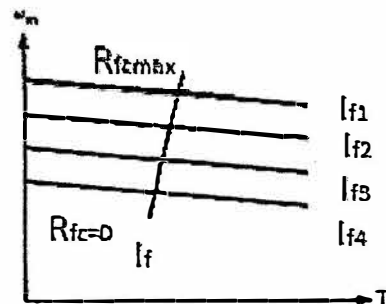
$$K_1 = V_t / K_f I_f$$

$$K_2 = R_a / (K_f I_f)^2$$

Fig. 1: Torque speed characteristics of field resistance control

In armature voltage method, shunt field current is maintained constant from a separate source while the voltage applied to the armature is varied. DC motors feature a speed, which is proportional to the counter e.m.f. At rated current, the torque remains constant regardless of the DC motor speed (since the magnetic flux is constant) and, therefore, the dc motor has constant torque capability over its speed range [4]. In this method of speed control, the armature resistance (R_a) remains unchanged, the field current I_f is kept constant (normally at its rated value), and the armature terminal voltage (V_a) is varied to change the speed. If armature reaction is neglected from equation:

$$\omega_m = K_3 V_t - K_4 T \qquad (4)$$

Where $K_3 = 1/ K_a \Phi$

$K_4 = R_a / (K_a \Phi)^2$

If the terminal voltage is kept constant and the load torque is varied, the speed can be adjusted by V_t as shown in Fig. 2
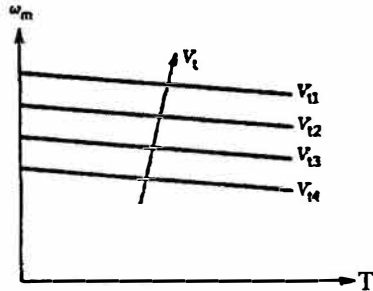

Fig. 2: Torque speed characteristics of armature voltage control

Therefore as V_t increase, the speed increase linearly. If I_a remain constant, so does the torque. The input power from the source ($P = V_t I_a$) also changes linearly with speed [4].

In armature resistance method, the armature terminal voltage V_t and the field current I_f are kept constant at their rated values. The speed is controlled by changing resistance in the armature circuit. An armature circuit rheostat R_{ac} is inserted at the armature circuit. An armature circuit rheostat R_{ac} is used for this purpose. Therefore:

$$\omega_m = V_t / K_a \Phi - (R_a + R_{ac} /(K_a \Phi)^2)T \qquad (5)$$

$$\omega_m = K_5 - K_6 T \qquad (6)$$

$K_5 = V_t / K_a \Phi$

$K_6 = R_a + R_{ac} / (K_a \Phi)^2$

The torque speed characteristics for various values of the external armature circuit resistance are shown in Fig. 3. The value of R_{ac} can be adjusted to obtain various speeds such that armature current I_a (hence torque $T = K_a \Phi I_a$) remains constant. Fig. 3 shows the various values of R_{ac} required operating at a particular value of torque T [4].
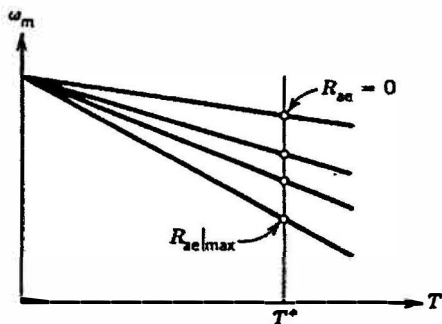

Fig. 3: Torque speed characteristics of armature resistance control

III. METHODOLOGY

In this section, Simulink models of these three methods [5] for DC motor drives for dynamic 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. Fig. 4 shows the Simulink implementation of the field resistance control method. Observe that 240 V DC source is applied to the armature and field circuits. An external resistance (field resistance) 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.

