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MASTER

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Option: **Control**

Title:

Design and Implementation of Four Level Elevator using PLC and VFD

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Abstract

Throughout this project a four-level geared traction elevator is modelled, designed and implemented. The controller used is a Programmable Logic Controller (PLC) which reads all inputs provided by the system from the different sensors and call buttons inside and outside the cabin and produces accordingly output signals based on a program written in Functional Block Diagram (FBD) language, developed to control the different functionalities of the system. The four level controller is based on the first-come first-served basis, with the exception of priority cases, to reduce energy consumption. The PLC used is a Siemens S7-200 with 24 digital inputs, 16 digital outputs, and an analog input/output expansion module. A Variable Frequency Drive (VFD) is used to drive the AC Motor in both directions, forward and reverse, in a suitable speed to move the elevator cabin between floors in a smooth manner, Altivar 312 from Schneider Electric is the one used.

Keywords: Elevator, AC motor, PLC, Siemens, VFD, Schneider Electric, Altivar 312, Function Block Diagram, first-come first-serve

Dedication

I dedicate this piece of work

To Mr. Hadouche Fawzi

To my dear Father, my beloved Mother

To my Brothers and Sisters,

To all my friends

Oussama

Acknowledgements

Bismi Allah ar-Rahman ar-Rahim

Thanks' to Allah, whom without his blessing we wouldn't be here or finish this project.

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Table of contents

Chapter One: General Overview of the Elevator System

Chapter Two: Elevator Components and Devices

Chapter Three: Software Design

Chapter Four: Implementation and Testing

General Conclusion

List of Figures

List of Tables

List of Abbreviations

DC: Direct Current.

AC: Alternative Current.

VFD: Variable Frequency Drive.

RPM: Revulsion Per Minute.

PLC: Programmable Logic Controller.

CPU: Central Processing Unit

LD: Ladder logic.

FBD: Function Block Diagram.

SFC: Sequential Function Chart.

ST: Structural Text.

IL: Instruction List.

IEC: International Electrotechnical Commission.

VSD: Variable Speed Drive.

ASD: Adjustable Speed Drive.

AFD: adjustable frequency drive.

PWM: Pulse Width Modulation.

VSI: Voltage Source Inverter.

IGBT: Insulated Gate Bipolar Transistors.

Mosfet: Metal Oxide Semiconductor Field Effect Transistor.

MCB: Miniature Circuit Breaker.

MCCB: Molded Case Circuit Breaker.

IP: Ingress Protection

LED: Light Emitter Diode.

IR: Infrared.

BCD: Binary Coded Decimal.

PB: Push Button.

SCR: Sequential Control Relay.

General Introduction

Thanks to technology the human living standards have risen to a point where skyscraper and towers became a very common view, which calls for the importance of elevators in daily life. An elevator or lift is a type of vertical transportation device that moves people or goods between floors of a building, vessel, or other structures. Elevator's technology has been developing throughout history from cabs on hump ropes powered by hand or animals to the modern fully automated versions seen nowadays.

Traction elevators are one very commonly used type; which are typically powered by electric motors that drive traction cables and counterweight systems to move the cabin between floors. This is the type that will be designed and implemented in the proceeding work, where a Programmable Logic Controller (PLC) is used to automate the different functionalities of the system. A Variable Frequency Drive (VFD) is utilized to drive the AC motor which itself drives a gearbox and traction cables to move the elevator cabin upward or downward with suitable speed. Function Block Diagram (FBD) is a language used to write the program required to implement the control strategy. Hence, an intelligent design is used to operate the elevator system based on the first-come-first-served basis except when there are priority cases.

The report consists of:

- **Chapter one**: A general overview on the elevator systems.

- **Chapter two**: A description of the main components i.e. PLC, VFD and position sensors design, linear encoder design, and the display circuit design.
- **Chapter three**: This chapter explains the programming side of the elevator system
- **Chapter four**: The implemented circuits and the VFD were interfaced with the PLC and this chapter deal with the testing of the system.
- **Conclusion**: the conclusion discusses the test results of the developed system, and suggest future work and enhancement.

CHAPTER ONE

General Overview of the Elevator System

1.1 Introduction

With the overall rapid development taking place in all spheres, the living standard of human being particularly in urban areas has tremendously increased such as the high-rise buildings, housing purposes and other structures. Thus, the installation of elevators in these buildings becomes an integral part of the infrastructure for the movement of goods and people. The control system is required to work in smooth and safe operation. It guides the elevator cabin in what order to stop at floors and when to open or close the cabin door.[1]

1.2 Elevator definition

An elevator or lift is a type of vertical transportation that moves people or goods between floors (levels, decks) of a building, vessel, or other structure. Elevators are typically powered by electric motors that either drive traction cables and counterweight systems like a hoist or pump hydraulic fluid to raise a cylindrical piston like a jack.[2]

1.3 Historical review

The first reference elevator was invented by Archimedes in 312. From some literacy source, the elevator was developed as cable on a hemp rope and powered by hand or through animals. This type of elevator was installed in the Sinai Monastery of Egypt. In the 17th century, very small type elevators were placed in the building of England and France. In 1793, Lvan Kuliben created an elevator with the screw lifting mechanism for the winter place of Saint Petersburg. In 1816, an elevator was established in the main building of Sub-Moscow village. In the middle 1800's, there were many types of curd elevators that carried freight. Most of them ran hydraulically. The first hydraulic elevators used a plunger below the car to raise or lower the elevator. A pump applied water pressure to a plunger, or steel column, inside a vertical cylinder. In 1852, Elisha Otis introduced the safety elevator, which prevented the fall of the cab, if the cable broke. In 1857, the first Otis passenger elevator was installed in New York City. The first electric elevator was built by Werner Von Siemens in 1880. In 1874, J.W. Meaker patented a method that permitted elevator doors to open and close safely.[3]

1.4 Types of Elevator

In general, there are two main types of elevators, hydraulic and traction:

1.4.1 Traction elevator

Electric traction elevator can nowadays be used in almost all applications without any considerable limitations regarding travel height, speed or load. A wide range of speeds is available from $0{,}25\ m/s$ to $17\ m/s$.

In the traction elevator, the car is suspended by ropes wrapped around a sheave that is driven by an electric motor. The weight of the car is usually balanced by a counterweight that equals the mass of the car plus 45% to 50% of the rated load. The purpose of the counterweight is to make sure a sufficient tension is maintained in the suspension system to ensure adequate traction is developed between ropes/belts and drive sheave. In addition, it maintains a nearly constant potential energy level in the system as a whole and heavily reducing energy consumption.

Traditionally, electric traction elevators were equipped with DC motors due to their easy controllability, but the development of variable frequency drives (VFD) led to the introduction of the now prevalent AC induction motors or permanent magnet DC motors. These drives provide excellent ride conditions, with smooth acceleration and deceleration and high leveling accuracy.[4] There are two types of traction elevators, Geared and Gearless:

Geared Traction Elevator:

Geared traction machines are driven by AC or DC electric motors. As the name implies, the electric motor in this design drives a worm-and-gear-type reduction unit, which turns the hoisting sheave. While the elevator rates are slower than in a typical gearless elevator, the gear reduction offers the advantage of requiring a less powerful motor to turn the sheave. These elevators cabin typically operate at speeds from 0.63m/s to 2.5 m/s and carry loads of up to $13{,}600\ kg$. An electrically controlled brake between the motor and the reduction unit stops the elevator, holding the car at the desired floor level.[5]

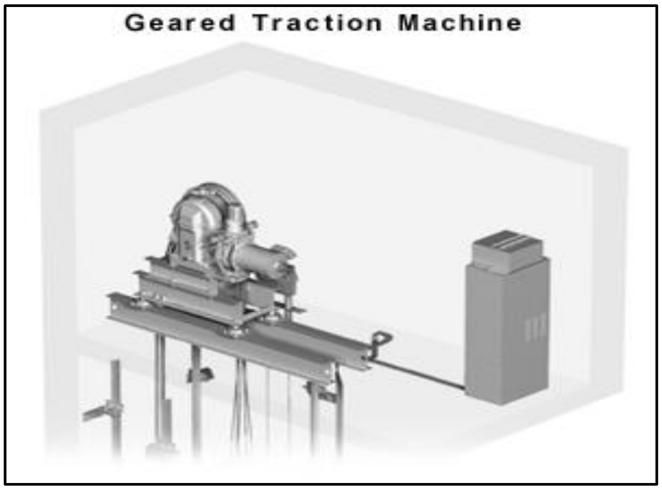


Figure 1.1: Configuration of Geared traction lift machine-room

Gearless Traction Elevator:

Gearless traction machines is low-speed (low-RPM), high-torque electric motor-powered either by AC or DC. The sheave is driven directly by the motor, thus eliminating losses in the gear train. This type of elevator has normally been used in high rise applications with nominal speeds between 2,5 m/s and 10 m/s. The machine in gearless elevators consists of a motor, traction sheave and brake. Since the motor is directly coupled to the traction sheave, there are no transmission losses and they both rotate at the same speed. The motor must, therefore, rotate at a very low speed.[5]

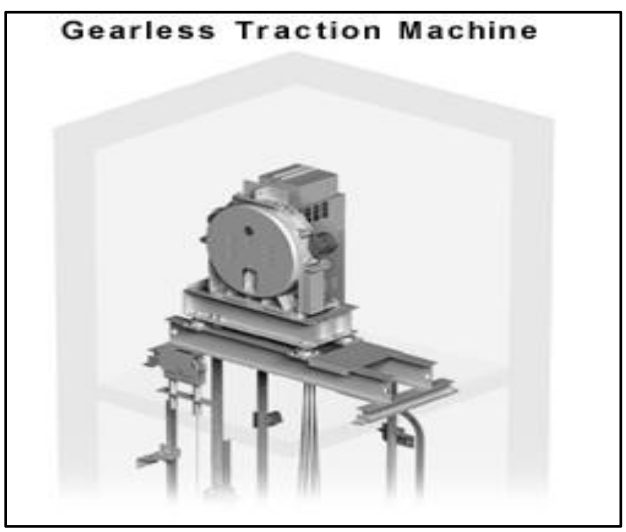


Figure 1.2: Configuration of Gearless traction lift

1.4.2 Advantages and disadvantages of traction elevator

Advantages:

- Uses less energy
- Serve mid to high-rise buildings
- Ride smoother

Disadvantages:

- The main disadvantage is its cost, 20% more expensive than Hydraulic Elevator
- Traction elevators may also be difficult to maintain, as the machine's controls are located in the shaft headroom. This area could be difficult to access.

1.5 Hydraulic Elevators

Hydraulic elevator is powered by a piston that travels inside a cylinder. An electric motor pumps hydraulic oil into the cylinder to move the piston. The piston smoothly lifts the elevator cabin. Electrical valves control the release of the oil for a gentle descent.

Hydraulic elevators are used extensively in buildings up to five or eight floors. These elevators, which can operate at speeds up to $1m/s$, do not use the large overhead hoisting machinery the way geared and gearless traction systems do.

1.5.1 Advantages and disadvantages of Hydraulic Elevator:

Advantages:

- Lower cost of equipment and maintenance than traction elevator
- More efficient building space utilization than tractions. E.g. hydraulic elevators would require 9.6 m^2 less floor space than tractions. Moreover, the overhead machine room isn't required.
- Most effective for high load capacity requirements, that is why it is highly used for freight, automobile elevators
- Since it imposes no vertical loads on the building structure, column sizes can be reduced significantly in the hoist way area.

Disadvantages:

- High energy consumption since the entire weight of the car must be lifted
- The Performance of hydraulic elevator becomes erratic as the oil in the system varies in temperature.
- Since it has no safety device to prevent it falling it depends wholly on the pressure.
- Inherently high heat producing device.

1.6 Energy consumption

In terms of energy usage, traction elevators are generally more energy efficient. This is due to the differences in the way of working. With hydraulic elevators, the pump works against gravity to push the elevator car and contents in the upwards direction but this energy is lost when the elevator car descends on its own weight. Whereas with traction elevator, these are counter balanced and do not use as much energy due to the counterbalancing effect.[6]

Elevators' energy use can be reduced through a variety of means, including the use of more efficient AC motors and regenerative drives:

1.6.1 AC Motors

One of the most significant advances in elevator technology has been the steady move over the past few decades from direct current (DC) to more efficient alternating current (AC) elevator motors.

1.6.2 Regenerated Energy

In any lifting system, potential energy can be gained or lost by the system. Thus, in some cases, it draws energy from the supply and in other cases, it returns energy to the main supply. Lifts always need to dissipate excessive energy from the system. In some cases, this is returned to the main supply naturally; if a direct connection to the mains is used as would be the case for a single speed or two speed AC motor, which will attempt to regenerate energy back into the mains when acting as an induction generator or through a special power electronic setup as in the case of inverter driven systems with regenerative capabilities[1]. In other cases, the energy is dissipated through resistors, or just as heat in the motor.

