International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Modelling of Separately Excited DC Motor Using Simulink

Mahaviradhan Narayanasamy [a*], Sathish Pandurangan [a], Manickavelan Kolandasami [a], Kumaradhas Paulian [a], Venkatesan Tharanipathy [a], Ahmed Sameh Eid AlGhafri [a], Salim Mohammed Ali Said Al-Maashani [a]

[a] *University of Technology and Applied Sciences- Salalah, College of Engineering and Technology, Department of Engineering and Technology, P.Box. :608, Postal code: 211, Sultanate of Oman*

A B S T R A C T

The modeling of a DC motor using Simulink, a potent simulation and model-based design tool created by MathWorks, is thoroughly examined in this research. The dynamic performance and control properties of the DC motor, a mainstay in many consumer and industrial applications, are examined. The main goal is to replicate the motor's performance under various settings and create an accurate mathematical model that captures its physical behavior. The first step in the investigation is the formulation of the governing equations for the motor, which include the mechanical and electrical dynamics and are stated in terms of torque, angular velocity, voltage, and current. To improve model fidelity, important characteristics including moment of inertia, armature resistance, inductance, and back electromotive force constant are included. A modular and scalable design is then made possible by translating the obtained equations into a block diagram representation in Simulink.

To assess the DC motor's transient and steady-state performance under various input voltages and load torques, simulations are run. The outcomes show how well the model captures real-world behaviors by offering insights into the motor's speed, current, and torque responses.

Simulink is a useful tool for research, education, and industrial applications because of its modular nature, which makes it simple to integrate with other systems. This study serves as a practical guide for engineers, researchers, and educators, providing a foundational framework for modeling and analyzing DC motors using Simulink, thereby contributing to the optimization and control of electromechanical systems.

Keywords: Modelling, DC Motor, Simulink

1. Introduction

One of the most popular electromechanical devices, Direct Current (DC) motors are essential to consumer, business, and industrial applications [1]. For applications needing precise speed and position regulation, such robots, conveyor systems, electric vehicles, and home appliances, their simplicity, dependability, and controllability make them perfect [2]. For DC motors to be used and controlled in such systems effectively, it is imperative to comprehend their dynamic behaviour [3]. By mathematically representing a DC motor's physical properties, modelling allows engineers and researchers to forecast how well the motor will function in different scenarios [4]. A strong model ensures optimal functioning and integration into larger systems by providing a basis for design, analysis, and control system development [5-8]. However, the interaction of several elements, including resistance, inductance, back electromotive force (EMF), and inertia, makes it difficult to adequately depict the motor's electrical and mechanical dynamics [9-12].

For modelling and evaluating dynamic systems like DC motors, MathWorks' Simulink model-based design and simulation tool provides an adaptable platform [13-15]. Simulink enables users to effectively construct, simulate, and improve system models because to its user-friendly graphical user interface and large library of blocks [16-18]. The program is an effective tool for both academic study and industrial applications because of its capacity to combine mathematical equations, visualize dynamic responses, and apply control measures [19-22].

The goal in this study is to use Simulink to create a thorough model of a DC motor. The electrical and mechanical dynamics of the motor, including how it reacts to external loads and input voltages, are captured by the model. To assess important performance metrics, like torque, speed, and current, under various circumstances, we run simulations. The outcomes show how accurate the model is and how well it can forecast behavior in the real world.

Nomenclature

V - Supply voltage of the motor

R_a - Resistance of the armature winding

I_a - Current flowing through the armature winding

E_b - Back electromotive force

L_a - Inductance of the armature winding

J - Moment of inertia of the rotor

B - Viscous friction coefficient.

ω - Angular velocity of the rotor

dω/dt - Angular acceleration of the rotor

K - Motor constant

K_t - Torque constant

T - Motor torque

T_L - Load torque

2. Mathematical Model

The mathematical model of a DC motor is derived by analysing its electrical and mechanical dynamics. It is governed by the interaction between electrical and mechanical components, represented by voltage, current, torque, and angular velocity

2.1 Electrical Dynamics

The electrical circuit of a DC motor consists of an armature with resistance(R_a) and inductance (L_a). The input voltage (V) applied to the motor terminals drives the current (I_a) through the armature, producing torque. The back electromotive force (Eb) opposes the input voltage and depends on the motor's angular velocity (ω).

The governing equation for the armature circuit is:

$$V = I_a\, R_a + E_b + L_a \left(\frac{dI_a}{dt}\right) \qquad (1)$$

In practical applications, the motor's inductance L_a affects the transient response. For DC motors, the inductance smooths out the changes in the current when the voltage is applied or removed. This effect is crucial when switching the motor on and off. For an ideal analysis, the inductance effect is often ignored in steady-state conditions, but in transient conditions, it affects the current rise or fall time.

