

Effects of Single Phase AC/DC Converter Drive on the Torque-Speed Characteristic of DC Motor

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Abstract — This paper describes a MATLAB/Simulink realization of the DC motor speed control method by controlling the voltage applied to the armature circuit using single phase AC/DC converter drive. A comparison between the application of single phase semi converter and single phase full converter is presented. Torque-speed characteristics are obtained for different values of firing angle to demonstrate its effect on the linearity of the characteristic.

Index Terms— MATLAB/Simulink, DC motor drive, Single phase AC/DC converter drive.

I. INTRODUCTION

MATLAB with its toolboxes such as Simulink and SimPowerSystems is one of the most popular software packages, which has been used to support and enhance electric machinery courses [1-3]. There are many methods of speed control of DC motors, namely field control, armature voltage control, and armature resistance control methods [4]. In practice, the commonly method used to control the DC motor speed is the armature voltage control method. In this method, a power electronic converter controllable rectifier or PWM chopper will supply the DC motors. Therefore, nonlinear torque-speed characteristics would be observed in the DC motor performance [5]. This paper presents a Simulation model of a DC motor speed control method in which a single phase AC/DC semi and full converters drive are used to control the voltage applied to the armature. Torque speed characteristics are obtained for different values of firing angle to demonstrate its effect on the linearity of the characteristic.

II. TORQUE-SPEED CHARACTERISTICS AND SPEED CONTROL METHOD ANALYSIS

To analyze the torque speed characteristics using the equivalent circuit, the dynamic and steady-state models are needed. The schematic representation of the model of a separately excited DC motor is shown in Fig.1. In this figure, V_t is the terminal voltage applied to the motor, R_a and L_a are the resistance, and inductance of the armature circuit; respectively; R_f and L_f are the resistance, and inductance of the field circuit, respectively; E_a is the generated speed voltage; ω_m is the angular speed of the motor; T_e and T_l are the

electromagnetic torque developed by the motor and the mechanical load torque opposing direction.

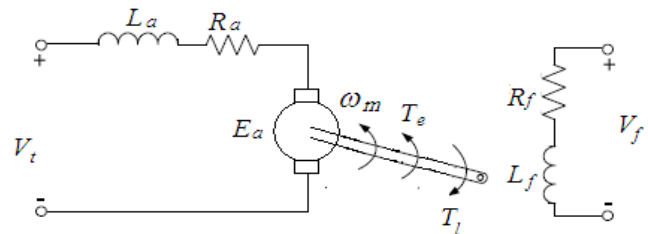


Fig. 1 Equivalent circuit of separately excited DC motor.

The torque-speed characteristic of a separately excited DC motor under the steady-state conditions is described by the following equation [6]:

$$\omega_m = \frac{V_t}{K\phi} - \frac{R_a}{(K\phi)^2} T_e \quad (1)$$

Where K is the design constant depending on the construction of the motor.

Equation (1) indicates 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. The three most common speed control methods are field resistance control, armature voltage control and armature resistance control methods [6, 9]. Since this paper presents Simulink model of speed control method by controlling the terminal voltage applied to the armature using a single phase AC/DC converter drive, only the armature voltage control method is briefly described in this section.

In the armature voltage control method, the voltage applied to the armature circuit, V_t is varied without changing the voltage applied to the field-circuit of the motor. As equation (1) indicates, the torque-speed characteristic is represented by a straight line with a negative slope when the DC motor is driven from an ideal DC source. This characteristic is illustrated in Fig. 2. In order for the speed of the motor vary linearly with torque, the terminal voltage V_t and the flux ϕ must remain constant as the load changes. Typically a rectifier is required to provide the controlled armature voltage for the motor whose speed is to be controlled. Observe that the no-load speed of the motor increases while the slope of the curve remains unchanged since the flux is kept constant in this method. By the armature voltage control method, it is possible

to control the speed of the motor for speeds below base speed but not for speeds above base speed. In order to achieve a speed faster than the base speed, an excessive armature voltage is required, which possibly damages the armature circuit.

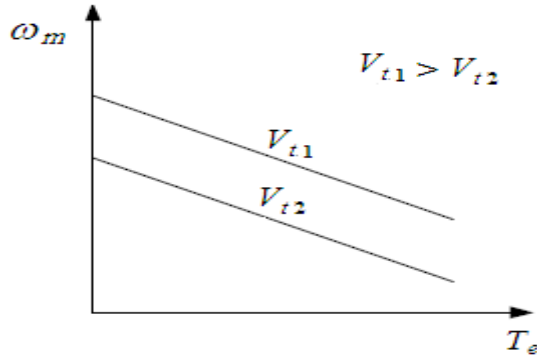


Fig. 2 Torque speed characteristics of the separately excited DC motor at different armature voltages.