In the armature voltage control method, the voltage applied to the armature circuit, V_a is varied without changing the voltage applied to the field circuit of the motor. When the armature voltage is increased, the no-load speed of the motor increases while the slope of the torque-speed curve remains unchanged since the flux is kept constant [6]. Fig. 5 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 Fig. 4. The main difference is that the armature is supplied from an external DC sources. Moreover, the external resistance (field resistance) in Fig. 4 is removed in this model.

In the armature resistance control, 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 [6]. This simulation (Fig. 6) model is similar to that of the field resistance control method shown in Fig. 4. The only difference is that field resistance in Fig. 4 is removed and an external resistance (armature resistance) is inserted in series with the armature circuit to vary the armature resistance.

The last part of the project is called MATLAB Graphical User Interface (GUI) Software. The MATLAB GUI design system allows you to create applications consisting of one or more 'dialogs' containing typical 'controls' such as buttons, edit boxes, lists and pictures [7].

The projects continued with designing an Option Window which consists of three push buttons which are represent the 'Field Resistance Control', 'Armature Resistance Control', Armature Voltage Control'. The work continued with designing all the Option Window. Design a window for each of the control method. After that design an adjust parameter to adjust the parameter of the load torque and the value of the external resistance and voltage. Then design a push button represents the 'show circuit' to see the actual circuit of the DC Shunt motor. Also design a push button to simulate the circuit from the simulation circuit.
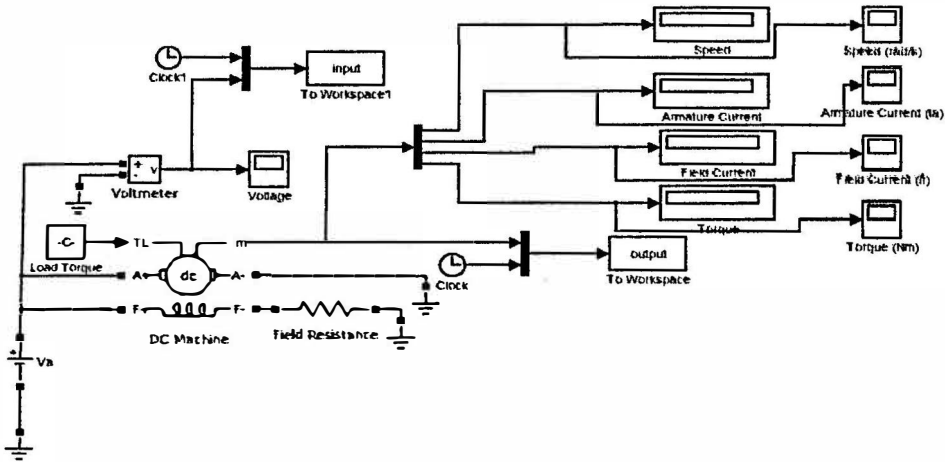
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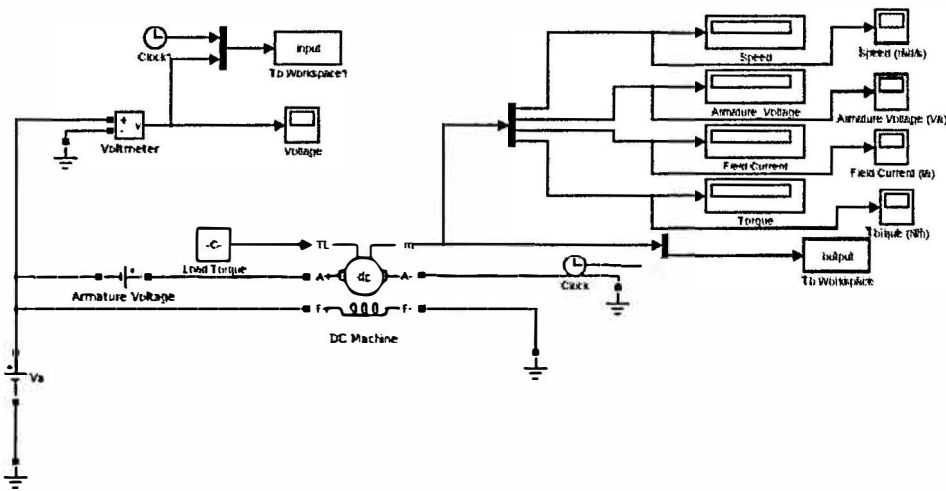Fig. 4: Simulation circuit of field resistance speed control method

