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International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 4 | Pages 1162-1166 | e-ISSN: 2347-470X

Modeling, Design and Control of Speed DC Motor using Chopper

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ABSTRACT- An electric motor, a power controller, and an energy-transmitting shaft make up an electrical drive. Power electronics converters are utilized as power controllers in contemporary electrically driven systems. DC actuators and AC drives are the two primary categories of electric drives. This study presents design and modeling techniques for very effective individually stimulated DC motor speed control. A DC motor speed controller can be implemented using a chopper circuit as a converter. The controller transmits a signal into the chopper firing circuit, which in turn generates the desired speed of the chopper by varying the voltage supplied to the motor's armature.

One type of controlling loop is the speed controller, and another is the current controller. A proportional-integral controller is used. Eliminating the delay with the aid of this controller makes rapid control possible. It creates a separately stimulated DC motor. A current and speed regulator are built in to give the DC motor high-speed control in a steady condition. Under different speed and torque conditions, the model is simulated and examined in MATLAB (Simulink). Results that are satisfactory are achieved, validating the capacity of the chopper approach to control the speed of a DC motor.

Keywords: Chopper, Current controller, DC drive, DC motor, MATLAB/Simulink, PI controller, Speed control.

ARTICLE INFORMATION

Author(s): Rokan Ali Ahmed and Enas Dawood Hassan;

Received: 03/10/23; **Accepted**: 20/12/23; **Published**: 23/12/23;

E- ISSN: 2347-470X;

Paper Id: IJEER230741;

Citation: 10.37391/IJEER.110437

Webpage-link:

https://ijeer.forexjournal.co.in/archive/volume-11/ijeer-110437.html

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1. INTRODUCTION

Motors, a power source, a controller, and a shaft for power transmission are components of electric drive systems. Electronic power converters are used in today's electric drive systems to control power. Electric drives can be divided into two main categories: alternating current (AC) and direct current (DC) [1, 2]. In contrast to AC drives, which employ an alternating current (AC) motor as their power source, DC drives rely on a direct current (DC) motor [3]. DC motors are a major component of position-control systems and variable-speed drives. A DC motor's speed can be easily changed by operating it at a speed higher or lower than its rated speed. Their speed is controlled by armature voltage below their rated speed [4].

High-performance motor drives have a wide range of applications in industry [5]. A high-performance motor drive system will have fast response times and accurate tracking of dynamic speed commands [6]. DC drives have commonly employed in applications that require variable speed control, reliable speed regulation, regular starting, reversing and effective braking [7].

There are many places where this is used: mills, rolling mills, hoists, machine tools, printing presses, mine winders, textile mills, excavators, cranes, and traction. Creating high-performance motor drives is crucial for use in industrial settings [8]. DC drives have various options for adjusting their speed. These consist of modifying the field flux, armature resistance, and armature voltage. DC motor speed and current are managed by speed and current regulators [9]. The main responsibility of the controller is to minimize error, which is ascertained by contrasting the actual output with the intended value, also known as the set point. The main objective of this research is to use a chopper, a power converter, to regulate the speed and current of a DC motor [10,11]. Induction motors, synchronous motors, and brushless D.C. motors are commonly used in contemporary electric traction systems. DC motors continue to be a good choice since the theory underlying speed control in them is more understood than in other types. Techniques for changing the armature voltage at low speeds to control the speed of a separately excited DC motor [12].

Chopper circuits use power semiconductor components including GTOs, force commutated thyristors, MOSFETs, power BJTs and IGBTs. The total drop in voltage is between 0.5V and 2.5V [13], owing to their low c. There are a number of available controllers for use in speed-control operations. The Proportional-Plus-Integral (PI) controller is widely used because it provides automatic control of the system without requiring constant attention from the operator [14]. This study discusses the utilization of MATLAB to create a model of a DC chopper and PI controller. The purpose of this model is to regulate the velocity of a DC motor in a closed-loop system. The motor that is separately activated is examined in speed regulation to enhance efficiency through control.

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2. MATHEMATICAL MODEL

2.1. DC Motor Model

Separately excited DC electric motors [15,16] are commonly utilized in DC motor systems for tuning velocity and adjusting position. The matching model of the individually excited DC motor [11] is shown in *figure 1* [17-22].

