EXPERIMENTAL AND MATLAB/Simulink VERIFICATION OF VARIOUS SPEED CONTROL FOR D.C DRIVE SYSTEMS

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Abstract: *This paper presents the experimental and MATLAB/Simulink verification of different speed control methods via. Field resistance, armature voltage and armature resistance, and feedback control system for D.C motor drive system. Also, the performance of proposed system using classical controllers is analyzed and designed by using state-space averaging model of D.C motor system. Both experimental and simulation models of the proposed system are developed as a section of a simulation software/electrical machinery laboratories to support and enhance teaching methodology of undergraduate electrical machinery courses.*

Keyword: *D.C motor, Education, Simulation software laboratory, MATLAB/Simulink, Electrical machine laboratory, Classical controllers.*

1. Introduction.

The theoretical analysis of electrical machine represents one of the vital roles of any electrical engineering education [1]. The computer software based modeling and simulation tools have been extensively used to support and improve the electrical machinery courses.

MATLAB/Simulink with it toolboxes like Basic Simulink, SimPowerSystems and Control Systems, which is one of most famous software platform packages used by educators to improve the teaching methodology in start-up transient and steady state performance characteristics of electrical machines [2]-[7]. Simulink models for induction motor and transformer experiments have been developed and most successfully integrated them into undergraduate electrical machinery courses have been reported in past [8].

The simulation software and state–space average model for D.C motor drive and controllers design for luo converters has been discussed in [10]-[13]. In this paper, the experimental and MATLAB/Simulink evaluation of various speed control techniques namely field resistance, armature voltage and armature resistance, and feedback controller for D.C motor drive system is proposed. The state-space average model of D.C motor system is derived at first and then feedback controller or classical controllers are designed.

Section 2 is discussed about the mathematical model of D.C motor drive system. Section 3 is presents the developed model of both experimental and MATLAB/Simulink model of proposed system at various speed control methods. Classical controllers design using proposed system is presented in section 4. Simulation and experimental results are presented in section 5. Conclusion and future work is presented in section 6.

2. Modeling of D.C motor drive system.

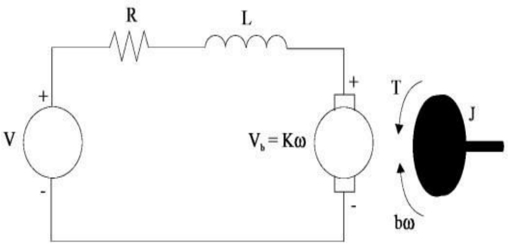

Fig. 1. Electrical and mechanical model of D.C motor system.

The motor torque, “T” is related to the armature current “i" by a constant factor “K”,

$$T=Ki \tag{1}$$

The back electromotive force (emf), V_b, is related to the angular velocity by

$$V_b=K\omega = K\frac{d\theta}{dt} \tag{2}$$

From Fig.1 we can write the following differential equations based on the Newton’s law combined with the Kirchhoff’s law

$$J\frac{d^2\theta}{dt^2}+b\frac{d\theta}{dt}=Ki \tag{3}$$

$$L\frac{di}{dt}+Ri=V-K\frac{d\theta}{dt} \tag{4}$$

Using the Laplace transform, equations (3) and (4) can be written as:

$$Js^2\theta(s)+bs\theta(s)=KI(s) \tag{5}$$

$$LsI(s)+RI(s)=V(s)-K(s)=K(s)\theta(s) \tag{6}$$

Where, s denotes the Laplace operator. From (6) we can express I(s)

$$I(s)=\frac{V(s)-Ks\theta(s)}{R+Ls} \tag{7}$$

and substitute it in (5) to obtain

$$Js^2\theta(s)+bs\theta(s)=K\left(\frac{V(s)-Ks\theta(s)}{R+Ls}\right) \tag{8}$$

From equation (8), the transfer function from the input voltage, V(s), to the output angle, θ directly follows

$$G_a(s)=\frac{\theta(s)}{V(s)}=\frac{K}{s\left(\left(R+Ls\right)(J+sb)+K^2\right)} \qquad (9)$$