Regenerative drives represent one of the most significant innovations in the latest generation of energy-efficient elevator technology. it captures the heat generated by elevators during use and converts it into reusable energy for the building rather than wasting it as heat.

When power flows into the elevator motor, it creates a lifting torque on the shaft and elevator sheave, lifting the cab. When the cab travels down, the motor acts as a generator, transforming mechanical power into electrical power and pumping current back into the facility's electrical grid where it can be reused by another elevator or to power other electrical loads.

Over time these small amounts of power generated during the deceleration of each elevator add up to noticeable savings. Regenerative drives can reduce the energy consumed by building transportation systems by up to 70% and can even reduce the strain and cost of the HVAC system by eliminating excess heat in the building.[7]

1.7 Traction Elevator main Components

The main parts of traction elevators are:

- Hoist Ropes or suspension means: it connects the car to the counterweight, which is represented by steel wire ropes.
- Driving Machine: it is the power unit consisting of:
    - Electric Motor
    - Mechanical Gearing
    - Brake
    - Traction Sheave
    - Coupling, shaft, Journals and Bearing
- Car: it carries passengers or other loads, it is composed of the sling, a metal framework connected to the means of suspension, the platform which form

[1] For inverter driven motors, a special setup has to be used to enable regeneration back into the mains, which effectively is another inverter, fed from the DC link of the main inverter, and feeding back onto the three phase mains.

the floor of the car and directly support the load and car enclosed attached to the car platform, its mechanical accessories are:

    - Suspension gear
    - Guide shoes providing guidance for the car sling along the car trajectory
    - Safety gear
    - Car door and door operator

- Counterweight: it is used to balance the mass of the complete car and portion of the rated load.
- Elevator well (Hoist way): the space completely or partially enclosed, extending from the pit floor to the roof, in which the car and the counterweight, if there is one travel. it is equipped with guide rails for both the car and counterweight, landing doors and buffers or bumpers in the pit.
- Safety gear: a mechanical device for stopping and holding the car or the counterweight on guide rails in the event of breakage, slackening of suspension ropes or if the speed of a descending car exceeds the rated speed by a predetermined value. The braking action of the safety gear is initially by overspeed governor, usually located in the machine room.
- Buffers: they represent a resilient stop beyond the normal limit of the car or the counterweight travel. They may be of polyurethane, spring or oil type in respect of the rated speed and are designed to store (accumulate) or dissipate the kinetic energy of the car or the counterweight.
- Electric installations: it is including safety devices and lighting.
- Control system: is a device which manages the visual monitoring, interactive command control and traffic analysis system to ensure the elevators are functioning efficiently.

1. Elevator machine
2. Car
3. Suspension ropes or hoist ropes
4. Counterweight
5. Car guide rails
6. Counterweight guide rails
7. Car buffer
8. Counterweight buffer
9. Controller
10. Selector
11. Selector driving tape
12. Overspeed governor
13. Governor tension pulley
14. Traveling cable
15. Door operator
16. Roller guide
17. Car safety gear
18. Car door safety edge
19. Diverting pulley
20. Safety limit switch
21. Final limit switch

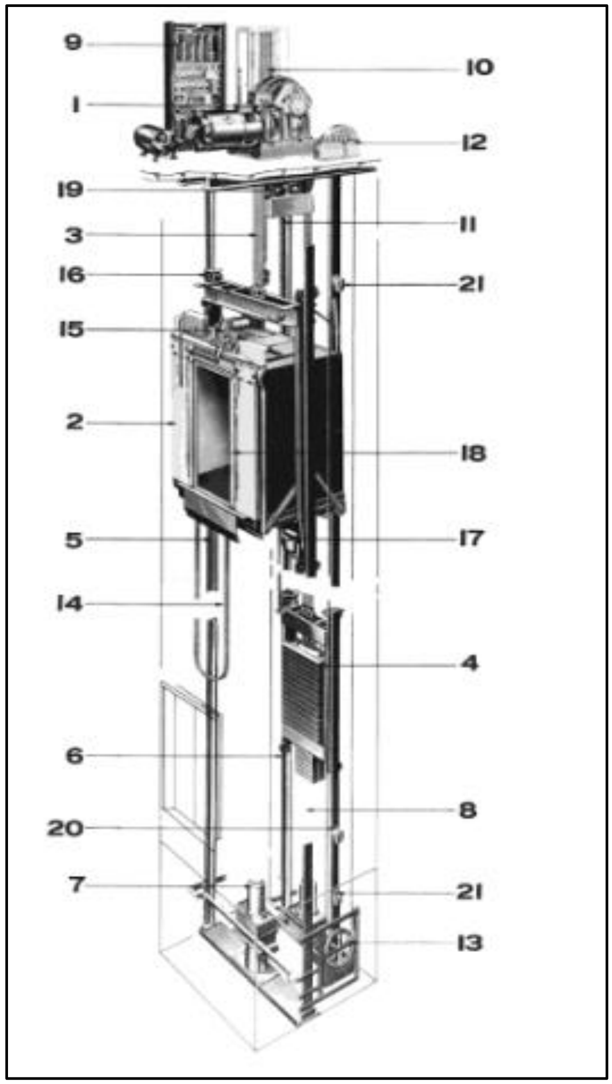


Figure 1.3: Typical passenger traction elevator (Otis Elevator Co)

1.8 Elevator safety mechanism

The first elevators in use were not quite safe because once in a while a cable would break, and a car, pulled by gravity, would come crashing down. Safety devices were soon added, though, to keep such disasters from occurring. Additional ropes attached to cars and powerful metal "jaws" that grip guard rails keep elevators from falling if their main cables break. Other safety devices keep elevators from moving when their doors are still open and from traveling too fast. Automatic switches in the shaft allow an elevator to hurry past unwanted floors, or to slow and stop when a chosen floor is reached, unlocking its doors to admit and release passengers.

Without safety mechanisms, no one would dare use elevator systems. Therefore, safety is a mandatory issue that needs special attention. Elevators are built with several safety systems that keep them in position.

1.8.1 The Rope System

This is the line of defense. One rope can support the weight of the elevator car. In essence, elevators are built with multiple ropes, if one of the ropes snaps, the rest will hold the elevator up. Roped elevator cars have built in braking systems that grab onto the guide rails when the car moves too fast.

1.8.2 Speed Governor

When the elevator moves too quickly, braking is activated by a governor. A governor rope is connected to the elevator car, so it also moves when the car moves up and down. As the car speeds up, so does the governor, therefore controlling the speed of the elevator car.

1.8.3 Electromagnetic brake

Safeties are activated by a governor when the elevator moves too quickly. Most governor systems are built around a sheave positioned at the top of the elevator shaft. The governor rope is looped around the governor sheave and another weighted sheave at the bottom of the shaft. The rope is also connected to the elevator car, so it moves when the car goes up or down. As the car speeds up, so does the governor.

1.8.4 Flyweights braking system

In this governor, the sheave is outfitted with two hooked flyweights (weighted metal arms) that pivot on pins. The flyweights are attached in such a way that they can swing freely back and forth on the governor. But most of the time, they are kept in position by a high-tension spring.

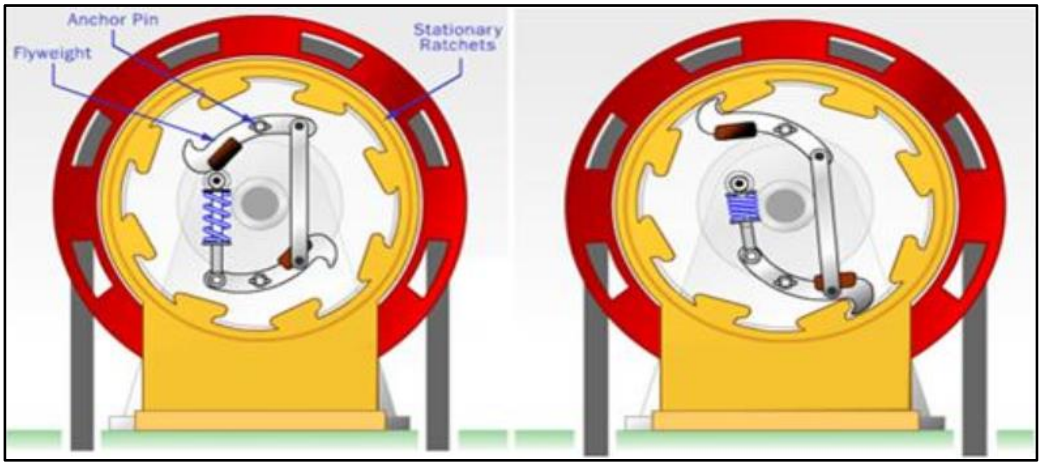


Figure 1.4: Flyweights safety system working principle

As the rotary movement of the governor builds up, centrifugal force moves the flyweights outward, pushing against the spring. If the elevator car falls fast enough, the centrifugal force will be strong enough to push the ends of the flyweights all the way to the outer edges of the governor. Spinning in this position, the hooked ends of the flyweights catch hold of ratchets mounted to a stationary cylinder surrounding the sheave. This works to stop the governor.[9]

1.8.5 Actuator arm braking system

The governor ropes are connected to the elevator car via a movable actuator arm attached to a lever linkage. When the governor ropes can move freely, the arm stays in the same position relative to the elevator car (it is held in place by tension springs). But when the governor sheave locks itself, the governor ropes jerk the actuator arm up. This moves the lever linkage, which operates the brakes. In this design, the linkage pulls up on a wedge-shaped safety, which sits in a stationary wedge guide. As the wedge moves up, it is pushed into the guide rails by the slanted surface of the guide. This gradually brings the elevator car to a stop.[9]

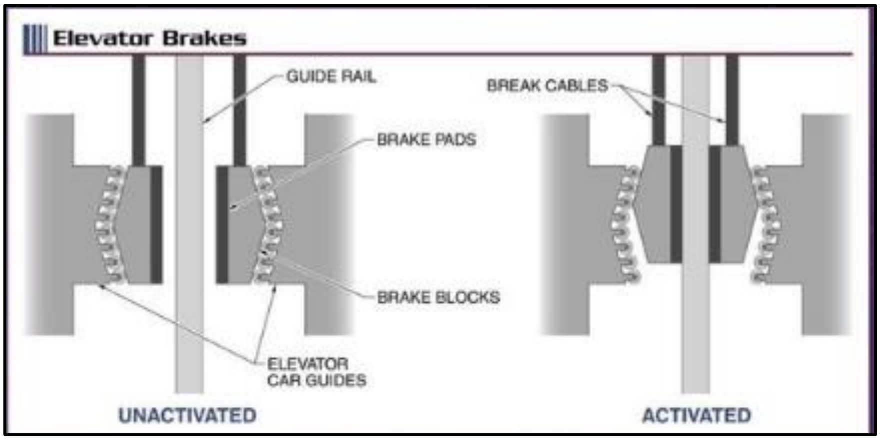


Figure1.5: Actuator arm braking system

1.8.6 More backups

Elevators also have electromagnetic brakes that engage when the car comes to a stop. The electromagnets actually keep the brakes in the open position, instead of closing them. With this design, the brakes will automatically clamp shut if the elevator loses power Elevators also have automatic braking systems near the top and the bottom of the elevator shaft. If the elevator car moves too far in either direction, the brake brings it to a stop.

If all else fails and the elevator did fall down the shaft, there is one final safety measure that will probably save the passengers. The bottom of the shaft has a heavy-duty shock absorber system. Typically, a piston mounted in an oil-filled cylinder. The shock absorber works like a giant cushion to soften the elevator car's landing.[9]

1.9 Elevator Control

Elevator controllers are electronic devices that will manage visual monitoring, interactive command control and traffic analysis system control to ensure that the elevator is functioning right.

The main function of the elevator controller is to receive and process signals from various elevator components. It is able to send response signals to the signals it receives to keep the operation of other parts in the system. The signal exchanging is how an elevator controller is able to keep the elevator running smoothly every day.

There are 3 primary types of elevator controllers which include PLC, Relay and Solid-State Logic elevator controllers.

1.9.1 Relay Controller Elevator

Relay controller is made of electromagnets that will close and open dry contacts and will route the logic to various circuits. Relay controller is best for elevators that only have few stops and use manual door operations.[10]

Relay Elevator Controller Applications:

- Passenger lifts in a 3 story or less building such as residential buildings, nursing homes or small hotels.
- Commercial buildings that are low rise such as offices, hospitals, or hotels.
- Drive speeds that are less than 1m/s.
- Single lift elevators.

