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(Research Article)

Speed control and characteristics of DC shunt motor using Simulink

Basavarajappa Sokke Rameshappa *, Karibasavaraju Shivalingappa Telagi, Manjunath Malleshappa Hirekeri and Arunkumar Parashuramappa

Department of E and E, Bapuji Institute of Engineering and Technology, Davanagere, Karnataka, India.

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Abstract

The speed control and characteristics of a DC motor has an enormous impact on industries and applications in day-to-day life. The motors are selected for different applications based on speed - torque characteristics, efficiency and horse power rating. The load test on the DC motor determines its performance characteristics the. With the rise in the usage of power electronic devices in regulating motor speed. With the most extensively used method of Armature Voltage Control, a single-phase full converter model using thyristors has been designed to regulate the motor speed. A MATLAB/Simulink model has been presented along with graphs, representing the time response characteristic between firing angle, armature voltage and speed, speed and load torque, and the load characteristics.

Keywords: DC Shunt Motor; Full Wave Rectifier; Speed; Torque

1. Introduction

A DC motor is a direct current electrical machine which converts electrical energy to mechanical energy. The capability to modify the rotation velocity of a direct current motor by adjusting the applied voltage to the armature is known as speed control. Standard speed regulation methods have long been researched and armature voltage control is one of the most frequently used techniques to control DC drives. The operation principle is “When a current carrying conductor is placed in a magnetic field, it experiences a mechanical force” [1]. The two main components that constitute a DC motor are armature and field, which are analogous to a conductor and magnetic field. Motor armature current and torque are proportional to each other, keeping armature resistance and supply voltage constant. The armature voltage is controlled using a power converter. All power electronic converters [2] manage the flow of electrical energy between a source and a load. The function of the power converter is that of controlling energy flow between an electrical source and a load. As a power converter connected between a source and a load, any energy or power used within the converter is lost to the overall system. Choristers are commonly used in power converters. These are three-terminal devices with four layers of alternating p- and n-type material in their main power handling section. In contrast to the linear relation between load and control currents in a transistor, the chorister is bistable. The control terminal of the chorister, called the gate (G) electrode, may be connected to an integrated and complex structure as part of the device. The other two terminals, anode (A) and cathode (K), handle the large applied potentials and conduct the major current through the chorister. The anode and cathode terminals are connected in series with the load to which power is to be controlled.

Thyristors are utilized to mimic ideal closed (no voltage drop between anode and cathode) or open (no anode current flow) switches for controlling power flow in a circuit. There are four main types of thyristors:

- Silicon-Controlled Rectifier (SCR)
- Gate Turn-Off thyristor (GTO)
- MOS-Controlled Thyristor (MCT)

* Corresponding author: Basavarajappa Sokke Rameshappa

- Static Induction Thyristor (SITh)

When the anode is positive with respect to the cathode, a thyristor can be activated using any of the following methods:

- Forward voltage triggering
- Gate triggering
- Temperature triggering
- dv/dt triggering and
- Light triggering

When the firing angle of thyristors α is decreased, the thyristor is fired earlier-conduction period increases - which in turn increases the voltage applied across the armature. Hence, the motor speed increases. A few other methods to regulate motor speed using different control schemes include flux control, rheostat control, phase lock loop control technique for zero speed regulation and precise speed control and so on. Different types of voltage control methods also include Multiple Voltage control and the Ward Leonard System. Developing a Simulink Model using MATLAB for a single-phase full converter drive using armature voltage control technique for a DC motor.

The speed control of separately excited DC motor using different single-phase AC/DC converter has been performed. With the increasing use of power semi-conductor units, the speed control of DC motor is increasingly getting sophisticated and precise. The speed of the DC motor is controlled by controlling the armature voltage and is controlled using different single-phase AC/DC converter. From the results, it can be observed that the reason for non-linearity in speed torque curve is discontinuity in armature current which is highly non-desirable for industrial applications. To remove the discontinuity in armature current, an inductor should be used in series [3]. The mathematics behind the speed control and verifies it with a state-space model. In this model, armature voltage control technique is concentrated where the speed and the back EMF of the DC motor are proportional to each other, keeping armature resistance and supply voltage constant [4].

A digital speed control method of rectifier fed separately excited dc motor incorporating a phase locked loop technique has been demonstrated. The smooth control of firing angle in the range of 0^0 to 180^0 permits motoring and regeneration is the full range and four quadrant operation is possible by reversing to motor field [5]. An innovative converter topology that allows to improve the performance of electronically commutated motor drives, aimed at equipping home appliance. The proposed topology is based on a modified c dump convertor configuration. Where the energy recovery stage acts as an active power factor controller (PFC) for offline operation. This is made possible by introducing a new technology to manage the free-wheeling energy that is recovered back to the DC bus by a suitable high frequency (HF) transformer. Moreover, the proposed convertor topology features only low side or high side configuration switches, allowing to simplify the design of the drives and easily integrate the power semiconductors in a single chip exploiting smart power technologies [6].

