Modeling and Analysis of Position Control of DC Motor Drive System for Elevator Application using Particle Swarm Optimization

By: Emnet Ashenafi Bekele

A Thesis Submitted to
The Department of Electrical Power and Control Engineering
School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of
Master of Science in Electrical Power and Control engineering
(Control Engineering)

Office of Graduate Studies
Adama Science and Technology University

August 2021
Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled “Modeling and Analysis of Position Control of DC Motor Drive System for Elevator Application using Particle Swarm Optimization” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled “Modeling and Analysis of Position Control of DC Motor Drive System for Elevator Application using PSO” prepared under our guidance by **Emnet Ashenafi Bekele** submitted in partial fulfillment of the requirements for the degree of Masters of Science in electrical power and control engineering (control). Therefore, we recommend the submission of the revised version of the thesis to the department following the applicable procedures.

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Advisor	Signature	Date
______________________________	______________	_______________
Co-Advisor	Signature	Date

APPROVAL SHEET

We, the advisors of this thesis entitled “Modeling and Analysis of Position Control of DC Motor Drive System for Elevator Application using Particle Swarm Optimization” and developed by **Emnet Ashenafi,** hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Advisor	Signature	Date
Co-Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Emnet Ashenafi** have read and evaluated the thesis entitled “Modeling and Analysis of Position Control of DC Motor Drive System for Elevator Application using Particle Swarm Optimization” and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electrical Power and Control Engineering (Control).

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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LIST OF SYMBOLS

ω_m	Angular speed of motor
I_a	Armature current
L_a	Armature inductance
V_L	Armature inductor voltage
R_a	Armature resistance
V_R	Armature resistor voltage
V_a	Armature voltage of motor input
M_c	Car mass
v_{ci}	Control input
K_r	Converter gain
M_{cw}	Counter weight mass
α	Delay angle of convertor
T_r	Delay time of convertor
T_r	Delay time of convertor
v_{dc}	Direct current voltage
η	Efficiency of the transmission system
τ_{em}	Electromagnetic torque of the motor
K_b	Electromotive force constant
$e_a(t)$	Electromotive force of motor
g	Gravity acceleration
K_{ic}	Integral gain for current
K_{ip}	Integral gain for position
K_{is}	Integral gain for speed
K_i	Integral gain of Proportional Integral controller
S	Laplace operator
v_{rms}	Line to line voltage
v_c	Linear car velocity

M_l	Load mass
B_l	Load torque constant
τ_l	Load torque placed on the motor’s shaft
v_{cm}	Maximum control input voltage
v_{cm}	Maximum control input voltage
J_p	Moment of inertia of driving pulley
θ_m	Motor angular position
J_m	Motor’s moment of inertia
v_m	Peak supply voltage
K_{pc}	Proportional gain for current
K_{pp}	Proportional gain for position
K_{ps}	Proportional gain for speed
R_p	Pulley radius
Q	Quadrant
fs	Supply frequency
T_c	Time constant of the Proportional Integral controller
K_t	Torque constant
B_t	Total friction coefficient
J	Total moment of inertia on the motor shaft
P	Total power on motor shaft
G_{pi}	Transfer function of PI controller
b_m	Viscous friction coefficient of the motor

LIST OF ACRONYMS

Abbreviations	**Description**
AC	Alternating Current
DC	Direct Current
EMF	Electromotive Force
GA	Genetic Algorithm
hp	Horse Power
IGBT	Insulated Gate Bipolar Transistor
MRL	Machine Room-Less
MATLAB	Matrix Laboratory
PSO	Particle Swarm Optimization
PMDC	Permanent Magnet Direct Current
PID	Proportional Integral Derivative
RPM	Revolution Per Minute
UK	United Kingdom
VSC	Voltage Source Convertor
VSI	Voltage Source Invertor

ABSTRACT

Due to its higher speed and energy-efficient due to the regenerative energy usage approach of its drive system hydraulic elevators are replaced by traction elevator. There are different electric motors are available to be used as prime mover of traction elevator. PMDC motor is highly efficient as compared to other electric motor and is selected to be used in the traction elevator drive system. An elevator drive control system design is very important in the elevator performance profiles for the safety and comfort of passengers. These profiles include slowly accelerating to the recommended maximum speed, running smoothly at a specific constant speed, and then safely decelerating and braking to a stop when the elevator reaches the desired elevator position. This research work proposes cascaded PI controller for the position, speed, and current control of permanent magnet direct current (PMDC) motor using Particle Swarm Optimization (PSO) for electric elevator drive under load variation. Realize a smooth-running elevator drive system to improve the accuracy, precision and avoid vibration of the elevator system's response to position commands. Then for design aspects such as drive modeling, adjust the parameters of the control system to drive the motor as needed. Finally, the cascaded position, speed, and current-controlled elevator PMDC motor drive using PSO have been modeled in MATLAB Simulink, and simulation studies are carried out. The simulation results show that the proposed control produces 0% overshoot means its operation is smooth and no vibration when it reaches its desired positions of 4 m and 40 m during the full load test, in the upward and downward direction, with its standard speed 0.8 m/s and 2 m/s, respectively. This shows that the cascade controller designed using PSO can effectively and efficiently control the operation of the elevator transmission while ensuring the comfort of passengers and ensuring a smooth driving system.

Keywords: *Permanent magnet direct current (PMDC) motor, cascaded Position, Speed, and Current control system, and PSO-PI.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

An elevator is a device that consists of an electromechanical system used for transporting passengers or goods from one floor (level) to another in the vertical dynamics of the buildings. By the mechanism of lifting and lowering in either of ascending or descending direction respectively in fixed guides. The elevator drive system is one of the important design aspects which need proper design considerations in modern buildings technology. In the last two centuries, the development based on design quality and construction of elevator drive systems is increased gradually with the achievements of the technologies in electromechanics, power electronics, and mechatronics [1].

There are two main types of elevators based on their prime mover and the mechanism of their drive operations. The first one is a hydraulic elevator, which operates by the hydraulic pressure tube principle as a prime mover of the system. In this type of elevator, the elevator car deriving is a result of hydraulic pressure generated from the pumped fluid into or out of the cylinder of the elevator. The second type of elevator is a traction elevator (electrical elevator), in which the overall system is driven by using an electric motor as a prime mover of the system**.**

Traction elevator is the type of elevator mostly used throughout the world, and it is the ideal choice especially for the range of medium to high-rise buildings. Because it is more energy-efficient due to the regenerative energy usage approach of its drive system, and higher speed compared to hydraulic elevators. And this traction elevator drive system is composed of the driving pulley, the electric motor, the elevator car, and a counterweight suspended on either side of steel ropes looped around the sheave [2].

The traction elevators can be further grouped into geared and gearless types based on whether the prime mover of the drive is connected through a reduction gear or directly to the driving sheave. To transform rotational angular position to linear motion of elevator. The geared type of elevator drive is the drive system generated by the interconnection between the prime mover (motor) and the wheel of the driving pulley through the gear train. In gearless type elevators, the motor is connected to the driving sheave directly, which is more advantageous due to about 25% more energy can be saved than using geared motor drives. Due to its better torque-speed characteristics, smaller and compact size, higher efficiency, wide speed range and longer operational life, the popularity of the permanent magnet direct current (PMDC) motors is increasing rapidly in elevator drive applications[3].

For energy saving, a four-quadrant operation is required in any elevator design. Based on the speed and torque relationship there are four modes of operations. Quadrant one is forward speed and forward torque. On the other hand, quadrant three is reverse speed and reverse torque which makes the motor operate in motoring mode. Quadrant two is where the motor is spinning in the forward direction, but torque is being applied in reverse. Torque is being used to brake the motor and making the motor to be in generating mode of operation. Finally, quadrant four is exactly the opposite of the operation of quadrant two. The motor is spinning in the reverse direction, but the torque is being applied in the forward direction[4].

Control system design for monitoring the overall elevator system and its prime mover to be operated in good accuracy is mandatory. It can be considered as the brain of the elevator system. So, the elevator drive control system design is a very important issue in elevator drive construction. Generally, an electrical (traction) elevator drive is a complex system containing both mechanical and electrical components. To achieve good precision on every floor the position control is required and it can be achieved by using a PID controller. However, every electric motor has a high starting current and this may lead to overshoot and burning of the motor winding. To regulate the starting current, there should be a speed controller cascaded with the position and current controllers.

Cascade control involves the use of two controllers with the output of the first controller providing the set point for the second controller, the feedback loop for one controller nestling inside the other. Such a system gives an improved response to a disturbance. So, in this research work the cascade control system is applied for controlling the position, speed, and current of the PMDC motor. And Particle Swarm Optimization (PSO) is used for determining the optimal tuning of the cascade controllers. For the comparison analysis, the Genetic algorithm-based cascade PI controllers have been carried out.

1.2. Statement of the Problem

Elevator systems are one of the complex mechatronic systems in modern building design. The elevator drive system should be efficiently and accurately operated with the proper control system that will monitor its input signal and be able to translate the signal into a control signal that will direct the actual elevator drive system operation. The electric drive is the main part of the elevator. DC motors are popular for this specific system. Even though DC motors have good speed ranges and torque density, due to brushes its operating life is low. Nowadays, the brushed DC motor is replaced by the PMDC motor in the applications like an elevator.

The basic factors that govern the good performance of an elevator drive system include the speed of operation, safety, minimization of energy consumption, and accuracy. Furthermore, investigating the relevant operating conditions of the system is too complicated, and attaining an efficient accuracy, faster control operation, and stability for the system by using a single controller is too difficult especially in the presence of disturbance and load variation. This difficult situation and conditions related to modeling, testing, and performance analysis of elevator drive system can be solved by accompanying the design and simulations of electrical elevator drive control system with cascaded position, speed, and current control drive system using a PI controller. In order to find the optimal gains for PI controllers particle swarm optimization is used. In this research study, particle swarm optimization (PSO) is considered for tuning the cascade controller of the PMDC motor.

1.3. Objectives of the Study

1.3.1. General Objective

The main objective of this research work is to design a PSO tuned PI cascade control for position, speed, and current of permanent magnet direct current (PMDC) motor for electric elevator applications.

1.3.2. Specific Objectives

The specific objectives of this research are:

- To design a cascade controller for the position, speed, and current control of the PMDC motor for the electric elevator system.

- To optimize the designed controller using particle swarm optimization.
- To model elevator drive using the proposed cascaded control system in MATLAB/Simulink.
- To conclude and make recommendations for electric elevator drive control system based on the findings of this research.

1.4. Scope of the Study

The thesis will focus on the modeling, analyzing, and simulating of cascaded position, speed, and current-controlled electric elevator drive parts using a gear-less PMDC motor as a prime mover for the drive system. Analyzing how to improve the performance and stability of electric elevator driving system by designing and tuning a proposed controller for each cascaded loop and proving its performance using MATLAB software.

1.5. Limitation of the Study

The thesis is limited to the simulation of the system using MATLAB Simulink by controlling the position, speed and current of the system interact with each other. But does not include the complete futures of the entire elevator system such as alarm system, door opening and closing operations. And the implementation of a real system is difficult to procure the components. Along with it takes the additional time and cost acquired in making the actual prototype implementation.

1.6. Motivation of the Study

Nowadays traction elevator is used than that of a hydraulic elevator because it is more energy-efficient due to the regenerative energy usage approach of its drive system, and higher speed. In an electric elevator, the motor is used as a prime mover and this motor needs to have good dynamic performance, high efficiency, etc. Different motor drives are available but a permanent magnet direct current (PMDC) motor is better due to its high efficiency, smaller size, and compact weight, etc. for elevator application.

The control of PMDC drive especially in traction elevators is influenced by load variation and disturbance. So, to get good dynamic performance in the system cascade controllers have to be implemented. Cascade control involves the use of two controllers with the output of the first controller providing the set point for the second controller. Such a system can give an improved response to disturbance.

1.7. Significance of the Study

Safety and comfort of the passengers are the main concern of controlling elevator drive system. Thus position, speed and current control is necessary to have a stable and smooth operation for the safety and comfort of the passengers. These types of researches are implemented in elevator companies all over the world. Especially, for Dan lift technology which is an elevator company in Ethiopia this research is helpful to obtain the smooth operation of the elevator.

1.8. Thesis Organization

This thesis organizes into five chapters:

Chapter 1: Presents introduction of the research work, statement of the problems, objectives, scope, limitation, motivation, and significance of the research.

Chapter 2: Includes a literature review on the background of traction elevator, selection of motor for the elevator drive system, and related works.

Chapter 3: Describes the materials and methods that I followed in this research thesis.

Chapter 4: Results and discussion of the proposed controller.

Chapter 5: Presents conclusion and recommendation for future work.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Chapter overview

In this chapter, the theoretical background about traction elevator, selection of appropriate motor for the traction elevator and compare the selected motor with other electric motor types for elevator application. The existing controlling mechanism of the selected motor, the driving techniques, and other related applications of the motor are discussed. Closely related works especially in position control of the electric motor for elevator application are reviewed and discussed.

2.2. Traction Elevator

A traction elevator is a type of elevator that uses an electric motor as its prime mover. And this electric motor used for elevators must satisfy the following requirements like high starting torque, simple speed control, sufficient overload capacity, regenerative braking, handle small disturbances in supply suitable speed-torque characteristics, high efficiency, and size of the motor[5].

To select an appropriate type of motor for the traction elevator a comparison of different motors based on electric elevator requirements is needed. The following are the most common requirements of a traction elevator:

- Encounter the defined capacity
- Be used easily and comfortably
- Efficient and economic
- Not disturb the users while accelerating and decelerating
- Easy and cheap for maintenance
- Robustness and reliability of the motor
- High torque at low speeds
- Size and weight of the motor with the load requirement of the elevator

Based on the above requirements the comparison of different electric motors that can be used for traction elevators is discussed in the following section.

2.3. Electric Motor Types

Different types of electric motors are classified and differentiated by their structure and power sources. Generally, the motors are categorized into three types: DC motor, AC motor, and other types of motors. The classification of motors is described in Figure 2.1 as shown below[6]:

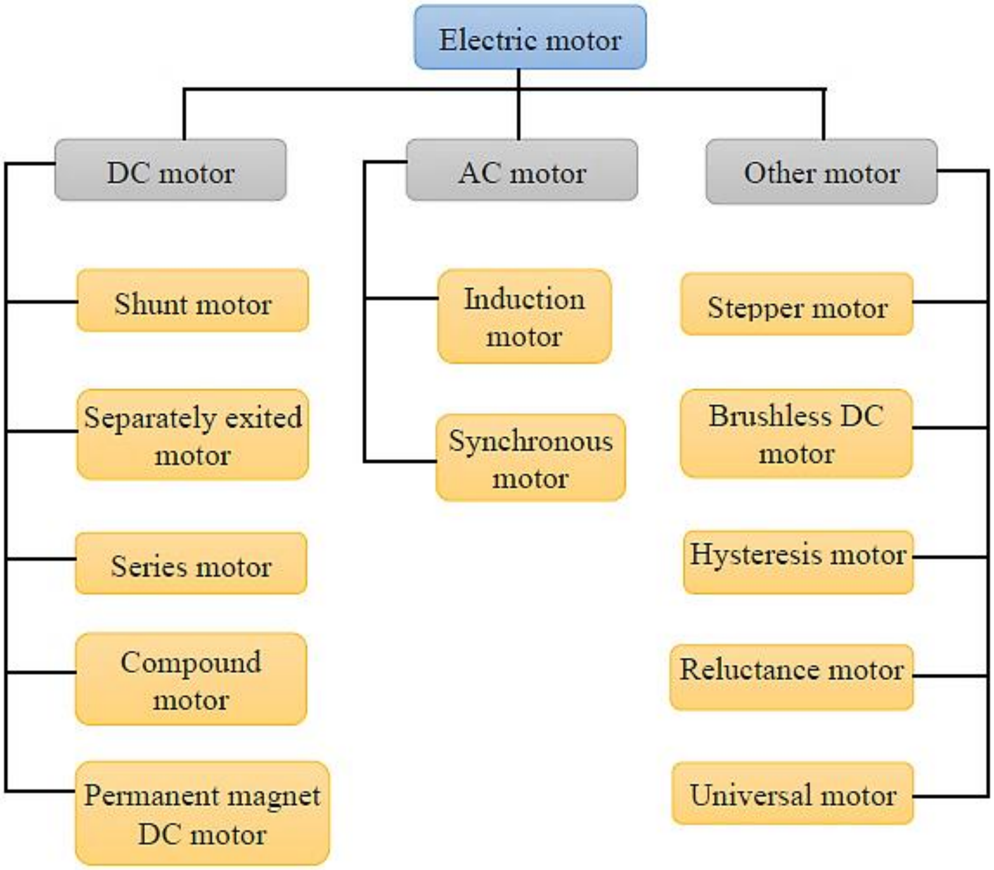

Figure 2.1 Motor classification

2.3.1. Performance Comparisons of Motor

The electric motor plays a significant role in any electric elevator. The most suitable motor among various electric motors for the elevator is the PMDC motor because it has many advantages over brushed DC motor and others motors. These are:

- Do not require any field winding and no field circuit which reduces copper losses,
- Less maintenance,
- Low electric noise,

- Due to a permanent magnet in the rotor, it has low inertia which improves dynamic response,
- Better speed versus torque characteristics,
- Portability in size,
- Lower manufacturing cost,
- Long operating life,
- High efficiency.

2.4. Regenerative Electric Drive Systems

Regenerative drives represent one of the most significant innovations in the latest generation of energy-efficient elevator technology and providing a reduction of energy wastage. There are different phases of operation of regenerative drives in which energy-saving and harnessing occur.

The first one is when an elevator goes up with a light load, the system generates more power than it uses. That power is lost as heat in a non-regenerative (traditional) elevator drive, wasting substantial amounts of energy over the life of the elevator. But regenerative drives capture the heat generated by elevators during use and convert it into reusable energy for the building rather than wasting it as heat.

Furthermore, when an empty or lightly loaded elevator goes up, most of the work is done by the elevator’s counterweight. The regenerative drive harnesses that energy by transforming mechanical power into electrical power [2]. The overall regenerative operation of the electrical elevator drive system can be given as shown in Figure 2-2 below.

Similarly, when a heavy elevator goes down, it applies brakes to maintain the desired speed. The regenerative drive harnesses that energy. Further, when a heavy elevator goes down, the motor partially rotates but gravity does most of the work. The regenerative drive again harnesses and saves that spinning energy by transforming mechanical power into electrical power. Generally, a regenerative drive can reduce energy consumption between 20% and 40% depending upon the designed system considerations [7]. But the accumulated amount of energy savings depends on several factors including the length of the traveling journey, design considerations, and type of equipment.