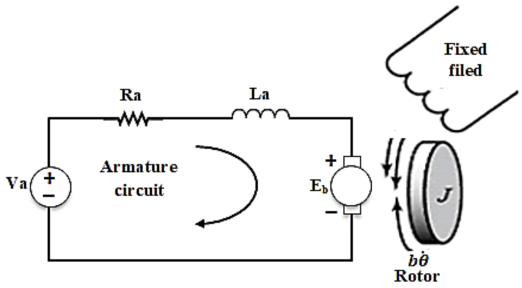

Figure 1: DC motor equivalent model

The equation for armature voltage is derived by utilizing Kirchhoff's voltage law.

$$V_a(t) = R_a i_a(t) + L_a \frac{di(t)}{dt} + Eb(t) \qquad (1)$$

Torque (T) of a motor as a result of current (i) in the armature times a constant (K):

$$T = Ki \qquad (2)$$

The angular velocity and the e.m.f. (Eb) are connected as follows:

$$Eb = K\omega = k\frac{d\theta}{dt} \qquad (3)$$

Modeling a D.C. motor with Newton's and Kirchhoff's laws yields

$$J\frac{d2\theta}{dt} + b\frac{d\theta}{dt} = Ki \qquad (4)$$

$$L\frac{di(t)}{dt} + Ri = V - K\frac{d\theta}{dt} \qquad (5)$$

After that, the Laplace transform is applied to these equations in order to generate the transfer functions for the motor, which are displayed in the equation down below.

$$JS^2\theta(s) + bS\theta(s) = K\frac{V(s) - KS\theta(s)}{R + LS} \qquad (6)$$

The motor's block diagram is shown in *figure 2*, and *equation (7)* provides a transfer function that could be used to characterize the D.C. motor [23-26].

$$\frac{\omega(s)}{V(s)} = \frac{K}{(LJ)S^2 + (RJ + Lb)S + (Rb + K2)} \qquad (7)$$

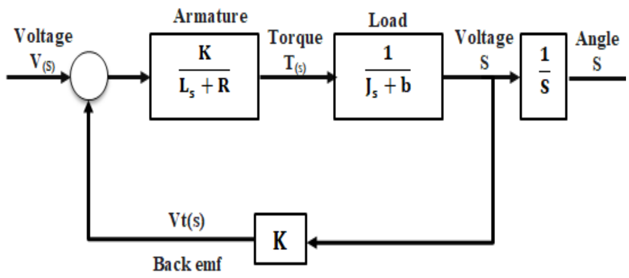

Figure 2: Block diagram for separately exciting D.C. motor

2.2 Chopper Circuit

A DC-DC converter, often known as a chopper, is a kind of power technology that takes a fixed dc voltage as input and produces an adjustable dc voltage as output. Because of their comparable operational properties, a chopper and an AC transformer in DC form are comparable [3]. These days, choppers are an essential component of numerous systems, including public transit, maritime hoists, and EHVs (electric hybrid vehicles). Choppers are a crucial component of today's power electronics infrastructure and modern dc applications across many industry sectors since they may significantly increase the efficiency of DC machines [27, 28]. The output voltage and current waveform of a basic chopper circuit are shown in *figure 3*. The chopper only requires a single stage of conversion, making them more efficient [29,30].

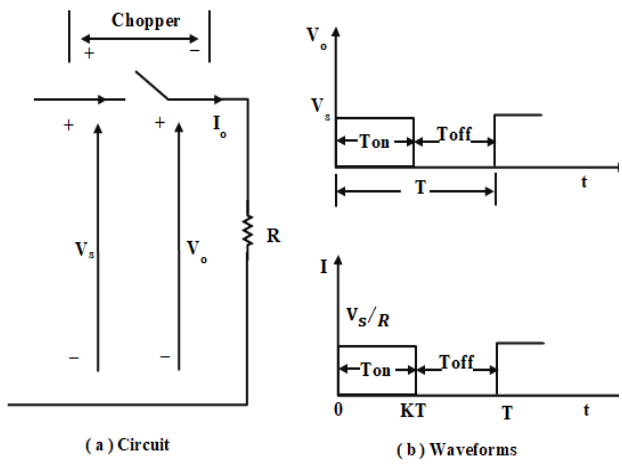

Figure 3: Voltage and current waveforms in a chopper circuit

The inductor with energy stored is as

$$Vo = (Ton/(Ton + Toff))^{\wedge} * Vs = (Ton/T) * Vs = \alpha Vs \qquad (8)$$

$$Ton = on - time. \quad Toff = off - time.$$
$$T = Ton + Toff = Chopping\ period$$

$$\alpha = Ton/T.$$

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3. PROPOSAL DESIGN OF SPEED CONTROLLER

A DC motor, controller, and converter make up an electrical DC drive. As a converter, we employ choppers. A DC motor can be made to run slower than its rated speed by varying the armature voltage while maintaining a constant field voltage. After comparing the output speed to the standard speed, the speed controller receives an error signal. The controller's output will alter if the feedback speed deviates from the baseline pace. The control voltage that the speed controller outputs determine the duty cycle of the converter's functioning. Voltage is supplied by the converter output to resume motor speed. A basic block diagram for regulating a DC motor's speed is shown in *figure 4*.