The conventional controller (PID) and fuzzy logic controller are used to control the speed of a DC shunt motor based on a MATLAB simulation program. A mathematical model has been developed using real plant data and then conventional controllers and fuzzy logic controller [7]. A review study of different tuning controllers for speed control of DC motor. It is widely used in industries even if its maintenance cost is higher than the induction motor. Speed control of DC motor is attracted considerable research and several methods are evolved. All controllers are widely used in many different areas like process control, manufacturing, automation, aerospace, etc. [8].

1.1. Problem Statement

The primary issue in industrial DC motor drives is the control of motor speed, especially when faced with load variations and disturbances. As the load torque changes, the motor speed changes in response. Therefore, it is essential to design a voltage control system that can provide precise control over speed and torque. This study aims to introduce a system for controlling the speed of a DC motor by utilizing single-phase full converter drives with an armature voltage control approach.

Objectives

The following objectives are framed to answer the problem statement:

- To develop a full wave-controlled rectifier system using MATLAB Simulink.
- To simulate the developed control system and to observe the variations in armature current, speed and torque, ensuring precise speed regulation by armature voltage control.

- To simulate the DC Motor for load characteristics.

2. Material and Methods

2.1. Speed Control Method

The block diagram of the speed control of a separately excited DC motor is illustrated in Figure 1. This setup includes a source - single-phase AC supply, power modulator - single-phase full wave-controlled rectifier with triggering circuit, DC motor, and load.

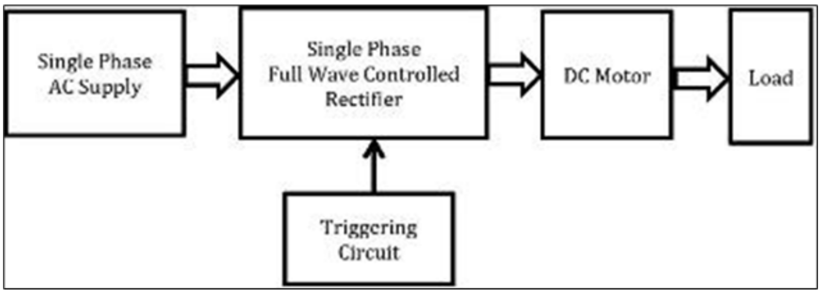

Figure 1 Block Diagram

Thyristors are semiconductor devices that are semi-controllable and can function as a switch, rectifier, or voltage regulator. The operation of a thyristor is similar to that of a transistor. The gate serves as the control terminal. When a small current passes through the gate, a large current flow from the anode to the cathode.

A thyristor can be used as a rectifying diode or an open circuit. Therefore, it can only serve as a switch and not as an amplifier. Thyristors are preferred over diodes for several reasons. When diodes are utilized in power converters, the output DC voltage remains unregulated. This can be improved by passing it through a smoothing capacitor, which reduces ripples and results in a smoother regulated DC output. Once the anode current reaches the latching current value, the thyristor switches ON. Subsequently, even if the gate signal is applied or removed entirely, it will not affect the thyristor, and it will remain in the ON-state.

2.2. Simulink Model with Variable Voltage

A Simulink model is developed to control the speed of a DC motor by armature voltage control method. The model shown in Figure 2 consists of single-phase full wave-controlled rectifier with triggering circuit and DC motor. The 'powergui' block is used with simulation of power systems and power electronics. It is used for the analysis and measurement of parameters like voltage, current, active power, reactive power. It gives the steady state values of the system. Without 'powergui' block electrical circuits cannot be solved in Simulink.

The bridge firing circuit comprises a DC pulse generator block that produces four pulse trains to control a four-pulse thyristor bridge converter consisting of four silicon-controlled rectifiers (SCRs) T1 to T4. The single-phase full converter operates in two quadrants and ensures that the output current remains unidirectional thanks to the thyristors. This full converter is suitable for applications up to 20HP.

The single-phase full wave-controlled rectifier circuit is fed from a 240 V, 50 Hz AC supply. Its output DC voltage is 215 V. The DC motor has the following specifications:

Rated power P = 5 HP = 3.73kW, rated voltage V = 240V, speed N = 1750 rpm, field supply voltage V_f = 300V,

armature resistance R_a= 2.581 Ω, armature inductance L_a= 0.028 H, total inertia J = 0.02215 kg-m^2.