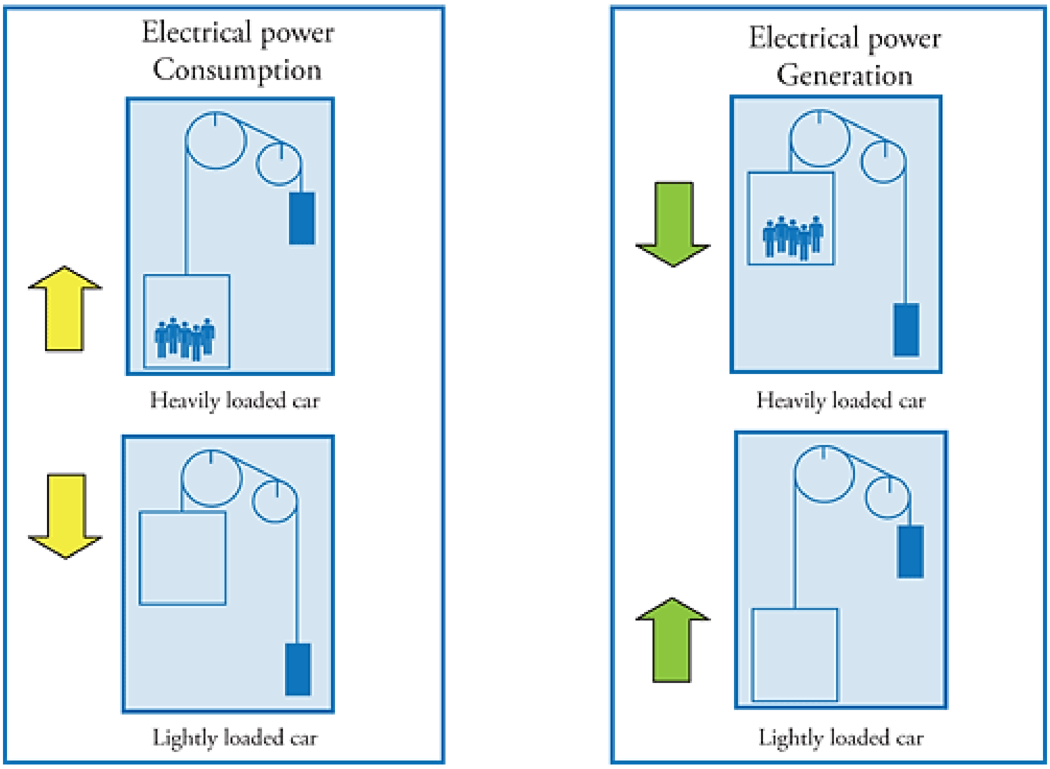

Figure 2.2 The regenerative elevator drive system [2]

2.5. Four Quadrant Operation of Electric Drive

Four Quadrant Operation of any electric drive means that the machine operates in four quadrants. They are Forward Braking, Forward motoring**,** Reverse motoring and Reverse braking. In motoring mode**,** the machine works as a motor and converts the electrical energy into mechanical energy, supporting its motion. Whereas in braking mode, the machine works as a generator and converts mechanical energy into electrical energy, and as a result, it opposes the motion. The Motor can work in both, forward and reverse directions, i.e., in motoring and braking operations.

The four possible quadrants or modes of operation of DC elevator drive are shown in Figure 2.3. In the plot of speed versus torque relation-ship, quadrant one operation is called forward motoring in which the torque is rotating the motor in the forward direction to attain a positive speed convention [8]. Conversely, quadrant three operation is known as reverse motoring. The motor works, in the reverse direction and spinning backward with the reverse torque. Both the speed and the torque have negative values while the power is positive**.** Quadrant two is where the motor is spinning in the forward direction, but torque is being applied in reverse which is known as braking. Torque is being used to brake the motor and making the motor to be in generating mode of operation and generating power as a result.

Finally, quadrant four is exactly the opposite of the operation of quadrant two which is reverse braking. The motor is spinning in the reverse direction, but the torque is being applied in the forward direction. Again, torque is being applied to attempt to slow the motor and change its direction forward. Once again, power is being generated by the motor[9]. When the PMDC motor is operating in the first and third quadrant, the supplied voltage is greater than the back EMF which is forward motoring and reverse motoring modes respectively. When the motor operates in the second and fourth quadrant the value of the back EMF generated by the motor should be greater than the supplied voltage which is the forward braking and reverse braking modes of operation respectively.

Therefore, PMDC motors have the capability of regenerating energy when operating in the negative load condition in traction elevator drive systems. Regenerative braking involves sending the regenerated energy from the elevator drive motor back to the electrical power source. PMDC motor is the best selection of DC motors due to its robustness, high efficiency with minimum energy consumption, and reliability.

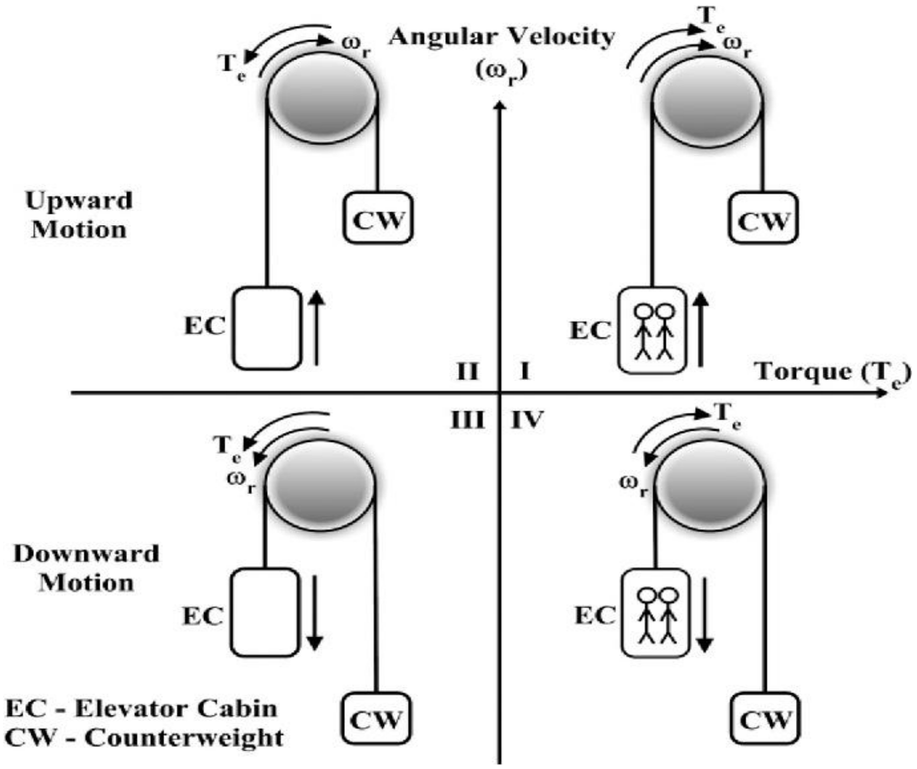

Figure 2.3 Four quadrant operation of elevator drive system

2.6. Speed Profile of Elevators Working Principle

Elevator speed is determined by the elevator service standard corresponds to the traveling distance. The speed should be selected such that it will provide a short round time, almost 25 to 30-second intervals for a medium height building to serve the passengers efficiently with a minimum waiting time as much as possible by handling the peak loads. The principal requirements of an elevator system such as the shortest travel time and passenger comfort are directly related to the shape of the elevator speed versus the time curve. Additionally, the elevator should increase speed slowly after it starts and reduce speed gradually before it stops to smooth the operation of the elevator and avoid vibration to provide a safe journey [10].

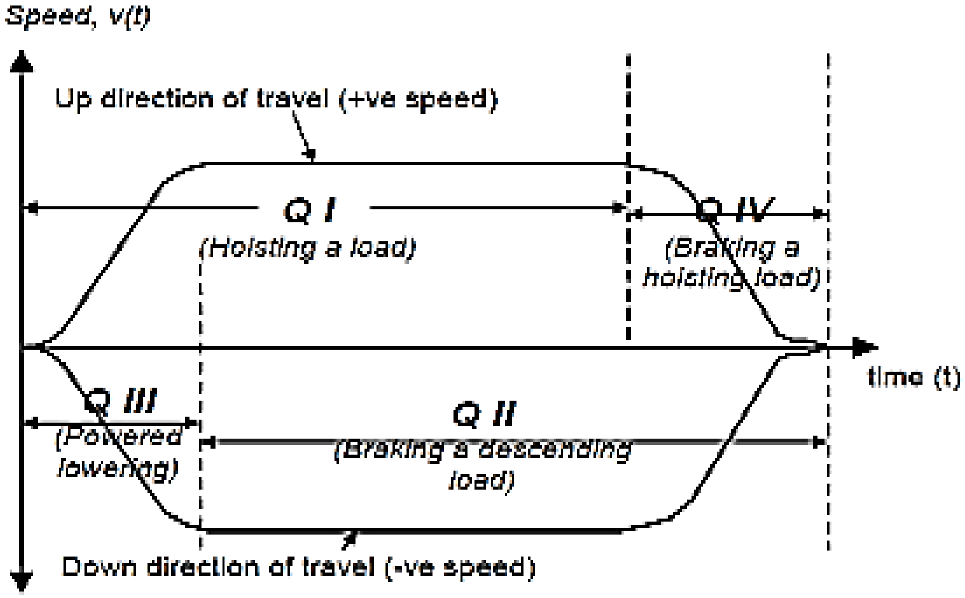

Figure 2.4 Speed profile of an elevator system [11]

The speed-time curve as given in Figure 2.4 indicates the standard characteristics of elevator speed, which consists of three sections illustrating the three modes of operation in the elevator drive system from starting to the destination point of its journey.

First, the motor is rapidly accelerated or decelerates with high positive or negative torque respectively up to the recommended maximum constant speed, at which only small or no torque is required. After the constant speed phase, high braking torque is required to rapidly decelerate or accelerate the motor to stop at the desired position safely [11]. The general standard rules of recommended speed are given in Table 2.1 which is applied basically to commercial buildings, and may also use for similar height and purpose buildings with a wide range of speed.

Table 2-1 Recommended elevator speeds for a different specified range of traveling distances [10]

Recommend standard of the elevator speed (v_c) range (m/s)	Traveling distance (h) of elevator (m)
$v_c \leq 1.00$	$h \leq 20$
$1.00 < v_c < 1.50$	$20 < h < 30$
$1.50 \leq v_c < 2.50$	$30 \leq h < 45$
$2.50 \leq v_c < 3.50$	$45 \leq h < 60$
$3.50 \leq v_c < 5.00$	$60 \leq h < 120$
$v_c \geq 5.00$	$h \geq 120$

2.7. Related Works

Several research papers have been proposed on the position control of an elevator drive by using different optimization algorithms. Usually, the elevator drive control is the combination of the position, speed, and current control loops. These control loops are configured as a one cascade control system. A permanent magnet DC motor is highly used in the history of electric elevators. The cascade control loop configuration is a combination of three control loops, so the outer loop is position control, the inner loop is speed control, and the innermost loop is the current control system.

A comparative analysis of speed control of PMDC motors under variable loads and reference speeds using a proportional-integral controller (PI) and fuzzy logic controller (FL) is proposed in [13]. The result shows that fuzzy logic controller, the time to reach steady state is less as compared to the PI controller for unloaded, loaded, and then suddenly changing load conditions.

An implementation for a microcontroller-based elevator positioning-control method on a microcontroller family of HCS-12 employing fuzzy logic has been developed in [14]. The upward or downward movement of the elevator is achieved through the signal generated by the fuzzy logic control (FLC) unit, which is incorporated with the microcontroller (MC) unit. The result shows a smooth operation in the upward direction. The operation is not smooth for the downward direction based on the setpoint tracking and loaded conditions.

A comparative analysis of PID and fuzzy-PID based on PLC has been formulated in [15]. According to the results when the load is suddenly increased, the elevator with the fuzzy-PID control method adjust timely the system to effectively weaken the interference signals, and quickly re-enter a predetermined steady-state operating point. There is a high overshoot when there is a load variation and this distracts the operation of the system.

The authors in [16] compare PID and PI controllers for speed control of PMDC motor under both load and without load. The result shows at no-load condition PI controller has minimum overshoot than the PID controller but leads to high overshoot with the loaded condition. Whereas, the steady-state error is 0% for PID controller and minimum error for PI controller. The main drawback is the overshoot leads to instability problems.

An artificial neural network (ANN) controller for speed control of PMDC motor has been carried out in [17]. In this work, the result is compared with the PID controller. It shows the PID controller has both steady-state error and overshoot. Whereas the ANN controller has minimum steady-state error and 0% overshoot. Their result can be further improved through advanced optimizations. ANN learning algorithm takes more computation time when it trains the weights online.

A comparative analysis of PID, fuzzy, and fuzzy-PID-based control of PMDC motor speed control has been analyzed in [18]. The PID controller has the highest overshoot and hence a faster reaching time and zero steady-state error while FLC has significantly reduced the overshoot and no steady-state error, therefore causing rise time to increase. For the Fuzzy-PID controller, the percentage overshoot has almost vanished but a minimum steady-state error occurs.

Position control of permanent magnet direct current motor by PID controller parameters using Ziegler-Nichols (ZN) and Particle Swarm Optimization (PSO) have been done in literature [19]. The conventional gain tuning of PID controller (such as Ziegler-Nicholas method) usually produces a big overshoot, to overcome this difficulty a PSO is employed to improve the capability of conventional techniques. However, the D-controller in the PID configuration may lead to an instability problem for position control.

A comparison of Ziegler Nichols, fuzzy logic control (FLC), genetic algorithm (GA), and particle swarm optimization (PSO) for tuning PID parameters of DC motor speed control has been analyzed in [20]. In the case of tuning PID parameters of DC motor speed control, the PSO optimization techniques performance better than the rest. Nevertheless, the derivative controller in the PID leads to an overshoot.

In general, from the above-reviewed literature in this section position and speed control of permanent magnet direct current (PMDC) motor using different controller techniques are discussed. The elevator drive system must have a smooth and safe operation in the existence of load variation. From the above-related works, most of the authors use PID controller, the derivative controller cause noise and overshoot.

So, by using PI controller for position, speed and current control system it avoids the overshoot. Therefore, the will have smooth operation by avoiding the vibration that occurs by the overshoot using PSO-PI controller for the position, speed and current control. The proposed control system performance is checked at no-load and load conditions based on the ascending and descending movement directions of the elevator.

CHAPTER 3

3. MATERIALS AND METHODS

3.1. Chapter Overview

In this chapter the data collection and analysis, mathematical modeling of the elevator dynamics and permanent magnet direct current (PMDC) motor, and design of controllers for position control of PMDC motor is included. The system is simulated by using MATLAB/2019b software both in Simulink and script. The cascade PI controller is used for position, speed, and current control of the PMDC motor for electric elevator drive application. To determine the optimal gains of the three PI controllers in the cascade system a particle swarm optimization (PSO) is used. For the comparison of optimal results, the proposed system is tuned using genetic algorithm optimization. Then the overall permanent magnet direct current (PMDC) motor drive setup is discussed.

3.2. Materials

This research work used MATLAB / 2019b, Microsoft office 2019, Microsoft Visio, Math Type 6.0, and other software. MATLAB is a computing software composed of a technical toolbox and Simulink. Microsoft Office is used to edit thesis documents. Microsoft Visio is used to draw block diagrams in Microsoft Office. Math Type 6.0 is used to write mathematical formulas and equations in Microsoft Office Word and PowerPoint presentation tools.

3.3. Methods

The method used in this thesis to accomplish the required task is shown in Figure 3.1. The closely related papers and literature are reviewed. Then the necessary data used throughout this research is collected and analyzed. PMDC motor specifications for the electric elevator drive system have been taken from the manufacturing company and some of the other specifications taken from the literature. Then, dynamics modeling of the overall elevator drive system and PMDC motor are analyzed. The PMDC motor cascade control drive for the position, speed, and current are designed and implemented in MATLAB/Simulink. Then the result of the position controller is compared with different optimization techniques. Finally, conclusions and recommendations are given based on the result.

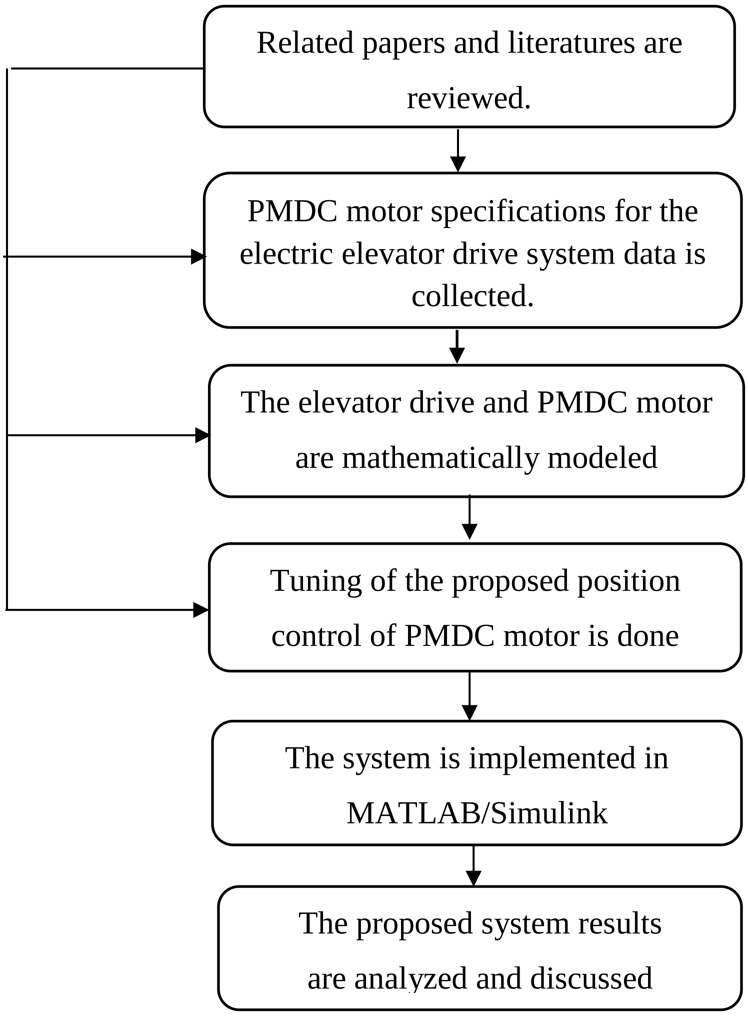

Figure 3.1 Block diagram of the thesis methodology.