1.9.2 Solid State Elevator Controller

The solid-state logic elevator controllers will have integrated circuit boards as well as transistor circuits. It helps to provide easy fault diagnosis, improved reliability and lower power consumption when compared to relay controllers. [10]

Solid State Elevator Controller Applications:

- Commercial low-rise buildings such as offices, hospitals, and hotels.
- Duplex groups and single lift elevators.
- Passenger lifts in 12 story of less buildings such as residential buildings or small hotels.
- Drive speeds less than $2m/s$.

1.9.3 PLC Elevator Controller (Computer Based Controller)

Personal computer has made microprocessor technology affordable for many other fields. Elevator Concepts utilizes a special type of industrial computer called a Programmable Logic Controller PLC to control the logic of more complex jobs. it is very dependable, compact, and simple to troubleshoot. [10]

PLC Elevator Controller Applications:

- All sizes of lift groups.

- All types of elevator lifts.
- Any drive speed less than $10m/s$.

1.10 Conclusion

In this chapter, a presentation of Elevator system including its types with advantages and disadvantages of each type, its operation principles, and its safety mechanisms utilized nowadays, as well as the technologies used to control it which are Relay control, solid-state logic and Programmable Logic Controller (PLC). The latter offers a great flexibility in programming, low cost, reliable and better functionality.

Chapter Two

Elevator Components and Devices

2.1 Introduction

The construction of an electric traction elevator calls for the employment of multiple electronic and mechanical segments and techniques, in this present work, a VFD is used to drive the AC electric motor. This chapter is a description of the different aspects involved in the implementation of the project, from the PLC to the position and speed tracking systems.

2.2 Programmable logic controllers

Programmable logic controller also called programmable controllers or *PLCs*, are solid-state members of the computer family, using integrated circuits instead of electromechanical devices to implement control functions. They are capable of storing instructions, such as sequencing, timing, counting, arithmetic, data manipulation, and communication, to control industrial machines and processes. Figure 2.1 illustrates a conceptual diagram of a PLC application.[11]

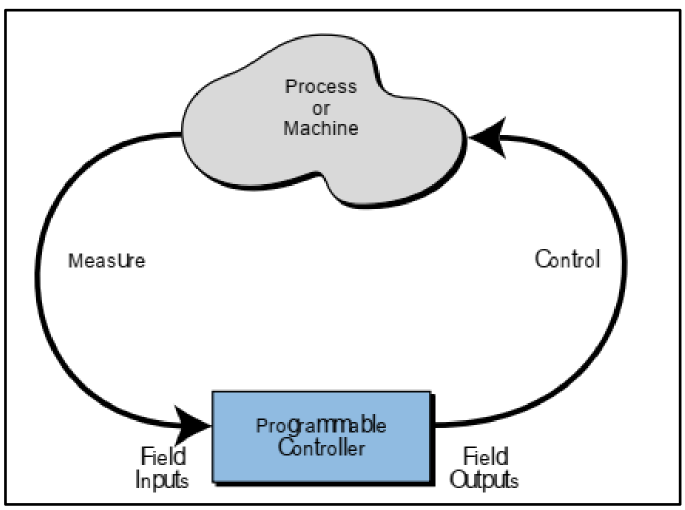


Figure 2.1: PLC conceptual application diagram.

2.2.1 Advantages of PLC

The PLC architecture is modular and flexible, allowing hardware and software elements to expand as the application requirements change. In the event that an application outgrows the limitations of the programmable controller, the unit can be easily replaced with a unit having greater memory and I/O capacity, and the old hardware can be reused for a smaller application. A PLC system provides many benefits to control solutions, Table 2.1 lists some of the many features and benefits obtained with a programmable controller.[11]

Table 2.1: The Features and Benefits of PLC

Features	Benefit
Solid-state components	High reliability
Programmable Memory	Simplifies changes Flexible control
Small size	Minimal space requirement
Microprocessor-based	Communication capability Higher quality products High level of performance Multifunctional capability
Software Timers/Counters	Eliminate hardware Easily changed presets
Software control relays	Reduce hardware wiring & cost Reduce space requirements
Modular architecture	Flexibility and easily installed Reduce hardware cost Expandability
Variety of I/O interface	Control a variety of devices and eliminate customized control
Modular I/O interface	Neat appearance of the control panel Easily maintained and wired

2.2.2 PLC Hardware

A PLC system has the basic functional components of the processor unit, memory, power supply unit, input/output interface section, communications interface, and the programming device. Figure 2.2 shows the basic arrangement.

The processor unit or central processing unit (CPU) is the unit containing the microprocessor. This unit interprets the input signals and carries out the control actions according to the program stored in its memory, communicating the decisions as action signals to the outputs.

The power supply unit is needed to convert the mains AC voltage to the low DC voltage (24 V) necessary for the processor and the circuits in the input and output interface modules.

The programming device is used to enter the required program into the memory of the processor. The program is developed in the device and then transferred to the memory unit of the PLC.

The memory unit is where the program containing the control actions to be exercised by the microprocessor.[11]

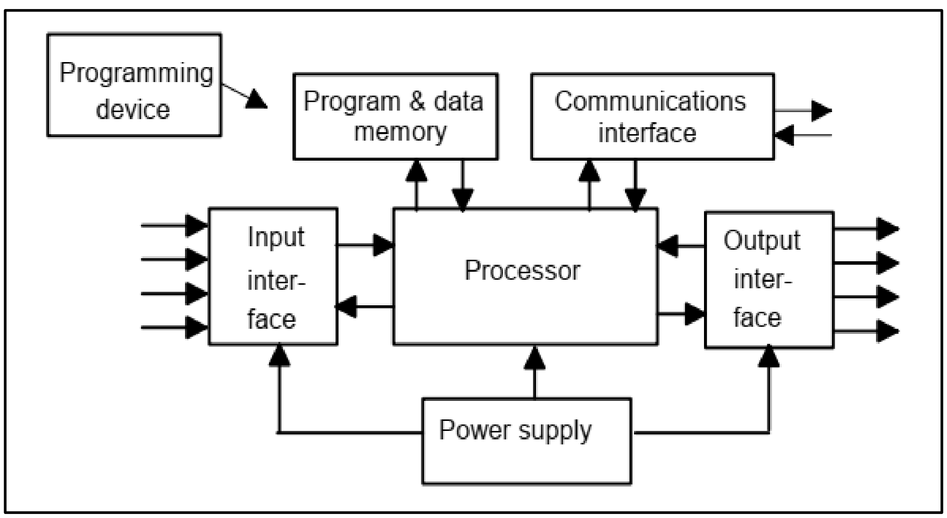


Figure 2.2: The PLC System

2.2.3 PLC Programming

Programming a PLC can be done using one of these language formats:

- Ladder Logic Diagram (LD). Graphical.
- Function Block Diagram (FBD). Graphical.
- Sequential function chart (SFC). Graphical
- Structured text (ST). Textual.
- Instruction List (IL). Textual.

These languages are outlined in IEC[2]61131-3 standard. IEC61131-3 is the international standard which defines the programming languages. It also provides different guidelines about implementations and various applications of PLC programming language.

2.2.4 SIEMENS S7-200 PLC

The Micro PLC SIMATIC S7-200 is the smallest member of the SIMATIC S7 family, it is a powerful PLC considering its real-time response, its fast, features, great communication options and it comes with easy software and hardware to operate. S7-200 PLCs have a compact modular design for a customized solution for less complex processes.it is a great choice for open loop control and lower performance range.

S7-200 CPU 226 AC/DC/Relay:

- Description: S7-200 CPU 226 comes with 24 digital inputs and 16 digital outputs; it can add up to 7 expansion modules. It is integrated RS485 interface or use as system bus

2.3 Variable Frequency Drive

A Variable Frequency Drive (VFD) is a type of motor controller that drives an induction motor by varying the frequency and AC voltage supplied to the AC electric motor. Other names for a VFD are variable speed drive (VSD), adjustable speed drive (ASD), adjustable frequency drive (AFD), AC drive, Microdrive, and inverter. it is largely used in industrial applications such as pumps, ventilation systems, elevators, and machine

[2]IEC stand from The International Electrotechnical Commission is an international standards organization that prepares and publishes International Standards for all electrical, electronic and related technologies – collectively known as "electrotechnology"

tool drives. Frequency (or hertz) is directly related to the motor's speed (RPMs). In other words, the faster the frequency, the faster the RPMs go according to the following relationship:

$$RPM = \frac{120 \times f}{P} \tag{2.1}$$

Where:

RPM: Revolution per minute.

f: The frequency.

P: Number of poles in the stator winding (Even number).

Single-speed drives start motors abruptly, subjecting the motor to high torque and current surges up to 10 times the full-load current or nominal current I_n. Variable frequency drives (VFDs) offer a soft start, gradually ramping up a motor to operating speed. The variable frequency lessens mechanical and electrical stress on the motors and can reduce maintenance and repair costs and extend the motor life.

2.3.1 Working Principle of the Variable Frequency Drive

The VFD controller is a solid-state power electronics conversion system consisting of three distinct sub-systems; a rectifier bridge converter, a direct current (DC) link, and an inverter.

The first sub-system of a Variable Frequency Drive (VFD) is the Converter. It is comprised of six diodes as shown in the figure bellow. Thus, we get six current "pulses" as each diode opens and closes. This is called a "six-pulse VFD", which is the standard configuration for current Variable Frequency Drives.

In the second subsystem, the AC ripple passes through the DC bus which is large DC capacitors. They absorb the AC ripple and deliver a smooth DC voltage. The actual DC voltage will depend on the voltage level of the AC line feeding the drive, the level of voltage unbalance on the power system, the motor load, the impedance of the power system, and any reactors or harmonic filters on the drive.

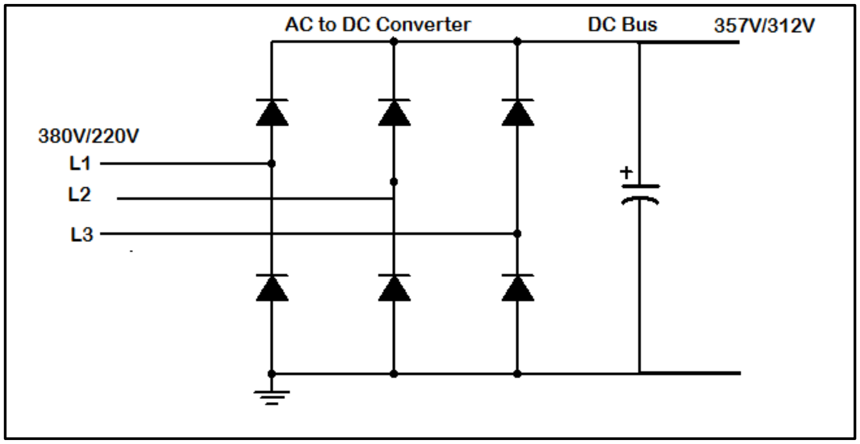


Figure 2.3: Three phase rectifier diode bridge with DC Bus

The third subsystem of the drive is the inverter, in this stage, many techniques and methods are used, in this report, we focus on the most used technique which is Voltage Source Inverter (VSI) Pulse Width Modulation.

<u>Voltage source inverter PWM design:</u>

Pulse width modulated (PWM) inverters are among the most used power-electronic circuits in practical applications. These inverters are capable of producing AC voltage of variable magnitude as well as variable frequency.

PWM uses transistors that switch the DC voltage ON and OFF in a defined sequence to produce the AC output voltage and frequency. Most VFD's today utilize insulated gate bipolar transistors or IGBTs. The typical configuration of the IGBTs in the inverter section of a VFD is shown in Figure 1.4.

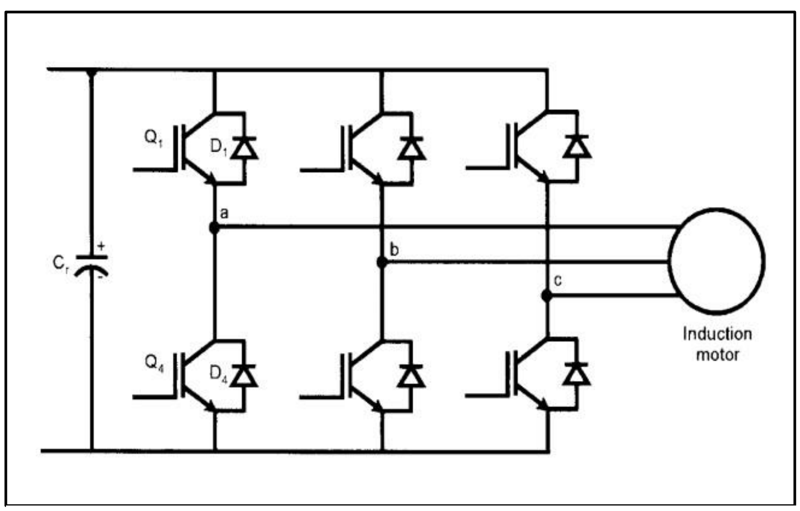


Figure 2.4: three phase Inverter using IGBTs

Once the output frequency required to satisfy the speed regulator is given to the control system, it calculates the three-phase voltage commands. A triangle voltage waveform (the carrier waveform) is generated and synchronized with the desired IGBT switching frequency. This is the PWM carrier waveform that sets the basic inverter switching frequency. The average width of the PWM waveforms generated approximates the sine wave reference as shown in the Figure 2.5.

