

# Simplified Model of a DC Rotating Machine for Mechanical Energy Generation using MATLAB/SIMULINK

S. T. Yusuf, A. S. Samosir, M. Abdulkadir

Department of Energy Conversion, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM).

**Abstract--** The mechanical energy generated by a DC rotating machine (motor) is proportional to the armature current and the strength of the magnetic field. Based on the mathematical model of a DC rotating machine, a simplified model using Matlab/Simulink is presented in this study. The simulation results and analyses of the machine output with loading and unloading condition is discussed in detail. The results indicated that the established model has a good response to the machine speed, armature current and the load torque. This offers foundation for the design of DC rotating machine.

**Index Terms--** Modeling, Matlab, Rotating machine, Simulation.

## I. INTRODUCTION

In modern electrical machine industry productions, DC rotating machines (motors) are rapidly gaining popularity, due to performance optimization, simple structure and high reliability output torque. MATLAB has a powerful scientific computing and graphics processing functions. It is an interactive software system developed by Math works Company for system simulation. Simulink is a systematic module for establishing system block diagrams and simulation models in MATLAB environments, which can be use to build or provides electrical system models. Control system is important in DC rotating machine, the purpose of developing a control system is to enable stability and reliability of the system. Technique for designing a DC machine speed controller with continuous time based on system theory concepts was presented in [1]. Once the control system has been specified and the type of control has been decided, then the design and analysis are done. There are three major objectives of system analysis and design: producing the desired transient response, reducing steady-state error, and achieving stability [2]. In [3], A. S Othman successfully designed and implements a closed loop control system to control the speed of a DC motor. In [4], Ayasun and Nwankpa described the MATLAB/Simulink realization of the DC motor speed control methods (field resistance, armature voltage and resistance) and feedback control system for DC motor drives. Putting together control blocks from Simulink library, based on the equation derived from a single loop equivalent circuit of a DC rotating machine, a simplified model is established in Matlab/Simulink. Additionally, simulation result shows an effectiveness of a current waveform, machine speed

waveform and a load torque curve under load and no-load condition with speed control (regulations).

### A. Operation of DC Rotating Machine (motors)

DC rotating machine can generates mechanical energy by creating an interaction between a fixed and rotating magnetic field. The fixed field is supplied by high energy permanent magnets. The rotating field is created by passing a DC current through several different windings on the armature (rotating part) and timing which winding is powered through a device called a commutator. Power is supply to the armature by brushes which ride on the commutator. To understand how the machine responds to load, the machine is divided into four major components. These components are the ideal machine, back e m f (electromotive force), resistance and inductance. These parts are really not physically separable, but for modeling purposes this is important and convenient. DC rotating machine (motor) can be turned into a DC rotating machine (generator) simply by turning the shaft. When a machine rotates due to supply voltage, it generates back e m f which opposes the supply voltage. The difference between the supply voltage and the back e m f is the net voltage that the machine actually sees. As the mechanical load on the DC rotating machine is increased, the machine slows down, back e m f is reduced and the net voltage that the machine sees increases. It turns out that the actual machine current is determined by the difference between the supply voltage and the back e m f divided by the resistance. When the machine speed is zero and back e.m.f will therefore be zero. The amount of current generated is controlled by the resistance, and if the resistance is small, the resultant current is much higher than it would be under normal running conditions [5].

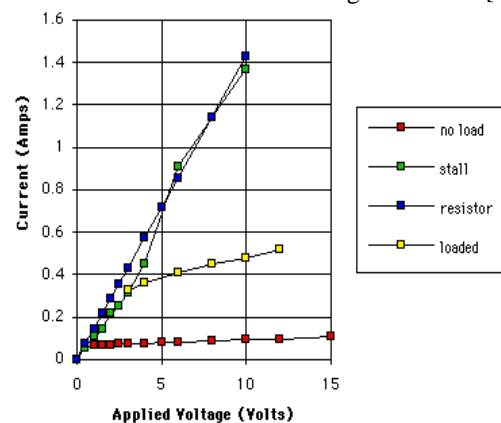
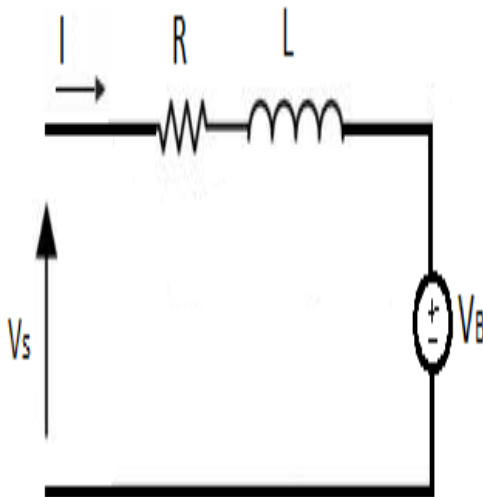