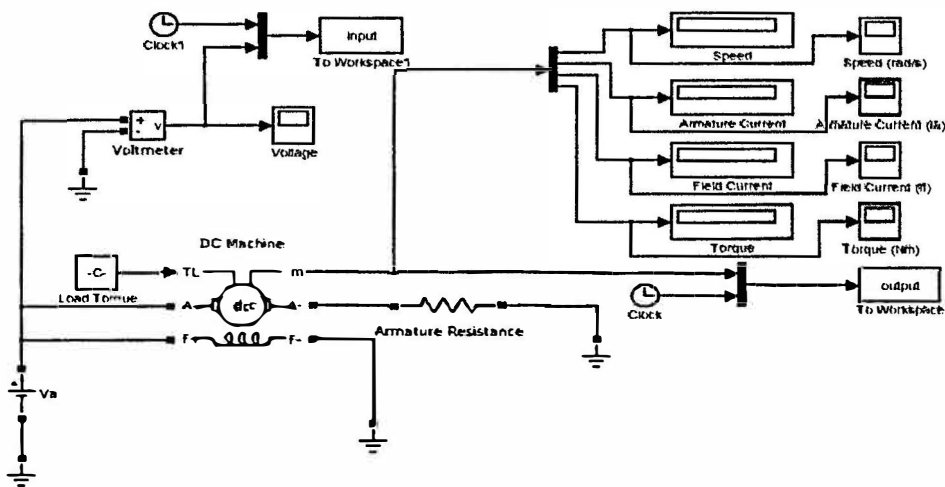Fig. 5: Simulation circuit of armature voltage speed control method

Fig. 6: Simulation circuit of armature resistance speed control method

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III. RESULTS AND DISCUSSION

This section presents simulation results for the speed control methods for DC motor. The torque-speed curves for the speed control methods are determined using the Simulink models presented in the previous section.
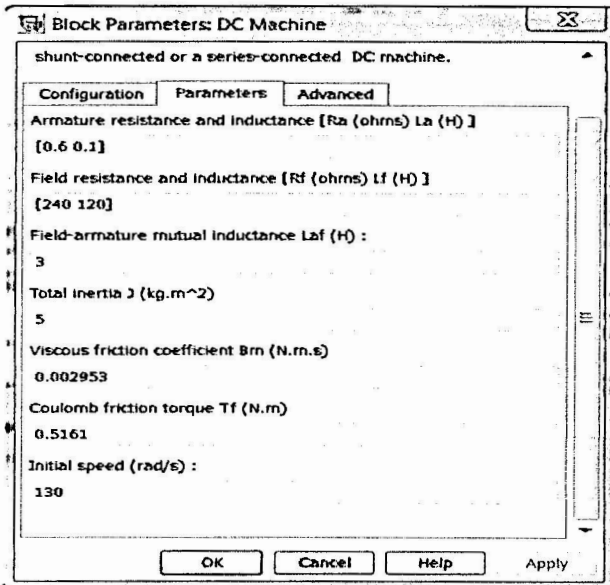

Fig. 7: Parameters of DC motor

Fig. 7 shows the parameters of the DC machine. The circuit will run with several value of load torque (TL) to see the effect on the torque speed characteristics. First of all, simulate the circuit with no external field resistance. The circuit runs only with the internal field resistance R_f. Run the simulation to see the effect of the motor speed when the torque increased.