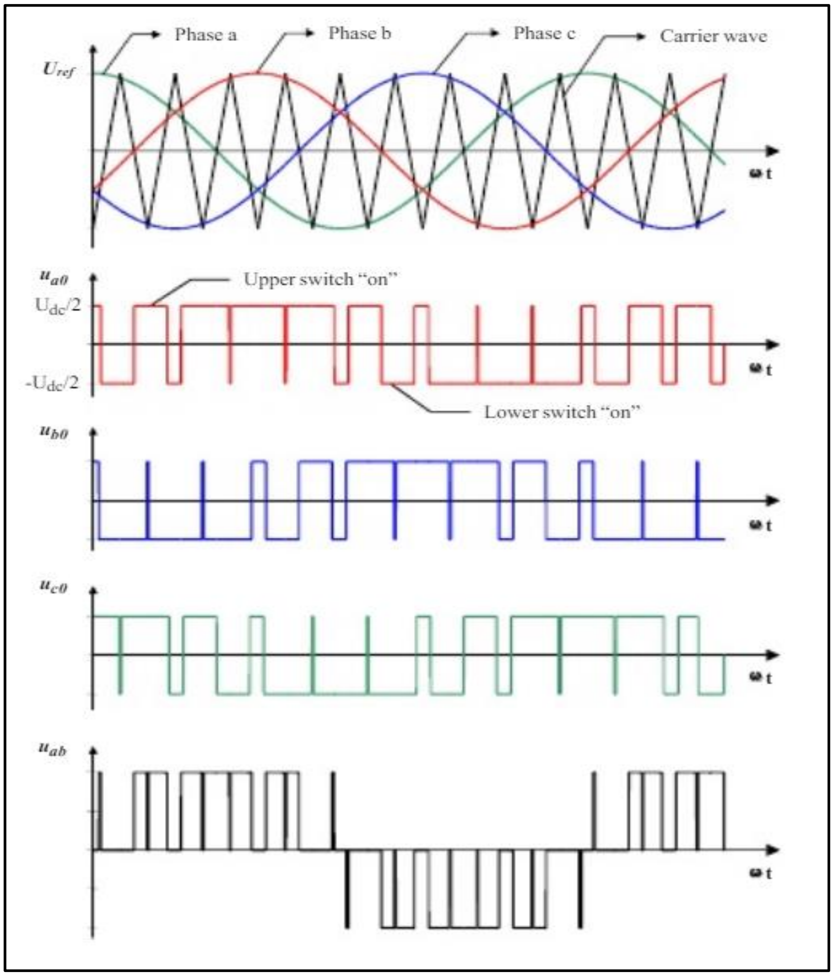


Figure 2.5: Line and Phase voltage waves of PWM Inverter

The output from the VFD is a rectangular waveform. VFD's do not produce a pure sinusoidal output. This rectangular waveform would not be a good choice for a general-purpose distribution system, but it is perfectly adequate for an induction motor. The current waveform will be sinusoidal because the motor is inductive.

Advantages of the PMW technique:

- Excellent input power factor due to fixed DC bus voltage.
- No motor cogging normally found with six-step inverters.
- Highest efficiencies: 92% to 96%.
- Compatibility with multi-motor applications.
- Ability to ride through a 3 to 5 Hz power loss.
- Lower initial cost.

Disadvantages:

- Motor heating and insulation breakdown in some applications due to high frequency switching of transistors.
- Non-regenerative operation.
- Line-side power harmonics (depending on the application and size of the drive).

2.3.2 Advantages of Variable Frequency Drive

AC Drives are often the best choice:

- **Save energy**: significant energy savings can be realized in many fan and pump applications that previously used dampers or ON/OFF control: AC drives a low motor speed to be fine-tuned to the process.
- **Reduce start up current:** controlling the inrush current at motor start-up allows the use of smaller fuses, and reduces electrical peak load.
- **Reduce mechanical stress:** controlled/smooth starting and stopping minimize mechanical shock and wear and tear on the system.
- **Power Factor:** motors have very poor power factors (especially at light loading). Drives significantly increase power factor (even at light loading) and can eliminate the need for power factor correction capacitors and/or utility power factor charges

- **Variable Speed and integrated functionality:** AC drives can vary motor speed and direction by operator input (keypad buttons/speed control knob) or by digital and analog inputs from pushbuttons/switches/pots or PLC outputs).

2.3.3 Altivar 312 Schneider Electric

Figure 2.6: Altivar 312 Schneider Electric Front Side

Description: The Altivar 312 drive or ATV 312 drive is designed to make industrial and commercial machines more efficient while at the same time, simplifying its integration into a single control system architecture. With the highest over torque and the only drive with a remote graphic keypad in its class, the Altivar 312 is ideally suited for a variety of machines.

Serial Number: ATV312HU40N4.

Software version: V5.1 IE54.

Drive Nameplate:

Table 2.2: The drive Specification

Motor Power /Power Horse	4 kW / 5HP
rated supply voltage	380V3Ø ~ 500 V3Ø (-15% … 10%)
Rated supply frequency	50Hz ~ 60 Hz (-5% …+5%)
Line Current	13.9 A for 380 V, 10.6 A for 500 V
Communication port protocol	CANopen Modbus
IP degree of protection	IP20 on upper part without cover plate IP21 on connection terminals IP31 on upper part
Motor Overload protection	Class[3] 10 at the nominal Power

[3] Motor Overload Protection class: it is the time required for the drive to trip at 600% of the drive nominal current; class 10 takes 10 sec or less to trip.

2.3.4 Trip curve of the drive

Trip curve is a graphical representation of the expected behavior of a circuit protection device. Circuit protection devices come in many forms, including fuses, miniature circuit breakers (MCB), molded case circuit breakers (MCCB) etc. it is a plot of time versus overcurrent based on the nominal current of the device I_n.

The drive's trip curve is shown in the figure below:

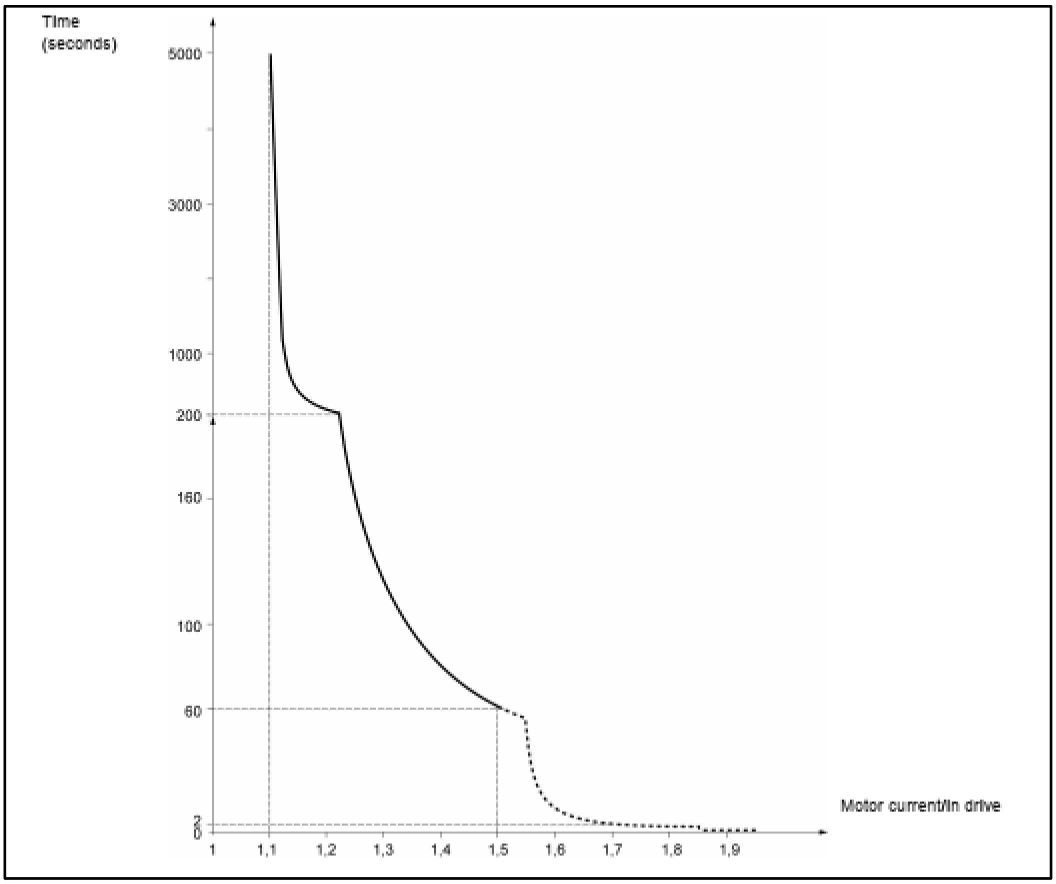


Figure 2.7: The trip curve of Alvitar312

At 150% of nominal drive current ($1.5I_n$): the drive trip after 60s.

At 185% of nominal drive current ($1.85I_n$): the drive trip after 2s.

2.4 Three Phase AC Motor

The three-phase AC induction motor is a rotating electric machine that is designed to operate on three phase supply. This 3-phase motor is also called as an asynchronous motor.

- Motor Nameplate:

Table 2.3: Motor Nameplate

Motor Power /House power	500W / 0.75Hp
Voltage Input	380V Y /220V∆
Current Input	1.4Amp Y/ 2.1 Amp ∆
Pf = cosφ	0.83
Turns per minute	2750 RMP

2.5 Photoelectric Sensor

A photoelectric sensor is a sensor that emits a light beam (visible or infrared) from its light emitting element like infrared emitter LED and detect this light beam by a receiving element like photodiode. Photoelectric sensors are available in a variety of operating modes, two of these modes are used in this project which are:

- Diffuse Reflective mode.
- Thru-beam mode.

2.5.1 Diffuse reflection IR Sensor

The emitter and the receiver are in one unit. The sensor receives the light reflected from the target as shown below:

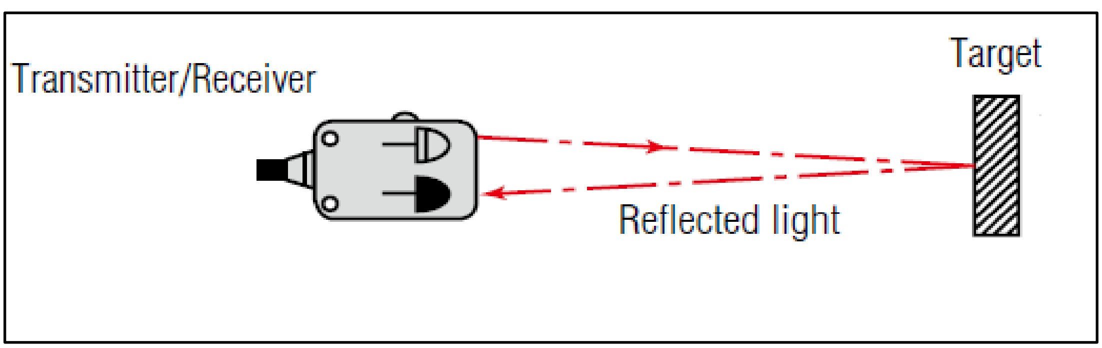


Figure 2.8: The diffuse reflection mode

One advantage of the diffuse reflection mode is the ability to distinguish between black and white where the black color absorbs all the light spectrum while the white color reflects all the light spectrum. It can use this feature to generate HIGH state (24V) and LOW state (0V) according to the circuit describe bellow. In this project, the diffuse reflection mode is used for two different tasks:

1. The first task is to set three IR sensors spaced from each other a few centimeters apart at the top of the cabin to determine its current floor. To do this a binary coding is used as the table indicates bellow:

Table 2.4: The Binary code of the Cabin position

Floor Level	Binary Code
Floor 1	001
Floor 2	010
Floor 3	011
Floor 4	111

2. The second task, IR sensor works as a linear encoder to determine the speed of the hoist motor, it is essentially consisting of a bar marked in black color and white color in a specific arrangement where the white color generates a HIGH state (24V) and black color generates a LOW state (0V).