Then, the motor torque $T = \frac{3.73\times10^3}{((2\pi\times1750)/60)} = 20.35$ N-m, and armature current $I_a = \frac{3.73\times10^3}{240}$ =15.54 A.

2.3. Simulink Model with Variable Load

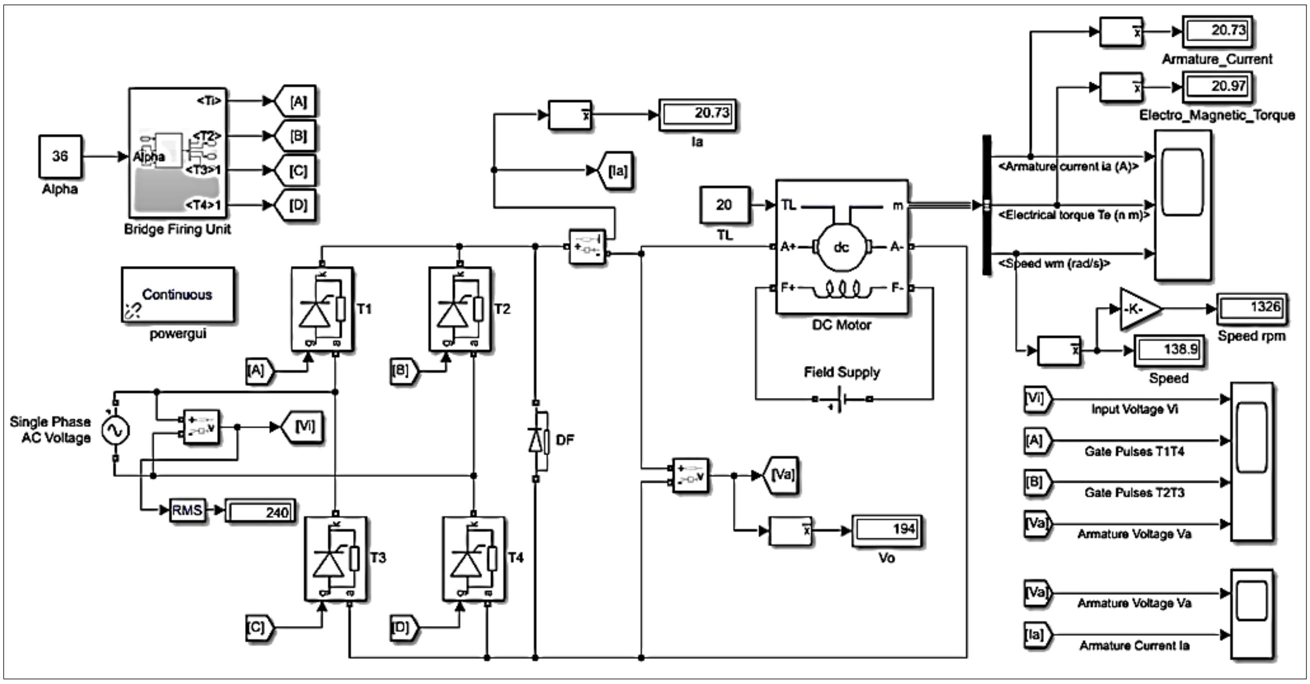

Figure 2 Simulink Model of Speed Control of a DC Shunt Motor

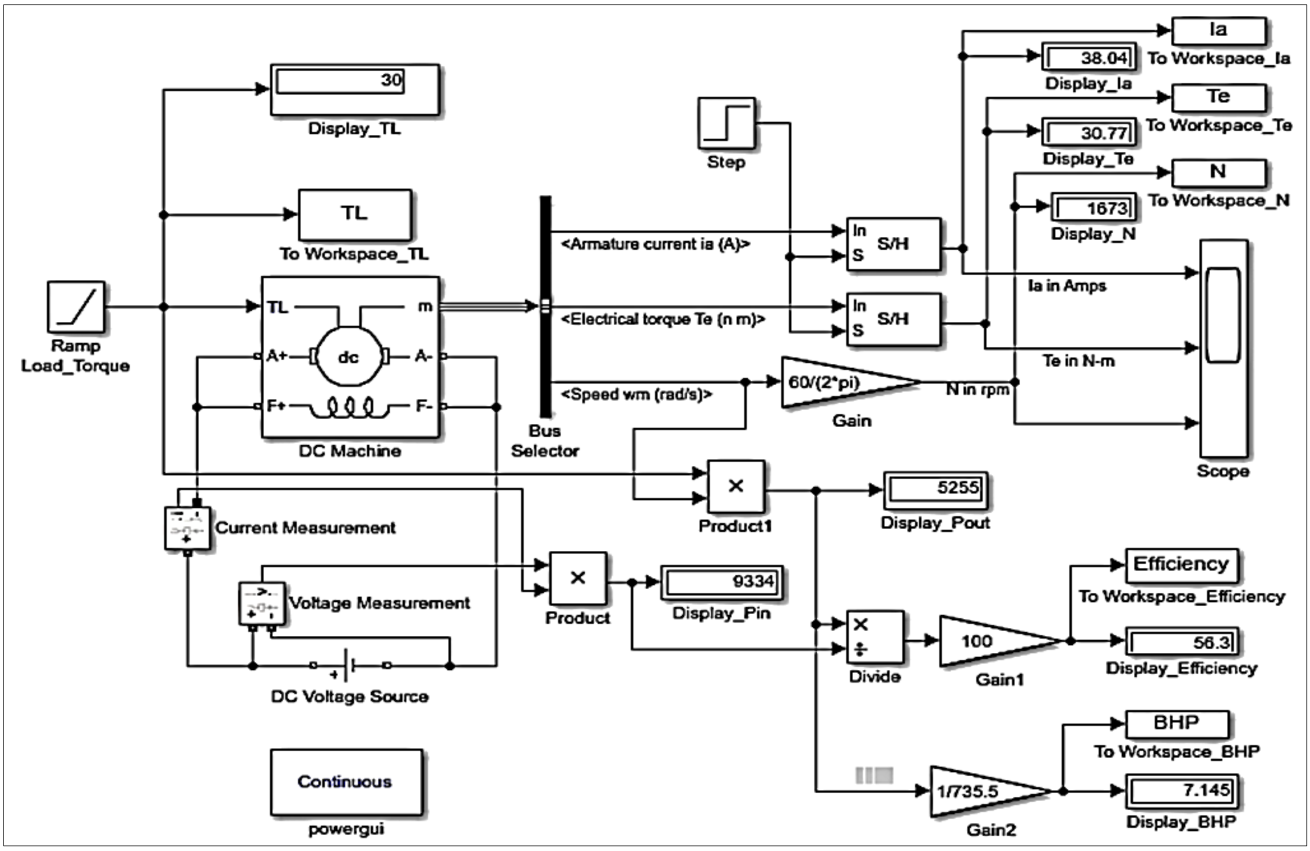

Figure 3 Simulink Model of a DC Shunt Motor with Variable Load

A Simulink model is developed to load characteristics of a DC motor by varying load torque. The model shown in Figure 3 consists of a DC motor with variable load. The ratings of the motor are the same as given in section 2.2. Make the entries of respective components. In the bus selector block selects signals – armature current, electrical torque and speed. As the load torque varies linearly from the minimum to rated value of the machine. Collect the variables (armature current, electrical torque, speed, efficiency and BHP) data into the work space and plot various motor characteristics. Then plot the characteristics using MATLAB code and observe in the figure window.

3. Results and Discussion

The simulation is performed with constant load torque 20 N-m (rated torque) and varying firing angle α from 0° to 108°. At each step, the armature current, armature voltage, and speed are noted, as shown in the Table 1. The plot of firing angle verses armature voltage and speed is shown in Figure 4.

Table 1 Firing Angle, Armature Current, Voltage and Speed at $\mathbf{T_L = 20\ N-m}$

Sl. No.	Load Torque in N-m	Firing Angle in Deg	Armature Current in Amps	Armature Voltage in Volts	Speed in rad/sec	Speed in rpm
1	20	0	20.75	214.4	159.1	1520
2		18	20.76	209.2	153.9	1470
3		36	20.73	194.0	138.9	1327
4		54	20.68	170.1	115.5	1103
5		72	20.60	140.1	86.0	822
6		90	20.51	106.8	53.31	510
7		95	20.48	97.34	44.02	421
8		108	20.41	73.5	20.63	197