The back EMF is directly proportional to the angular velocity and is given by:

$$E_b = K\, \omega \qquad (2)$$

2.2 Mechanical Dynamics

The torque generated by the motor (T) is proportional to the armature current (I_a)

$$T = K_t\, I_a \qquad (3)$$

The generated torque is used to overcome the load torque (T_L), friction, and inertia of the rotor. Using Newton's second law for rotational motion:

$$T = T_L + J\left(\frac{d\omega}{dt}\right) + B\, \omega \qquad (4)$$

2.3 Laplace Transform Representation

Using the Laplace transform, the system equations are expressed in the s-domain for easier analysis and implementation in control systems.

Electrical equation is given as;

$$V(s) = I_a\,(s)R_a + K\omega(s) + sL_a\, I_a(s) \qquad (5)$$

Mechanical equation is given as;

$$K_t\, I_a(s) = T_L(s) + J\, s\, \omega(s) + B\, \omega(s) \qquad (6)$$

These transfer functions are used to simulate the DC motor's behavior in Simulink and analyze its dynamic response.

3. Modelling in Simulink

Simulink is an ideal tool for implementing and simulating the DC motor model due to its block diagram-based interface and extensive library of components. Below, we outline the key steps to build the DC motor model in Simulink, incorporating both electrical and mechanical dynamics. The DC motor is represented as a combination of subsystems corresponding to its electrical and mechanical equations. Each subsystem models a specific aspect of the motor's behaviour, and they are interconnected to reflect the coupling between electrical and mechanical domains.

Electromechanical system

For modelling the electromechanical system, various blocks are connected in an orderly manner.

- Constant block is used to input the supply voltage.
- Sum block is used with [+-] sign to sum up the supply voltage with back emf.
- Transfer function block is used with [1/R_a] as numerator and [ta 1] as denominator.
- Gain block is used represent the torque constant, K_t.
- Constant block is used to input the load torque.
- Sum block is used with [+-] sign to sum up the motor torque with load torque.
- Transfer function block is used with [1/B] as numerator and [tm 1] as denominator.
- Gain block is used represent the motor constant, K.
- Gain block is used to convert the obtained angular velocity in rpm
- Bus creator block is used to combine the input signals or messages into a bus, which retains the separate identities of the signals and messages.
- Scope block is used to visualizes outputs like armature current, motor torque, motor speed and back emf with respect to time.
- Display block is used to get the mathematical output value for armature current, motor torque, motor speed and back emf

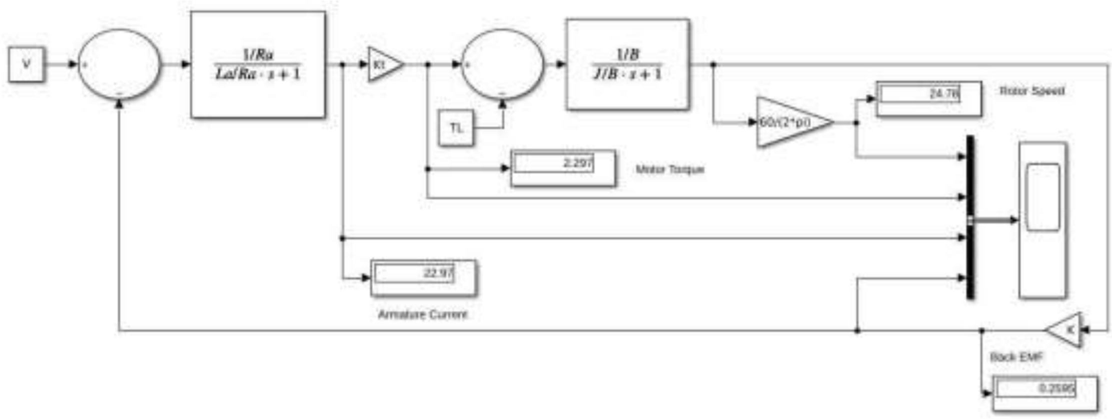

Figure 1 – Simulink model of DC motor

The following parameters are used for the simulation:

- Damping coefficient, B = 0.5 N·m·s
- Moment of inertia, J = 0.01 kg·m²
- Motor constant, K = 0.1 V/rad/s
- Torque constant, K_t = 0.1 Nm/A
- Armature inductance, L_a = 0.1 H
- Armature resistance, R_a = 10 Ω
- Load torque, T_L = 1 Nm
- Supply voltage, V = 230 V

4. Simulation Result

The response of the DC motor to a constant input voltage is analysed. The simulation results show the transient and steady-state behavior of the motor. In total, four scope blocks used with bus connector block in order to plot the graph for armature current, motor torque, back emf and motor speed. In all the four plots, time is taken as abscissa with 10 seconds scale and the four output parameters are plotted in ordinate.