Fig 1 Relationship between Machine Current and Voltage

Figure 1 shows, at no load the machine is able to turn fast, allowing the back e.m.f to be almost equal to the supply voltage. As the load increased the machine slow down and draws more current from the supply voltage. In this case, the graph shows that increasing load causes increasing current.

**B. Mathematical Model of a DC Rotating Machine**

The use of mathematical models can speed up design process, and minimize the time wasted on trial and error design methods. Two balanced equations can be developed by considering the electrical and mechanical characteristics of the system. The equivalent electrical circuit of DC rotating machine is illustrated in Figure 2. The circuit has a voltage source  $V_S$  across the coil of the armature. The armature coil can be described by a resistance R in series with inductance L in series with an induced voltage  $V_B$  which opposes the voltage source. The induced voltage is generated by the rotation of the electrical coil through the fixed flux lines of the permanent magnets. This voltage is often referred to as the back emf.



**Fig 2 Equivalent Circuit of DC Rotating Machine**

According to Ohm's law, the voltage across the resistor R, inductance L and the back emf  $V_B$  can be represented as

$$V_S = RI + L \frac{dI}{dt} + V_B \tag{1}$$

$$T = I_L W \tag{2}$$

$$T = K_T I \tag{3}$$

Where:

$$V_S = \text{Dc source voltage} = 12V$$

$$I = \text{Armature current}$$

$$L = \text{Armature inductance} = 0.2H$$

$$R = \text{Armature resistance} = 1\Omega$$

$$W = \text{Machine speed}$$

$$K_T = \text{Torque constant} = 0.02N\text{-m/A}$$

$$I_L = \text{Inertia constant} = 0.005Kg/m^2$$

$$K_B = \text{Voltage constant} = 0.22V/rad/s$$

$$T_L = \text{Load torque}$$

The voltage induced in the machine armature can be calculated for any rotational speed by multiplying the  $K_B$  (Voltage Constant) by the rotational speed of the armature.

$$V_B = K_B W \tag{4}$$

$$V_S = RI + L \frac{dI}{dt} + K_B W \tag{5}$$

By substituting equation 3 into 2:

$$K_T I = I_L W \tag{6}$$

$$W = \frac{K_T}{I_L} I \tag{7}$$

By taking the derivative of the current with respect to time. The induced voltage (back emf) opposes the voltage  $V_S$  applied to the machine.

$$\frac{dI}{dt} = \frac{1}{L} [V_S - RI - K_B W] \tag{8}$$

$$\int \frac{dW}{dt} = \int \frac{K_T}{I_L} I \tag{9}$$

$$\int \frac{dI}{dt} = \int \frac{1}{L} [V_S - RI - K_B W] \tag{10}$$

$$W = \int \frac{K_T}{I_L} I \tag{11}$$

$$I = \int \frac{1}{L} [V_S - RI - K_B W] \tag{12}$$

**II. MATLAB MODEL OF DC ROTATING MACHINE**

Based on the proposed mathematical model above, the simulation model of the DC Rotating Machine has been established in a Matlab/Simulink environment. Simulation block diagram [6] of the machine is shown in Figure 3 and 4.