TABLE I
MOTOR SPEED FOR DIFFERENT VALUE OF FIELD RESISTANCE R_f

Load Torque(Nm)	Load Torque(p.u)	Motor Speed (rad/s)	
		$R_f = 240\,\Omega$	$R_f = 300\,\Omega$
0	0	159.7	179.6
50	1	146.4	162.8
100	2	133.1	145.9
150	3	119.8	129
200	4	106.5	112.3
250	5	93.1	95.4
300	6	79.8	78.6
350	7	66.5	61.8
400	8	53.2	44.9
450	9	39.9	28.1
500	10	26.5	11.2

TABLE I above shows the effect on the speed of the motor when the torque increased. It also shows the effect on the speed of the motor when external field resistance $R_f = 60\Omega$ is inserted to the field circuit.
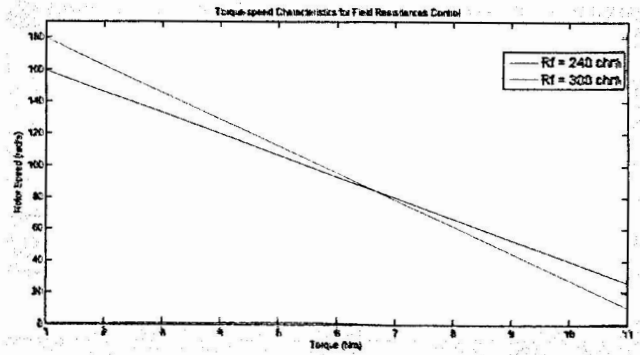

Fig. 8: Torque speed characteristics of field resistance control

The torque-speed curves for both resistance values are shown in Fig. 8. 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=0-500 Nm), an increase in field resistance causes an increase in the motor speed. On the other hand, at very slow speed (TL>300Nm), an increase in field resistance will decrease the speed of the motor [6].

TABLE II
MOTOR SPEED FOR DIFFERENT VALUE OF ARMATURE VOLTAGE V_A

Load Torque(Nm)	Load Torque(p.u)	Motor Speed (rad/s)		
		V_a=180V	V_a=240V	V_a=300V
0	0	139.9	159.9	179.9
50	1	136.6	156.6	176.6
100	2	133.2	153.2	173.2
150	3	129.9	149.9	169.9
200	4	126.6	146.6	166.6
250	5	123.2	143.2	163.2
300	6	119.9	139.9	159.9

TABLE II above shows the effect on the speed of the motor when the torque is increased. It also shows the effect on the speed of the motor when external voltage is inserted to the armature circuit.
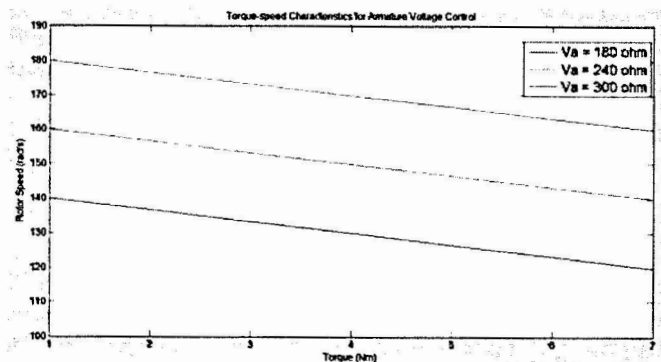

Fig. 9: Torque speed characteristics of armature voltage control

For the armature voltage control, simulations are performed using the model shown in Fig. 5 for three different armature voltages, V_a=180, 240, and 300 V while the voltage applied to the field circuit is kept constant at its nominal value 240 V. Fig. 9 compares the torque-speed characteristics. Fig. 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. It is also concluded that when the value of armature voltage increases, the armature current also increases thus increasing the speed of the motor.