III. SIMULINK MODEL OF ARMATURE VOLTAGE SPEED CONTROL

In this section, MATLAB/Simulink model of DC motor driven from single phase AC/DC semi and full converters are presented and the performance of the DC motor drive is analyzed. A 5-HP DC motor of 240-V rating 1220 rpm is used in the simulation model. Fig. 3 shows the Simulink realization of the semi converter drive. The armature circuit is supplied from a single phase semi converter in which a thyristor is used as an electronic switch and a freewheeling diode is used to solve the stored inductive energy problem in the circuit. The field circuit is separately excited from an ideal DC voltage source. A DC motor block of SimPowerSystems toolbox is used.

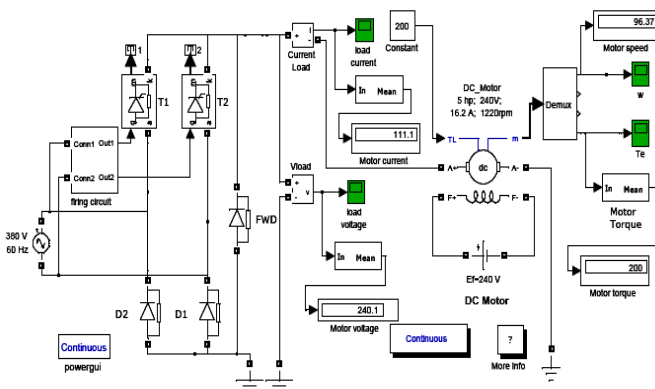


Fig. 3 Simulink realization of armature voltage speed control method using a single phase semi converter drive.

Where, Fig. 4 shows the Simulink realization of the full converter drive. The armature circuit is supplied from a single phase full converter in which a thyristor is used as an electronic switch and no freewheeling diode is used. The field circuit is

separately excited from an ideal DC voltage source. A DC motor block of SimPowerSystems toolbox is used.

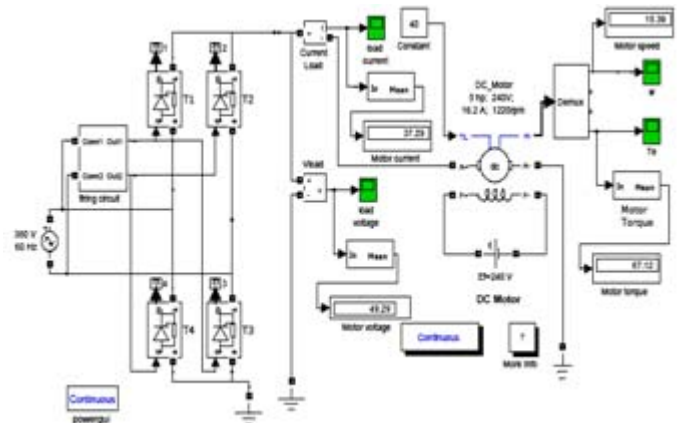


Fig. 4 Simulink realization of armature voltage speed control method using a single phase full converter drive.

IV. SIMULATION RESULTS

A. Single Phase Semi converter Drive

In order to investigate the effect of armature voltage on the torque-speed characteristic, Four different armature voltages with average values $V_i = 240$ V, 200 V, 160 V and 120 V are applied while the voltage applied to the field circuit is kept constant at its nominal value 240 V. A constant 380 V, 60 HZ AC is applied to the input of single phase semi converter. The average value of the converter output is changed by changing the firing angle (α). A pulse generator is used to change the firing angle. The following firing angles are used to obtain 120, 160, 200 and 240 V average output voltages applied to the armature: $\alpha = 89^\circ$, 70° , 47.5° and 0° . The torque-speed characteristics are obtained for these armature voltages.

Fig. 5 shows the torque-speed curves for a single phase semi converter drive.