3.4. The Proposed Block Diagram of PMDC Motor Drive

The proposed system block diagram of the cascade control of the PMDC motor drive for the propulsion of the electric elevator is shown in Figure 3.2. The AC power from the supply is converted to DC using an AC-DC converter. Then DC to DC converter is a static device that converts fixed DC input to a variable DC output voltage directly to supply DC electrical machines. And this Direct Current (DC) power source is connected to the motor.

The speed of the motor is captured by the sensor and fed back to the controller. The position of the motor is obtained by integrating the speed of the drive over time and is also fed back to the controller. The current flow out of the DC-DC converter is monitored and reported back to the controller as well. With these three real-time inputs the controller can bring the motor to the desired position.

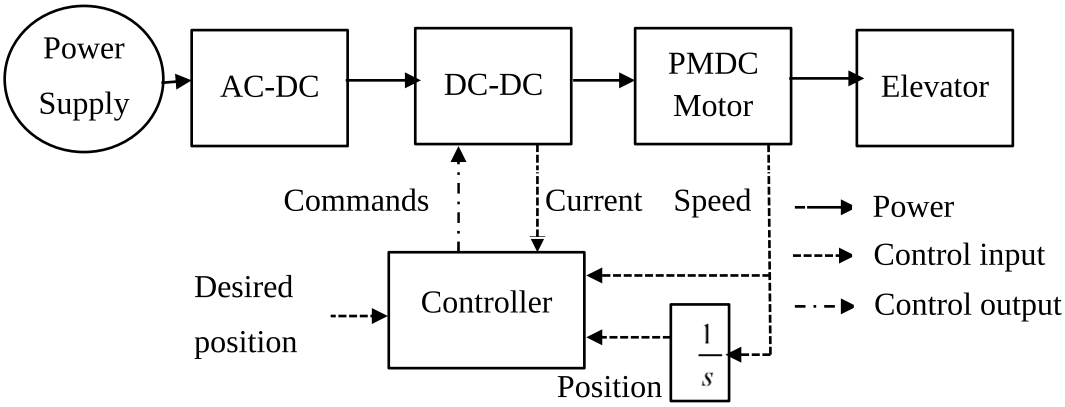

Figure 3.2 Block diagram of the proposed drive control system

3.5. Modeling A Driving Dynamic of the Overall Elevator Drive System

By applying Newton's law of motion in the general elevator drive system for energy balance analysis, a mathematical model in the form of differential equations describing the characteristics of the elevator drive system can be generated. When developing the mathematical model of the mechanical elevator drive system, several assumptions were made.

In this work, the basic assumptions used to develop the mathematical model of the elevator drive system are the following:

- When modeling the system with compensating cables, the suspension cables are considered without mass, in which the inertia of the cables integrates with the elevator car is related to the inertia of the counterweight.
- In addition, the dynamics of the moving string, governor influence, air pressure, and other similar non-basic friction effects are ignored.

Using this assumption and consider the elevator drive system shown in Figure 3.3, the general characteristics of the elevator drive system in the upward and downward conditions will be mathematically modeled and given below.

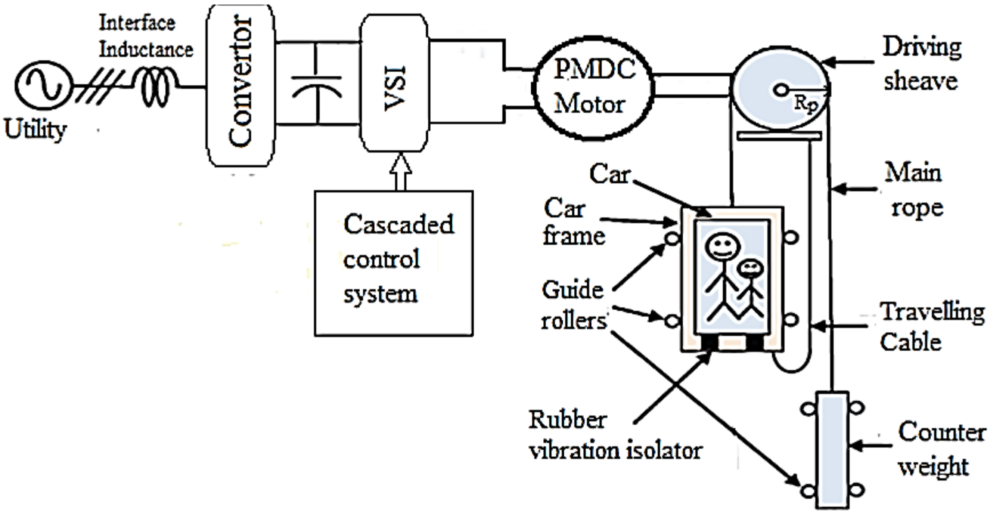

Figure 3.3 Physical model of traction elevator drive system[21]

The sum of the total driving torques of the overall drive system must equal to zero, so that:

$$\tau_{em} - J_m \frac{d\omega_m}{dt} - b_m \omega_m - \tau_l = 0 \tag{3.1}$$

$$\tau_{em} = J_m \frac{d\omega_m}{dt} + b_m \omega_m + \tau_l$$

By applying Newton's law of motion to the general physical system of the elevator in Figure 3.3, the drag torque (load) can be calculated, and then the motion equation of the entire elevator drive system can be calculated.

The load force for elevator car moving upward direction is given by [21]:

$$F_l = (M_l + M_c - M_{cw})g + (M_c + M_l)\frac{dv_c}{dt} \tag{3.2}$$

The car linear speed v_c is in terms of the motor angular speed and radius of the driving pulley attached to the motor shaft given by:

$$v_c = R_p \omega_m \tag{3.3}$$

Then the load force equation can be rewritten as:

$$F_l = (M_l + M_c - M_{cw})g + (M_c + M_l)R_p \frac{d\omega_m}{dt} \tag{3.4}$$

The load torque is directly related to the load force and inertia of the driving pulley with a radius R_p as:

$$\tau_l = F_l R_p + J_p \frac{d\omega_m}{dt} \tag{3.5}$$

Substituting Equation (3.4) in (3.5) for load force, the load torque equation when elevator car moving up is rewritten as:

$$\tau_l = (M_l + M_c - M_{cw})gR_p + (M_c + M_l)R_p^2 \frac{d\omega_m}{dt} + J_p \frac{d\omega_m}{dt} \tag{3.6}$$

Then by substituting Equation (3.6) in (3.1) the overall equation of elevator drive system for ascending elevator car will be obtained as follows:

$$\tau_{em} = (J_m + (M_c + M_l)R_p^2 + J_p)\frac{d\omega_m}{dt} + b_m\omega_m + (M_l + M_c - M_{cw})gR_p \tag{3.7}$$

Similarly, when the elevator car accelerates moving downwards, the mass of the counterweight (M_{cw}) should be considered by ignoring the mass of the elevator car (M_c). So, the load force when an elevator car moving downwards will be:

$$F_l = (M_{cw} - (M_l + M_c))g + M_{cw}R_p \frac{d\omega_m}{dt} \tag{3.8}$$

Then the load torque developed during elevator car is lowering is given by:

$$\tau_l = (M_{cw} - (M_l + M_c))gR_p + M_{cw}R_p^2 \frac{d\omega_m}{dt} + J_p \frac{d\omega_m}{dt} \tag{3.9}$$

Finally, the overall equation when the elevator car is moving downwards (lowering) will be given by:

$$\tau_{em} = (J_m + M_{cw}R_p^2 + J_p)\frac{d\omega_m}{dt} + b_m\omega_m + (M_{cw} - (M_l + M_c))gR_p \tag{3.10}$$

where:

τ_{em} - electromechanical torque

J_m - motor’s moment of inertia

τ_l - load torque placed on the motor’s shaft

g - gravity acceleration

R_p - pulley radius

M_c - car mass

b_m - viscous friction coefficient of the motor M_{cw} - counterweight mass

M_l - mass of the load

3.6. Elevator Drive Components Design and Selection

Under this topic, the design of the transmission components considers and specifies the maximum load capacity of the electric hoist running under the hoist transmission control system that will be designed later in this section. The required materials and maximum load capacity specifications for the required elevator drives that will be controlled by cascade control technology are discussed below.

3.6.1. Designing Elevator Car, Counterweight, and Rope Strength

The elevator car design considers the number of passengers it will accommodate and serve in a single trip. In addition, it should be able to support the weight of the passengers in the elevators. In this article, assuming that the proposed elevator can accommodate 10 passengers with a mass of about 80 kg at a time, the maximum load that the car can withstand will be equal to 80 * 10 = 800 kg.

The car design with a size of 1.5m * 1.5m * 2m can effectively handle this load. Assuming the mass of an empty car is about 100kg, as mentioned earlier in this article, the mass of the counterweight is generally designed to be the sum of the mass of the car and about 50% of the maximum load. The entire mass of the loaded counterweight is suspended by the rope on the drive pulley. The total force exerted on the string and your choice can be determined using Newton’s formula [22]. The force acting on the rope is the sum of the counterweight, the weight of the empty car, and the weight of the passengers. Using Newton's law, the force in the string can be given by:

$$F = mg \tag{3.11}$$

Where g is the acceleration due to gravity and m is the total mass suspended on the rope. Then substituting from the design values above, the force in the rope will be:

$$F = (100kg + 500kg + 800kg) * 9.81 m/s^2 = 13734N = 13.734KN \tag{3.12}$$

Therefore, a rope with the capacity to bear at least 14kN with a specified thickness has to be chosen from the rope manufacturer’s datasheet.

3.6.2. Selection of Motor Power Rating and Driving Pulley Radius

Motor selection refers to the process of selecting the correct motor to run a given load. For the following basic reasons, the correct motor size is important:

- If the motor is too small for the application, it may not be enough to start the load and accelerate it to the corresponding elevator speed, or even If you can charge the in operation to the required speed, the motor will overheat and may burn out as a result.
- If the motor runs much larger than the required load, it will cost too much money to buy a large motor, which in turn increases the cost.
- Also, when the power is less than its corresponding power rating, the motor generally runs with low efficiency

The motor used in this thesis work is a permanent magnet DC motor. Based on the design the specification given above, the output power of the motor is calculated by using the general equation of force on the rope by assuming constant maximum linear car speed of 2m/s, which is taken from the desired standard speed given in Table 2-1 to design an elevator drive system for a building with ten floors above the ground (40m in height). Considering the elevator car moving upward (ascending) with the specified linear speed above, the total load-lifting force (F_l) developed during the journey can be given by the following equation [23]:

$$F_l = (M_l + M_c - M_{cw})g + (M_c + M_l)\frac{d\nu_c}{dt} \tag{3.13}$$

This equation is further simplified by an assumption of constant car speed, and then its time derivative is zero, and Equation (3.13) will be rewritten as:

$$F_l = (M_l + M_c - M_{cw})g \tag{3.14}$$

Then the energy required for upward moving elevator car is given by the energy equation based on load force and the linear distance traveled by the elevator car as given by the following equation.

$$E = FS \tag{3.15}$$

So, the power on the motor shaft is given by a time rate of energy and given by the equation below.

$$P = \frac{E}{t} = \frac{FS}{t} = Fv_c \tag{3.16}$$

From the elevator drive system, while ascending (upward moving) elevator car the counterweight moves downward (opposite direction to car movement) and doing certain work which reduces the required lifting force. This is the basic advantage of a regenerative elevator drive system. Then the equation of power is rewritten by substituting for lifting force as:

$$P = (M_l + M_c - M_{cw}).g.v_c \tag{3.17}$$

Where:

P - total power on motor shaft

v_c - linear speed of elevator car

Substituting for designed parameters and evaluating for motor power gives:

$$P = (800 + 100 - 500) * 9.81 * 2\, {}^{m}\!\!\diagup_{s^2} = 7848watt = 7.848Kw = 10.52432hp \tag{3.18}$$

Additionally, the losses in transmission of power to the driving pulley must be considered and included due to that several assumptions are considered when compared to the real physical elevator drive system. Therefore, the mechanical power output (P) required for driving the load is given by another equation including the efficiency of the system as:

$$P_{tractive} = P/\eta \tag{3.19}$$

Let us consider the efficiency of the transmission system to be 0.85. Therefore, the mechanical power output required is:

$$P_{total} = P/\eta = 7.848Kw/0.85 = 9.232941Kw = 12.381558hp \tag{3.20}$$

Therefore, the motor with a power rating of 13hp is selected to drive the specified elevator load safely. Assuming the selected motor is kept at a rated speed of 200RPM with a drive pulley directly connected to the motor shaft we can design for the radius of the pulley too much with the motor rating speed. Then the radius of the pulley (R_p) using the angular speed of driving pulley (N_p) = 200RPM can be determined by the relation of linear speed and angular speed of the pulley as follows.

$$v_c = \omega_p R_p$$
$$R_p = \frac{v_c}{\omega_p} \tag{3.21}$$

Then, changing the angular speed into rad/s form, substituting the parameters, and evaluating for the driving pulley gives:

$$R_p = \frac{2\,{}^{m}\!/_{s}}{20.944\,{}^{rad}\!/_{s}} = 9.55cm = 0.0955m \tag{3.22}$$

Therefore, a pulley with a radius dimension $0.0955m$ is selected in this design.

3.7. Parameters of the PMDC Motor and Elevator drive system

The value of the desired elevator car mass, counterweight mass, and load of ten passengers (80kg each) is considered and selected as 100kg, 500kg, and 800kg respectively as indicated in this chapter. Based on these load parameter values the drive prime mover components a rope with the capacity to bear at least 14KN, a motor with a power rating of 13hp, and a rated angular speed of 200PM with a driving pulley radius of 9.55cm are selected [24].

The computer simulations were done with typical standard values of the system parameters and the braking occurs when a passenger-defined position is reached. Outputs of the system which have been used to evaluate the performance of the controller proposed are the actual stopping linear position of the elevator, the motor current (torque), and the elevator linear speed profile which is initially accelerated, driving with the desired constant value and finally decelerated to zero at the destination point to make the passenger journey safe and smooth. During the simulation of cascaded position, speed, and current-controlled elevator drive, the basic input for controlling the controlled variables are the initial and destination position of the elevator. The desired input position and the desired elevator linear speed to be achieved are 40m by 2m/s and 4m by 0.8m/s in both up and down directions respectively based on the standard speed profile of the elevator. [25] As it is shown in Table 3-1, the Parameters of the electrical elevator drive System with corresponding load specifications are generated to be used in the simulation.

Table 3-1Parameters of the PMDC Motor and Elevator drive system[8][24]

PMDC motor parameters		Elevator drive design parameters	
Motor armature resistance, R_a	0.5Ω	Nominal motor speed, ω_m	$200 rad/s$
Motor inductance, L_a	$10mH$	Travel height	$4m@0.8m/s$ and $40m@2m/s$ (10 floors)
Motor rated DC voltage, v_a	$220v$	Pulley radius, R_p	$0.0955m$
Torque constant, K_t	$0.75 N.m/A$	Pulley inertia, J_p	$0.1kg.m^2$
Motor inertia, J_m	$0.05kg.m^2$	Car mass, M_c	$100kg$
Total viscous friction gain, B_t	$0.0869N.m.s$	Maximum load weight, M_l	$800kg$
Equivalent inertia of the entire system, J	$4.6189kg.m^2$	Counterweight mass, M_{cw}	$500kg$
		Gravitational acceleration, g	$9.81m/s^2$

3.7.1. Selection of Power Semiconductor Device

For this work, a metal oxide semiconductor field-effect transistor (MOSFET) is selected for the PMDC motor drive. MOSFET ratings are fulfilling the requirements of the PMDC motor drive. Hence in the application of switched-mode power supply like inverter and chopper, MOSFET and (insulated gate bipolar transistor) IGBT are highly competent. Usually, they are selected based on their ratings [26].

MOSFET is a low voltage device that is mostly available up to 600V and it is voltage-controlled and it is certainly the device of choice for devices with voltages below 250V. Currently, MOSFET and IGBT are competent semiconductor devices. But, IGBT has a collective characteristic of BJT and MOSFET. The gate behavior of IGBT and MOSFET is similar and is easy to turn on and off. The rating of IGBT is in thousands of volts (>1000V). However, voltage levels below 1000V are available and have better performance, but its cost is very high for low voltage applications. The voltage rating of the PMDC in this study is 220V [27]. Due to these, metal oxide semiconductor field-effect transistor (MOSFET) is selected for the design of the three-phase inverter because it has the appropriate ratings that will fit with the PMDC drive used in this study.

3.7.2. Mathematical Modeling of PMDC Drive

The overall structure of the elevator system is shown below, which indicates how the major components are integrated as general overall of an elevator system. The whole system is modeled by integrating the electrical system and the mechanical system. As shown in Figure 3.4, the electrical system mainly refers to the PMDC motor circuits as a prime mover of the elevator, a convertor to feeding the motor input voltage from the utility, a circuit controlling its voltage input, and also the sensors that provide input to the control system by monitoring the status of the mechanical system.