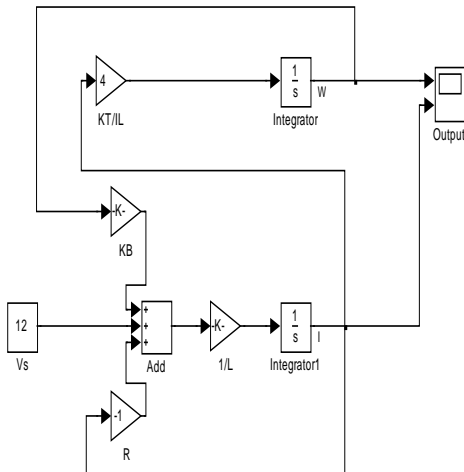


Fig 3 Model of DC Rotating Machine under No-Load Condition

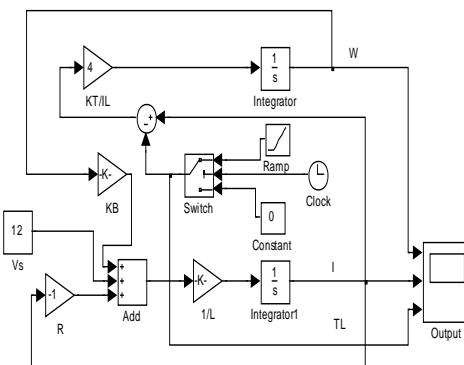


Fig 4 Model of DC Rotating Machine under Load Condition

**A. Significance of Back E.M.F.**

The presence of back e.m.f. makes the DC rotating machine a self-regulating system which makes the machine to draw as much armature current as sufficient to develop the torque required by the load. When the machine is running on no load, small torque is required to overcome the friction and windage losses. Therefore, the armature current I is small and the back e.m.f. is nearly equal to the applied voltage. When the machine is suddenly loaded, the first effect is to cause the armature to slow down. Therefore, the speed at which the armature conductors move through the field is reduced and hence the back e.m.f  $V_B$  falls. The decreased back e.m.f allows a larger current to flow through the armature and larger current means increased driving torque. Thus, the driving torque increases as the machine slows down. The DC rotating machine will stop slowing down when the armature current is just sufficient to produce the increased torque required by the load. If the load on the machine is decreased, the driving torque is at that moment in excess of the requirement so that armature is accelerated [7], As the armature speed increases, the back e.m.f  $V_B$  also increases and causes the armature current I to decrease. The machine will stop accelerating when the armature current is sufficient to produce the reduced torque required by the load. It follows; therefore, that back e.m.f.

in a DC rotating machine regulates the flow of armature current which automatically changes the armature current to meet the load requirement.

**III. SIMULATION RESULTS**

Based on the model for DC rotating machine, the following results were obtained as presented in figures 5-9.

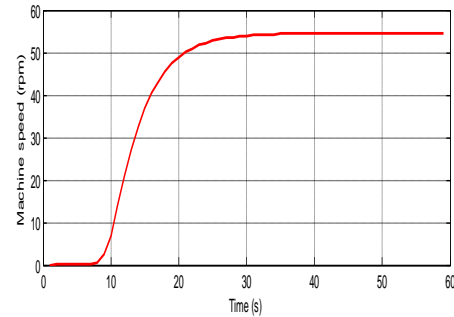


Fig 5 Machine Speed Waveform Under No-Load

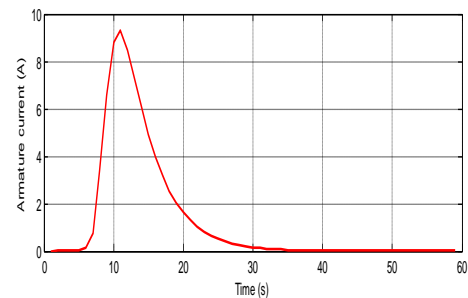


Fig 6 Armature Current Waveform Under No-Load.

Based on the model for DC machine figure 4, results were obtained and presented.