All the four parameters show an increase during the transient stage where the armature inductance is considered. Whereas in the steady state condition, the parameters hold a constant position. The results demonstrate that the Simulink model accurately represents the dynamic behavior of a DC motor. The ability to simulate various conditions provides valuable insights into the motor's performance and the effectiveness of control strategies. Furthermore, the impact of parameter variations highlights the importance of precise modelling in control system design.

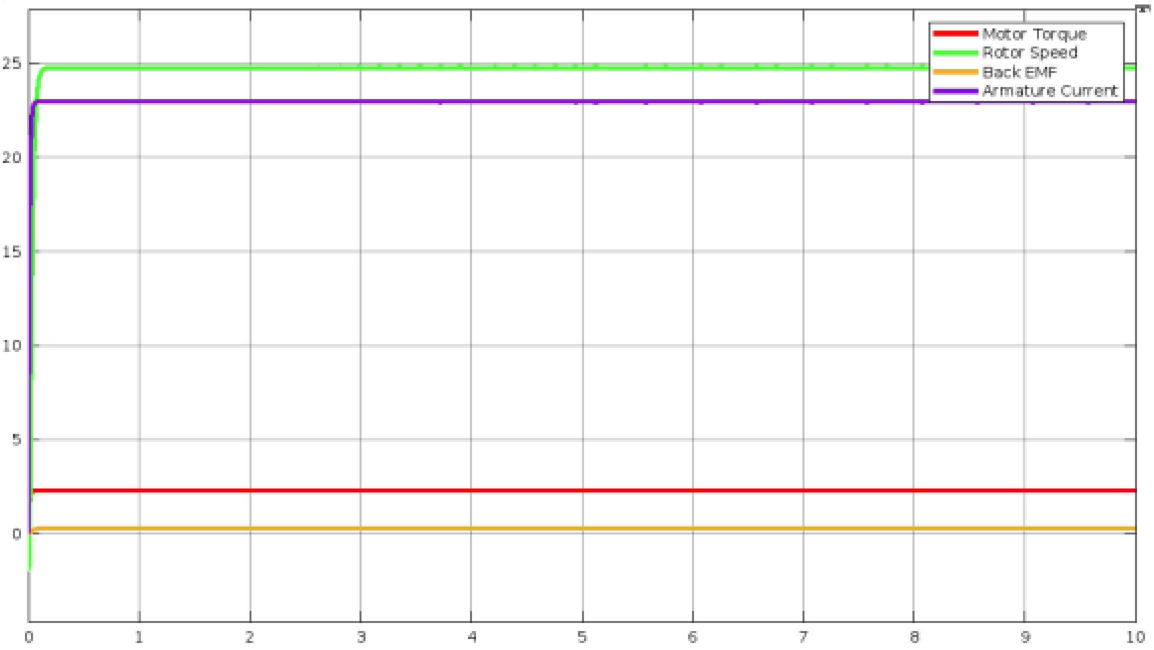

Figure 2 – Output parameters plot Versus Time

5. Conclusion

The modelling and simulation of a DC motor using Simulink provide valuable insights into its dynamic behavior and control. This study has demonstrated a systematic approach to developing a comprehensive mathematical model that accurately represents the electrical and mechanical dynamics of the motor. By translating the governing equations into Simulink's graphical environment, a modular and flexible framework was created for analysing key performance characteristics such as speed, current, and torque.

The DC motor model successfully captures the interaction between the electrical and mechanical domains, as evidenced by its response to varying input voltages, load torques, and control strategies. The inclusion of key parameters, such as armature resistance, inductance, back EMF constant, and moment of inertia, ensures the fidelity of the simulation. Through sensitivity analysis, it is clear how parameter variations affect the motor's performance, which can guide the optimization and design of motor-driven systems.

The results of this study emphasize the importance of simulation tools like Simulink in engineering practice. Simulink not only provides a platform for verifying theoretical models but also serves as a powerful tool for prototyping and testing control algorithms before hardware implementation. This reduces development time and costs while enhancing system reliability.

The presented model can be extended to include advanced features, such as: thermal modelling to account for the effects of heat generation, nonlinear effects like saturation and hysteresis for higher accuracy, advanced control techniques, such as adaptive or model predictive control, to handle complex operating conditions.