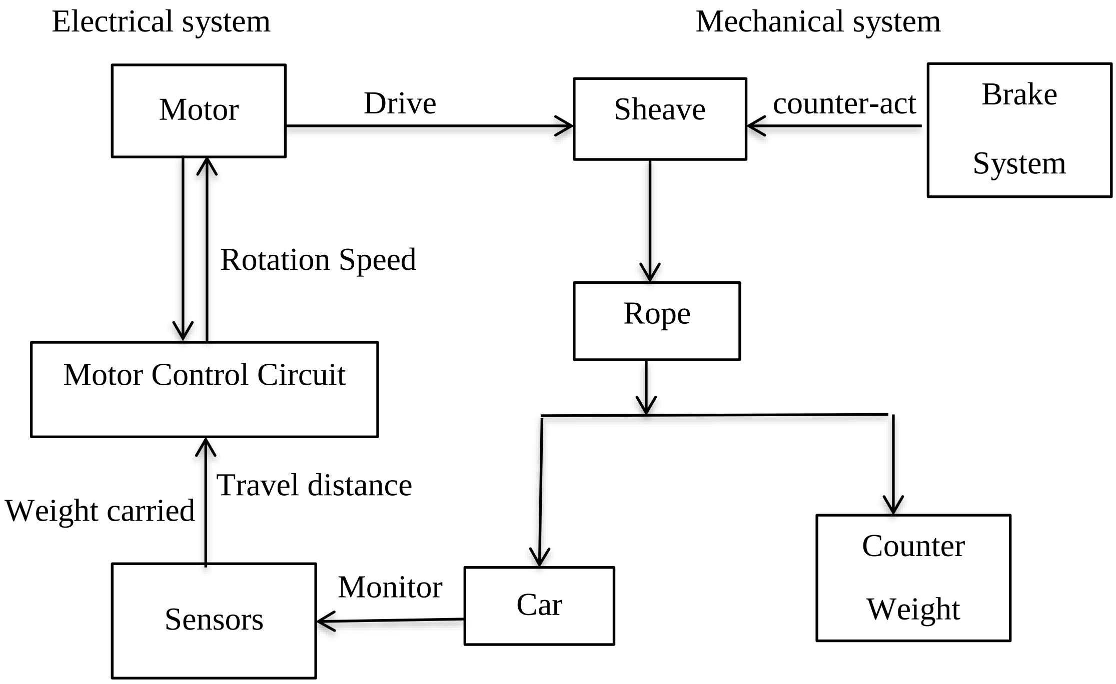

Figure 3.4 The general structure of the electrical elevator system model

The mechanical system includes a car, a counter-weight, a rope connecting the two, a sheave that drive the rope to roll from the car side to counterweight or vice versa, and a brake system that helps to stop the car when reached the desired destination. A pair of guide rails are placed on two opposite sides of the car to guide the car during the elevator motion. The weight of the car and part of its load are balanced by the counterweight. The counterweight is constructed from a steel frame and stacked fillers or weights secured by two or more tie-rods.

Both elevator car and counterweight are connected through traction ropes that pass through the traction system surrounding the driving pulley at the top of the hoist way consisting of driving sheaves and an electric motor. Similar to the passenger car, the counterweight is also guided by two guide rails along its sides during the vertical motion.

3.7.2.1. Mathematical Modeling of the Electrical Part of PMDC motor

The Permanent magnet direct current (PMDC) motor is a type of DC motor and its poles are constructed from permanent magnets. Its system is an example of electromechanical systems with electrical and mechanical components. In modeling PMDC motors and to obtain a linear model, the hysteresis and the voltage drop across the motor brushes are neglected. A simplified equivalent representation of the PMDC motor circuit is shown in Figure 3.5 below [29].

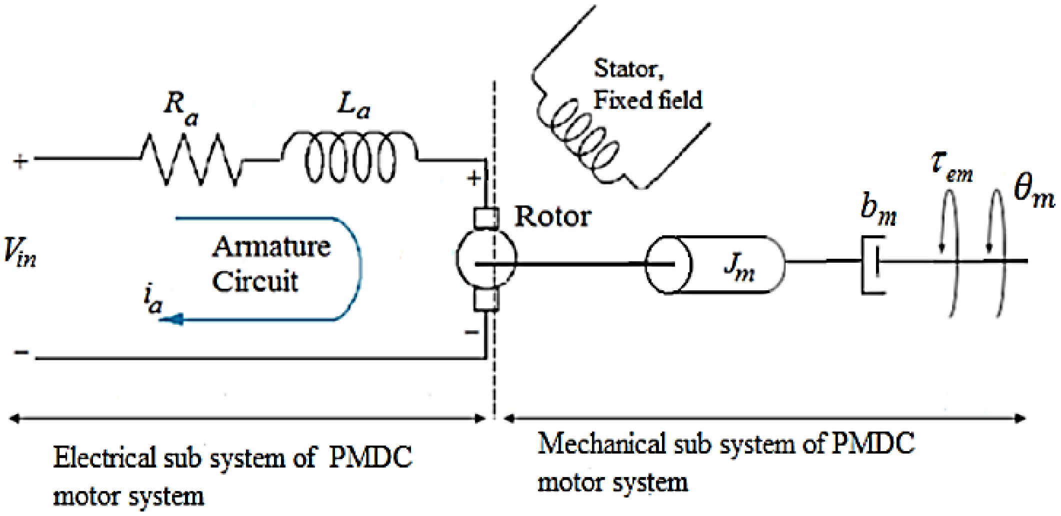

Figure 3.5 Equivalent circuit representation of the PMDC motor [29]

The torque developed by the motor, τ_m is related to the armature current, i_a by a torque constant, K_t which can be written as:

$$\tau_m = K_t * i \tag{3.23}$$

Similarly, the induced electromotive force (EMF) is related to the motor shaft angular speed, ω_m by a linear relation as:

$$e_a(t) = K_b \frac{\theta_m d(t)}{dt} = K_b \omega_m \tag{3.24}$$

where:

K_b - EMF constant

θ_m - motor angular position

Based on Newton's law combined with Kirchhoff's law, the mathematical model in the form of differential equations describing electric characteristics of the armature controlled PMDC motor can be derived. Applying Kirchhoff's law around the electrical loop of the motor:

$$\sum v = v_{in} - v_R - v_L - emf = 0 \tag{3.25}$$

Applying Ohm's law, substituting and rearranging, the differential equation that describes the electrical characteristics of PMDC motor can be obtained as follows.

$$v_{in}(s) = R_a * i_a(t) + L_a \frac{di_a(t)}{dt} + K_b \frac{d\theta(t)}{dt} \tag{3.26}$$

Taking Laplace to transform and rearranging, gives:

$$v_{in}(s) = R_a I_a(s) + L_a s I_a(s) + K_b s \theta_m(s) \tag{3.27}$$

$$(L_a s + R_a) I_a(s) = v_{in}(s) - K_b s \theta_m(s)$$

where:

I_a - armature current	v_{in} - Input voltage of the motor
R_a - armature resistance	v_L - armature inductor voltage
L_a - armature inductance	v_R - armature resistor voltage
θ_m - motor angular position	K_b - EMF constant

3.7.2.2. Mechanical Characteristics of the Motor

Performing the energy balance on the PMDC motor system the mathematical model in the form of differential equations describing mechanical characteristics can be derived. The sum of the torques must equal zero, which is given by:

$$\sum \tau = J * \alpha = \frac{J * d^2\theta}{dt^2} \tag{3.28}$$

$$\tau_e - \tau_\alpha - \tau_\omega - \tau_{emf} = 0$$

$$K_t * i_a - \tau_{load} - J_m \frac{d^2\theta_m}{dt^2} - b_m \frac{d\theta_m}{dt} = 0$$

Taking Laplace transform of the equation above and rearranging, gives:

$$K_t * I(s) - \tau_{load}(s) - J_m * s^2\theta_m(s) - b_m s\theta_m(s) = 0 \tag{3.29}$$

$$K_t I(s) - \tau_{load}(s) = (J_m s + b_m) s\theta_m(s)$$

From the derived equations above and rearranging, the PMDC motor open-loop system transfer functions can be derived. We can solve for the current from equation (3.27) which is given by:

$$I(s) = \left[\frac{1}{(L_a s + R_a)}\right]\left[v_{in}(s) - K_b\omega_m(s)\right] \tag{3.30}$$

Then, the PMDC motor electrical component transfer function relating armature current and voltage is given by:

$$\frac{I(s)}{\left[v_{in}(s) - K_b\omega_m(s)\right]} = \frac{1}{(L_a s + R_a)} \tag{3.31}$$

Similarly, the motor’s mechanical component transfer function in terms of output torque and rotor speed is obtained from Equation (3.29) as:

$$\frac{\omega_m(s)}{\left[K_t I_a(s) - \tau_{load}\right]} = \frac{1}{(J_m s + b_m)} \tag{3.32}$$

In case of no load attached $\tau_{load} = 0$, the equation becomes:

$$\frac{\omega_m(s)}{\left[K_t I_a(s)\right]} = \frac{1}{(J_m s + b_m)} \tag{3.33}$$

3.8. Block Diagram Representation of PMDC Motor Model

The PMDC motor electrical part transfer function relating input armature current, i_a and input voltage, and also the motor's mechanical component transfer function relating to output torque and rotor speed is derived above.

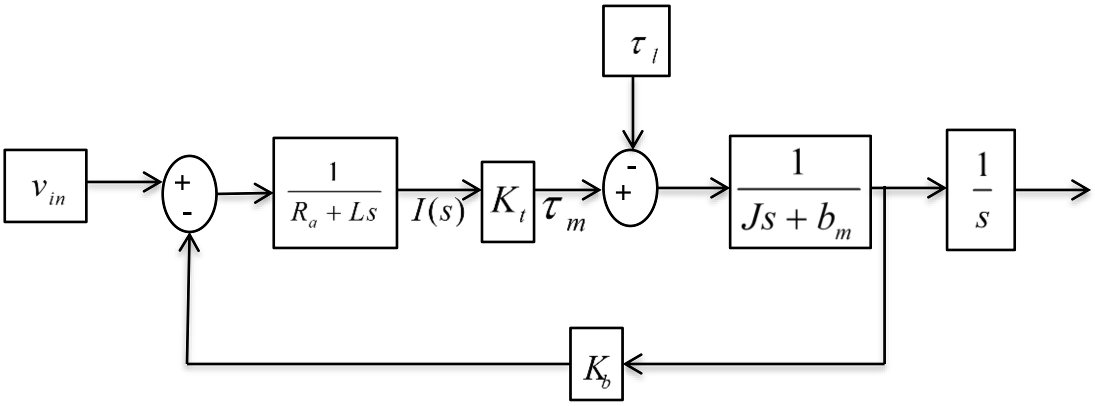

Figure 3.6 The block diagram representation of open-loop PMDC motor system

Also, the electrical and mechanical components of the motor are coupled to each other through an algebraic torque equation by torque constantK_t. Using these relations, we can build the block diagram model of the open-loop PMDC motor system shown in Figure 3.6.

3.9. Controller Design

There are different basic considerations in designing the passenger elevator system, specifically the elevator drive control system. The basic and important specifications needed to be considered in the design aspect of elevator drive include [30]:

- The number of floors in the building
- The distance between each floor
- The maximum load capacity of the elevator
- The specific standard speed based on the height of the building and
- The time in which the elevator operates with consideration of passenger's comfort and safety to reach the desired destination.

So, to meet these requirements, it is needed to design the basic parameters related to the above specifications as well as the control system which governs the drive system to operate smoothly and accurately. The design parameters to be considered before controller design consists of specifying and fixing elevator car dimension, rope strength, the selection of driving pulley radius on which car and counterweight are suspended, selection of the correct prime mover (efficient and cost-effective motor rating) of the elevator drive system. Then select a proper controller type and designing its parameters to develop a proper control system to achieve a stable and efficient elevator drive system.

3.9.1. PID Controller

Feedback loops are key elements to the control of a system's behavior and are used in a variety of areas. Taking advantage of closed-loop operation makes it possible to accelerate transient processes, reduce the impact of disturbances on the system and tune its steady-state behavior [31].

The PID controller first compares the system's output with a user-defined setpoint and generates an error signal. It then tries to minimize this error signal by adjusting its output, which in turn drives the system. This driving signal is obtained by adding three terms calculated separately from the error signal: the terms are referred to as proportional (P), integral (I) and derivative (D), and each has its gain.

The PID controller in the time-domain is described by the relation:

$$u(t) = k_p + k_d \frac{d}{dt} e(t) + k_i \int e(t)\, dt \tag{3.34}$$

The PID controller has a transfer function:

$$K(s) = k_p + k_d s + \frac{k_i}{s} \tag{3.35}$$

The controller gains for the three basic modes of control are given as: $\{k_p, k_i, k_d\}$ of these, the proportional term serves as a static controller, the derivative term helps speed up the system response, and the integral term helps reduce the steady-state error.

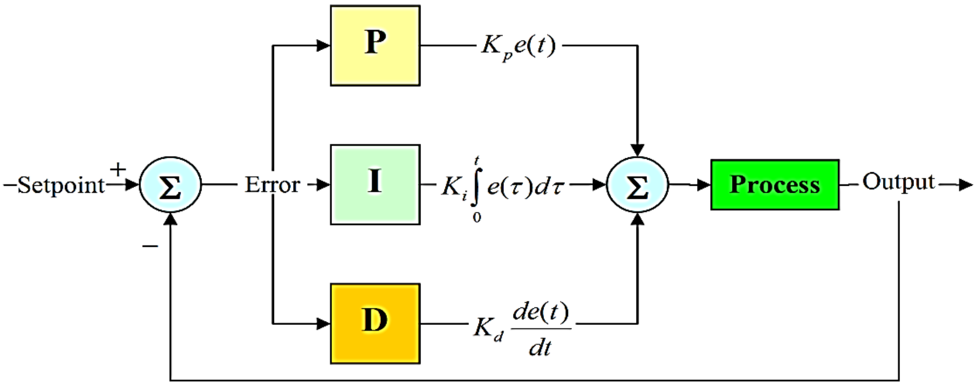

Figure 3.7 Structure of PID controller

3.9.1.1. Closed-loop Characteristics Polynomial

Let $G(s)=\frac{n(s)}{d(s)}$; then the closed-loop characteristic polynomial with a PID controller in the loop is given as:

$$\Delta(s)=sd(s)+\left(k_d s^2+k_p s+k_i\right)n(s) \tag{3.36}$$

For noise suppression, a first-order filter may be added to the PID controller; the modified controller transfer function is given as:

$$K(s)=k_p+\frac{k_i}{s}+\frac{k_d s}{T_f s+1} \tag{3.37}$$

The filter additionally makes the controller transfer function proper and hence realizable by a combination of low-pass and high-pass filters. The control system design objectives may require using only a subset of the three basic controller modes. The two common choices, the proportional-derivative (PD) controller and the proportional-integral (PI) controller. In this thesis, a PI controller is used. Because the derivative action cause noise and disturbance and the main factor in an elevator are to avoid the noise and disturbance.

3.9.2. Structure of PI Controller

The structures of PI controllers as their names indicate consist of parameters named as proportional and integral components. The derivative controller (D) can be used to reduce the rapid speed oscillation caused by high proportional gain of the controller, but it is not used in many controllers of different application areas because the derivative action causes the noise (random error) in the main signal to be amplified and reflected in the output. Hence the most suitable controller for the position, speed, and current (torque) control is the PI type controller.

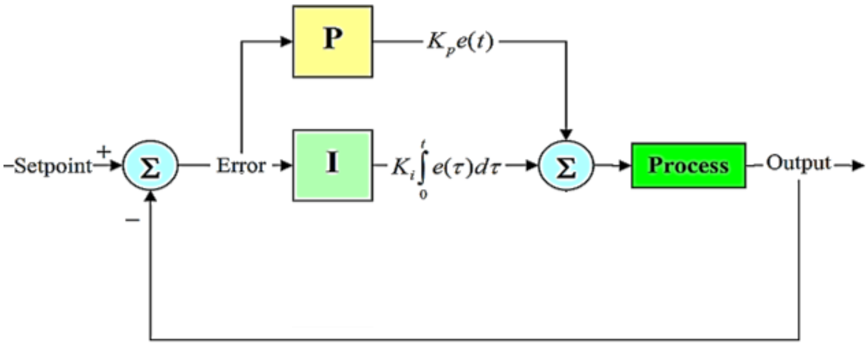

Figure 3.8 PI controller structure

So, the Proportional Integral type (PI) controller transfer function is given by:

$$G_{PI}(s) = K_p + \frac{K_i}{s} = K_p\left(\frac{K_p s + K_i}{K_p s}\right) = K_p\left(\frac{\frac{K_p}{K_i}s + 1}{\frac{K_p}{K_i}s}\right) \tag{3.38}$$

By substituting T_c for K_p to K_i ratio in the above equation, the PI controller transfer function can be further simplified and represented by a more general, equivalent transfer function as given by the equation below.

$$G_{PI}(s) = K_p\left(\frac{1 + T_c s}{T_c s}\right) \tag{3.39}$$

3.9.3. Designing Cascaded Position, Speed, and Current Controller Parameters

To design a particular control loop, the values of the parameters have to be adjusted so that the control input provides acceptable performance from the plant. To get an acceptable solution, several controller design methods can be applied. One of those methods is cascade control which is the use of two controllers with the output of the first controller providing the set point for the second controller, the feedback loop for one controller settling inside the other. Such a system can give an improved response to disturbance. This is because the inner loop is both closer to the source of the disturbance and faster than the outer loop.

Although the method provides a first approximation in design, the response produced usually needs further manual retuning by the designer for robust performance. The general bock diagram of the cascaded control system of elevator drive with convertor fed PMDC motor as a prime mover of the system is shown in Figure 4.2. In this paper, the classical design approach followed by manual retuning is applied to achieve a stable system which is the system with no overshoot and the fastest settling time possible.

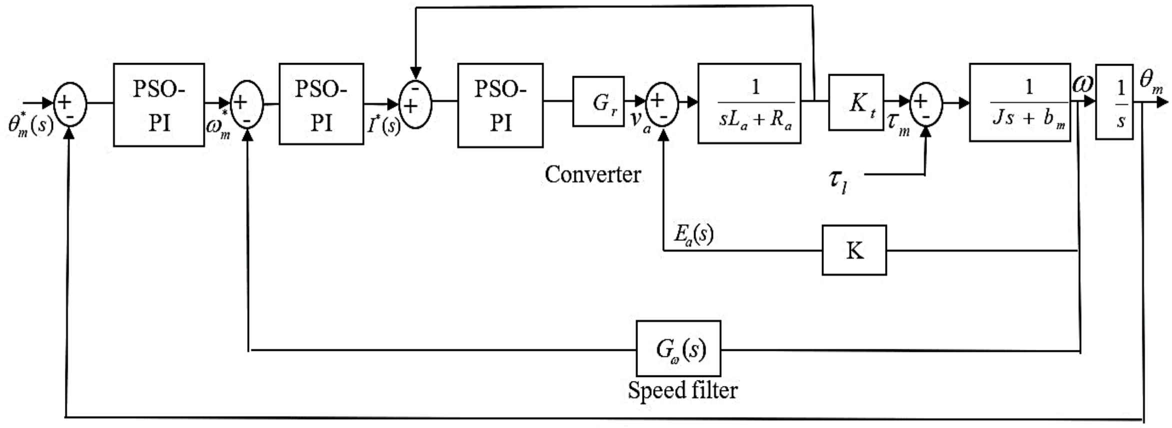

Figure 3.9 Block diagram representation of cascaded control system with PMDC motor drive

First of all, the current control loop, which is the innermost loop, is designed due to that the performance of the outer loop is dependent on the inner loop. This innermost loop control is useful in preventing too much high-current flow in both the converter and the motor. The control of the current is equivalent to the control of the torque, although there is not a direct measurement of torque.

