Modelling and Simulation Speed Control of DC Motor using PSIM

Z S Al-Sagar¹, M S Saleh², K G Mohammed³, A Z Sameen⁴
¹Electrical Department, Baqubah Technical Institute, Middle Technical University, Baghdad, Iraq
²Electronic Department, Engineering College, Diyala University, Baqubah, Iraq
³Electrical Power and Machine Department, Engineering College, Diyala University Baqubah, Iraq
⁴Department of Medical Instrumentation Engineering Techniques, Collage of Medical Techniques, Alfarahidi University, Baghdad, Iraq

Abstract. Speed control DC motor (SCDCM) methods are widely used in power electronic circuits. This paper presents various SCDCM methods such as armature voltage control, the results show when armature voltage increases, the speed of the motor increases and when the armature voltage decreases, the motor speed decreases. However, in field resistance methods, when the field resistance increases the speed increases and when field resistance decreases the speed is reduced. While in feedback control when using feedback SCDCM method, two blocks have been used, the first block includes reference speed of motor and the second block includes the added value of speed to reference speed of motor. Power simulation (PSIM) is used to design and simulate the DC motor speed control circuits.

Keywords: Speed control, DC motor, PSIM, armature voltage control, field resistance.

1. Introduction

The Direct Current (DC) motor is an electrical rotary machine that produces mechanical energy converted from electrical power. It has variable characteristics. The DC motor must have an internal mechanism to change the direction of the current [1]. This internal mechanism could be either electronic or electromechanical. The DC motor speed range is widely controlled either by changing the current in the field windings strength or by using variable supply voltage [2]. The DC motor provides a high starting torque. DC motors are essential in many fields such as robots and other machines. For instance, the speed of moving vehicle varies according to the texture of the surface, even if the same power is applied. In such situations the need of controller become very important for monitoring the speed of the DC motor.

In modern industry, the DC motor plays a significant role where DC motors are used in several types of applications such as printers, rolling mills process, textile industries, and many others [3]. These applications may demand good dynamic responses and high-speed control accuracy. Fuel pump control, engine control, electric vehicle control, and electronic steering control are examples of DC motor applications. There are two kinds of DC motors, which are separately excited DC motor and self-excited DC motor.

The rest of this paper will be organized as follows: Section 2 is the DC motor shunt excited motors, Section 3 is about power simulation. Section 4 is the results, and finally, Section 5 is the conclusion. The speed motor depends on the supply voltage if the field current is kept constant. These
observations lead to the application of variable DC voltage to control the speed and torque of the DC motor [4].

1.1 Speed Control Using Thyristor

Figure 1 shows the block diagram of a speed control DC using thyristor. The thyristor is used to control the motor speed by supplying it with variable DC voltage.

![Figure 1. Block diagram of DC Motor speed controls using thyristor](image)

AC to DC converter thyristor with phase angular is popular for big size DC motors. Full four-quadrant thyristor converter of the armature circuit and two-quadrant converter of the field circuit is required for a high-performance drive with wide speed range. Figure 2 shows the single-phase thyristor bridge converter drive.

![Figure 2. Single-phase thyristor bridge converter drive](image)

Consider the DC drive that is shown in Figure 2 which is used with the armature supply voltage $V_{ave}$ to the motor and is given by the following equation:

$$V_{ave} = \frac{2V_m}{\pi} (\cos \alpha)$$  \hspace{1cm} (1)

Where $V_m$ is the line to line AC converter’s supply voltage peak value, and $\alpha$ is the firing angle. The firing angle $\alpha$ controls the DC output voltage $V_{ave}$. From Equation (1), it is easy to verify the average DC voltage output by controlling the firing angle $\alpha$. The sensor’s frequency speed will be below the reference frequency when the motor speed is low. Thyristor causes change in the firing by producing different frequencies. This means that the firing angle $\alpha$ is reduced, and the motor speed will increase to maintain the matching between the reference frequency and the output speed. When the output speed frequency is higher than the reference frequency, the firing circuit will be modified to allow the SCR to reduce the DC motor speed and conduct for a shorter time [5, 6].

1.2 Speed Control Using a Step-Down Chopper Motor Drive
Servo motor drives DC to DC converters using duty cycle pulse width modulated switch controller are very popular. Figure 3 shows a simple motor circuit.

![Simple motor circuit](image)

**Figure 3. Simple motor circuit**

The motor supply 0 V when the switch is open and 12 V when it is closed. The motor will rotate slowly when the switch is open and close to the same amount of time by gaining 6V. Power MOSFETs performs the ON-OFF switching, which can turn high currents on or off using a low voltage controller. Figure 4 shows the average voltage that supplies the DC motor which is given by Equation (2):

\[
V_{ave} = \frac{t_{on}}{T} \times V_{in}
\]  

(2)

Where \( V_{ave} \) is the DC motor average voltage supplies, \( t_{on} \) is the time ON of switches, \( T \) is chopping period and the \( \frac{t_{on}}{T} \) is the duty cycle of the chopper.