2.5.2 <u>Circuit description</u>

The circuit diagram shown below, a comparator is used to compare the detected value to the threshold voltage, an IR led is used for transmitting IR beam and when it collides with an obstacle (white/black surface), one of two scenarios can happen: one with the white surface, it reflects the light beam that’s received by the IR photodiode (the photodiode is connected in reverse bias). The receiver will act as a potentiometer whose value is directly dependent on the infrared ray falling on it. This relation is inversely proportional, the greater the light intensity the lower the resistance so, the voltage will be higher than the threshold voltage, therefore the output voltage of the comparator will be HIGH and turn on the MOSFET Transistor resulting LOW state (0V) at the output.

The second scenario is when the surface is black, there is no reflecting beam which results a voltage less than the threshold, therefore, the comparator output will be LOW keeping the MOSFET transistor OFF resulting a HIGH state (24V) at the output.

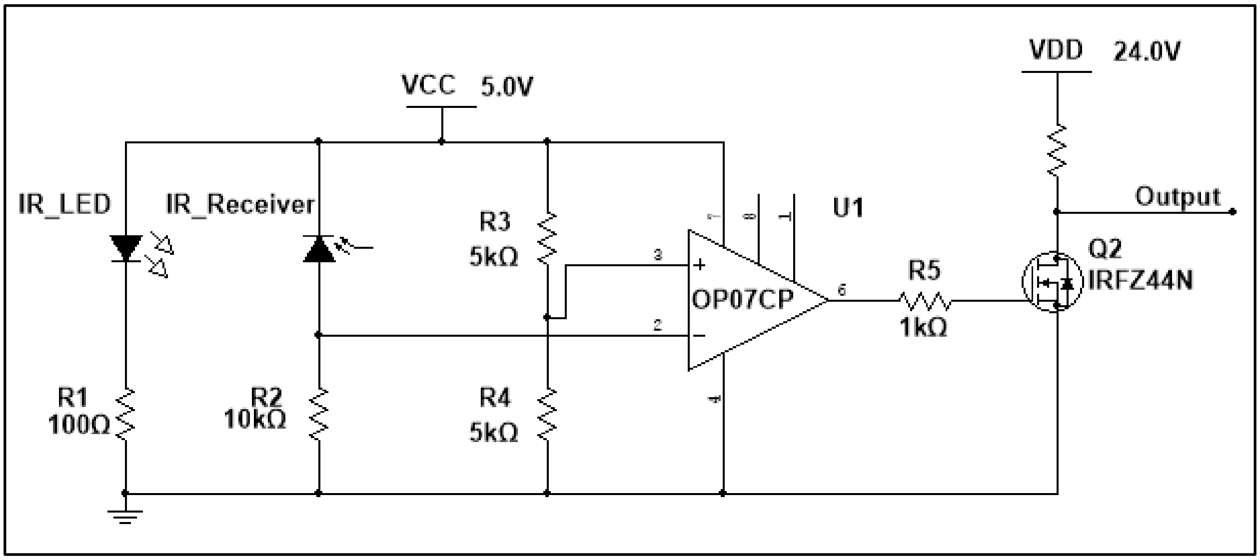


Figure 2.9: Circuit Design of the Diffusion-Reflective IR sensor

2.6 The Door Operation

To open or close the door, a DC motor connected to a toothed pulley which lies on a toothed rod that moves the door. The DC Motor is controlled by an H-bridge (L293D) to move the door in either direction. A voltage divider is used to step down the voltage supplied by the PLC which is 24V to 5V which is the voltage suitable for the input of the H-bridge. The circuit is shown in the figure below:

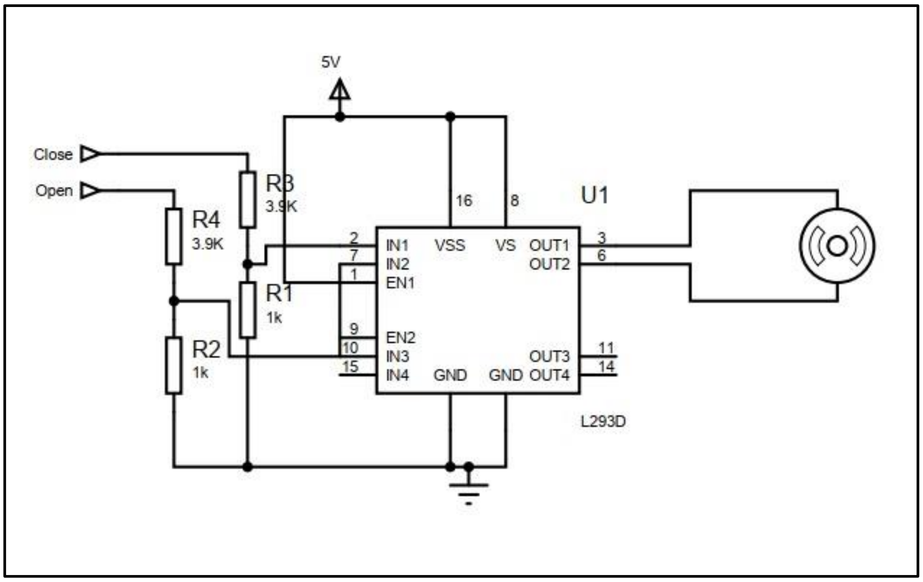


Figure 2.10: Circuit Design of the H-Bridge

Limit switches are used to detect the fully closed state and fully open so that the motor stops.

2.6.1 <u>Door obstacle detector</u>

The same circuit described in section 2.5.2 is used to detect an obstacle in the doorway with an exception of placing the IR LED and Photodiode in Thru-beam mode or the direct mode**.** in this mode, the IR LED and photodiode are kept in front of one another on opposite ends of the door, so that the IR radiation can directly fall on the photodiode, if any object is placed between them i.e. in the doorway, the IR light is prevented from reaching the photodiode and the door reopens instead of closing. The following figure illustrates the direct mode:

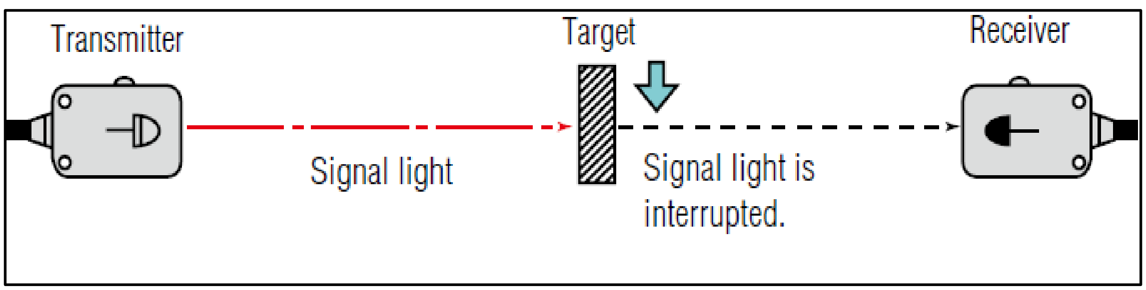


Figure 1.11: Thru-beam mode.

2.7 7-segment display

To display the floor level a common anode 7-segment display is used which is connected to a BCD (Binary Code Decimal) to 7-segment decoder (DM7447AN) that features active-LOW outputs designed for driving common-anode LEDs or incandescent indicators directly. The circuit diagram of the BCD to 7 segment display shown below:

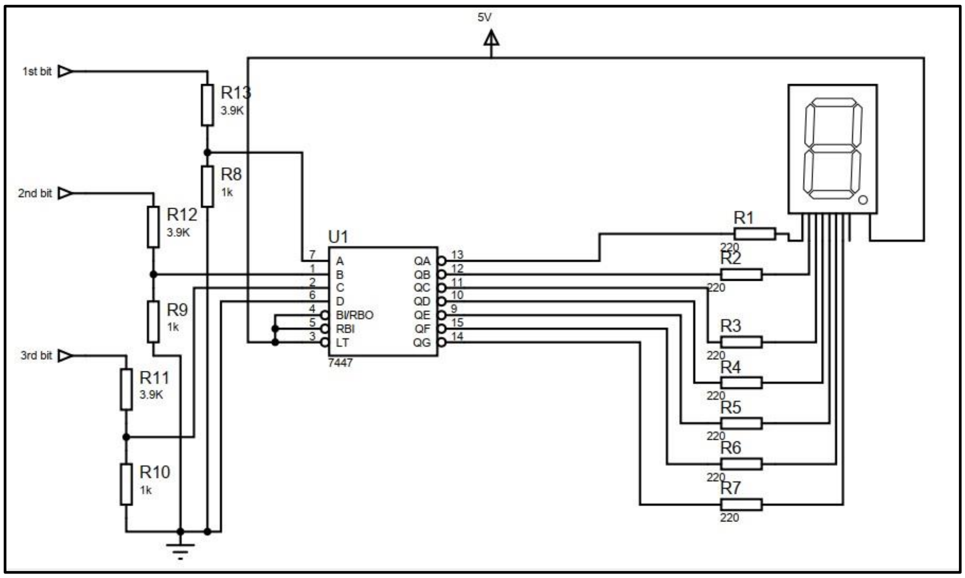


Figure 2.12: BCD to 7 segment display circuit diagrams

2.8 Conclusion

The components and circuits described above, PLC, VFD, AC motor and different detecting and tracking systems which are mainly based on the photoelectric principle, in this case the infrared sensors, are the separate segments that, when connected form the electric aspect of the elevator. The implementation and assembly of these parts are further explained in chapter four.

Chapter Three
Software Design

3.1 Introduction

In this chapter, software design of an elevator system is introduced. The PLC controller in this project is responsible for the safe and efficient operations of all the other components within the elevator system, its main goal is essentially to handle all the input signals that come from operator, different sensors and push buttons inside and outside the elevator cabin and respond accordingly with output signals such as moving the cabin upward or downward with suitable speed, lighting and displaying the cabin current floor.

3.2 The System Block Diagram

Figure 3.1 indicates the overall block diagram of the proposed system

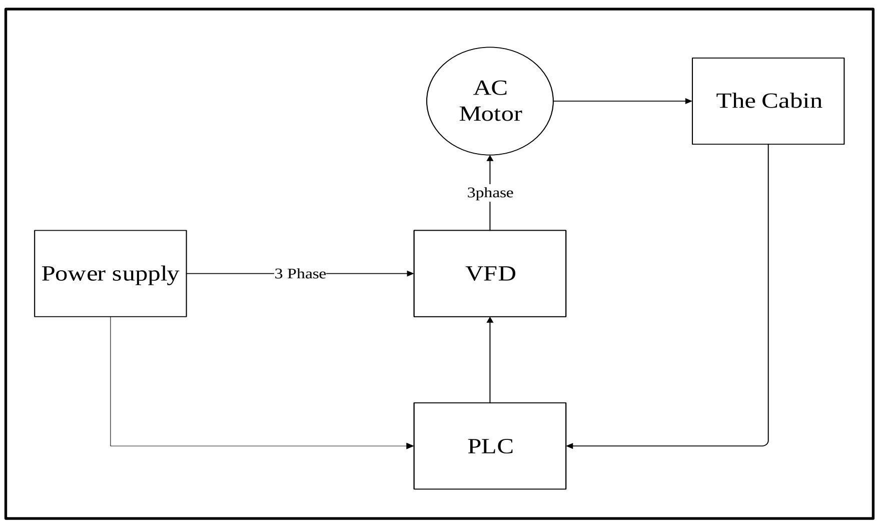


Figure 3.1: System block diagram

3.3 Elevator Control Panel

The Cabin: the cabin consists of four push buttons (1-4) for floor request, open door push-button, close push button.

The Hall Calls Push Buttons: at each floor there is an UP PB except the last floor and DOWN PB except the First Floor, there are six hall calls.

Direction Indicators: when the user presses a hall call, its corresponding LED turns ON to indicate that the hall button is pressed, there are six LEDs

<u>The 7 Segment display:</u> Seven-segment display is used to indicate the current position of the cabin to people at all floors and to people riding the elevator.

<u>Inverter:</u> it is used to drive the AC motor; it can be controlled by PLC signals and therefore control the motor direction (forward/reverse) as well as the motor speed.

<u>DC Motor:</u> it is used to open and close the cabin door.

<u>Load Cell:</u> load cell or weight sensor is used to measure the weight of the elevator cabin; it sends a signal to the controller when it reaches the maximum load of the elevator cabin.

<u>Position sensor:</u> it consists essentially of three IR circuits that generate binary sequence according to the description mention in chapter 2.

<u>Linear Encoder:</u> an IR sensor works as a linear encoder to determine the cabin position along the way and based on its position, the controller will set the hoist speed.