Therefore, the design and tuning of the inner loop have to precede the design and tuning of the outer loop. The current and torque are proportional in the PMDC motor because of the constant field flux so that the current can be considered as a control element. The inner current loop will cross this back emf loop, creating complexity in the development of the model as shown in Figure 3.8.

The interactions of these loops can be decoupled by the development of a reduced block diagram using step-by-step block reduction as shown below. The load torque τ_l is assumed to be proportional to angular speed and is given as:

$$\tau_l(s) = B_l \omega_m(s) \tag{3.40}$$

3.10. Convertor Modeling

The converter can be considered as a black box with a certain gain and phase delay to model it as a source conversion subsystem in dc drive control system applications. The dc output voltage of the three-phase controlled AC/DC converter is characterized mathematically as given by the equation below:

$$V_{dc} = \frac{3}{\pi}\cos\alpha = \cos\left(\cos^{-1}\left(\frac{v}{v_{cm}}\right)\right) = \frac{3}{\pi}\frac{v}{v_{cm}} \tag{3.41}$$

Similarly, the gain of the linearized controller-based converter, K_r for a maximum control voltage v_{cm} is determined from the gridline to line root mean square voltage and the specified maximum control input voltage.

$$K_r = \frac{3v_m}{\pi v_{cm}} = \frac{3\sqrt{2}v}{\pi v_{cm}} = \frac{1.35v}{v_{cm}} \tag{3.42}$$

We can consider a converter as a sampled-data system in which its sampling interval gives an indication of its time delay by using electronic switches, usually, thyristors, in which the delay angle can be corrected in each cycle and will be ready for implementation within 60 degrees which is the angle between two thyristors gating so that the converter time delay can be considered as one half of this interval in time. Therefore, the delay time of the converter is given by:

$$T_r = \frac{60/2}{360} \text{*(Time period of one cycle)} = \frac{1}{12} * \frac{1}{f_s} \text{sec} \tag{3.43}$$

In this thesis, a linear source convertor with a maximum control voltage of ±10V is modeled to generate the appropriate DC voltage needed to supply the PMDC motor used in the elevator drive system from a 3-Phase AC source at 50Hz. Substituting for the supply frequency in the equation, the time delay of the convertor is equal to 1.667ms.

Then the converter with first-order transfer function is modeled by using its gain and time delay which is given by:

$$G_r(s) = K_r e^{-T_r s} \tag{3.44}$$

Then equation can be re-represented as a first-order time lag converter transfer function as:

$$G_r(s) = \frac{v_a(s)}{v_c(s)} = \frac{K_r}{1+T_r s} \tag{3.45}$$

where,

$$K_r = \frac{1.35v}{v_{cm}} = \frac{1.35*230}{10} = 31.05 \tag{3.46}$$

Then the transfer function of the modeled converter with numerical values of its parameters is given by:

$$G_r(s) = \frac{31.05}{1+0.001667s} \tag{3.47}$$

3.10.1. AC/DC Voltage Source Converter

The power conversion system of the AC/DC voltage source converter (VSC) is given below as shown in Figure 2-5 which consists of six electronic switches with full-bridge diode rectifiers to allow bidirectional current flow capabilities and a filter capacitor at the output DC side. Voltage source converters are electronic circuits for which input power to the system is from the ac power source and generates the desired output dc voltage [32].

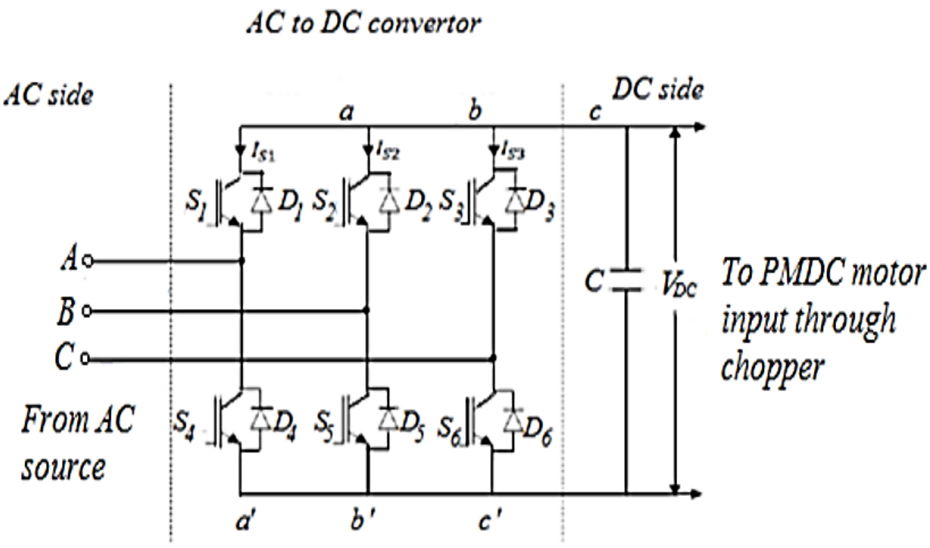

Figure 3.10 AC/DC voltage source converter[33]

Generally, there is a frequency difference between the power converters and the supply. The power convertor switches are operating at a frequency usually higher than the supply frequency. Such higher switching frequencies effectively reduce the harmonics content of the current waveform with smoother torque. To increase power quality by reduction of current ripple and total harmonic distortion in the conversion system, either an inductive or inductive-capacitive filter can be added to the voltage source converter [33].

When the convertor input is directly from the ac-grid line source, the DC-link voltage produced from the ac-grid voltage, using a diode rectifier is given by:

$$v_{DC-link} = 3\frac{\sqrt{2}}{\pi} v_{rms-grid} = 3\frac{\sqrt{2}}{\pi} * 380 = 513.17v \qquad (3.48)$$

In this thesis, a transformer on the supply side is needed to step down the magnitude of the voltage that comes from the grid to generate the appropriate DC voltage needed to generate the appropriate output voltage that matches with the desired motor input. So, the thyristor bridge in a convertor model gets its ac supply through a step-down three-phase transformer and the dc output from the converter is fed to the armature of the dc motor through four quadrant choppers.

3.10.2. DC/DC Four-quadrant Chopper

A chopper is a static device that converts fixed DC input to a variable DC output voltage directly to supply DC electrical machines. It can be given another name as DC to DC converter. In choppers, the transistors are commonly operating in the switching mode technique known as pulse weeds modulation (PWM), usually at frequencies between 1 kHz to 10 kHz. In the PWM technique, the average DC voltage is proportional to the pulse width. It is widely used in an electric motor control system to operate in regenerative braking [34].

Essentially, a chopper is an electronic switch that is used to interrupt one signal under the control of another by the actions of switches components (usually transistors). The switches in the four-quadrant chopper can be switched in two different modes; the first mode is that output voltage swings in both directions from positive DC to negative DC voltage, and the second mode of operation is that a voltage swing from zero to positive DC voltage or from zero to negative DC voltage.

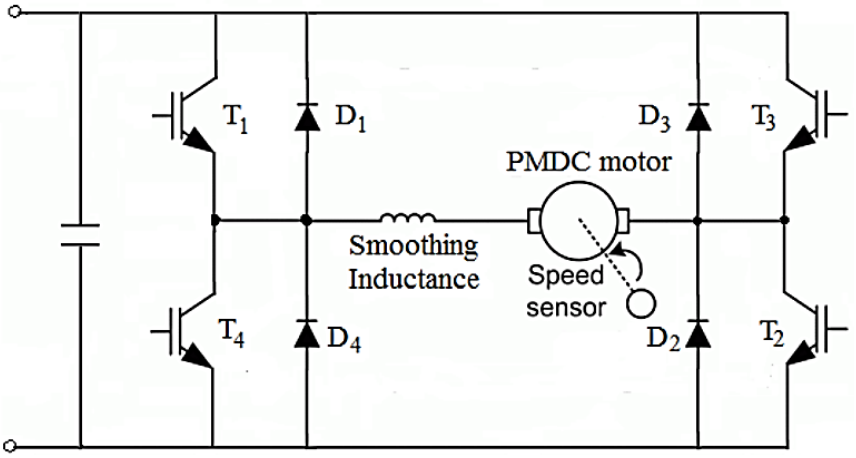

Figure 3.11 DC/DC four-quadrant chopper[34]

The regenerative operation of the four-quadrant chopper given in Figure 3.11 is directly related to the conducting behavior of corresponding switch components (transistors) in the circuit [24]. When transistors T_1 and T_2 are in conducting mode of operation, the chopper operates in quadrant one which is known as a forward motoring mode of operation. In this mode of operation both voltage and current are positive which results in positive power flows from the source to the load. In the second quadrant, the transistors T_4 and T_2 are switched on, in which the voltage is still positive but current is negative and results in a negative power, which means a power flows from a load back to the source if a load is an inductive type or back emf source such as motors.

In the third quadrant is the operation of the chopper in which T_3 and T_4 are in conducting mode in pairs. In this case, both the voltage and current are negative which results in a positive power flow from a source to the load. Finally, in the fourth quadrant, the voltage is negative but the current is positive which is achieved through the reverse conduction of transistors T_2 and T_4. Therefore, the power is negative in this quadrant.

3.10.3. Pulse Generator

PWM generator is used for DC to DC converter to have a four-quadrant operation. Figure 3.11. Shows the general block diagram for the structure of the PWM signal generation. It includes the high-frequency carrier signal and message signal. The message signal is from the motor.

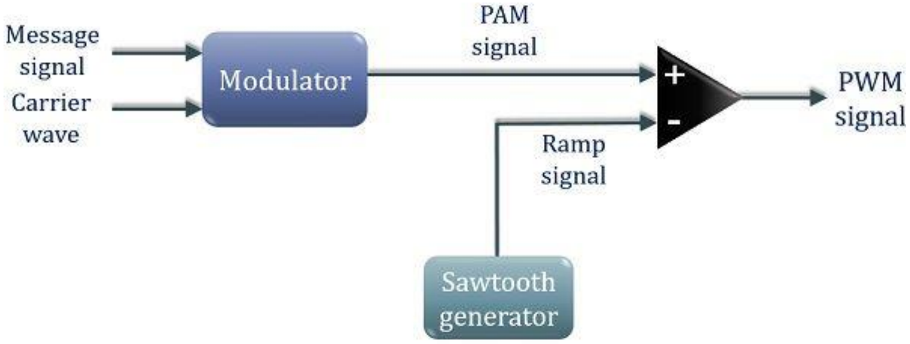

Figure 3.12 Pulse signal generation using PWM

3.11. Parameter Tuning of a Cascade Controller using PSO

Based on the social behavior of birds or fish, PSO is a well-known algorithm for optimizing a system. It is improved by Eberhart and Kennedy in 1995. In recent years, in a wide range of applications, the PSO algorithm has been used, including mathematics difficulties, theoretical optimization problems, and highly specialized engineering domains.

Algorithm for locating positions or places in search space that are near to the global minimum or maximum solution (s). Because there are a large number of parameters that must be optimized, there is a large amount of search space. For example, if the search space has n dimensions, the variable number of the objective function will be n as well. Algorithm PSO has a lot of parameters. The fitness value at that location is calculated using each particle's current position. Position $x^i \in R^n$, velocity, i.e. rate of position change (v^i), and previous best positions $(p^i)$are the three parameters for each particle. Furthermore, the global best location refers to the position of the particle with the best fitness value. [35]

In the search space, each particle is represented by a set of coordinates denoted by xi. The fitness function is used to evaluate the present positions of all particles during the search process. Following that, the fitness value of each particle is compared to the current position, and the best position is saved in the previous best positions (p^i). To put it another way, the previous best positions also save positions of particles with better values. Update the velocity of the particle and particle position (v^i, x^i) was determined by the equation below.

$$v_i^{t+1} = \omega v_i^{t} + c_1 r_1 (p_i^{t} - x_i^{t}) + c_2 r_2 (g_i^{t} - x_i^{t}) \tag{3.49}$$

$$x_i^{t+1} = x_i^{t} + v_i^{t+1} \quad i = 1, 2, ..., n \tag{3.50}$$

whereas

p^i: - Best position of the particle

g^i: - Global best

whereas t is the number of iterations, c_1 and c_2 are the positive constants, ω is the weight inertia and r_1 and r_2 are two random numbers which are changing in the range [0, 1].

Parameter settings of the PSO for optimizing the cascade PI controller of the PMDC motor

Table 3-2 Parameter settings of the genetic algorithm optimization

Particle Swarm Optimization	
PSO parameters	Value
Number of birds	30
Number of iterations	20
Lower boundary	[0.0001 0.0001 0.0001 0.0001 0.0001 0.0001]
Upper boundary	[150 10 20 20 5 1]

PSO algorithm pseudocode is shown in Figure 3.13.

```
Initialize parameter
Initialize randomly position (xi)
Initialize randomly velocity (Vi)
Set pbest and gbest in particle
While (t < final iterations)
Calculate fitness value of new particle xi using objective function (ITAE)
If xi is best than pbest
Set xi as pbest
end
If xi is best than gbest
        Set $x_i$ as gbest
end
for i: No. Population
        Update ($x^i$) and (Vi) of particle by using equation
        end
t=t+1
end
Return gbest as optimal value of controller (STSMC and PID)
```

Figure 3.13 Pseudocode of the PSO algorithm

3.12. Parameter Tuning of a Cascade Controller using GA

Genetic Algorithm GA is a stochastic global adaptive search optimization technique based on the mechanisms of natural selection. Recently, GA has been recognized as an effective and efficient technique to solve optimization problems [35].

GA consists of three main stages: Selection, Crossover, and Mutation. The application of these three basic operations allows the creation of new individuals who may be better than their parents. The steps involved in creating and implementing a genetic algorithm are as follows:

1. Generate an initial, random population of individuals.
2. Evaluate their fitness (to minimize integral square error).

3. Select the fittest members of the population.
4. Implement crossover operation on the reproduced chromosomes (choosing probabilistically both the crossover site and the mates).
5. Execute mutation operation with low probability.
6. If the termination criteria are reached then the process ends. If the termination criteria are not reached search for another best chromosome.

The pseudo-code of the GA is:

```
Initialize parameter
Create initial population
While (t < Max number of iterations)
        Calculate the value of fitness for individual in the population using (ITAE)
    For i: max iteration
        Select individuals for the new population –selection
        Perform cross-over operation
        Perform mutation of individual
        Evaluate individuals
        Replace old population with the new one
    end
  t=t+1
end
```

Figure 3.14 Pseudo code of the GA.

The complete response of the system for each PI control parameter value and initial fitness value of integral absolute error (IAE) is computed and optimized using GA. This process will be repeated every generation until the end of the generation where the best fitness value is achieved.

The ultimate aim of GA is to seek PI position, speed, and current control values (K_{pp} , K_{ip} , K_{ps} , K_{is} , K_{pc} , and K_{ic}) with minimum fitness value to operate the PMDC motor cascade control system in the entire range. The block diagram is shown in Figure 4.3. depicts the implementation of GA optimization for the cascade control system of the PMDC motor.

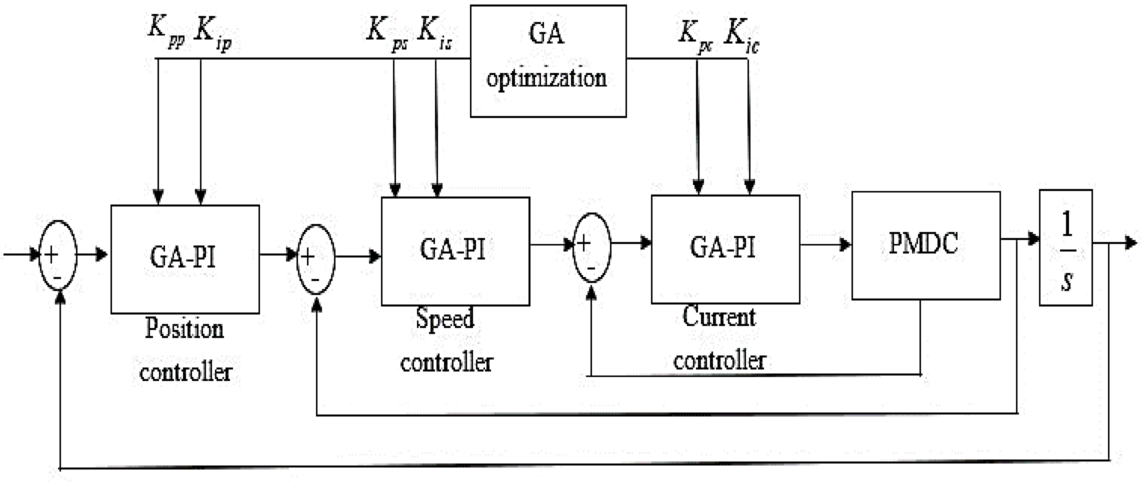

Figure 3.15 Block diagram of GA implementation in cascade control of PMDC motor

Parameter settings of the GA for optimizing the cascade PI controller of the PMDC motor are shown in Table 3.2.

Table 3-3Parameter settings of the genetic algorithm optimization

Genetic Algorithm	
GA property	Value
Population size	30
Maximum number of generations	20
Mutation probability	0.01
Lower boundary	[0.0001 0.0001 0.0001 0.0001 0.0001 0.0001]
Upper boundary	[150 10 20 20 5 1]

CHAPTER 4

4. RESULT AND DISCUSSION

4.1. Introduction

This chapter presents the Simulink model of the elevator drive system modeled mathematically in chapter three, with cascaded position, speed, and current control. The numerical values are assigned for the designed controller parameters in chapter four. Then the model of the elevator drive system is developed in computer Simulink by considering both ascending and descending load. This model is used to simulate and observe the expected behavior of the system under the action of the proposed control system, and simulation results are presented in the form of graphs. Finally, the results have been discussed in terms of the selected parameters to illustrate the performance of the designed elevator drive.

4.2. Tuning Results

The cascade PSO-PI controller is tuned in MATLAB/Simulink. The optimized gains are chosen based on the minimum object function IAE result as shown in Figure 4.1. Its best value (minimum) after 5 times optimization samples is 1.238.