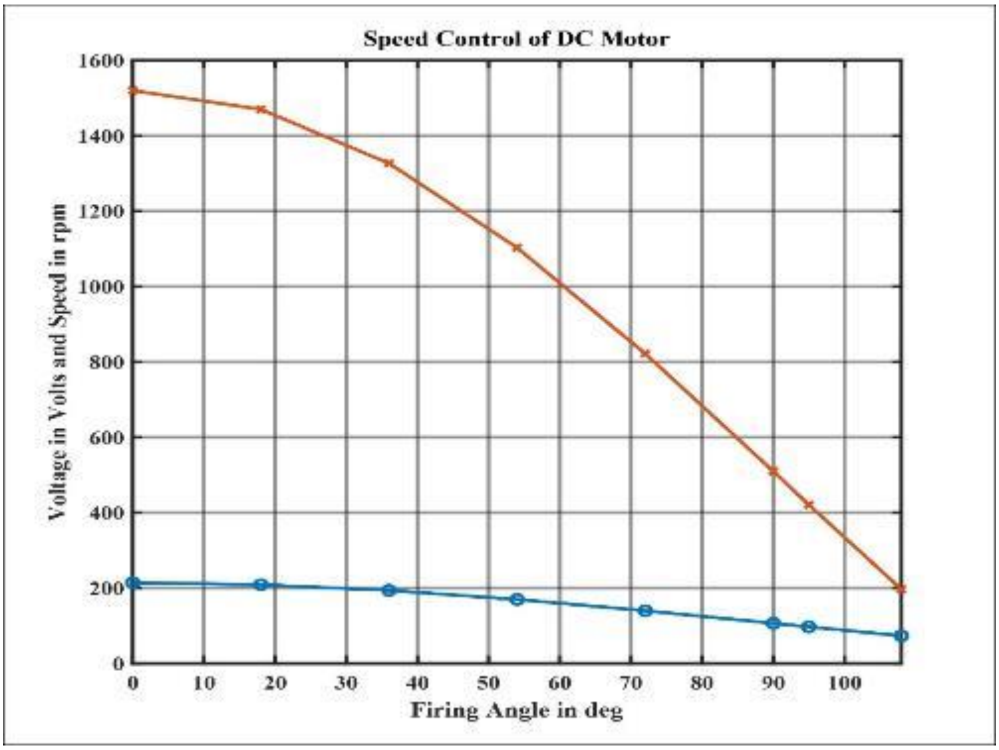

Figure 4 Firing Angle verses Armature Voltage and Speed Characteristics

The firing angle is inversely proportional to armature voltage which is the output voltage of fully controlled rectifier [2]. The armature voltage and speed are directly proportional. As the firing angle increases, the armature voltage and the speed decreases, at constant load torque.

Further, the simulation is performed with three different constant firing angles and varying the load torque from 8 N-m to 20 N-m. At each step, the armature current, armature voltage, and speed are noted, as shown in the Table 2, Table 3 and Table 4. The plots of load torque verses speed are shown in Figure 5.

Table 2 Load Torque, Armature Current, Voltage and Speed at $\boldsymbol{\alpha} = \mathbf{0}°$

Sl. No.	Firing Angle in Deg.	Load Torque in N-m	Armature Current in Amps	Armature Voltage in Volts	Speed in rad/sec	Speed in rpm
1	0	8	8.975	214.5	189.2	1807
2		10	10.94	214.5	184.1	1758
3		12	12.90	214.4	179.1	1711
4		14	14.86	214.4	174.1	1663
5		16	16.83	214.4	169.1	1615
6		18	18.79	214.4	164.1	1567
7		20	20.75	214.4	159.1	1520

Table 3 Load Torque, Armature Current, Voltage and Speed at $\boldsymbol{\alpha} = \mathbf{36}°$

Sl. No.	Firing Angle in Deg.	Load Torque in N-m	Armature Current in Amps	Armature Voltage in Volts	Speed in rad/sec	Speed in rpm
1	36	8	9.364	206.7	180.6	1725
2		10	10.99	196	165.8	1583
3		12	12.88	194	159.0	1518
4		14	14.84	194	153.9	1470
5		16	16.80	194	148.9	1422
6		18	18.77	194	143.9	1374
7		20	20.73	194	138.9	1326

Table 4 Load Torque, Armature Current, Voltage and Speed at $\boldsymbol{\alpha} = \mathbf{72}°$

Sl. No.	Firing Angle in Deg.	Load Torque in N-m	Armature Current in Amps	Armature Voltage in Volts	Speed in rad/sec	Speed in rpm
1	72	8	9.511	163.2	137.3	1311
2		10	11.14	152.0	121.9	1164
3		12	12.79	141.5	107.3	1024
4		14	14.71	140.1	101.0	965
5		16	16.68	140.1	96.03	917
6		18	18.64	140.1	91.02	869
7		20	20.6	140.1	86.00	822