<u>Service Switch:</u> it is used to switch between the automatic mode and manual mode

3.4 <u>The Elevator control system</u>

The main goal of the elevator controller is to respond to all the input signals that are operation mode (automatic mode or manual mode), car calls, hall calls, position sensors, linear encoder signal and safety signals and produce accordingly the output signals that control the inverter to determine the direction of the hoist motor, the travel speed, the seven segments display, direction LEDs and the door motor. See figure 3.1.

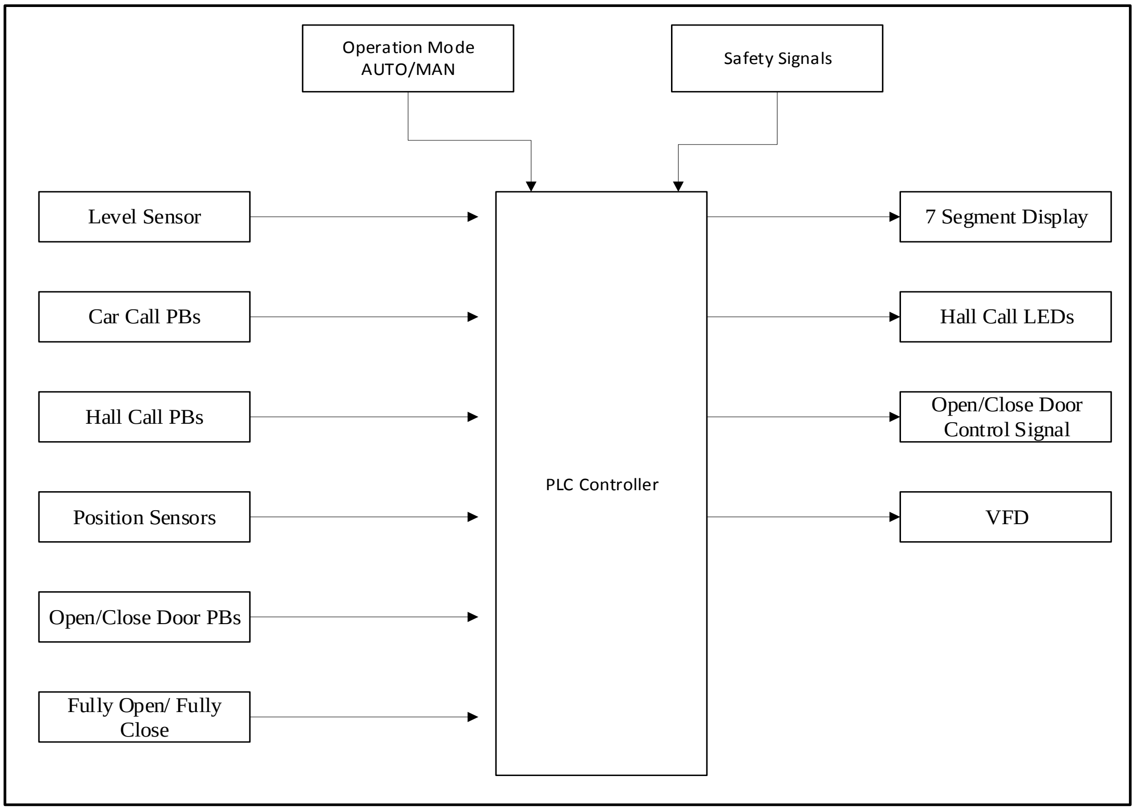


Figure 3.2: PLC Signals control system diagram.

3.5 <u>The Elevator control policy</u>

The dynamics of an elevator system is generally complicated in that the system behavior involves aggregating complexity of state descriptions, and can vary differently when imposing a different control policy. In this report an elevator control system of four floor numbered from one to four is modeled, our prototype is equipped with IR sensors to identify the cabin current position using binary coding and based on it the controller decides which direction should the elevator take after the passenger presses the floor he/she want to go to. Once a hall/car button is pressed, the elevator serves the hall/car call immediately by moving the cabin to the selected destination floor. When all calls are served, the elevator stops and waits for the next call to serve.

The capacity issue is also considered here: constraint on the maximum elevator load is considered to ensure safe service. As a result, a full elevator cannot load any more passengers until one or more leave the cabin and the overload signal turns off. To model the complicated system behavior involved, we first give some basic state definitions:

1) ***IDLE* state**: the elevator stops at a certain floor.
2) ***OPEN* state**: when the cabin of the elevator reaches the passenger's destination floor or the requested hall call position, the elevator door is to open.
3) ***WAIT* state:** the elevator stays at a certain floor, waiting for the passenger inside to leave or the passenger outside to enter.
4) ***CLOSE* state:** the elevator door is to close after the opening time, which is set at 10 seconds, is over or the close push button is pressed when the door is completely open.
5) ***UP* state:** the elevator is moving up.
6) ***DOWN* state:** the elevator is moving down.
7) ***OVERLOAD* state:** the elevator is overloaded.
8) ***OBSTACLE state:*** it is activated when a passenger passes or an obstacle preventing the door closing.

   To understand how a state is transferred to another state, we use a state transition diagram (e.g. Figure 3.3 to explain their relations.)

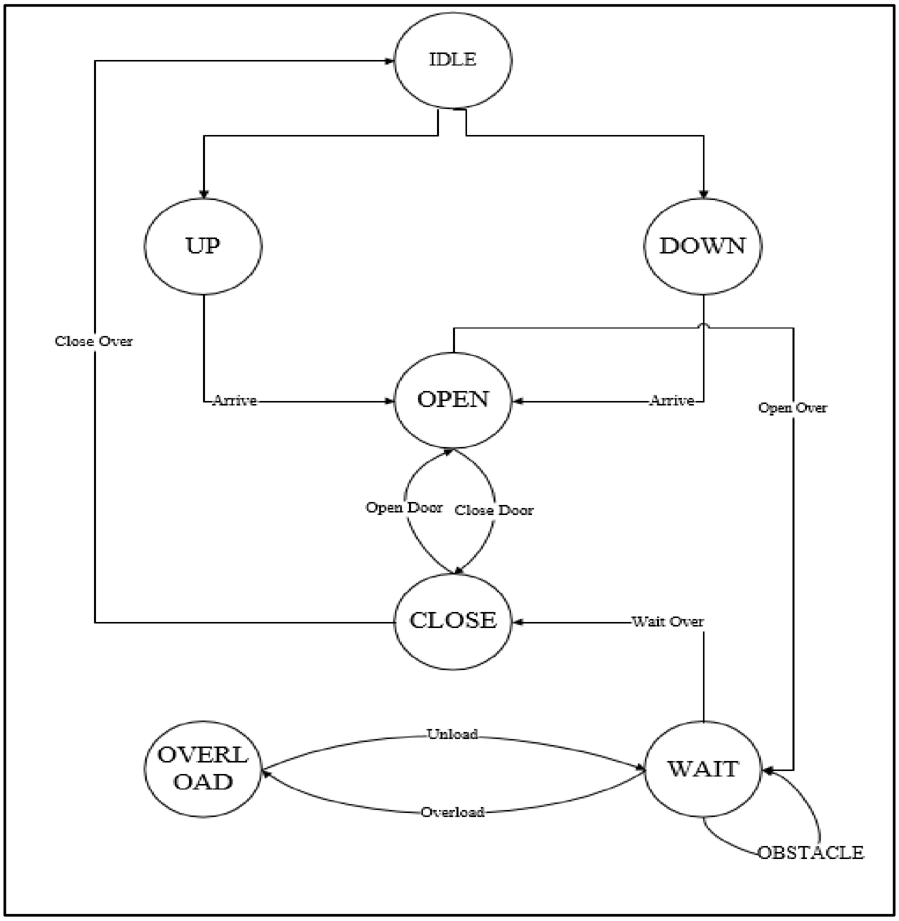


Figure 3.3: The system state transition diagram

Let assume the initial state is in IDLE state, when a Hall Call PB at a certain floor is pressed, if the elevator cabin is at the desired floor the condition moves from IDLE to OPEN state, if the elevator is above/below the requested floor the condition moves to DOWN/UP state. Upon entering the cabin, the passenger selects a destination floor by pressing a Car Call PB. The elevator state is transferred to UP/DOWN state accordingly. Once the elevator arrives to the destination floor, it changes to OPEN state and the door is ready to open. When the door is fully open, the state changes to WAIT state to let the passengers come out from the cabin or the outside passengers enter the cabin.

In the WAIT state, three scenarios are possible. The first scenario is when the overload signal is ON indicating the maximum load. The Elevator state changes to OVERLOAD state then it will change to WAIT state again, the cabin lamp will flash ON and OFF. The second scenario is to change to CLOSE state, the door will close but if there is an obstacle in the doorway, the state returns to WAIT state and keeps the door open until the doorway is cleared. When it is fully closed the state changes to IDLE State, thus, completing an operation cycle.

3.6 <u>The Elevator control Strategy</u>

The control objective for the elevator system is to direct the elevator movement in either UP or DOWN direction or stay at the same floor based on control decision and make sure that all the buttons pressed be served.

The control policy we use complies with the common elevator rule: service request are served at first come first served basis with the exception when the elevator is going in a particular direction, it will pick up all the requests in the same direction along the way and ignore temporary the requests that are in opposite direction. The Elevator cabin keeps moving UP or DOWN until all the upstanding requests are served.[12]

The elevator control strategy can be specified as follows:

- The people near the cabin elevator gain a higher priority if their position is on a similar direction as the elevator is going.
- However, the passengers' request should be ignored temporarily if they are in the opposite direction of the elevator heading.

3.5.1 <u>Use case:</u>

The operations of the elevator are divided into two categories:

- Passengers Transportation.
- Operator Intervention.

The following table explains it in more details:

Table 3.1 : The Use Case of the Elevator system

The Operator	The Passenger
Turn ON the system. **Set the Service Switch to**	**Request an Elevator at a floor (Outside the Cabin)**

• Automatic mode: 1. Press Reset Button. 2. Move the Elevator Cabin to the default floor i.e. The first floor. 3. Enable Hall Buttons and Car Buttons. • Manual mode: 1. Disable Hall Buttons. 2. Control the door manually.	1. Press the Hall Call PB. 2. Turn ON its corresponding LED indicator. 3. Show the cabin position at the 7-segment display. 4. Open the Elevator door. 5. Turn OFF the indicator LED. 6. Close the Elevator Door.
Reset the system	**Select the destination Floor (Inside the cabin)** 1. Select the desired floor by pressing the Car button. 2. Drive the Hoist UP/DOWN. 3. Show the cabin position at the 7-segment display. 4. Open the door at the Destination floor. 5. Close the Door.

3.7 The Software Design

One of the advantages of Siemens S7-200 software is the networking design which gives the code a better structure, easy to understand, debugging and easy to fix. Therefore, the code is divided into many networks for better functionality.

3.6.1 Setting the System to Operation

When the system is set to operation, the controller checks the operation mode if it is on Automatic mode, Manual mode or Stop mode.

In the Automatic mode or Normal mode, a reset PB should be pressed by the operator, the controller S7-200 executes AUTO/RST Subroutine that reset all the outputs and memories (except the memories that store the position of the cabin). Next, the controller checks the door status, close it if it is open and set the CLOSEOVER memory bit, when it is closed, the controller checks the next step which is the cabin position , if the cabin is not at the first floor, the controller sends a signal to the VFD to drive the motor down to the first floor. When it reaches the first floor, a timer is set for 5 seconds, after that, the USER ACCESS Memory bit is set to enable All the Hall buttons and Car buttons.

This subroutine can be used also to restart the system if there is an error, a malfunction, initialization process or when we switch from Manual mode to Automatic mode. It can be accessed only by the operator. (see figure 3.4).

In the Manual mode or the Independent mode, the controller cancels all the operation orders and the hall buttons are disabled, the elevator is controlled by the operator using Manual Access memory bit.

- When the cabin stops at a certain floor, the door shall open and remains open.
- At the manual mode, the hall buttons are disabled and the cabin buttons are enabled by setting MAN ACCESS memory bit.
- The door is controlled manually. Close it by holding the Close PB until it is fully closed, the same operation for the opening.
- To travel to a certain floor, the operator must close the door and then select the destination floor.

In the Stop mode, the controller clears all the operation orders.