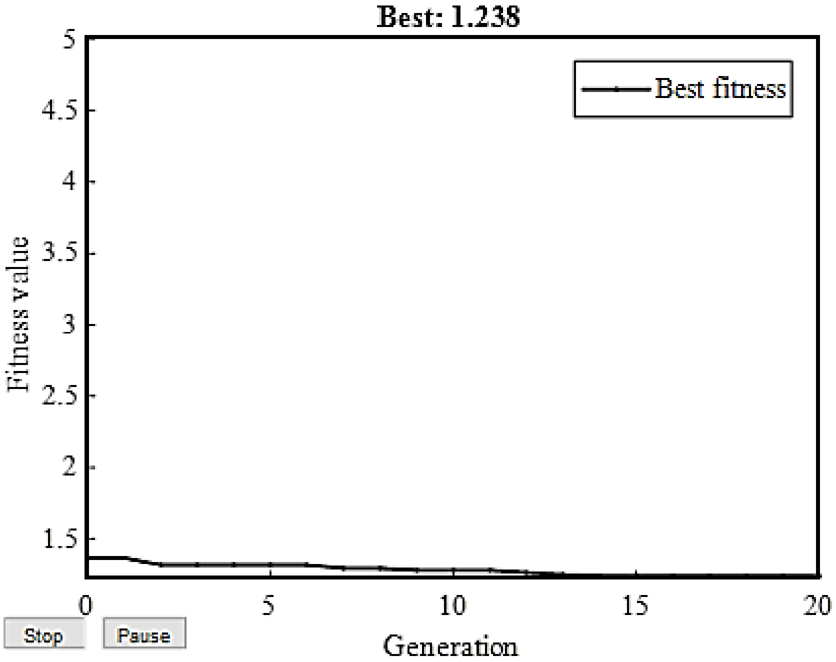

Figure 4.1 Object function result of PSO tuning

The optimized parameter gains of each controller in the cascade control system are shown below in Table 4.1.

Table 4-1 Optimized gain result of the cascade controller using PSO

Controller	Parameter	Values
PI- Position	K_{pp}	139.63
	K_{ip}	9.23
PI-Speed	K_{ps}	18.5
	K_{is}	18.5
PI-Current	K_{pi}	4.39
	K_{ii}	0.98

4.3. Simulation Results

The Simulink model of overall elevator drive with cascaded control system and PMDC motor as its prime mover is developed in MATLAB software. As it is given with mathematical modeling of the drive system dynamics, there are two cases of system model that characterizing the ascending (lifting) and descending (lowering) dynamics of the elevator drive system. Then the Simulink model, as well as simulation results of the overall drive system developed for the corresponding these two cases with the cascaded control system, are discussed below.

4.3.1. Setpoint Tracking Results

Case 1. When the elevator is moving in ascending direction

In this case, the elevator is initially placed at the lowest position of the system which is taken to be the ground floor of the building. A single floor height is four-meter-high. The elevator is then required to reposition itself by moving up to a reference position as a preference of the passenger from the whole surface of the building. The profiles of controlled variables in the cascade controller moving from the ground to the highest floor which is 40m above the ground are simulated as a sample journey and shown as Figures 4.2, 4.3, and 4.4 given below. Figure 4.2 shows the position response when considering the final floor and it takes 20sec with zero overshoot. This fulfills the standard performance of the elevators.

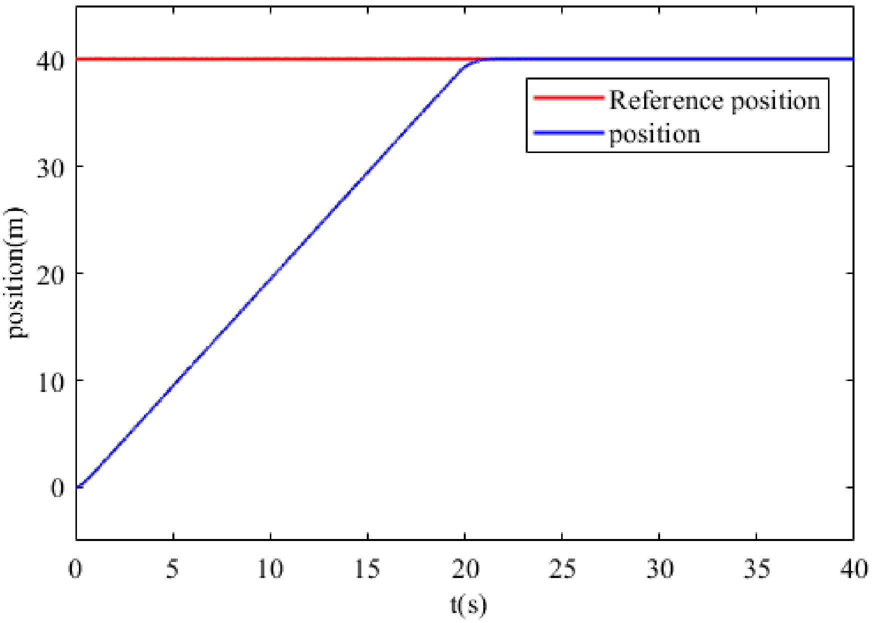

Figure 4.2 Position of PMDC when elevator moving to highest floor (40m)

Figure 4.3 demonstrates the speed result of the elevator when it moves to a 40m height position. To reach steady-state it takes 1sec with 0% overshoot. Now the elevator moves with the constant speed which is 2m/s until the position becomes 40m. Then the speed is zero when the position becomes constant meaning that the elevator is at rest at 40m height position.

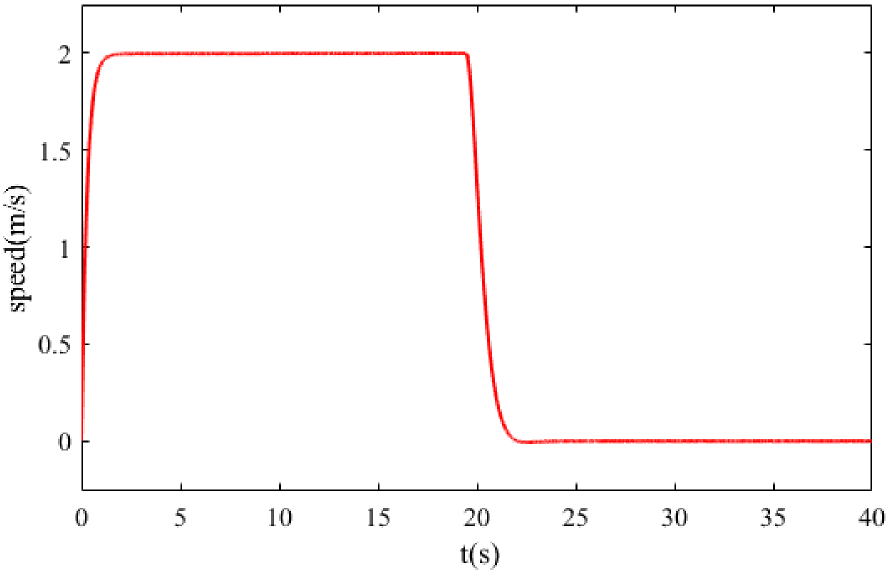

Figure 4.3 Speed of PMDC 40m ascending of elevator drive.

The current profile is shown in Figure 4.4 when the elevator is moving to 40m in height. As it can be seen from the result the current is constant until the speed becomes zero, because the reference current is the control signal of the speed controller.

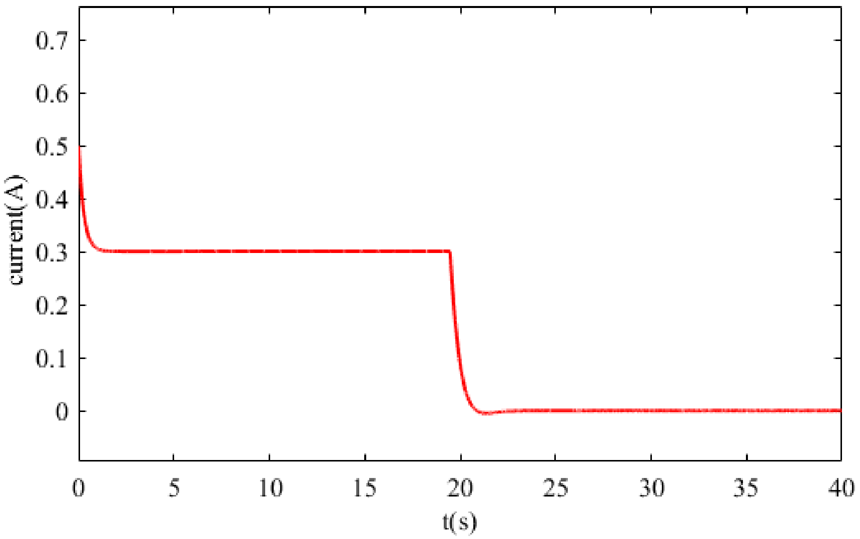

Figure 4.4 Current of PMDC motor when elevator moving to the highest floor.

The profiles of controlled parameters for moving to the first floor which is four-meter-high from the ground are simulated as a sample journey and shown as Figures 4.5, 4.6, and 4.7 given below. Figure 4.5 shows the position response when considering the first floor and it takes 5sec with zero overshoot.

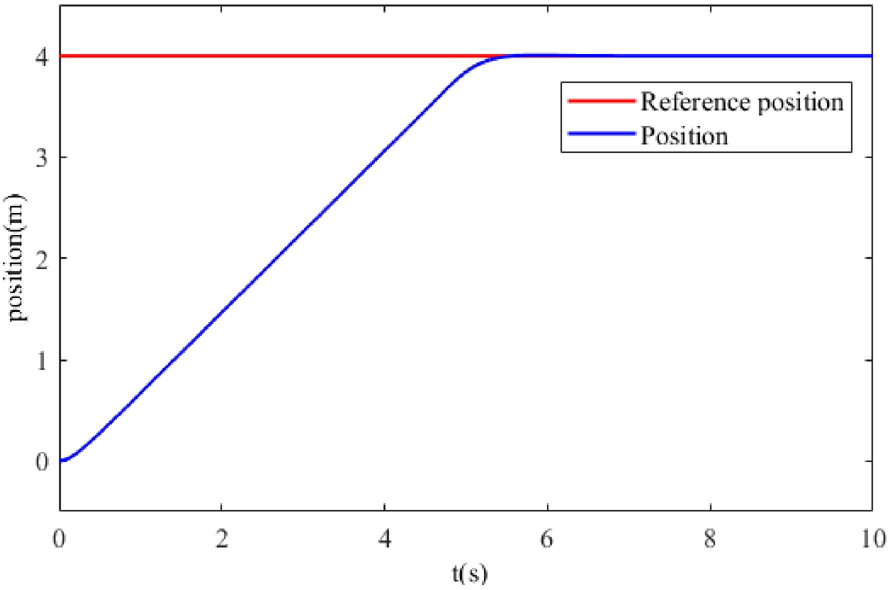

Figure 4.5 Position of PMDC when elevator moving to floor-1(4m).

The elevator speed result when it moves to a 4m height position is shown in Figure 4.6. To reach steady-state it takes 0.75 sec with 0% overshoot. Now the elevator moves with the constant speed which is 0.8m/s until the position becomes 4m. Then the speed is zero when the position becomes constant meaning that the elevator is at rest on the first floor.

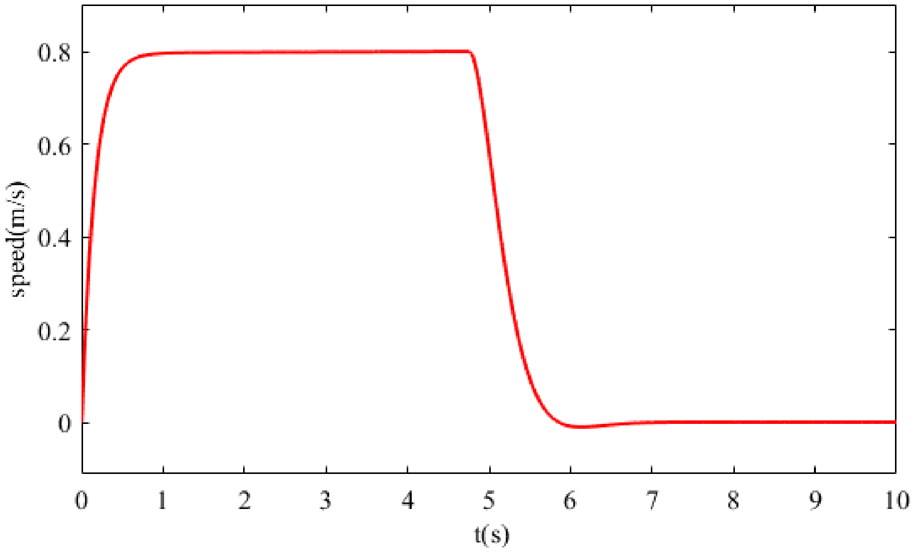

Figure 4.6 Speed of PMDC first floor (4m) ascending of elevator drive.

A current profile is shown in Figure 4.7 with 0.35A when the speed is 0.8m/s and zero when the speed is 0m/s. The reference is given from the speed control signal.

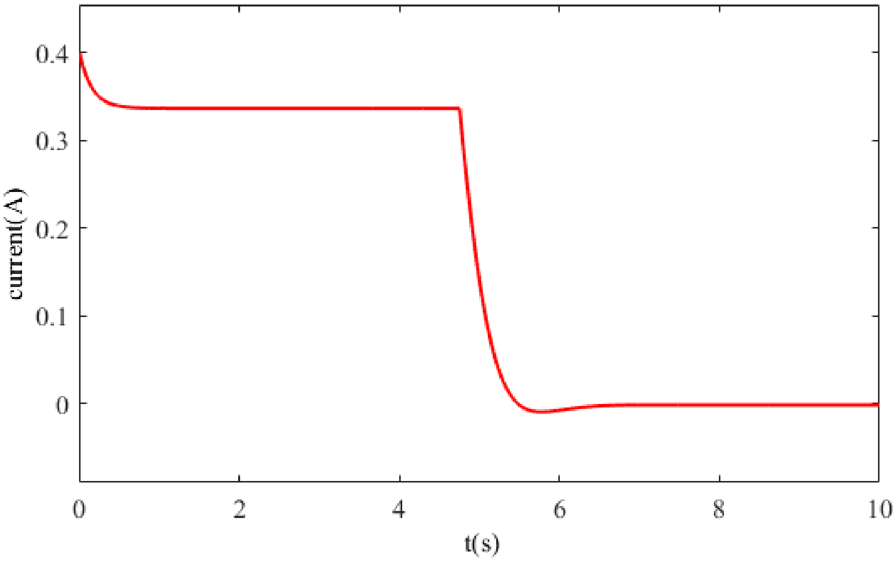

Figure 4.7 Current of PMDC motor when elevator moving to the first floor.

Case 2. When the elevator is moving in both ascending and descending direction

In this case, the elevator is moving both in ascending and descending directions. The elevator is initially placed on the ground floor which is at zero meter. It is then required to reposition itself by moving up to the end floor which is 40m high. After taking a rest for 20sec, the elevator is moving down which is in the ascending direction. The profiles of cascade-controlled variable parameters for ascending and descending are shown in Figures 4.8 - 4.10.

Figure 4.8 shows the position response when considering the final floor for ascending direction and it takes 20sec with zero overshoot. In this case, 20sec is considered the rest time of the elevator for persons entering the car and leaving from the car. Practically this can be implemented with the help of sensors and the control buttons inside the car. Then after a while ago (20sec) the elevator is moving to the ground floor which is 0m and it takes 20sec. This shows that the elevator is moving in ascending and descending with an equal duration of time. This fulfills the standard performance of the elevators.

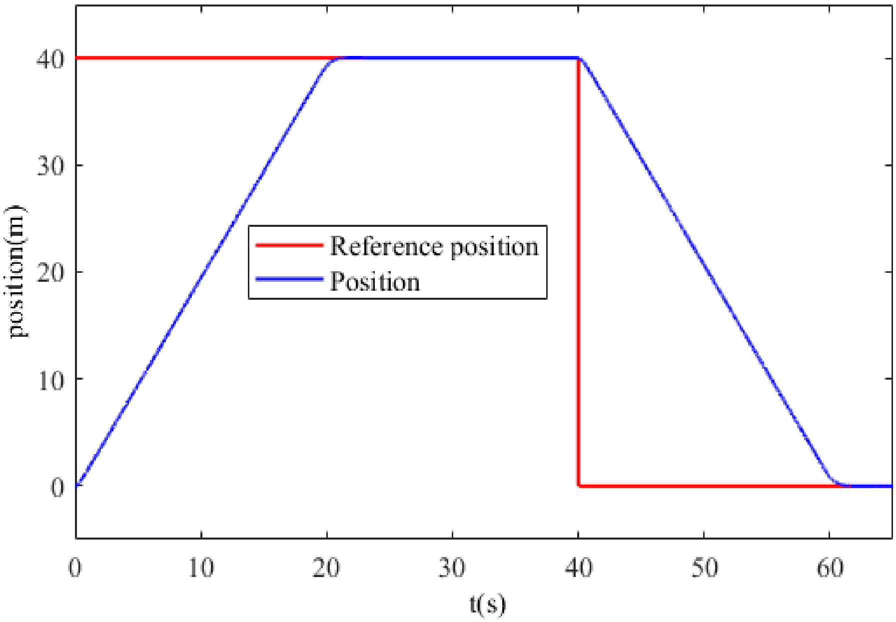

Figure 4.8 Position result of elevator drive for both ascending and descending order.

The elevator speed result when it moves both in the ascending and descending within the highest floor of 40m height position is shown in Figure 4.9. To reach steady-state (2m/s with 0% overshoot) it takes 1sec. And then when the position reaches the end floor the speed becomes zero which means that the position is constant. Finally, when the elevator moves in the descending order from 40m to 0m height position, the speed is going to be negative. The speed is -2m/s when the position reaches steady-state at 0m.

