Dynamic Simulation of Full-wave Controller for a Separately Excited DC Motor

ONWUGHALU M.K[1], IFEATU CHIDEBERE[2]
[1, 2] Department of Electrical/Electronic Engineering, Federal Polytechnic Oko

Abstract-* *This research investigates the use of dynamic simulations approach for full-wave control of a Separately Excited DC motor (SEDCM). The simulation considers the use of rectifier bridge circuit and employing the MATLAB/SIMULINK modeling and software development environment. The research specifically investigates the impact of various load torque on the SEDCM armature voltage, current, motor speed and firing angle. The results of simulation studies show that increasing the load torque leads to corresponding increases in armature voltage and current. But the firing angle is decreased as well. The results therefore demonstrates the direct and inverse relation property of SEDCM to armature current and the firing angles respectively.

I. INTRODUCTION

The DC motor is one of the most powerful and versatile machines in the modern day industry that serves the control needs of a broad range of electrical power products such as air-conditioning, servo-control and certain small power traction services. Its importance lies in the simplicity of its energy source – operating strictly on a DC source means it can run from batteries, and ease of control – by voltage adjustment, which obviates the need for complicated conversion circuitry.

However, its simplicity brings about the challenge of large weights or sizes for comparable power requirements in addition to the need for precise control of speed and torque.

Thus, researchers are beginning to investigate variants of the simple DC motor for reliable and efficient speed and torque control simulation studies.

In this research, the separately excited DC motor is investigated and simulation studies are performed to gain insight into its operational features.

II. MODEL EXPRESSIONS FOR THE SEPARATELY EXCITED DC MOTOR (SEDCM)

In order to model the SEDCM, one must consider the following key properties [1]:

- A Counter Electro-Motive Force (CEMF)
- A SEDCM voltage constant which is a function of its field current
- The SEDCM electromechanical torque which is a function of its armature current

The CEMF is directly proportional to the voltage constant and may be expressed as [1]:

$$E_{CEMF} = K_E w \tag{1}$$

where,

K_E = the SEDCM voltage constant
w = SEDCM motor speed

The SEDCM voltage constant can be further estimated as:

$$E_{CEMF} = L_{af} I_f \tag{2}$$

where,

L_{af} = the mutual inductance between armature and field windings
I_f = SEDCM field current

The generated electromagnetic torque is given as:

$$T_e = K_T I_a \tag{3}$$

where,

K_T = the torque constant

I_a = SEDCM armature current

Considering a load torque and following the sign convention, there are two possibilities:

$$T_e - T_L > 0 \tag{4}$$

$$T_e - T_L < 0 \tag{5}$$

The expression in equation (4), describes a motor-mode operation while that in equation (5) describes the generator mode.

a. Full-wave control

For full-wave control, SEDCM can be operated diagrammatically as shown in the circuitry of Figure 1.

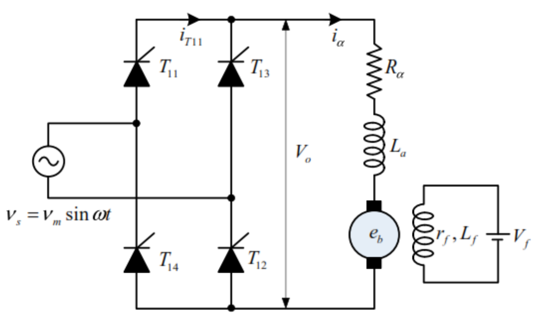

Figure 1: Full-wave control of SEDCM [2]

The circuitry represents a control type of the single-phase category where the full wave is performed by four thyristors T1 to T4 with an upper and lower AC source taps for T1-T4 and T2-T3 thyristors pairs.

The control is performed by changing firing angle with respect to firing voltage to control the output voltage; the output voltage is computed as [3-7]:

$$V_{out} = \frac{2V_M}{\pi} \cos(\alpha), \qquad 0 < \alpha < \pi \tag{6}$$

where,

V_M = maximum voltage

α = thyristors firing angle

The transfer function model of SEDCM is also as shown in Figure 2.

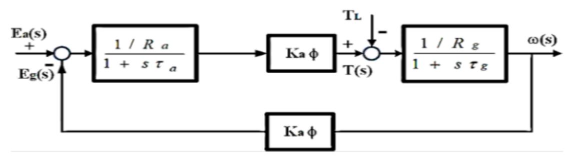

Figure 2: Transfer model of SEDCM [8]

III. RELATED STUDIES

Dynamic simulation experiments employing the SEDCM have been an active area of research in the times past and recently.

For instance, Ahmed et al [8] studied the torque control of SEDCM using microcomputer. Microprocessor controlled approaches are also adopted in [9-14].

In [15], PI controller is used to regulate armature current considering half-wave rectifier switching system.

IV. SIMULATION RESULTS AND DISCUSSIONS

The experiments considering dynamic simulation of SEDCM are conducted using the MATLAB/SIMULINK software development and emulation environment. The systems model used in the simulation studies are described in Figure 3. The parameters used in the simulation of SEDCM are also presented in Table 1.