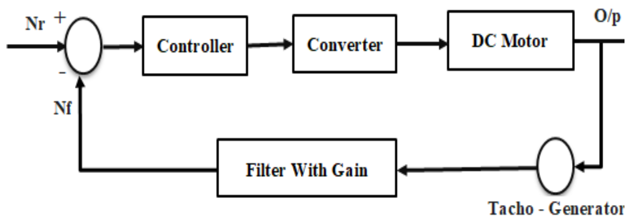

Figure 4: Dc motor speed regulation using a closed-loop approach

4. SIMULATION RESULTS

The chopper circuit, shown in Figure 5, is an electronic circuit that converts DC voltage from one level to another and is represented here in a simulated form. A chopper device is used in the environment of DC motors to control the speed as well as the direction of the motors. It works by quickly changing the amount of electricity provided to the motor, thus lowering the standard voltage and hence the motor's speed. This control approach is more practical than a resistor that is variable or a rheostat, which wastes a great deal of electricity as heat. Chopper circuits can also be used to disable the motor by swiftly switching its terminals, generating a voltage that is reversed and thereby slowing down the motor.

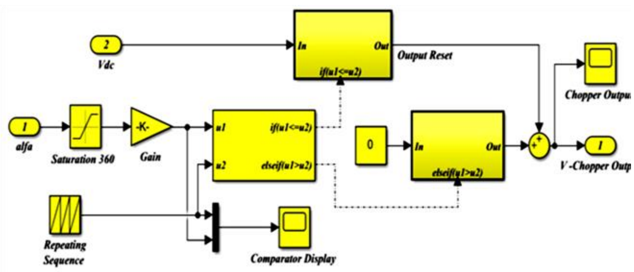

Figure 5: Block diagram of chopper circuit.

The performance parameters of the D.C. motor fed by the GTO thyristor converter were investigated during both transient and steady-state operation. The resultant waveform of the whole chopper circuit is depicted in *figure 6*, showcasing the influence of the smoothing inductor on the motor's performance. and source impedance (overlap phenomena) on the rectifier's output voltage have been taken into account.

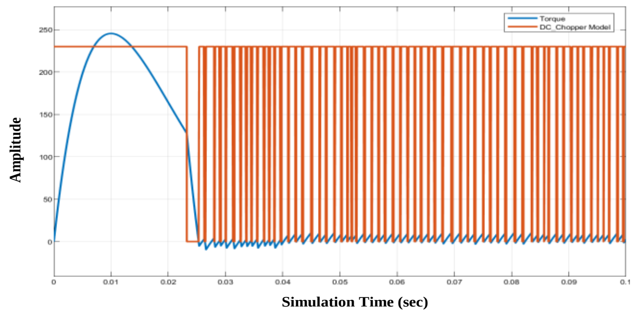

Figure 6: The simulation output of chopper circuit.

Figure 7 depicts the total DC motor speed system control based on the chopper circuit. The following elements were rated for the simulation described above: 230 V DC voltage source The DC machine has the following specifications: 5 HP, 230 V, 5 N-M, and 230 V in the field, and 240 rad/sec is the reference speed.

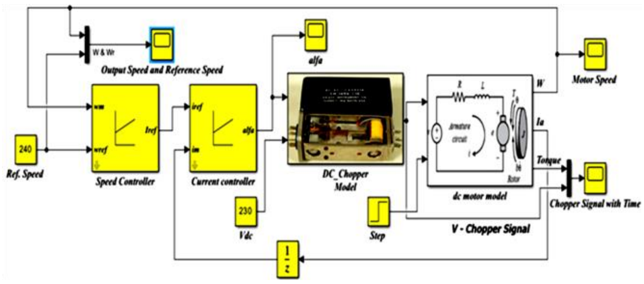

Figure 7: The overall block diagram of proposed model

The chopper circuit was utilized as a conversion device to effectively control a DC motor's rotational speed. For this aim, a Proportional-Integral (PI) kind speed and current controller was also used, which included a model of the DC motor. Initially, whether a DC motor requires an electric current driver and an improved speed control method is investigated. Subsequently, the DC motor is modeled broadly. The entire layout of the DC drive system is then retrieved. The speed controller's output speed and signal are shown in *figure 8*.