The next figure depicts the system operation flowchart:

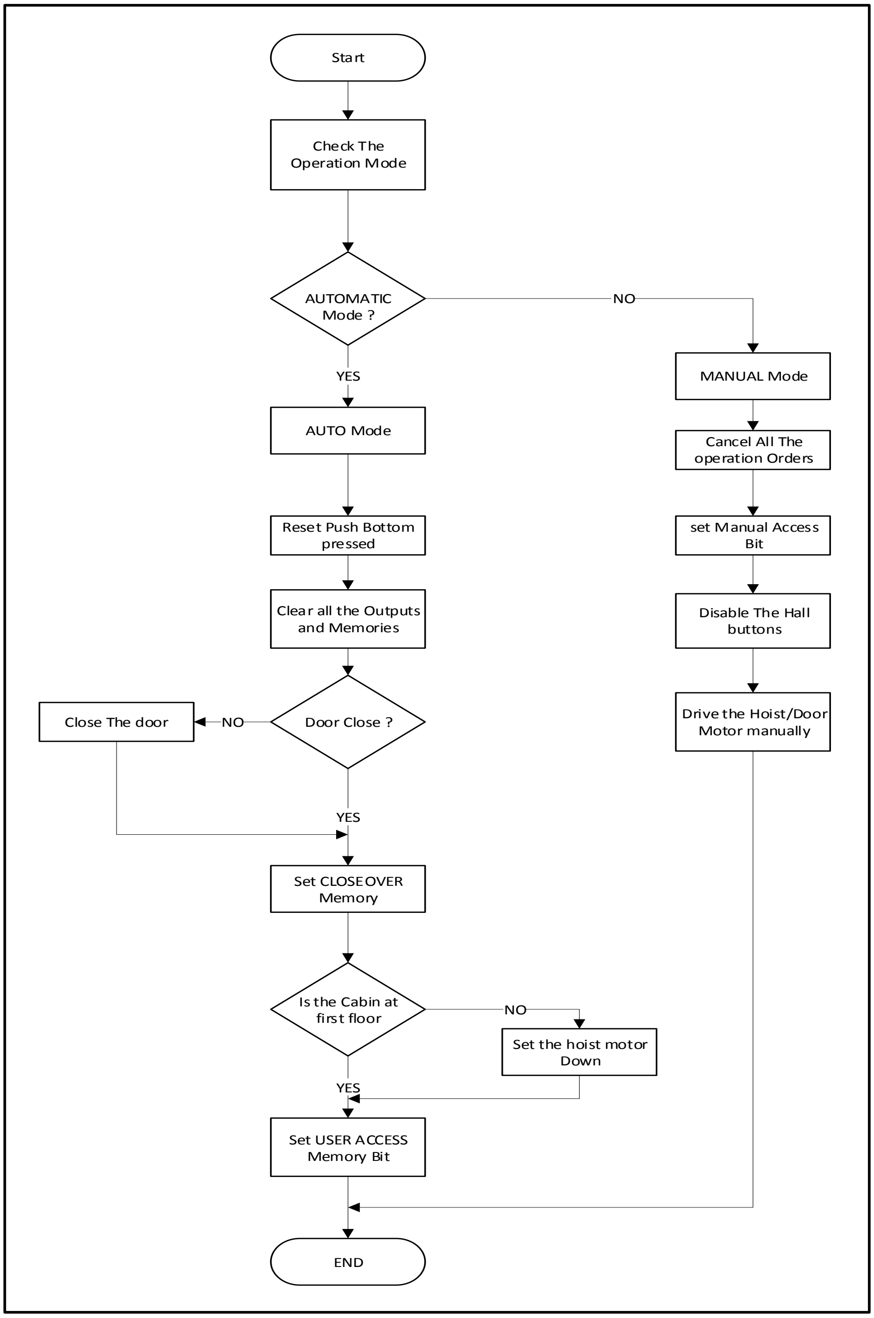


Figure 3.4: The system operation flowchart

3.6.2 Set the Auto/Reset subroutine

As the safety measure, the initialization will not take place if the OVERLOAD signal is ON which means the cabin is overloaded. Figure 3.5 illustrates all the conditions for setting and resetting the ENABLE memory bit which is responsible for enabling the AUTO/RST Subroutine.

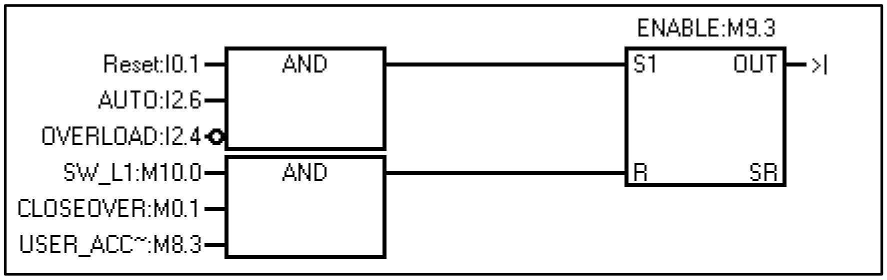


Figure 3.5: The activation of AUTO/RST Subroutine

3.6.3 The Position Decoding

As described in chapter two, IR sensors are used to generate a binary sequence based on the elevator cabin position. Figure 3.6 illustrates the decoding of the first-floor binary code according to the table 2.4.

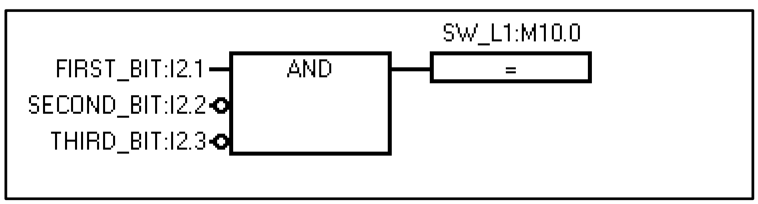


Figure 3.7: Decoding of the first-floor binary sequence.

3.6.4 The Floor Selection and Indicator Control

There are two ways to select the distention floor:

- The Hall Call PB.
- The Car Call PB.

If one of the push buttons is pressed, the floor selection is stored via an RS flip-flop and at the same time lit the corresponding LED indicator. The floor selection should be reset once the cabin reaches the destination floor and the door is opened.

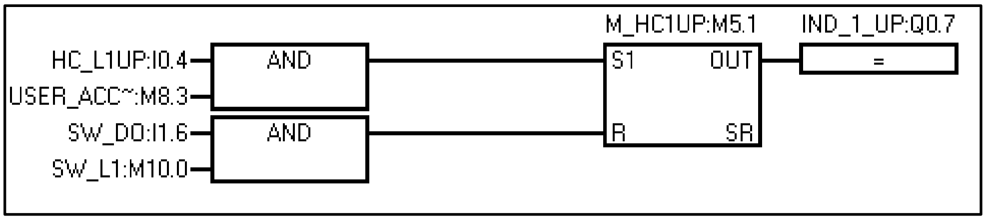


Figure 3.7: Memorize the UP first floor request.

3.6.5 The Floor Transitions

Our control depends on taking all the requests into consideration and ordering them in an intelligent manner to reduce the speed respond as well as the energy consumption. All possible transitions are shown in the state diagram in the following figure:

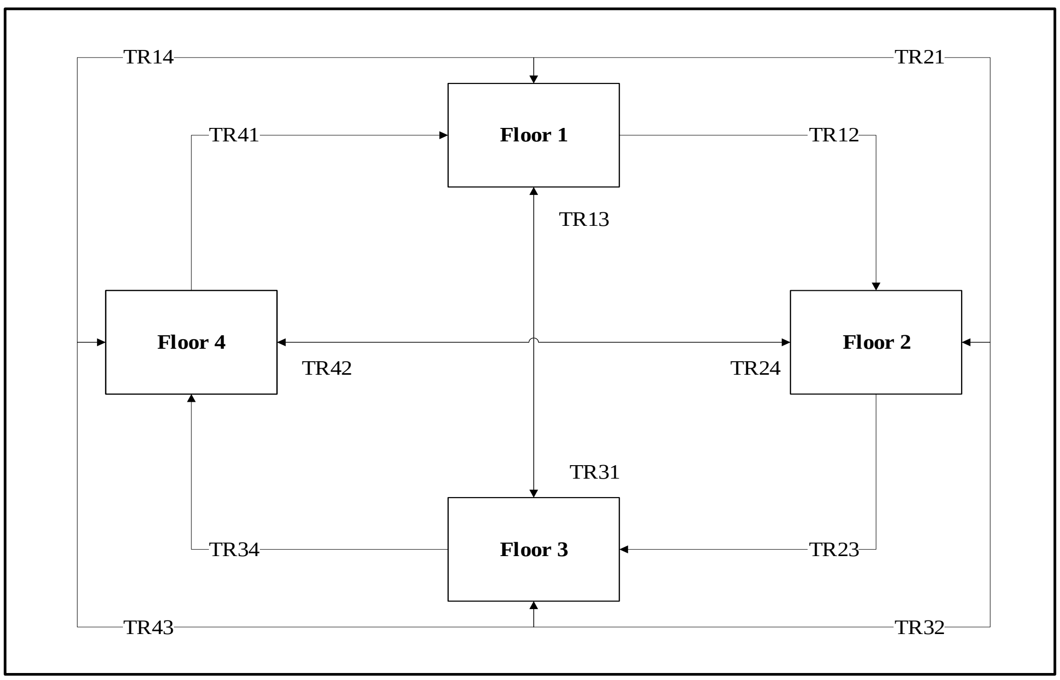


Figure 3.8: The possible transitions of the elevator system.

In Figure 3.8, the transitions TR_{ij} from floor i to j, with $i, j = 1{,}4$ and with $i \neq j$ are all defined below, where the bar denotes the 'logical complementation', operation(+) denotes the logical OR and the (.) denotes the logical AND . In constructing these transitions, the security issue of passengers is considered into account by ensuring that the door is closed before any transition takes place and the floor positions memory bits are activated based on their corresponding binary codes. To implement the control strategy stated above, the priorities of the transitions are defined as follows:

When the lift is going from floor i to j with $j > i$ (the lift is up), the request on the floor j to go up and the inside request to go to floor j have higher priority than the request on floor j to go down. In other words, When there is a request at the floor j to go down, the transition $TR_{ij}$with $j > i$ is done if there is neither a request at level j to go up nor an inside request to go to level j nor an outside request at the floor k; $(k > j)$ to go down.

When the lift is going from floor i to j with $j < i$ (the lift is down), the request on the floor j to go down and the inside request to go to floor j have higher priority than the request on floor j to go up. In other words, when there is a request at level j to go up, the transition TR_{ij} with $i \ < j$ is done if there is neither a request at level j to go down nor an inside request to go to level j nor an outside request at the floor k; $k < j$ to go up.[12]

The equations for the transitions between the floors based on the conditions mentioned above are:

- The transitions from level 1 up to levels 2,3 and 4

$$TR12 = SW_{DC}.SW_{L1}.CLOSEOVER.\overline{LOCK12}.\overline{WAIT1}.[M_{HC2} + M_{HC2UP} + (M_{HC2DOWN}.\{\overline{M_{HC3} + M_{HC3DOWN} + M_{HC3UP} + M_{HC4} + M_{HC4DOWN}}\})] \quad (3.1)$$

$$TR13=SW_{DC}.SW_{L1}.CLOSEOVER.\overline{LOCK13}.\overline{WAIT1}.(\overline{M_{HC2} + M_{HC2UP}}).\left[M_{HC3} + M_{HC3UP} + \left(M_{HC3DOWN}.\overline{\{M_{HC4} + M_{HC4DOWN}\}}\right)\right] \quad (3.2)$$

$$TR14 = \ SW_{DC}.SW_{L1}.CLOSEOVER.\overline{LOCK14}.\overline{WAIT1}.(M_{HC4} + M_{HC4DOWN}).(\overline{M_{HC3} + M_{HC3UP}}).(\overline{M_{HC2} + M_{HC2UP}}) \quad (3.3)$$

- The transitions from level 2 up to levels 1,3 and 4:

$$TR21 = SW_{DC}.SW_{L2}.CLOSEOVER.\overline{LOCK21}.\overline{WAIT2}.\{M32.(M_{HC1} + M_{HC1UP}) + \overline{M12}.\overline{M32}.(M_{HC1} + M_{HC1UP})\} \quad (3.4)$$

$$TR23 = \ SW_{DC}.SW_{L2}.CLOSEOVER.\overline{LOCK23}.\overline{WAIT2}.[M12(M_{HC3} + M_{HC3UP} + M_{HC3DOWN}\{M_{HC4} + M_{HC4DOWN}\}) + \overline{M12}.\overline{M32}.(M_{HC3} + M_{HC3UP} + M_{HC3DOWN}\{M_{HC4} + M_{HC4DOWN}\})] \quad (3.5)$$

$TR24 =$

$SW_{DC}.SW_{L2}.CLOSEOVER.\overline{LOCK24}.\overline{WAIT2}.(\overline{M_{HC3}+M_{HC3UP}}).(M12.[M_{HC4}+M_{HC4DOWN}]+\overline{M12}.\overline{M32}.[M_{HC4}+M_{HC4DOWN}])$ (3.6)