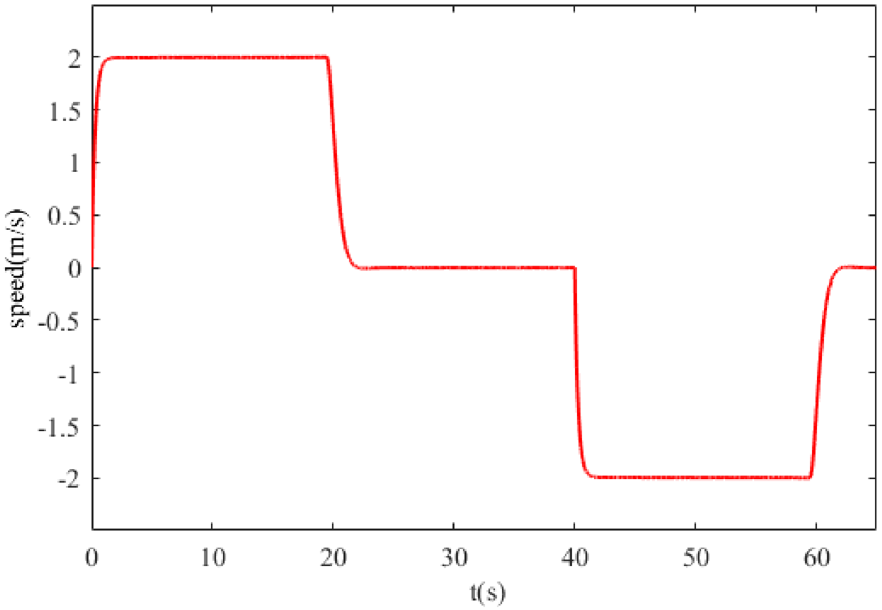

Figure 4.9 Speed result of elevator drive for both ascending and descending order.

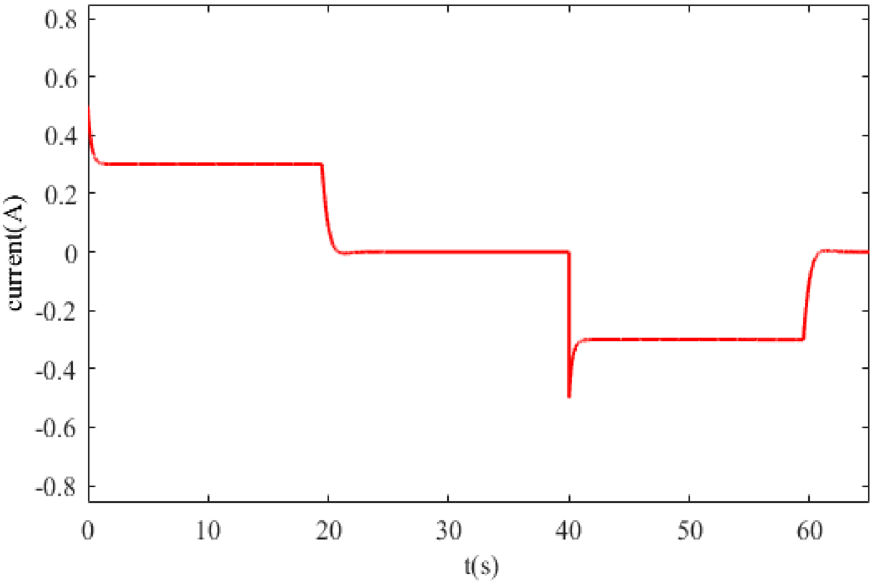

Figure 4.10 Current result of elevator drive for both ascending and descending order.

A current profile for ascending and descending movement of the elevator is shown in Figure 4.10. When the speed is 2m/s, the current is 0.35A and when the speed is zero at the 40m position the current becomes zero. The current result becomes -0.35A when the speed is going to be -2m/s at a position of 0m.

The position profile of the elevator moving both in the ascending and descending directions for 4m high is shown in Figure 4.11. Its result shows when considering the first-floor ascending direction and it takes 5sec with zero overshoot. In this case, 5sec is considered the rest time of the elevator for persons entering the car and leaving from the car. Then after a while ago (5sec) the elevator is moving to the ground floor which is 0m and it takes 5sec.

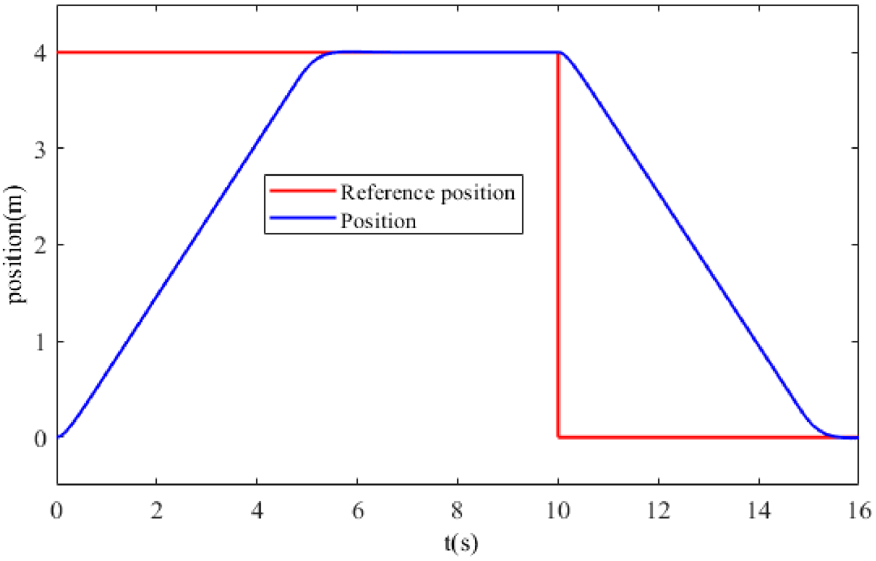

Figure 4.11 Position result of elevator drive for both ascending and descending order.

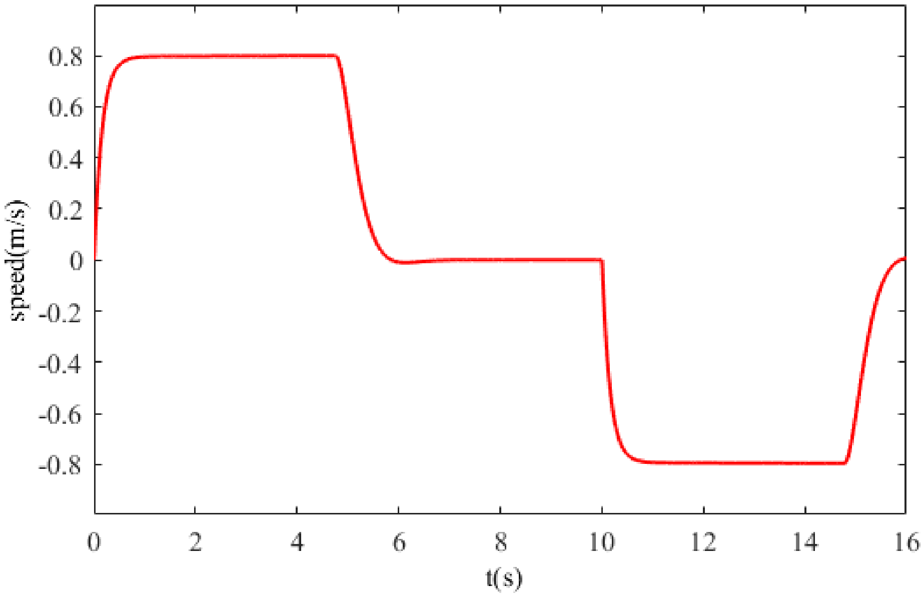

Figure 4.12 Speed result of elevator drive for both ascending and descending order.

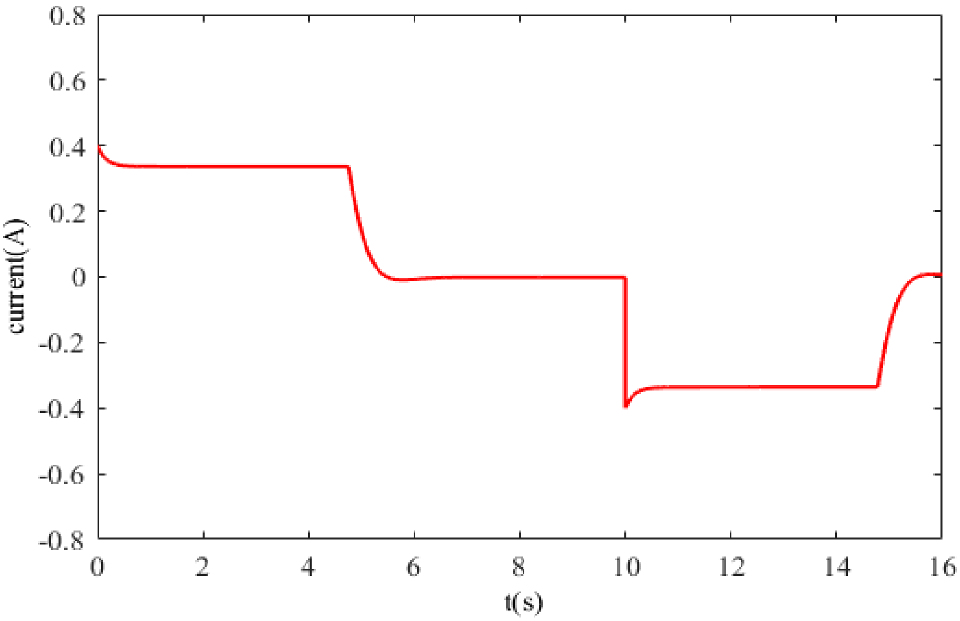

Figure 4.13 Current result of elevator drive for both ascending and descending order.

4.3.2. The nonlinear Simulink Voltage Results

From the nonlinear Simulink model, it is shown that the power from the grid is 380v three-phase voltage. And this voltage is converted to 220v using step down transformer which is the amount of voltage the motor needs. The simulation result of the three-phase voltage and the reduced voltage result is shown in the Figure 4.14 and 4.15 respectively.

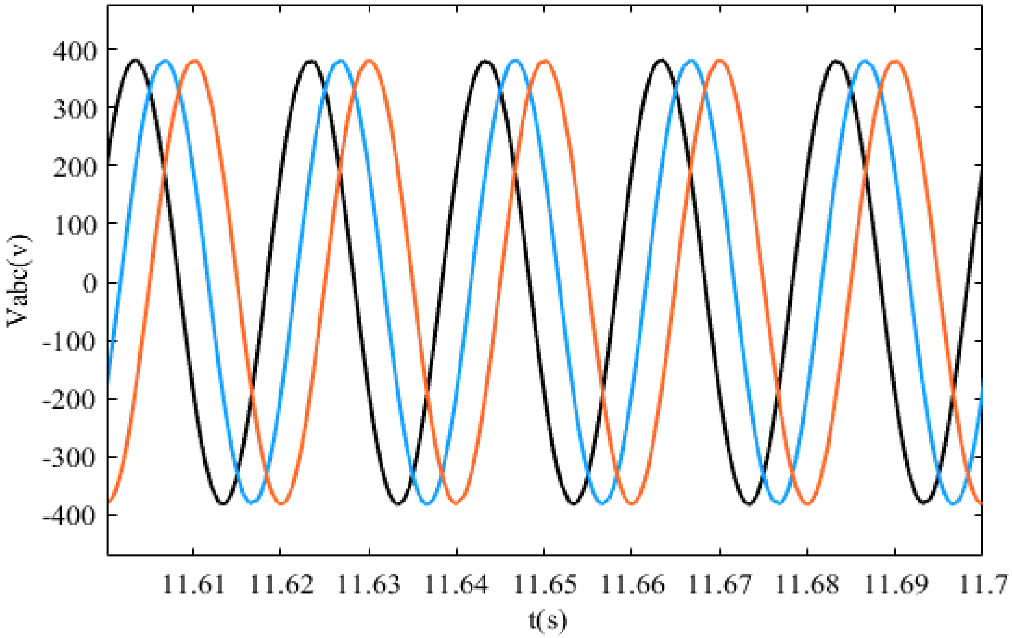

Figure 4.14 Three-phase supply voltage (380v).

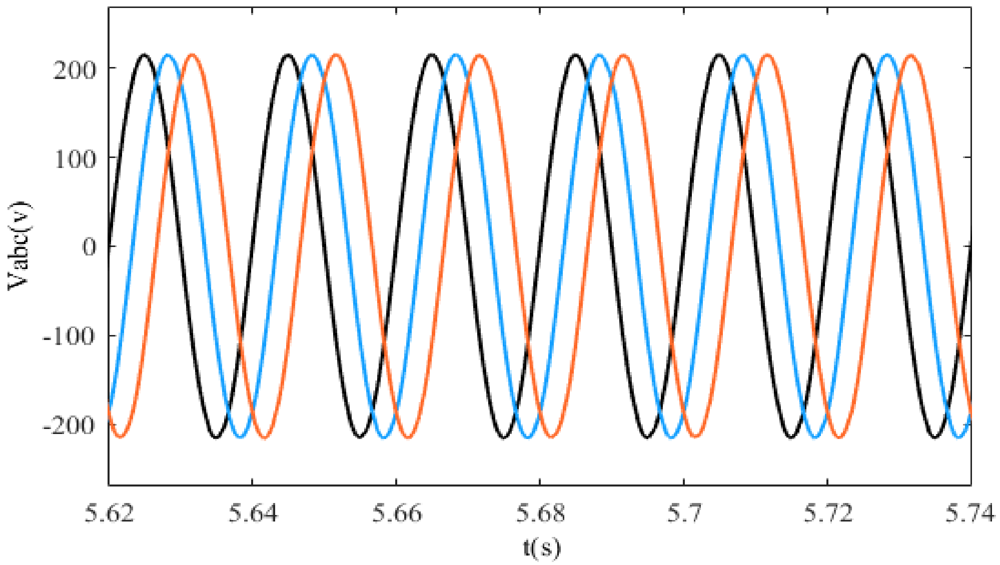

Figure 4.15 Three-phase step-down voltage (220v).

4.4. Discussion of the Results

4.4.1. Discussion of the results considering different load conditions

In the previous section, the simulation has been carried out considering no-load conditions. To check the performance of the controller, the variation of the load should be considered. By considering 40m position control, the following scenarios or conditions have been checked.

Scenario 1: Acceleration conditions at 40m height (T_L: 0Nm, 20Nm, and 30 Nm)

For the result of Scenario 1, the system is simulated at different loads as mentioned in the result shown in Figure 4.16. In the case of average load and full load conditions, the elevator car takes 23sec and 27sec respectively to reach at steady-state, which is at 40m height position.

From the control point of view, the difference of the time required to reach a steady-state when considering both at no load and full load is less, which is almost a 7sec difference. So, with and without load the controller is working properly by reducing overshoots with recommendable settling time.

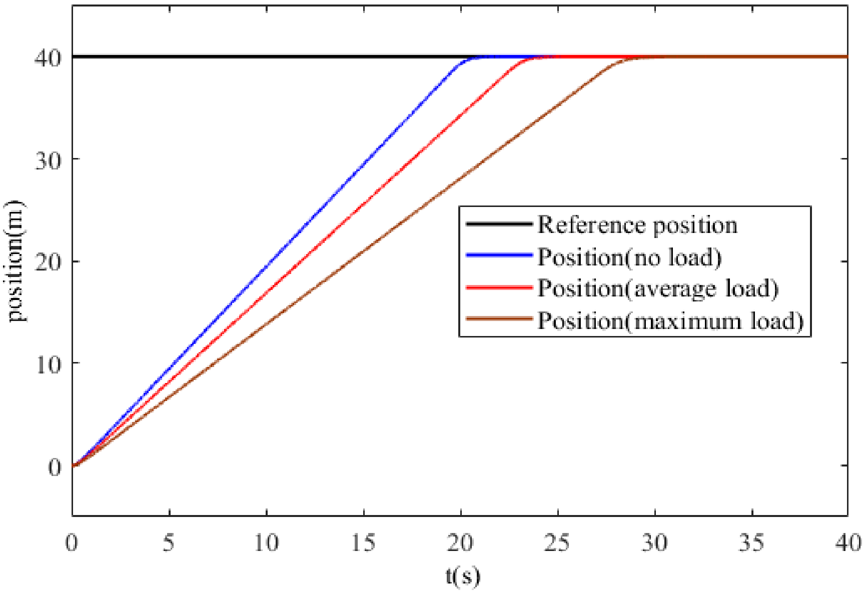

Figure 4.16 Position response of elevator drive for ascending car to the highest floor at different loads.

Scenario 2: Acceleration conditions at 4m height (T_L: 0Nm, 20Nm, and 30 Nm)

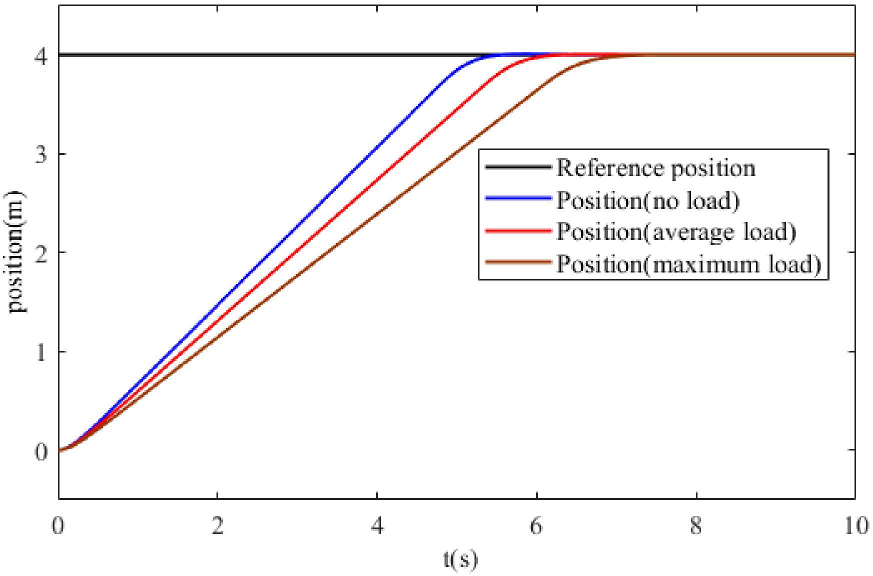

Figure 4.17 Position response of elevator drive for ascending car to the first floor at different loads.

For the result of Scenario 2, the system is simulated at different loads by considering the first-floor position (4m). In the case of average load and full load conditions, the elevator car takes 6sec and 7sec respectively to reach a steady-state, which is at a 4m height position as shown in Figure 4.17. As compared to the no-load and full load conditions, the time difference to reach the elevator car at a steady state is 2sec (5sec at no load and 7sec at full load).