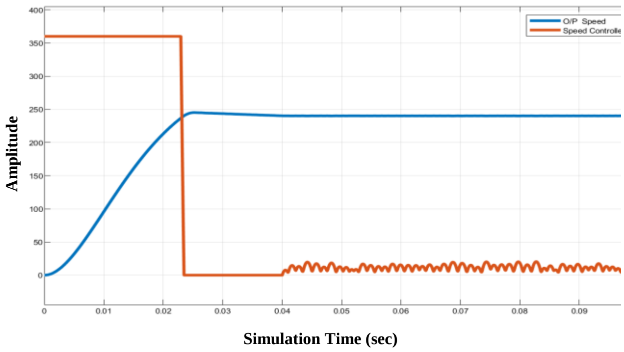

Figure 8: The output speed of DC motor related to input controller signal.

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The next step is to design the speed and current controls. MATLAB Ver. 2023A is now being used to run the simulation, and different input voltage, load circumstances, and reference speed settings are all being changed. Under the aforementioned circumstances, the outcomes are also investigated and assessed. Under every simulation condition, the model produces good results. *Figure 9* depicts an example of the output simulation.

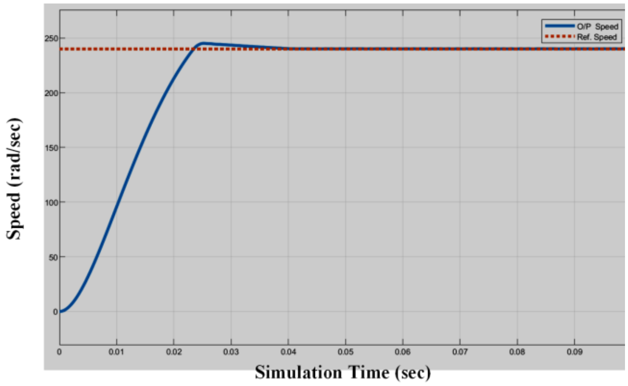

Figure 9: Simulation output of overall proposed system.

The primary focus of the discussion is the control system's exceptional capacity to respond quickly, reaching a stable state in 0.35 seconds or less, with a maximum overshoot of less than (2.08%) and a rising time of less than (0.0234 sec.). DC drives are often found in paper manufacturing operations, hoists, mine winders, staircases, printing presses, textile manufacturing devices, spinning mills, cranes, and traction. They are also frequently used for speed control that can be adjusted, frequent starting out, improved speed regulation, braking, and reversing. This management system with a DC motor is appropriate for the application purpose. The design and manufacture of outstanding performance motor drives are crucial for industrial applications. Since DC drivers are less expensive and less complicated than AC drives, they are frequently employed in manufacturing processes.

5. CONCLUSION

A "chopper" converter was successfully used to control the rotation speed in a DC motor, and a PI controller kind speed and the current controller relies on being closed -to-the-outside-world representation of a DC motor. First, the requirement for a current controller and a simpler system for managing a DC motor's speed is investigated. After that, the DC motors is broadly modeled. The entire layout of the DC drive structure is then retrieved. The next step is to design the speed and current controls. Presently, the simulation has been run in MATLAB (Simulink) with different input voltage, load, and standard speed circumstances. The results are also looked into and evaluated under the aforementioned conditions. Under every simulation condition, the model produces good results. Since then, a demonstration of controlling the speed of a DC motor has been done. Furthermore, we can do a practical examination on the hardware to determine its feasibility. In this case, the speed of the DC motor is regulated for both speeds that are considered within the specified rating, as well as speeds that are below the specified rating. Field flux control allows for accurate regulation of a DC motor's speed beyond its rated speed.

The controller used in the simulation of a DC motor enables the motor to keep its speed at any desired set-point speed, even when there are changes in the load conditions. If the setting point is increasing or decreasing at a predefined rate, the corresponding controller can be utilized to maintain the speed within the predetermined range. This outside of closed to the world speed controller receives a signal of voltage proportional to the motor's speed from the Tacho-generator installed on the rotor and feeds it back to its input. The error signal is then produced by subtracting this signal from the set-point velocity. After receiving this error signal, the controller orders a motor to operate at the proper set-point velocity.

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