This work serves as a practical guide for engineers, researchers, and educators, providing a foundational framework for understanding and simulating DC motor behavior. Future advancements in modelling techniques and computational tools will continue to enhance the design and control of electromechanical systems, contributing to innovations across industries.

In conclusion, the use of Simulink for DC motor modelling and control has proven to be an effective approach, bridging the gap between theory and application, and paving the way for further research and development in motor control systems.

References

1. İnci, M., Büyük, M., Demir, M. H., & İlbey, G. (2021). A review and research on fuel cell electric vehicles: Topologies, power electronic converters, energy management methods, technical challenges, marketing and future aspects. *Renewable and Sustainable Energy Reviews*, *137*, 110648.
2. Kwe, N. B., & Priyadarshini, R. (2024). Emerging trends in mobile robots. *Robotics and Smart Autonomous Systems*, 77-117.
3. Osman, M. (2010). Controlling uncertainty: a review of human behavior in complex dynamic environments. *Psychological bulletin*, *136*(1), 65.
4. Moseler, O., & Isermann, R. (2000). Application of model-based fault detection to a brushless DC motor. *IEEE Transactions on industrial electronics*, *47*(5), 1015-1020.
5. Feng, G. (2006). A survey on analysis and design of model-based fuzzy control systems. *IEEE Transactions on Fuzzy systems*, *14*(5), 676-697.
6. Ang, K. H., Chong, G., & Li, Y. (2005). PID control system analysis, design, and technology. *IEEE transactions on control systems technology*, *13*(4), 559-576.
7. Hoffer, J. A. (2012). *Modern systems analysis and design, 6/e*. Pearson Education India.
8. Schmidt, D. C. (2006). Model-driven engineering. *Computer-IEEE Computer Society-*, *39*(2), 25.
9. Cuevas, E., Zaldivar, D., Ayala, E., González, Ó., & Vega, F. (2024). Basic Concepts of Motors. In *DC Motors: Modeling, Designing and Building with 3D Printers* (pp. 17-62). Cham: Springer Nature Switzerland.
10. Bilgin, B., & Sathyan, A. (2014). Fundamentals of electric machines. *Advanced electric drive vehicles*, 107-186.
11. Jones, A., & Howe, A. (2024). Electromechanical Drive Systems. In *Introduction to Mechanical Engineering* (pp. 317-400). CRC Press.
12. Darba, A. (2015). *Current commutation and control of brushless direct current drives using back electromotive force samples* (Doctoral dissertation, Ghent University).
13. Krenicky, T., Nikitin, Y., & Božek, P. (2022). Model-based design of induction motor control system in MATLAB. *Applied Sciences*, *12*(23), 11957.
14. Molina Llorente, R., & Molina Llorente, R. (2020). Embedded Control System Development Process: Model-Based Design and Architecture Basics. *Practical Control of Electric Machines: Model-Based Design and Simulation*, 1-26.
15. Boll, A., Vieregg, N., & Kehrer, T. (2024). Replicability of experimental tool evaluations in model-based software and systems engineering with MATLAB/Simulink. *Innovations in Systems and Software Engineering*, *20*(3), 209-224.
16. Mikkili, S., Panda, A. K., & Prattipati, J. (2015). Review of real-time simulator and the steps involved for implementation of a model from MATLAB/SIMULINK to real-time. *Journal of The Institution of Engineers (India): Series B*, *96*, 179-196.
17. Altintas, A. (2011). A GUI-based education toolbox for power electronics converters using MATLAB/Simulink and SimPowerSystems. *International Journal of Electrical Engineering Education*, *48*(1), 53-65.
18. Reyneri, L. M. (2004). A Simulink-based hybrid codesign tool for rapid prototyping of FPGA's in signal processing systems. *Microprocessors and Microsystems*, *28*(5-6), 273-289.
19. Upson, C., Faulhaber, T. A., Kamins, D., Laidlaw, D., Schlegel, D., Vroom, J., ... & Van Dam, A. (1989). The application visualization system: A computational environment for scientific visualization. *IEEE Computer Graphics and Applications*, *9*(4), 30-42.
20. Rüde, U., Willcox, K., McInnes, L. C., & Sterck, H. D. (2018). Research and education in computational science and engineering. *Siam Review*, *60*(3), 707-754.
21. Parker, D. C., Manson, S. M., Janssen, M. A., Hoffmann, M. J., & Deadman, P. (2003). Multi-agent systems for the simulation of land-use and land-cover change: a review. *Annals of the association of American Geographers*, *93*(2), 314-337.
22. Roschelle, J. M., Pea, R. D., Hoadley, C. M., Gordin, D. N., & Means, B. M. (2000). Changing how and what children learn in school with computer-based technologies. *The future of children*, 76-101.