Scenario 3: Acceleration and deceleration conditions at 40m and 4m height (T_L: 0Nm, 20Nm, and 30 Nm)

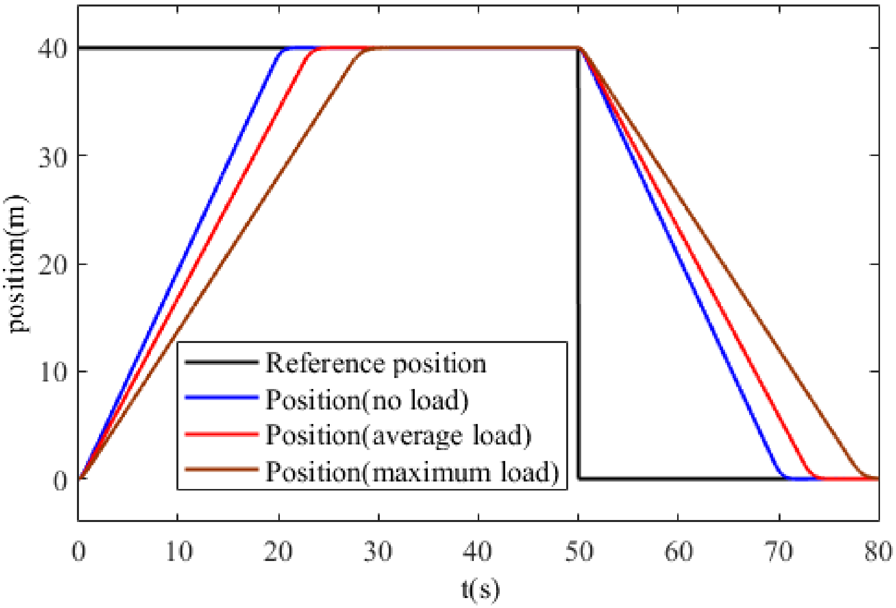

Figure 4.18 Position response of elevator drive for ascending and descending car to the highest floor at different loads

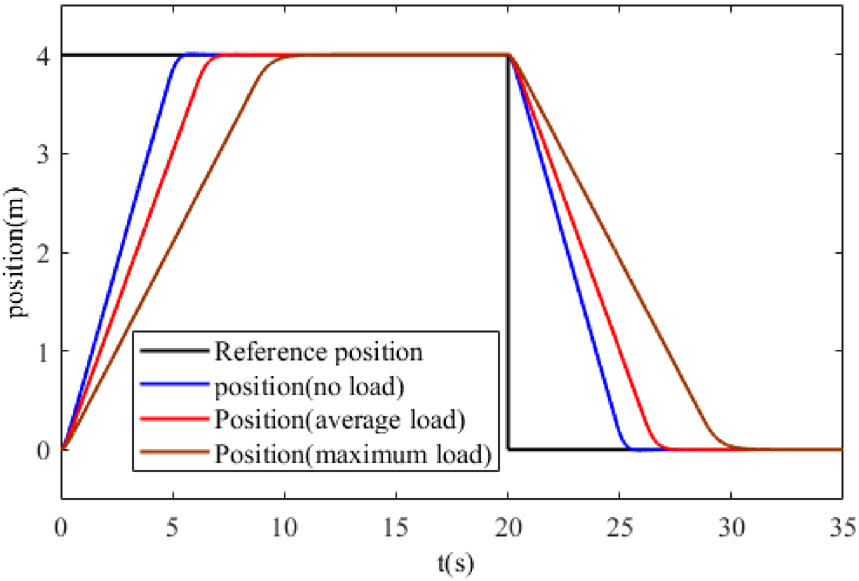

Figure 4.19 Position response of elevator drive for ascending and descending car to the first floor at different loads.

An acceleration and deceleration position of 40m (end floor) performance test has been analyzed by considering different loads as shown in Figure 4.18. The descending performance result (the time taken to reach steady-state) is almost similar to the result found considering only ascending direction as shown in Figure 4.16. The same is true for the result of descending position considering 4m height to the ground level as shown in Figure 4.19. Its performance result is similar to the performance of the ascending movement shown in Figure 4.17.

4.4.2. Discussion of position results when considering different tuning techniques

In this section, a comparison between position PI controller using Particle Swarm Optimization technique (PSO-PI) and position PI controller using Genetic Algorithm Optimization technique (GA-PI) is performed. The simulation is implemented by considering the highest and first floor positions which are 40m and 4m respectively.

As can be seen from the simulation result shown in Figure 4.20, the PSO tuned PI controller position result has taken 20sec to reach steady-state at 40m. Whereas the GA tuned PI controller position result has taken 22sec to reach the same steady-state 40m height. It can be concluded that the PSO-PI controller is just a little faster than the GA-PI controller and both give zero overshoot. From a practical point of view, the PSO-PI controller can be effective in the nonlinear environment.

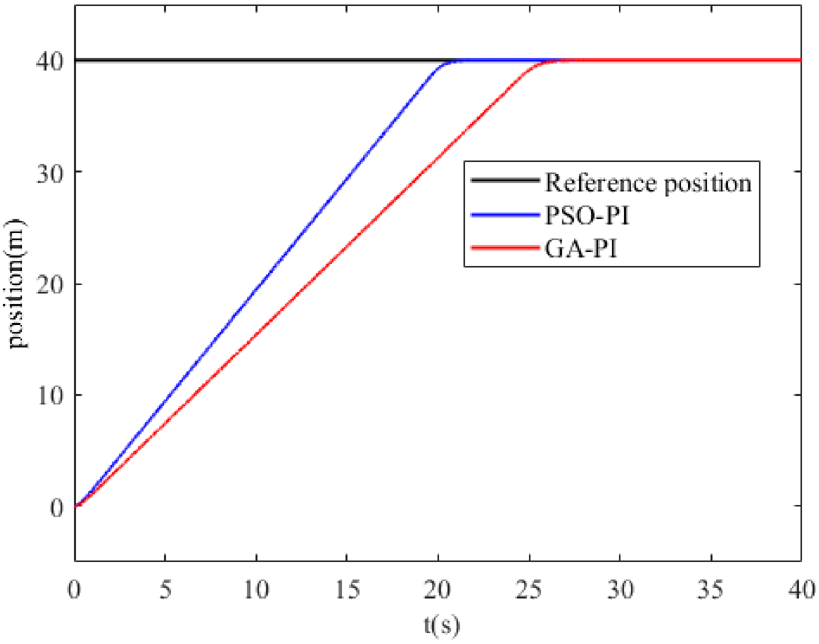

Figure 4.20 Comparison between PSO and GA when the elevator accelerates to 40m.

The simulation result considering ascending order of the elevator on the first floor (4m) is implemented using both PSO-PI and GA-PI controllers. Their result is shown in Figure 4.21. From the graphical result, the system has zero overshoot in both cases. The time taken for an elevator to reach steady-state at 4m height position using PSO-PI controller is 5sec whereas the GA-PI controller takes 6sec.

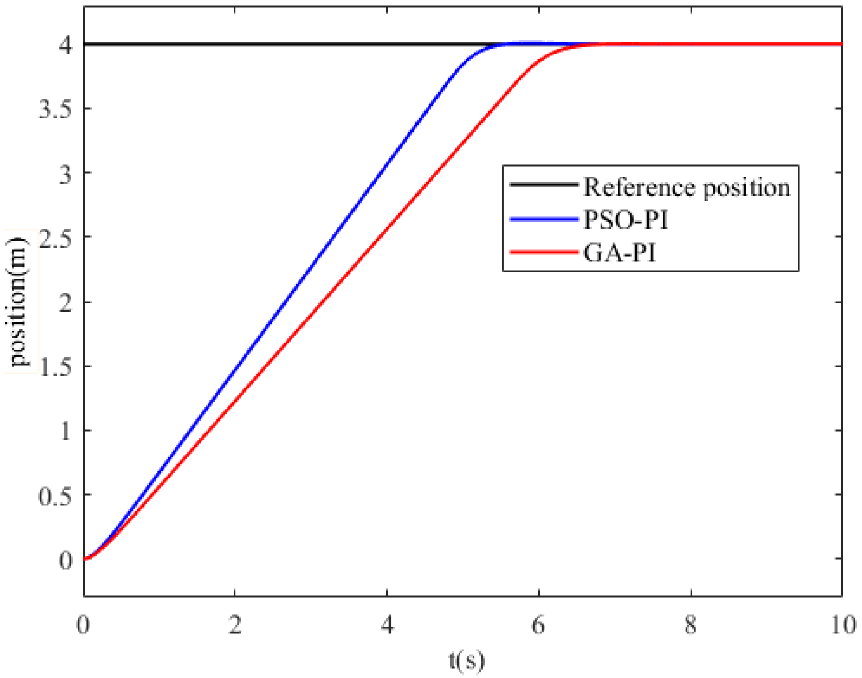

Figure 4.21 Comparison between PSO and GA when the elevator accelerates to 4m.

In the simulation, both the PSO and GA have taken the same optimization size and operation loops. However, the optimization period of the PSO tuning is much less than the GA optimization. The optimized gains are taken for the simulation of the elevator after five different tunings and the best for each optimization technique is selected based on the minimum object function result (IAE). Practically the faster optimization techniques are recommended.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This thesis work aims to design and simulate a controller for the cascaded position, speed, and current-controlled elevator drive using PMDC motor as a prime mover of the system. The mathematical model of the electrical elevator drive system with considerations of two cases, ascending and descending load movement has been discussed. Also, the kinematics (motion) of electric elevator drive relative to the known standards has been studied. Then control strategies and design parameters of the system that allow us to plot travel profiles for any input of journey distance with maximum velocity as a basis for developing a regenerative elevator drive control strategy were discussed. PSO-PI and GA-PI control techniques were used.

PSO-PI controller for the position, speed, and current controllers with a suitable design method for implementing the elevator drive control system have been presented. The elevator drive system model was demonstrated in a MATLAB/Simulink for testing and proving the controller performance of elevator specified controlled parameters for desired position and speed of elevator by using the system and design parameters. As seen from the simulation results, the system can run smoothly and has good control characteristics. Therefore, the designed PSO-PI controller for a position, speed, and current/torque control successfully tracked a given speed profile with the desired position.

The simulation that was carried out with the initial condition of the elevator position set to zero, and needed to ascend 4m and 40m above the ground and generated the desired rated speed of 0.8m/s and 2m/s respectively with 0% overshoot, which is in the range of recommended standard profiles of elevator drive. Also, the simulation that was carried out with the initial condition of elevator position set to zero, and lowering to 40m and 0m from the upper floor of the building to lower floor parts generated 2m/s and -2m/s the at steady state it is 0m/s respectively. These results illustrate that the performance of the designed controller for the elevator drives efficiently governing the performance of the drive to achieve passenger comfort.

From the tuning result, can be concluded that the PSO tuning takes less optimization time as compared to the GA tuning.

5.2. Recommendations

The modeling and analysis of position control of DC motor drive system for traction elevator using PSO demonstrate that the drive performance is satisfactory and yields the desired values of controlled parameters of the elevator drive system. The proposed control for the elevator system may be further applied to any other DC motor drive application areas such as escalators and in manufacturing companies for product motion control. In addition to this, due to the cost of materials, and the limited time I had, the system is not proved with experiment. So, it is recommended to make hardware implementation of the system.

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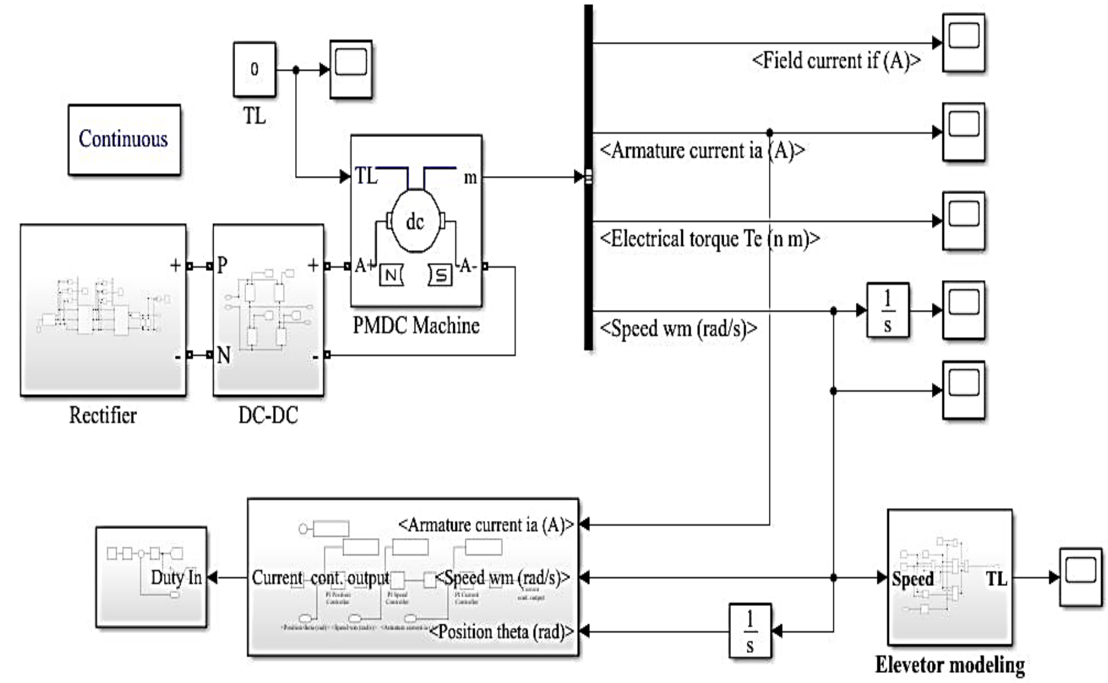
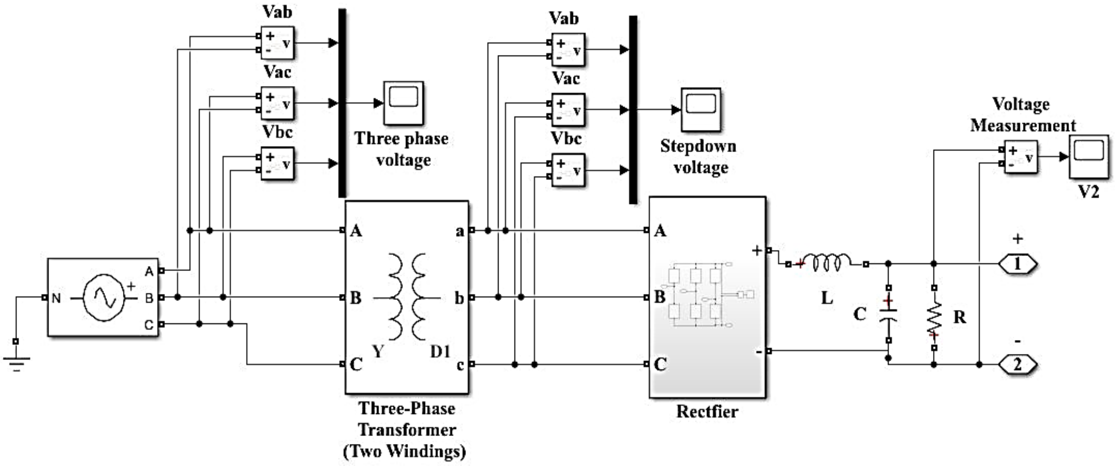
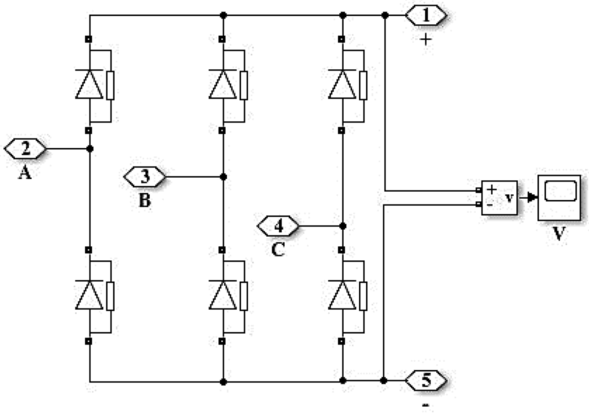
Appendix

APPENDIX A: Related to the nonlinear BLDC motor Simulink model



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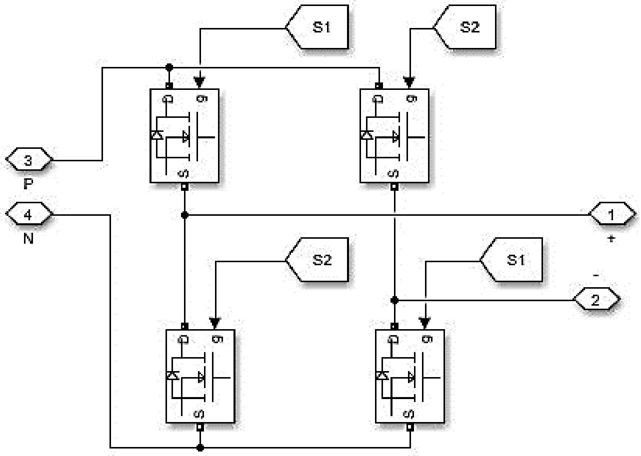
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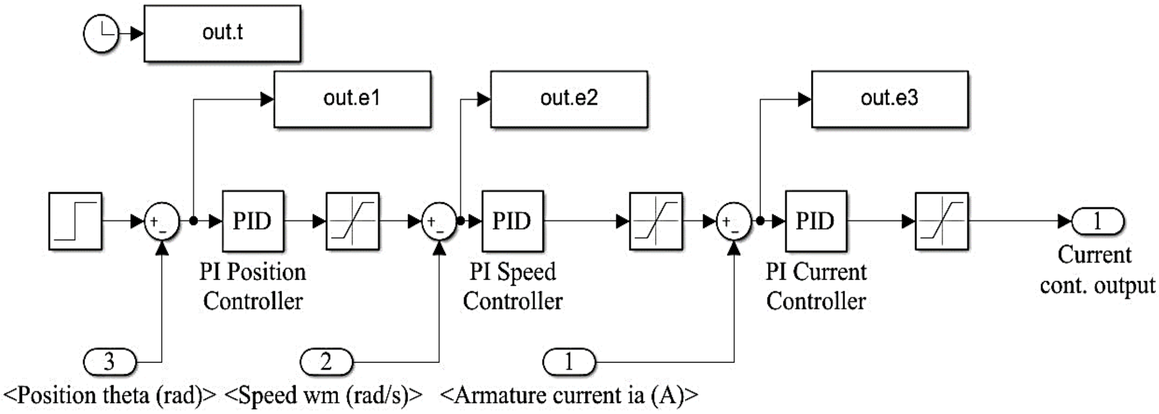
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PID
PI Speed Controller
PID
PI Current Controller
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Current cont. output
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1
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