![Chopper signal](image)

**Figure 4. Chopper signal**

The voltage increases by the period of time when the chopper is on compared to when the chopper is off, and the motor average speed will increase. Depending on the rotor inertia, the motor needs different times to speed up or slow down [7]. Basically, how heavy the rotor is and how much load torque and friction there is. Figure 5 shows the motor speed that is being turned on and off slowly.

![Motor speed supply voltage relation](image)

**Figure 5. Motor speed supply voltage relation**

From Figure 5, it can be seen that the average speed is around 150 RPM. The motor won't have time to change its speed, and it will remain steady if the supply voltage is switched fast enough. This is the principle of switch mode speed control [8].
1.3 Full bridge circuit
Each motor side can be connected to either positive or negative of the battery sides. On each side of the motor, only one MOSFET must be turned on per time. Otherwise, the battery will act as a short circuit. Figure 6 shows the full-bridge motor drive.

![Full bridge motor drive](image)

By turning Q4 on, the motor will go towards, and the PWM signal will be applied to Q1. On the opposite side, for making the motor goes backward, Q3 must be turned on, and the PWM signal must be applied to Q2 [9].

2. Power Simulation (PSIM)
PSIM is a simulation package with a friendly user interface and fast simulation explicitly designed for motor control and power electronics [10]. It provides a robust environment for analog and digital control, power electronics and motor drive systems. It covers three modules, which are the digital control module, motor drive module, and SIM coupler module. In system drive studies, the motor drive module has a built-in mechanical load and machine modules. The simulation package of PSIM consists of three programs, which are waveform processing program SIMVIEW, circuit schematic program, and the simulator. A circuit structure is represented in PSIM in four blocks, which are power circuit, control circuit, sensors, and switch controllers [11].

2.1 DC Motor with a Constant-Torque Load
Figure 7 shows the DC motor shunt-excited circuit with a constant-torque load CTL. The machine load torque is rotating towards because of the direction of the mechanical system. For a positive speed, positive output is provided when the speed sensor is along the reference direction. Figure 7 shows the speed and armature current of the stimulation waveform.

![DC motors with constant torque](image)
2.2 Field Resistance Speed Control of DC Motor Method

Speed control of DC motor by the field resistance method. To the flux, the series resistance is used for inserting in the motors shunt-field circuit by controlling the field current. When any value of field resistance is selected, the speed will change proportionally with field resistance. In general, when the field resistance increases, the speed will be increased, and when the field resistance decreases, the speed will be decreased. This method is considered important in practical circuits as shown in Figure 8.

![Figure 8. DC motor speed control using field resistance](image)

The speed control of a DC motor using armature voltage (variable voltage). The applied voltage $V_a$ on the armature circuit is varying without changing the applied voltage to the motor circuit. Figure 9 shows the separately excited motor using armature voltage. When the field voltage increases the speed of motor increase. Two different DC sources should be used to get a separate excited connection, one for the armature and the second in the field circuit. Two circuits of speed control DC motor are designed. The first one is by changing the field resistance and the second is by changing the armature voltage.

![Figure 9. DC motor speed control using armature voltage](image)

3. Simulation Results

The parameters of motor:
- $P = 3.5\text{KW}$
- $V = 300\text{V}$
- $I = 15\text{A}$
- $N = 1500\ \text{RPM}$
- $Ra = 0.6\Omega$
La=0.006763H  
R_f=84.91Ω  
L_d = 13.39H  
Total inertia (J) = 0.2053kg.m^2  
Viscous friction coefficient (Bm) = 0.007032 N.m.s  
Friction torque (T_f) = 5.282 N.m

The result of DC motor speed control is changing with the field resistance changes. When the field resistance values are changing, the speed is changing in proportional to field resistance (R_f). When R_f=50 Ω, W=150 rad/Sec and steady-state at t=0.2 Sec.

![Figure 10. The curve of the speed shown in PSIM](image)

When R_f=100 Ω, W=182 rad/Sec, steady-state at t=0.4 Sec.

![Figure 11. Curve of the speed shown in PSIM](image)

In the method, namely, DC motor speed control using field resistance. It is noticed in this method that the speed of the motor is proportional to field resistance that means, when the field resistance increases, the speed of the motor will be increased and when field resistance decreases, the speed of the motor will be decreased. If the field resistance R_f=50 Ω has been taken, the speed of the motor in PSIM N=1225 r.p.m. IF the field resistance R_f=100 Ω, the speed of motor in PSIM N≈1390 r.p.m.