The transfer function from the input voltage, V(s), to the angular velocity, w(s), is

$$G_v(s)=\frac{w(s)}{V(s)}=\frac{K}{\left(\left(R+Ls\right)(J+sb)+K^2\right)} \qquad (10)$$

3. Implementation of D.C motor drive system without power electronics converter.

A. MATLAB/Simulink Model Implementation

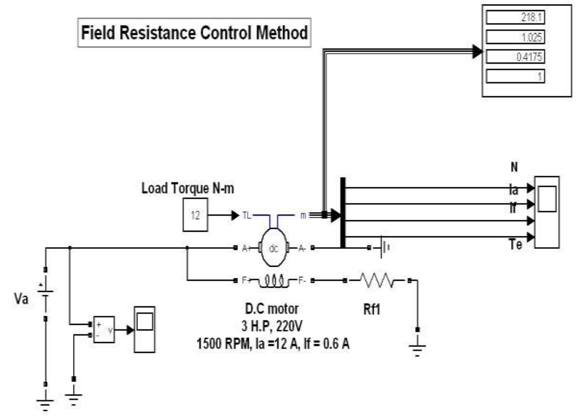

Fig. 2. MATLAB/Simulink model of field resistance control method.

The rotation of a DC motor drive can be varied by regulating the field flux, the armature resistance or the terminal voltage applied to the armature circuit. The three most common speed control methods are namely field resistance control, armature voltage control, and armature resistance control [10]. In this section, MATLAB/Simulink models of these three methods [11] for DC motor drives for dynamic analysis are well 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 [10]. Fig.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 La and resistor Ra in series with an electromotive force EA 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. Observe that 220 V DC source is applied to the armature and field circuits. An external resistance Rf1 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).

In the armature voltage control method, the voltage applied to the armature circuit, Va is varied without changing the voltage applied to the field circuit of the motor. Therefore, the motor must be separately excited to use armature voltage control. 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 [10]. Fig. 3 shows the MATLAB/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. 2. The main difference is that the armature and field circuit are supplied from two different DC sources to have a separately excited connection. Moreover, the external resistance Rf1 in Fig.2 is removed in this model.

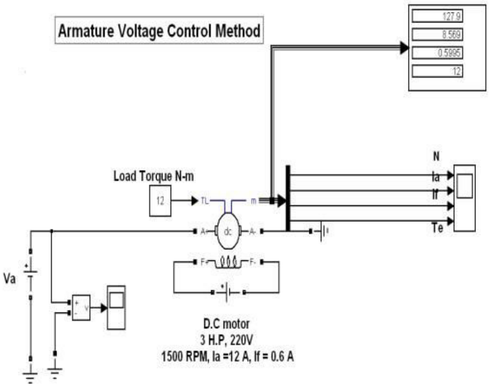

Fig.3. MATLAB/Simulink implementation of armature speed control method.

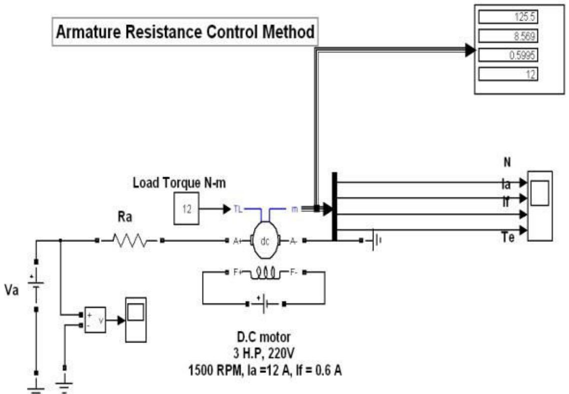

Fig.4. MATLAB/Simulink implementation of armature resistance control method.

The armature resistance control is the less commonly used 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 [10]. MATLAB/Simulink model of this method as shown in Fig.4. The only difference is that Rf1 resistance in Figure 1 is removed and an external resistance Ra1 is inserted in series with the armature circuit between the ports (A+, A-) to vary the armature resistance.

B. Laboratory model implementation

Fig.5. Laboratory experiment set-up model of D.C motor drive system at various speed control methods.

Fig. 5 shows the laboratory prototype set-up model of D.C motor drive system operating at various speed control methods. The straightforward MATLAB/Simulink simulation model of D.C motor at three speed control methods are implemented in electrical machinery laboratory.