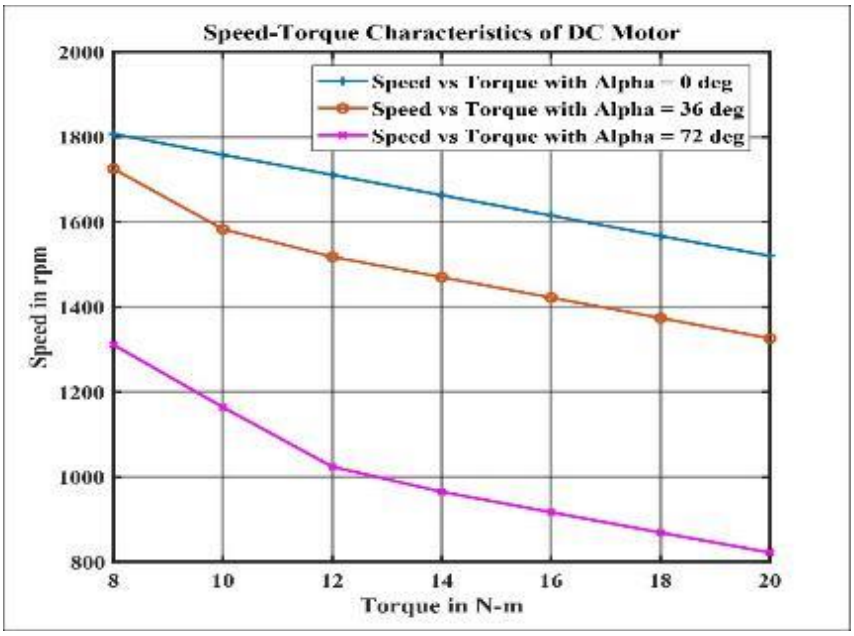

Figure 5 Load Torque verses Speed Characteristics

The load torque and speed are inversely proportional at given firing angle and the armature voltage is constant. As the load torque increases, the electromagnetic torque developed by the armature increase proportionately, but the speed decreases. This is the natural characteristic of a DC motor.

The transient waveforms of input voltage, gate pulses and output voltage are obtained from the simulation have shown in the Figure 6.

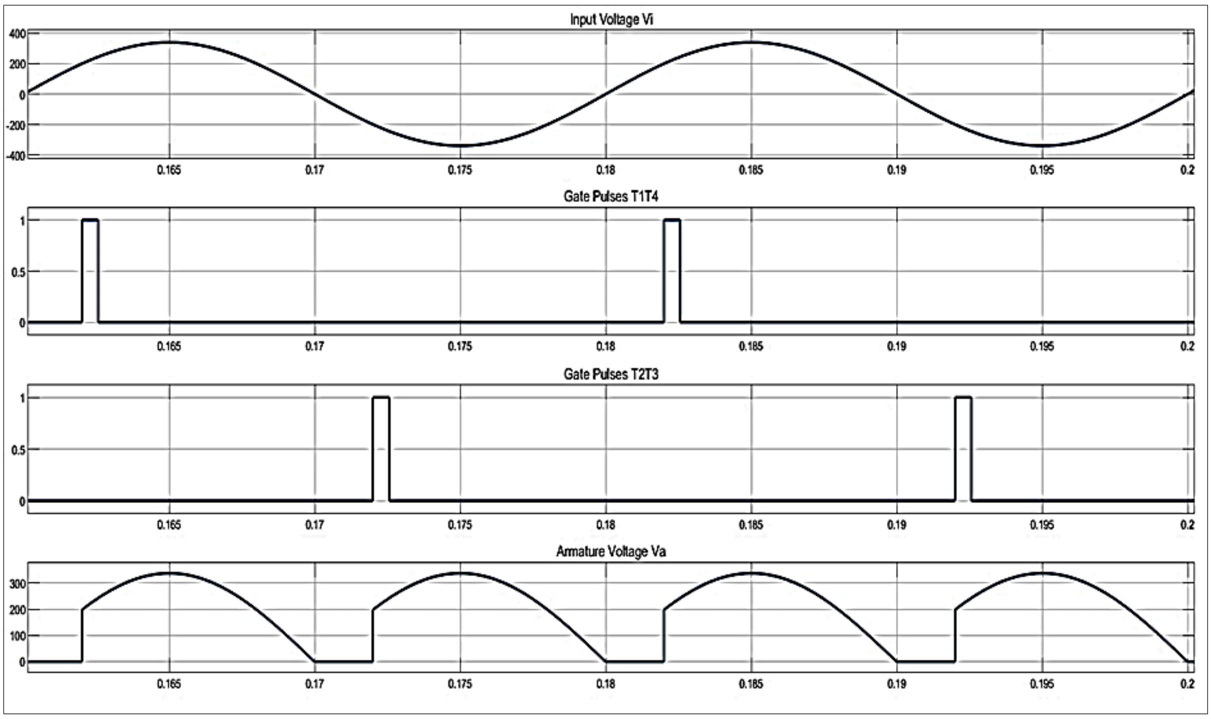

Figure 6 Waveforms of Input Voltage, Gate Pulses and Output Voltage

The waveforms of single phase fully controlled rectifier output voltage and current are shown in Figure 7. At a given firing angle, the out current of the rectifier or armature current is continuous, because of large inductance of the DC motor armature.