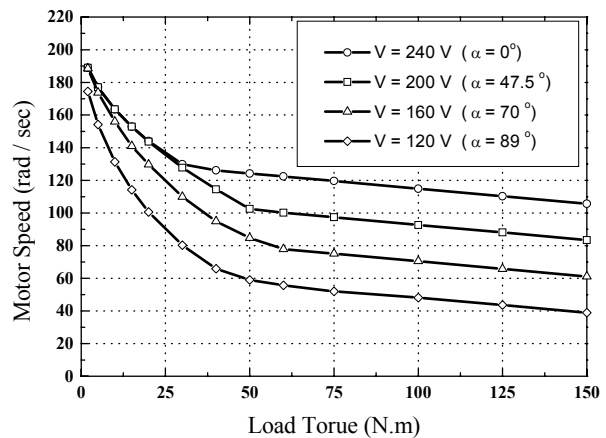


Fig. 5 Torque-speed characteristics for a single phase semi converter drive.

It is clear that torque-speed curves contain both linear and non-linear regions. The linear region of operation for 240V approximately starts at $T_L = 30$ N.m. But for 200V starts at $T_L = 50$ N.m. While for 160V approximately starts at $T_L = 60$ N.m. Finally for 120V approximately starts at $T_L = 75$ N.m. The discontinuous armature current results in a highly non-linear torque-speed characteristic. Fig. 6 and Fig. 7 show the armature voltage and current obtained at 25 Nm (in the non-linear region) and 125 Nm (in the linear region) for average value of 160 V. These figures clearly illustrate the discontinuous and continuous operation of the single phase semi converter drive in non-linear and linear regions, respectively.

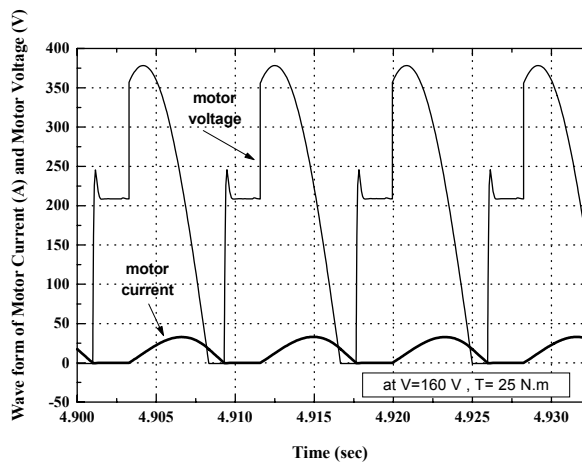


Fig. 6. Armature current and voltage for 160 V at 25 Nm for single phase semi converter drive.

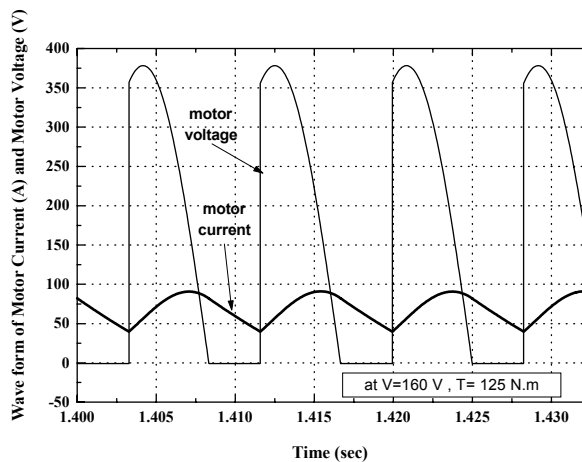


Fig. 7. Armature current and voltage for 160 V at 125 Nm for single phase semi converter drive.

B. Single Phase Full converter Drive

To investigate the effect of single phase full converter on the torque-speed characteristic, the average value of the converter output is changed by changing the firing angle (α). A pulse generator is used to change the firing angle. The following

firing angles are used to obtain 120, 160, 200 and 240 V average output voltages applied to the armature: $\alpha = 59^\circ$, 47.5° , 32.5° and 0° . The torque-speed characteristics are obtained for these armature voltages.

Fig. 8 shows the torque-speed curves for a single phase full converter drive.