4. Classical controller design.

There are many types of classical controllers like namely, Robust Controller (RC), Current Controllers (CCs), Sliding Mode Controller (SMC), Proportional Controller (PC), Integral Controller (IC) and Proportional- Integral Controller (PIC). In this paper, PC, IC and PIC is chosen as a classical controller which are designed to ensure the specifying desired nominal operating point for speed of D.C motor drive system, then regulating it, so that it stays very closer to the inal operating point in the case of sudden disturbances, set point variations, noise, modeling errors and motor parameters variations.

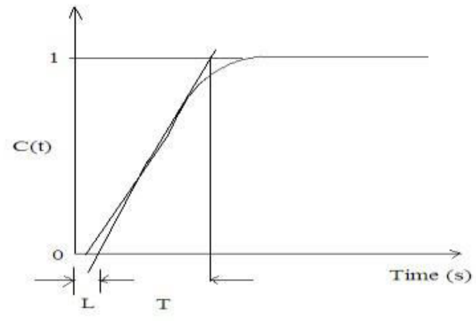

Fig. 6. S- Shaped curve of step response of D.C motor drive system.

The PI controller settings proportional gain (K_p) and integral time (T_i) are designed using Zeigler – Nichols tuning method [8]-[9] by applying the step test to (3) to obtain S – shaped curve of step response of D.C machine. From the S-shaped curve of step response of proposed system may be characterized by two constants, delay time L and time constant T. The delay time and time constant are determined by drawing a tangent line at the inflection point of the S-shaped curve and determining the intersections of the tangent line with the time axis and line output response c(t) as shown in Fig. 6. Ziegler and Nichols suggested to set the values of $K_p = 0.036$ and $T_i = 0.016$s according to the Table I.

The PI controller optimal setting values (Kp and T_i) for proposed system are obtained by finding the minimum values of integral of square of error (ISE), integral of time of square of error (ITAE) and integral of absolute of error (IAE), which is listed in Table II. The designed PI controller is used regulate the speed of the D.C motor.

TABLE I

ZIEGLER- NICHOLS TUNING RULES

Type of controller	*Kp*	*Ti*	*Td*
P	*T/L*		0
PI	0.9*T/L*	*L*/0.3	0
PID	1.2T/*L*	*2L*	0.5*L*

TABLE **II**

SIMULATED RESULTS OF MINIMUM VALUES OF ISE, IAE, ITAE AND OPTIMAL SETTING VALUES OF KP AND TI

ISE	IAE	ITAE	Kp	Ti (s)
4.377	0.123	0.0166	0.1	1

5. Experimental and simulation results discussions.

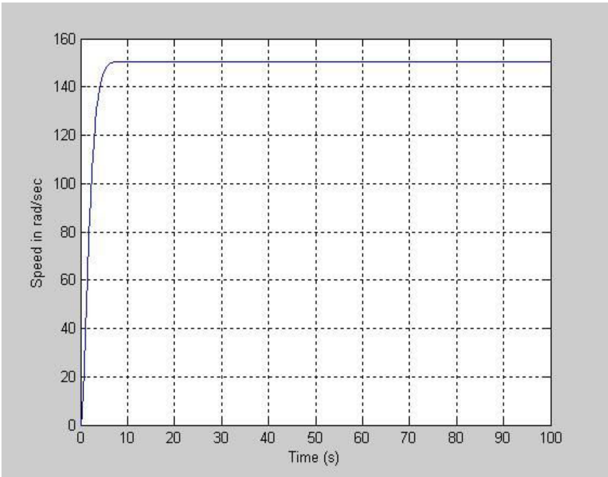

Fig. 7. Closed loop speed response of D.C motor drive system.

This section represents the simulation and experimental results for various speed control topologies and DC motor feedback control system. In this case, 3HP, 220V, 1500 rpm, R_a= 7.1 Ohm, I_a=12A, R_f = 367 Ohm and I_f =0.6 A DC motor is used in both simulation and experimental model. Fig. 7. show the closed loop speed response of DC motor with constant load. From this figure, it is clearly found that the speed response has negligible overshoot and quick settling time. In figs. 8 and 9 show the step change speed response of DC motor using PI controller. It can be found that the speed response has negligible overshoot and quick settling time in step change operating region.