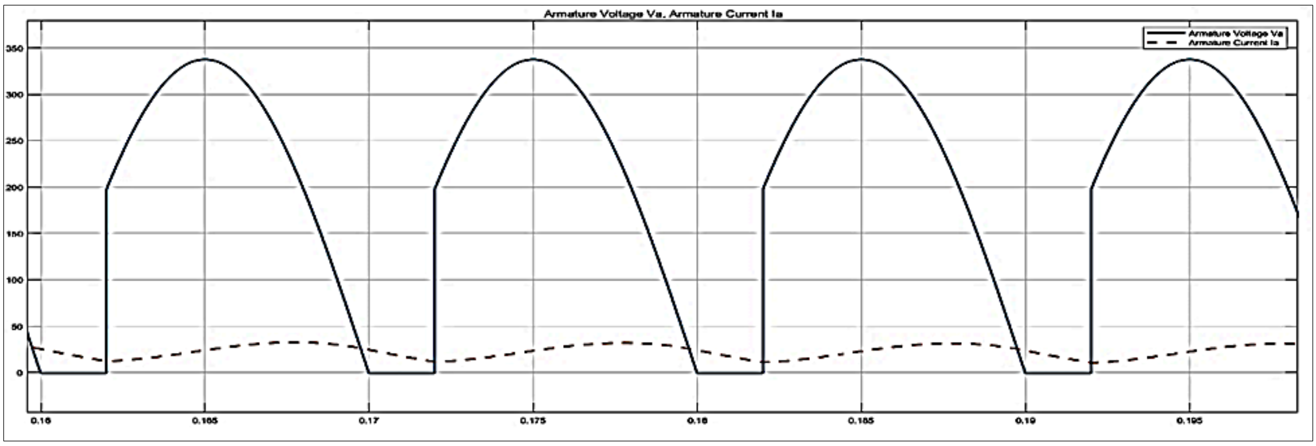

Figure 7 Waveforms of Output Voltage and Current

In the following section, the simulation of a DC motor is performed with variable load torque at a constant input voltage of 240V. As load torque varying linearly using ramp function, the various motor performance characteristics are plot and are shown in Figure 8.