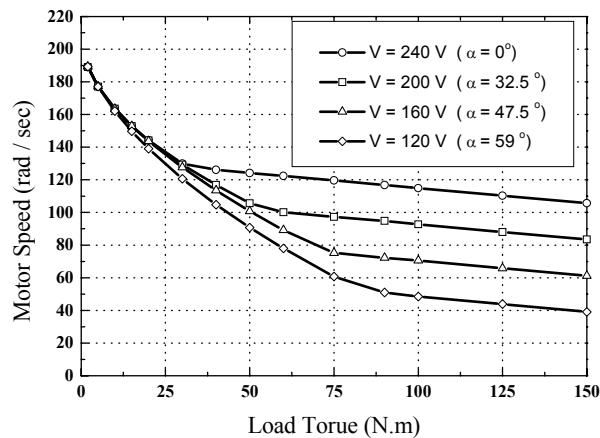


Fig. 8 Torque-speed characteristics for a single phase full converter drive.

It is clear that torque-speed curves contain both linear and non-linear regions. The linear region of operation for 240V approximately starts at $T_L = 30$ N.m. But for 200V approximately starts at $T_L = 60$ N.m. While for 160V starts at $T_L = 75$ N.m. Finally for 120V approximately starts at $T_L = 100$ N.m. The discontinuous armature current results in a highly non-linear torque-speed characteristic. Fig. 9 and Fig. 10 show the armature voltage and current obtained at 25 Nm (in the non-linear region) and 125 Nm (in the linear region) for average value of 160 V. These figures clearly illustrate the discontinuous and continuous operation of the single phase full converter drive in non-linear and linear regions, respectively.

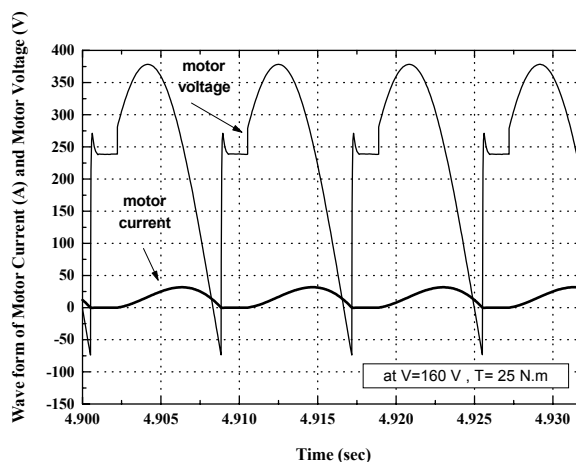


Fig. 9. Armature current and voltage for 160 V at 25 Nm for single phase full converter drive.

VII. REFERENCES

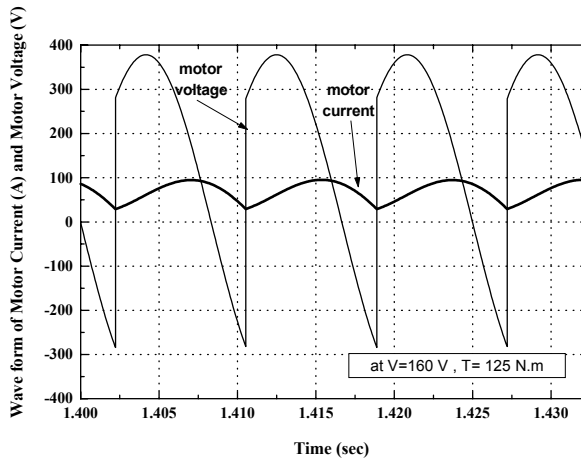


Fig. 10. Armature current and voltage for 160 V at 125 Nm for single phase full converter drive.

These figures illustrate the discontinuous and continuous operation of the single phase converter drive in non-linear and linear regions, respectively.

It is clearly seen that for all voltage values linear region of operation extends when single phase semi converter is used. For example, the region between 0 and 100 Nm was nonlinear for 160 V armature voltage for full converter drive. For semi converter drive the size of nonlinear region is shrunk to the region between 0 and 75 Nm. This is because of the fact that armature current becomes continuous and smoother for semi converter drive.

V. CONCLUSION

A Simulink model of DC motor speed control method which is realized using a single phase AC/DC converter is presented. Torque speed curves for two types of single phase AC/DC converter (full and semi converter) are obtained for a wide-range of loading conditions. It is shown that torque-speed curves become nonlinear due to the discontinuity in armature current. Moreover, linearity of curves could be improved by using semi converter drive.

VI. APPENDIX

The parameters of DC motor used in simulation are:

Rated output power (P) = 5 HP

Armature rated voltage (V) = 240 V

Armature resistance (R_a) = 0.6 Ω

Armature inductance (L_a) = 0.012 H

Field resistance (R_f) = 240 Ω

Field inductance (L_f) = 120 H

Rated speed (N) = 1220 rpm

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