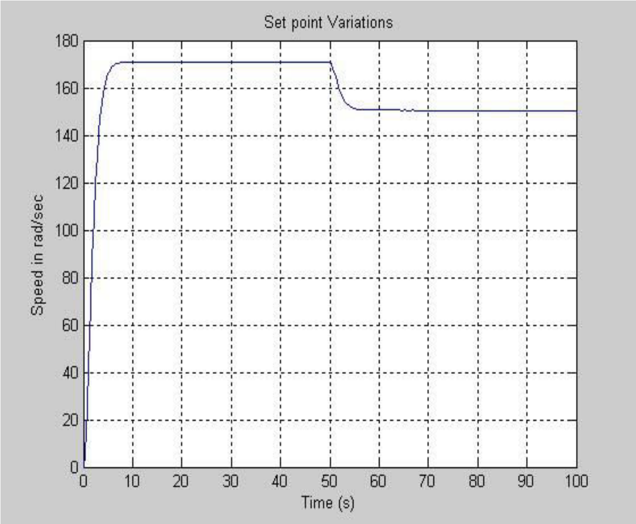

Fig. 8. Step change speed response of D.C motor drive system using PI controller.

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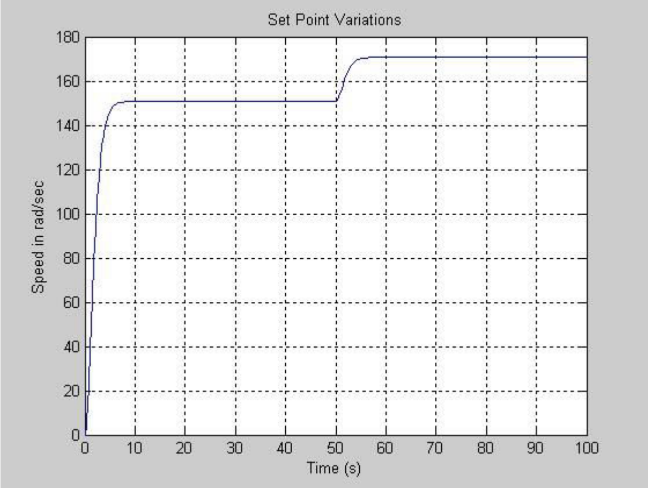

Fig. 9. Step change speed response of D.C motor drive system using PI Controller.

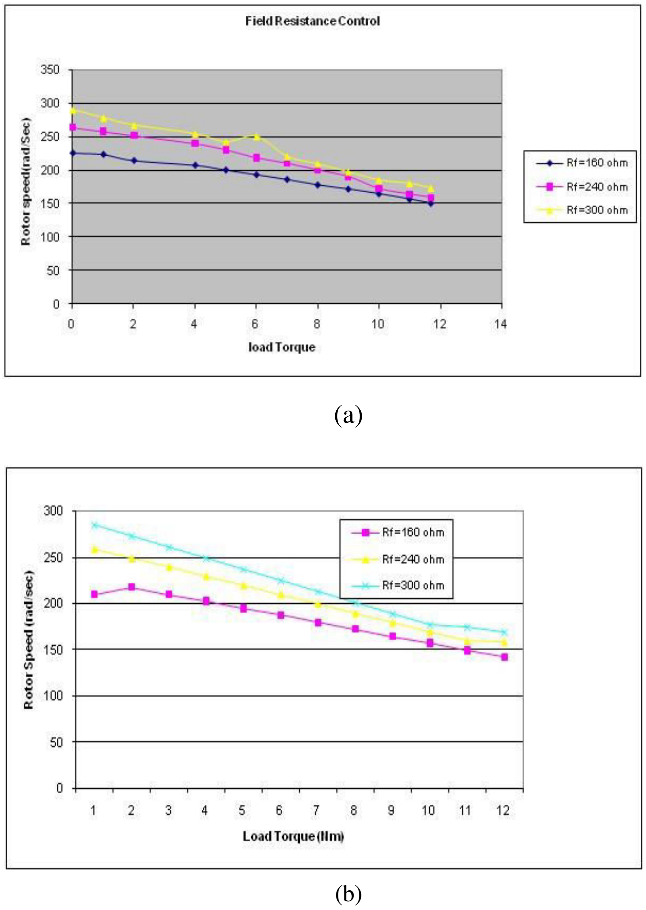

Fig. 10. Torque-speed characteristics for three different field resistances (a) Experimental, (b) MATLAB/Simulink.