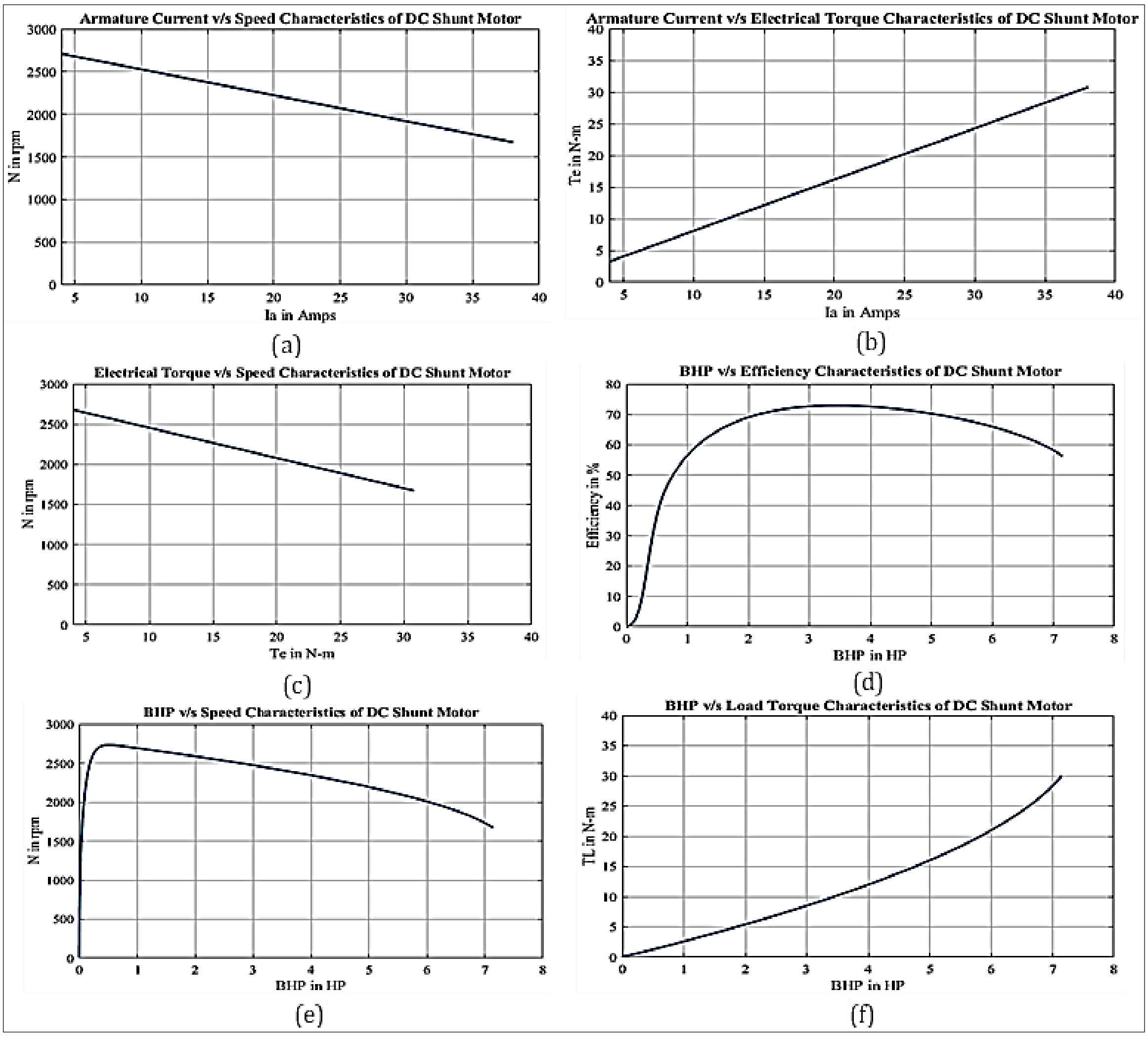

Figure 8 Load Characteristics of DC Shunt Motor (a) Armature Current verses Speed, (b) Armature Current verses Electrical Torque, (c) Electrical Torque verses Speed, (d) BHP verses Efficiency, (e) BHP verses Speed, and (f) BHP verses Load Torque

4. Conclusion

A simulated model of speed control of a separately excited DC motor using armature voltage control method with a single-phase full converter drive has been developed. The variation in the firing angle of thyristors causes changes in the armature voltage and speed. As the firing angle increases, the armature voltage and the speed of the DC motor decreases, at a constant load torque. Also, as the load torque increases, the electromagnetic torque developed by the armature increase proportionately, but the speed of the DC motor decreases. In order to maintain the same speed, the firing angle must be decreased. This method of speed control smooth and more commonly used in industrial DC drives.

Further, the DC motor model is simulated with variable load torque and observed the speed verses torque, armature current verses torque, BHP verses efficiency, BHP verses load toque. This method gives the performance characteristics and are useful in selection of motor for applications.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed

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Author's short biography

Basavarajappa Sokke Rameshappa

He has received his B.E degree in Electrical Engineering from RVCE, Bengaluru University in 1993 and M.E degree in Power Systems from UVCE, Bengaluru University in 1996. He is working as an Associate Professor in Bapuji Institute of Engineering and Technology, Davanagere, Karnataka, India. He has published five papers in IEEE conference and in international journals. He received his Ph. D degree from Visvesvaraya Technological University, Belagavi, Karnataka, India in 2023. His research interest includes power systems, load frequency control, control systems and AI techniques.

	**Karibasavaraju Shivalingappa Telagi** He is working as Assistant Professor at Bapuji Institute of Engineering and Technology, Davanagere affiliated to Visvesvaraya Technological University, Belagavi, Karnataka, India. He received M. Tech from Visvesvaraya Technological University, India in 2010. Currently he is pursuing Ph.D. in Jain University, Bengaluru, Karnataka, India. His main research interests are in the field Renewable Energy sources, Power System and Artificial Intelligence.
	**Manjunath Malleshappa Hirekeri** He received the B.E. degree in electrical and electronics engineering in 2009, the M. Tech. degree in computer application in industrial drives in 2012 and Ph.D. in 2022 from Visvesvaraya Technological University, Belagavi, Karnataka, India. He is currently working as Assistant Professor at Bapuji Institute of Engineering and Technology, Davanagere affiliated to Visvesvaraya Technological University, Belagavi, Karnataka, India. With over fourteen years of teaching experience, he is deeply committed to education. He has authored or co-authored more than 20 research papers published in international journals and conference proceedings. His main research interests are in Power System Operation and Control, Distribution Automation, Artificial Intelligence tools applied to Smart-Grid, Energy Trading, etc.
	**Arunkumar Parashuramappa** He is a Assistant Professor at Bapuji Institute of Engineering and Technology, Davanagere affiliated to Visvesvaraya Technological University, Belagavi, Karnataka, India. He received M.Tech from Visvesvaraya Technological University India in 2014. His main research interests are Renewable Energy sources, Power System.