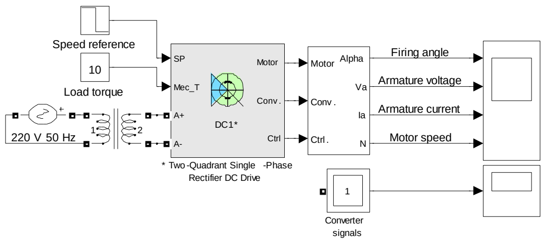

Figure 3: Dynamic Simulation Model of the SEDCM

Table.1. Core SEDCM Parameters

Parameter Name	Value	Unit
Armature Resistance, Ra	0.780	Ω
Armature Inductance, La	0.016	H
Field Resistance, Rf	150.0	Ω
Field Inductance, Lf	112.5	H
Total Inertia, J	0.250	kg.m^2
Viscous Friction Coefficient, Bm	0.010	N.m.s

The SEDCM system in Figure 3 is powered by a 2-quadrant single-phase full wave rectifier control which obtains its power source from a 220V 50Hz, power supply and operates in regenerative mode i.e. operation at 4th quadrant switching mode. Simulations are performed at a range between 0 and 6s and the results reported only for the rectifier mode after braking.

a. Results and Discussions

The results using the simulation model and considering load torque range from 10N.m to 22N.m and at intervals of 2N.m are as shown in Table 2. These results are reported based on the

Table.2. Results at various load torques

Load Torque (N.m)	Firing angle (^{o})	Armature Voltage (V)	Armature Current (A)	Motor Speed (rpm)
10	84.7817	31.5306	11.8152	199.5456
12	83.1227	32.6875	13.4737	199.5427
14	81.4269	33.8052	15.0808	199.5118
16	80.1546	34.8977	16.6398	199.5518
18	78.6149	36.0462	18.2851	199.5556
20	77.3170	37.1635	19.8873	199.5499
22	75.5969	38.2689	21.4711	199.5524

The results in Table 2 clearly shows that at higher load torque, the firing angle is automatically reduced to increase the armature voltage and hence armature current in order to subsequently maintain an motor speed of approximately 200rpm.

CONCLUSION

The research on the simulation of dc motors is an active one with quite a number of studies conducted. For the particular case of adjustable speed and torque control, the Separately Excited DC motor (SEDCM) plays an important role in the power and machines industry.

In this research, the simulation of SEDCM is conducted taken into account the impact of various load torque and its impact on the motor armature, current, voltage and speed in addition to the effect on the firing angle.

In future, further research may be conducted on the use of microprocessor and artificial neural networks or fuzzy logic controllers for enhancing the SEDCM performance during excessive torque loading.

REFERENCES

[1] MATHWORKS, R2007b

[2] Barkas, D. A., Ioannidis, G. C., Psomopoulos, C. S., Kaminaris, S. D., & Vokas, G. A. (2020). Brushed DC motor drives for industrial and automobile applications with emphasis on control techniques: A comprehensive review. Electronics, 9(6), 887.

[3] Mohan, N.; Undeland, T.M. Power Electronics, Converters, Applications and Design; John Wiley & Sons:New York, NY, USA, 1995.

[4] Manias, S.N. Power Electronics; Simeon Publications: Athens, Greece, 2012. (In Greek)

[5] Malatestas, P. Motor Drives; Tziolas Publications: Athens, Greece, 2013. (In Greek)

[6] Williams, B.W. Power Electronics: Devices, Drivers, Applications, and Passive Components; University of Strathclyde: Glasgow, UK, 2006.

[7] Nedeljkovic, M.; Stojiljkovic, Z. Fast current control for thyristor rectifiers. IEE Proc. Electr. Power Appl. 2003, 150, 636–638.

[8] Ahmed, M. M. R., Elemary, A. A., Alaas, Z. M., & Hamada, A. M. (2023). Torque control of a 5 KW, 220 V separately excited DC motor using microcomputer. International Journal of Power Electronics and Drive Systems (IJPEDS), 14(2), 727-740.

[9] A. Zemmouri et al., "A microsystem design for controlling a DC motor by pulse width modulation using microblaze soft-core, International Journal of Electrical and Computer Engineering, vol. 12, no. 6, pp. 1–11, 2022, doi: 10.11591/ijece.v13i2.

[10] K. Ohishi, M. Nakao, K. Ohnishi, and K. Miyachi, "Microprocessor-controlled DC motor for load-insensitive position servo system," IEEE Transactions on Industrial Electronics, vol. IE-34, no. 1, pp. 44–49, Feb. 1987, doi: 10.1109/TIE.1987.350923.

[11] A. S. Zein El Din, M. E. El-Shebiny, and M. M. Khater, "Microcomputer-controlled universal motor," IEEE International Symposium on Industrial Electronics, vol. 2, pp. 653–658, 1996, doi: 10.1109/isie.1996.551019.

[12] R. J. Hill and F. L. Luo, "Microprocessor-based control of steel rolling mill digital DC drives," IEEE Transactions on Power Electronics, vol. 4, no. 2, pp. 289–297, 1989, doi: 10.1109/63.24914.

[13] P. I. H. Lin and M. Rashid, "A PC-based measurement and control system for DC motors," Conference Record - IAS Annual Meeting (IEEE Industry Applications Society), no. pt 2, pp. 1829–1834, 1990, doi: 10.1109/ias.1990.152433.

[14] J. De Meester, R. Reekmans, A. J. A. Vandenput, R. J. M. Belmans, and W. J. D. Geysen, "Microcomputer-controlled torque calculator in DC drives," IEEE Transactions on Industry Applications, vol. 25, no. 1, pp. 113–118, Jan. 1989, doi:10.1109/28.18880.

[15] Fiyad, H., Mokhtar, W., & Ali, E. M. (2021). DC Motor Emulation of Wind Energy Conversion System. International Journal of Telecommunications, 1(01), 1-8