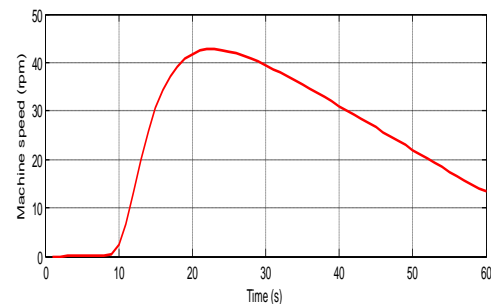


Fig 7 Machine Speed Waveform with Load

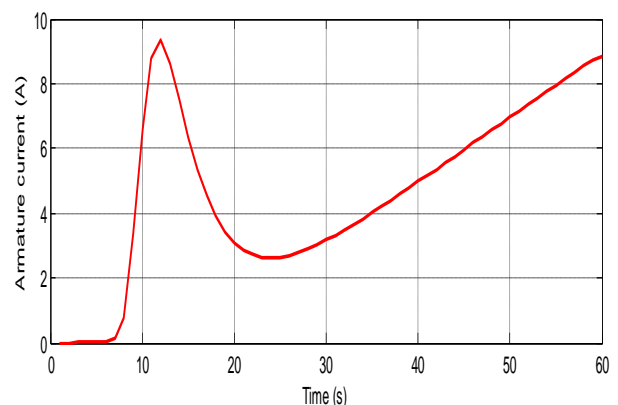
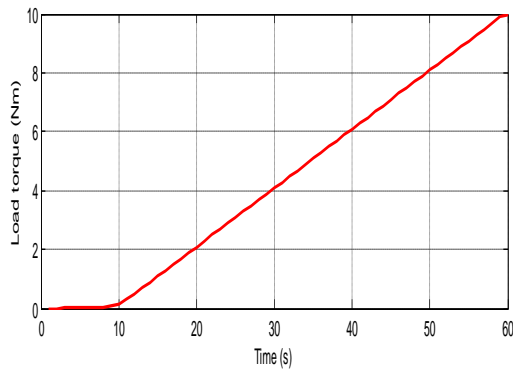


Fig 8 Armature Current Waveform with Load



**Fig 9 Load Torque Waveform**

The simulation results confirm the theoretical analysis of a DC rotating machine (motor) in Figure 1. The results in figure 5 and 6, shows the machine speed rises and maintain a steady speed at 55 rpm and the armature current at zero. Figure 7-9 waveform shows when the machine is loaded, the speed rises and eventually drops to a steady state of 14 rpm while the armature current and load torque increase. Future enhancement of the model can be done using PID controller technique.

#### IV. CONCLUSION

Electric machines are used to generate electrical power from power plants and provide mechanical work in industries. The DC machine is considered to be basic electric machines. This work will introduce students and technicians on how to use computer simulation tools for conducting studies on DC rotating machine (motor). MATLAB/SIMULINK was used because of its wide distribution and general-purpose in nature. The results demonstrate the simulated waveform of machine speed, Armature current and load torque which fits theoretical

analysis. Further Optimization of the Model in MATLAB can be performed by using PID controller technique which can also be analyzed in MATLAB Simulink.

#### REFERENCES

- [1] J. A. Mohammed, "Modeling, Analysis and Speed Control Design Methods of a DC Motor," Engineering and Technology, Vol. 29, PP. 141-155, 2011.
- [2] A. Klee, "Development of a Motor Speed Control System Using MATLAB and Simulink, Implemented with a Digital Signal Processor," MSc. Thesis, Orlando, Florida, 2005.
- [3] A. S. Othman, "Proportional Integral and Derivative Control of Brushless DC Motor," European Journal of Scientific Research, Vol. 35 No. 2, pp. 198-203, 2009.
- [4] S. Ayasun and C. O. Nwankpa, "DC Motor Speed Control Methods Using MATLAB/Simulink and Their Integration into Undergraduate Electric Machinery Courses," IEEE Trans Educ, pp. 347-354, 2007.
- [5] [http://www.girr.org/girr/tips/tip\\_s5/motor\\_tips.html](http://www.girr.org/girr/tips/tip_s5/motor_tips.html) .
- [6] [http://edu/media/academic/ece/documents/classexp/ee2081abs/12\\_\\_Permanent\\_Magnet\\_Simulation\\_in\\_MATLAB\\_Simulink](http://edu/media/academic/ece/documents/classexp/ee2081abs/12__Permanent_Magnet_Simulation_in_MATLAB_Simulink).
- [7] T. K. Howe, Thesis, "Evaluation of the transient response of a DC motor using MATLAB/SIMULINK," University of Queensland, 2003.
- [8] W. P. Aung, "Analysis on Modeling and Simulink of DC Motor and its Driving System Used for Wheeled Mobile Robot," World Academy of Science, Engineering and Technology Vol. 32, pp.299- 306, 2007.