Fig. 10a and 10b show the simulated and experimental results of torque-speed characteristics of DC motor for three different field resistances. From this figure, it would be found that the higher speed with higher value of resistance. Also the simulated results are very close the experimental results.

Fig. 11a and 11b show the simulated and experimental results of torque-speed characteristics of DC motor for three different armature voltages. From this figure, it would be found that the higher speed with higher voltage. Also the simulated results are very close the experimental results.

Fig. 12a and 12b show the simulated and experimental results of torque-speed characteristics of DC motor for three different armature resistances. From this figure, it would be found that the higher speed with higher value of resistance. Also the simulated results are very close the experimental results. Finally, the performance of various speed control method for DC motor drive system is listed Appendix –I in Table 3 and Table 4.

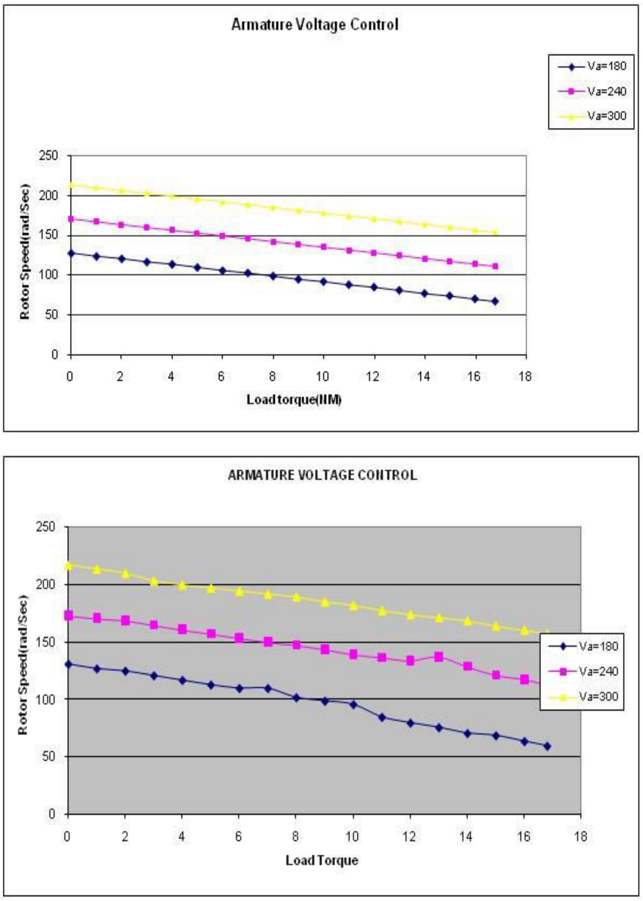

Fig. 11. Torque-speed characteristics for three different Armature voltages (a) Experimental, (b) Matlab/Simulink.

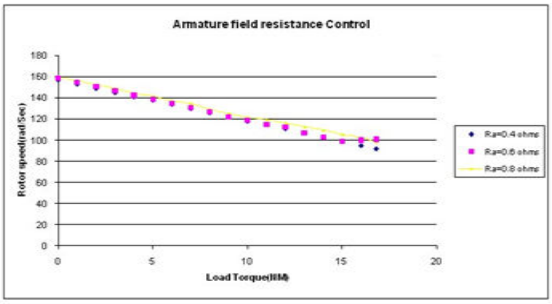

Fig. 12. Simulated Torque-speed characteristics for three different Armature resistance control.

6. Conclusions

The Experimental/MATLAB Simulation models of DC motor speed control methods and feedback control system for DC motor drives has been successfully demonstrated through power electronics converters. It has been shown that proposed experimental and simulation models are correctly predicting the effect of field resistance, armature voltage, and resistance on the performance characteristic of the DC motor system.

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