TABLE III
MOTOR SPEED FOR DIFFERENT VALUE OF ARMATURE RESISTANCE R_A

Load Torque(Nm)	Load Torque(p.u)	Motor Speed (rad/s)		
		R_a=0.6Ω	R_a=1.2Ω	R_a=1.7Ω
0	0	79.9	79.9	79.8
50	1	73.2	69.9	66.8
100	2	66.6	59.9	53.7
150	3	59.9	49.9	40.7
200	4	53.2	39.9	27.7
250	5	46.6	29.9	79.9
300	6	39.9	19.9	1.6

TABLE III above shows the effect on the speed of the motor when the torque is increased. It also shows the effect on the speed of the motor when inserted an external resistance in the armature circuit.
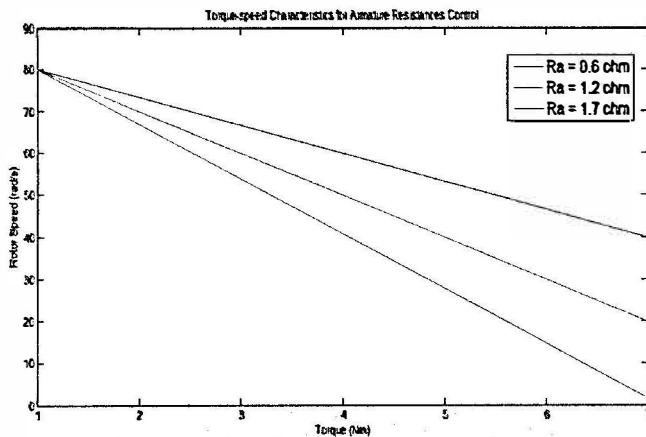

Fig. 10: Result of torque speed characteristics of armature resistance control

Finally, simulations are performed for three different values of the armature resistance R_a=0.6, 1.2, and 1.7 Ω in order to investigate the effect of armature resistance on the shape of the torque-speed curve. Simulation results are shown in Fig. 10. 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.
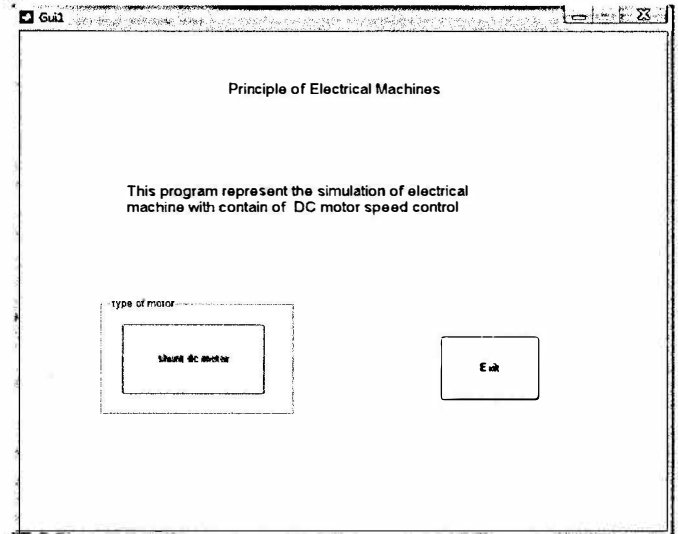

Fig. 11: Main Window for Graphical User interface

For MATLAB's graphical user interface programming, a main window will appear as shown in Fig. 11. This window will allow user to investigate the torque speed characteristics of the three speed control methods easier and friendly user. MATLAB's graphical user interface programming has been designed to offer students all simulation models in a single and easy-to-use software package.

V. CONCLUSION

Simulation models of DC motor speed control methods have been developed using MATLAB/Simulink. It has been shown that the proposed simulation models correctly predict the effect of field resistance, armature voltage, and resistance on the torque-speed characteristic of the DC motor. Furthermore, Simulink models have been successfully integrated into an electric machinery course as a part of the software laboratory. Simulated examples help students increase their understanding of DC motor operation, fundamentals of dynamic system controls and its application into DC motor speed control, providing them a complete view of a controllable DC machine and drive systems. The interface program is designed so that the user can vary all the parameters of the circuits using the program and display the various characteristics. MATLAB's graphical user interface programming has been designed to offer students all simulation models in a single and easy-to-use software package.

Future work will involve further development of simulation models to include power electronic, performance of induction machines and synchronous machines.

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