When the values of armature voltage (the source variable) are changing, the speed of the motor is changing as well is proportional to armature voltage. When V_a = 250V, W=140 rad/Sec and steady-state at t=0.5 Sec.
By changing the armature voltage, it is noticed that the speed of the motor changes in proportional with armature voltage, that means when armature voltage increases, the speed of the motor will increase as well and when the armature voltage decreases, the speed of the motor will be decreased. If we take armature voltage \( V_a = 250 \text{ V} \), speed of the motor in PSIM \( N = 623 \text{ r.p.m} \) and if we take armature voltage \( V_a = 275 \text{ V} \), the speed of the motor in PSIM with \( N = 700 \text{ r.p.m} \). In the method of speed control by using feedback control of DC motor method, two blocks have been used where the first block includes reference speed of motor and second block include the added value of speed to reference the speed of the motor. When reference speed =100 rad/Sec. added value of speed to reference speed =100 rad/Sec. and steady-state at \( t = 5 \text{ Sec} \). The speed will increase or decrease by feedback control. If reference speed =100 rad/Sec. has been taken and the final speed =200 rad/Sec. is required, the feedback control will be added value to reference speed. To make the final speed = 200 rad/Sec. The feedback will add speed = 100 rad/Sec. this will make final speed = 200 rad/Sec.

4. Conclusion

In the DC motor speed control using field resistance method, it is noticed that the speed of the motor is proportional to field resistance that means, when field resistance increase, the speed of the motor will be increased and when field resistance decreases, the speed of the motor will be decreased. If we take field resistance \( R_f = 50 \Omega \), the speed of the motor \( N = 1225 \text{ r.p.m} \) steady-state at \( t = 0.5 \text{ Sec} \). and if we take field resistance \( R_f = 100 \Omega \), speed of motor speed of the motor \( N = 1390 \text{ r.p.m} \) at steady-state at \( t = 1 \text{ Sec} \). In speed control by using the armature voltage method, the speed of motor proportional with armature voltage, that means when armature voltage increase, the speed of the motor will be increased and when the armature voltage decreases, the speed of the motor will be decreased. If we take armature voltage \( V_a = 250 \text{ V} \), Speed of motor \( N = 623 \text{ r.p.m} \), steady-state at \( t = 0.2 \text{ Sec} \) and if it is taken armature voltage \( V_a = 275 \text{ V} \), Speed of motor \( N = 700 \text{ r.p.m} \), steady-state at \( t = 0.2 \text{ Sec} \). DC motor speed control using a feedback controller method, the speed will increase or decrease by feedback control.
we take value for reference speed =100 rad/Sec. and if the final speed =200 rad/Sec. Feedback will control to add value to reference speed, to make the final speed=200 rad/Sec. When the reference speed of motor =100 rad/Sec. and added value of speed to reference speed =0, steady-state at t=3 Sec. and when reference speed =100 rad/Sec. added value of speed to reference speed =100 rad/Sec. steady-state at t=5 Sec.

References

[1] Jatin J P, Kubavat A M, and Jhala M B 2014 Speed Control of a Three Phase Induction Motor using PWM Inverter IJEDR, 21
[2] Frayyeh H F, Mukhlif M A, Abbood A M, and Keream S S, 2019 Speed Control of Direct Current Motor Using Mechanical Characteristics Journal of Southwest Jiaotong University 544.
[3] Telba A, 2014 Motor Speed Control Using FPGA WCE 1
[4] Lapçin E, Imeryuz M, and Ergene L T 2014 Analysis of PWM Inverter Fed Squirrel Cage Induction Motor with PSIM 16th International Power Electronics and Motion Control Conference and Exposition
[5] Sen P C, and MacDonald M L, 1978 Thyristorized DC Drives with Regenerative Braking and Speed Reversal IEEE Transactions on Energy Conversion, 25 347.
[6] Sen P C 1997 Principles of Electrical Machines & Power Electronics 2nd John Wiley & Sons Inc.
[7] Mohammed K G, Al-sagar Z S, Saleh M S 2018 Matlab Simulink of Three Phases Six-Pulse Thyristor- Rectifier Converter Journal of Advance Research in Dynamical & Control Systems, 10 4.
[8] http://homepages.which.net/paul.hills/Speed Control/SpeedControllessBody.html
[9] Ahmad A, and Taib M N, 2003, A study On the DC Motor Speed Control by Using Back-EMF Voltage Asia Sense Sensor 359.
[10] Natick M A, 2000 Model-based, and system-based design, using Simulink, Math Works Inc.
[11] Natick M A, 2002 Sim Power Systems for use with Simulink, user’s guide, Math Works Inc.