- The transitions from level 3 up to levels 1,2 and 4:

$TR31 =$

$SW_{DC}.SW_{L3}.CLOSEOVER.\overline{LOCK31}.\overline{WAIT3}.(\overline{M_{HC2}+M_{HC2DOWN}}).[M43.(M_{HC1}+M_{HC1UP})+\overline{M43}.\overline{M23}.(M_{HC1}+M_{HC1UP})]$ (3.7)

$TR32 = SW_{DC}.SW_{L3}.CLOSEOVER.\overline{LOCK32}.\overline{WAIT3}.[M43.(M_{HC2}+M_{HC2DOWN}+M_{HC2UP}.\{M_{HC1}+M_{HC1UP}\})+\overline{M23}.\overline{M43}.(M_{HC2}+M_{HC2DOWN}+M_{HC2UP}.\{M_{HC1}+M_{HC1UP}\})]$ (3.8)

$TR34 = SW_{DC}.SW_{L3}.CLOSEOVER.\overline{LOCK34}.\overline{WAIT3}.[M23.(M_{HC4}+M_{HC4DOWN})+\overline{M23}.\overline{M43}.(M_{HC4}+M_{HC4DOWN})]$ (3.9)

- The transitions from level 4 up to levels 1,2 and 3:

$TR41 =$

$SW_{DC}.SW_{L4}.CLOSEOVER.\overline{LOCK41}.\overline{WAIT4}.(\overline{M_{HC3}+M_{HC3DOWN}}).(\overline{M_{HC2}+M_{HC2DOWN}}).(M_{HC1}+M_{HC1UP})$ (3.10)

$TR42 = SW_{DC}.SW_{L4}.CLOSEOVER.\overline{LOCK42}.\overline{WAIT4}.(\overline{M_{HC3}+M_{HC3DOWN}}).(M_{HC2}+M_{HC2DOWN}+M_{HC2UP}.(\overline{M_{HC1}+M_{HC1UP}})$ (3.11)

$TR43 = SW_{DC}.SW_{L4}.CLOSEOVER.\overline{LOCK43}.\overline{WAIT4}.(M_{HC3}+M_{HC3DOWN}+M_{HC3UP}\{\overline{M_{HC2}+M_{HC2DOWN}+M_{HC2UP}+M_{HC1}+M_{HC1UP}}\})$ (3.12)

$\boldsymbol{SW_{DC}}$	The input signal indicates the door is fully closed.
$\boldsymbol{SW_{Li}}$	Memory bit that store the cabin current floor where:$1 \leq i \leq 4$.
$\boldsymbol{M_{HCi}}$	Memorize the inner requests; $1 \leq i \leq 4$
$\boldsymbol{M_{HCiUP}}$	Memorize the upper requests.

$M_{HCiDOWN}$	Memorize the down requests.

In the case of two activated transitions at the same time (e.g. TR_{12} and TR_{13}), lead to a problem where the system operation cannot work properly. Preventing this from happening by locking all the transitions TR_{ij} that are different from TR_{xy} being ON with $1 \leq i, j, x, y \leq 4\ , i \neq x\ and\ j \neq y$ using $LOCK_{ij}$ memory.

$LOCK_{ij}$ memory is a logic NOR of the transitions TR_{ij} different from the current transition TR_{xy}. As a result, only one transition is activated at a time. Example1 illustrates the operation.

<u>Example1:</u>

TR_{32} is activated, therefore, all the remaining transitions must be OFF and if one of these transitions is ON then TR_{32} will be OFF until the activated transition is OFF.

$$LOCK_{32} = \overline{TR_{12} + TR_{13} + TR_{14} + TR_{21} + TR_{24} + TR_{31} + TR_{32} + TR_{34} + TR_{41} + TR_{42} + TR_{43}} \quad (3.13)$$

Introducing the WAIT memory to prevent the elevator system from carrying two successive transitions.

$$WAIT_i = M\_HC_iUP + M\_HC_iDOWN + M\_HC_i \quad (3.14)$$

The CLOSEOVER memory is used to ensure that the door is fully closed and it is set in the falling edge of the signal CL_DOOR and reset by OP_DOOR signal.

The CLOSEOVER memory is defined as follow:

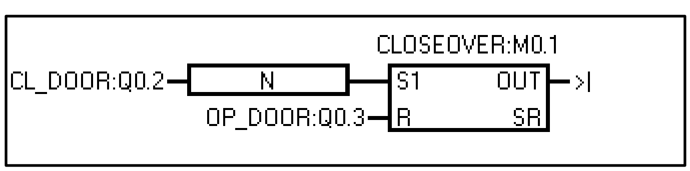


Figure 3.9: The Set and Reset of CLOSEOVER memory

The transitions mention above represent the condition to drive the Hoist motor in UP or DOWN direction but under what conditions the Hoist motor stops at the requested floor. Figure 3.10 illustrates the operation:

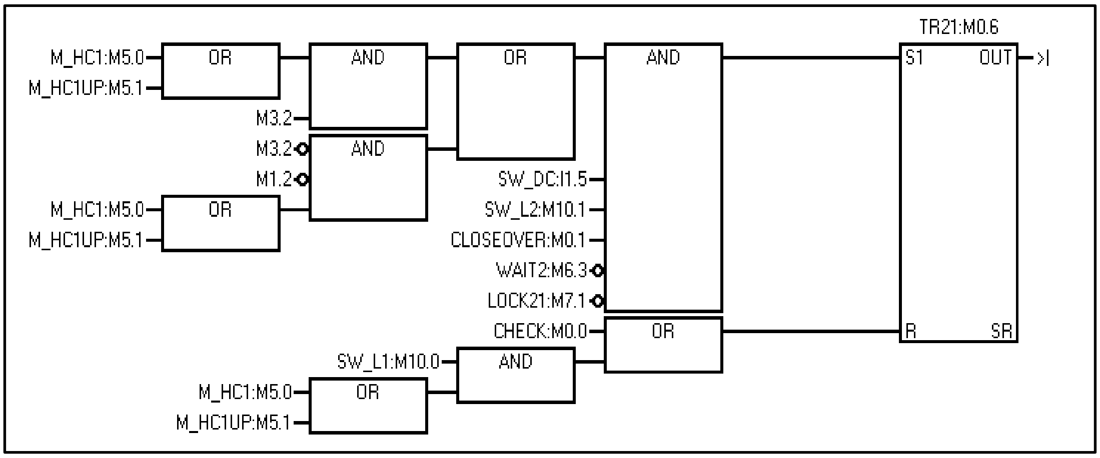


Figure3.10: the conditions that set and reset the transition TR21

To set the transition TR_{21} Flip-flop, the logic equation is implemented in function block diagram (FBD) language, here we assume that the cabin is at second floor, when a passenger presses the Hall call HC_1UP or Car call HC_1 then its corresponding memory M_HC1UP or M_HC1 is set and if the other conditions are met i.e. the door is fully closed and there is no other transition activated. The controller sends a signal to the VFD that drives the hoist DOWN, when the cabin reaches the first floor (SW_L1 is ON) the cabin will stop (see the block attached to the R signal). Here the CHECK memory is a security measure can stop the motor at any position when it is ON.

CHECK memory is defined as the figure illustrates:

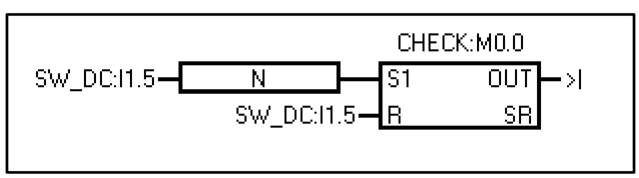


Figure 3.11: The CHECK memory Set and Reset condition

When the door is slightly open or open, it sets the CHECK memory indicating that the door is open and stops the hoist motor, and it is reset when the door is fully closed i.e. SW_DC goes high.

3.6.6 The elevator direction

When the elevator cabin is at the fourth floor, the direction will be downward i.e. $TR_{43}, TR_{32}$and TR_{21}. When it is at the first floor, the direction will be upward i.e. $TR_{12}, TR_{23}$and TR_{34}, however which direction the elevator should take when it is at the second floor or the third floor?

We treat this problem by creating memory bits $M1.2$, $M2.3, M3.2, and\ M4.3$. for example, when the elevator cabin was at the first floor and then traveled upward with a stop at the second floor i.e. $TR_{12}$is ON, an RS flip-flop is used to set and reset the memory $M1.2$ according to the following figure:

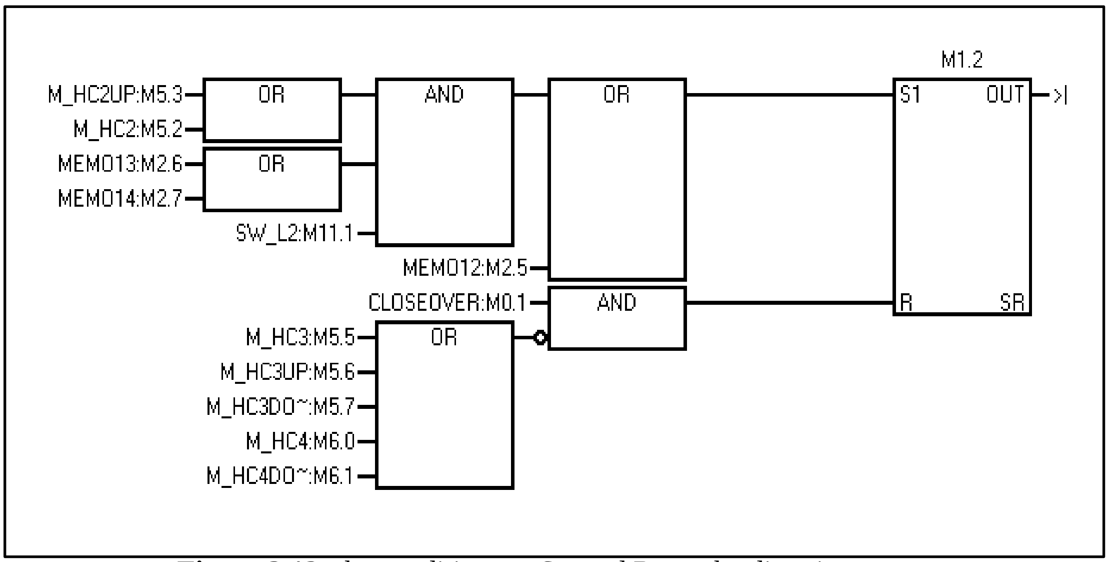


Figure 3.12: the conditions to Set and Reset the direction memory

The memory $M1.2$ is reset when the CLOSEOVER memory is ON and there are no requests from the higher floors. Combine the equations $Eq.$ 3.1, $Eq.$3.5 and $Eq.$3.6 with the above figure with the assumption that the cabin is at the second floor and there are requests in the first and the third floor at the same time, we can notice clearly that TR_{12}can not occur since $M3.2$ is OFF and $M1.2$ is ON which mean only $TR_{23}$and TR_{24} are allowed.

The same principle used with $M2.3$, $M4.3$ and $M3.2$, for example, $M2.3$ indicates the elevator cabin is currently at the third floor and It was last at the second floor.

$M1.2$ or $M2.3$ gives the priority to the request going upward and $M4.3$ or $M3.2$ gives the priority to go downward. As a result, the system must check every time these memories to decide the direction of the lift, when they all are OFF then the requests are served based on the first come first served basis.

$MEMO_{ij}$ memories are equal to the number of possible transitions TR_{ij} and are constructed in the same way as $MEMO12$ (see figure 3.13):

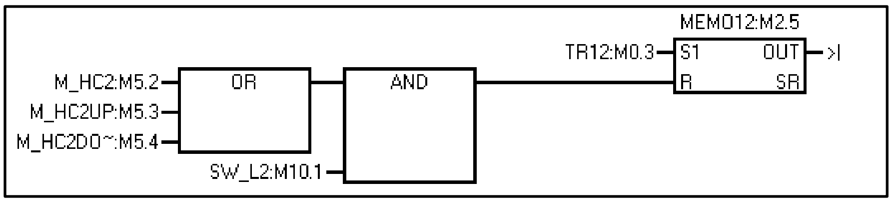


Figure 3.13: Set and Reset conditions of MEMO12 memory

$MEMO12$ is set when TR_{12} is ON and reset when the elevator is at the second floor.

3.6.7 The display control

To display the cabin current position, first, memorize the cabin current position using RS flip-flop as the figure 3.14 illustrates. Here, M_L2 memory bit is set when the cabin is at the second floor and it will reset when the cabin reaches the third or the first floor. The same operation for M_Li where $i = 1,3\ and\ 4$.

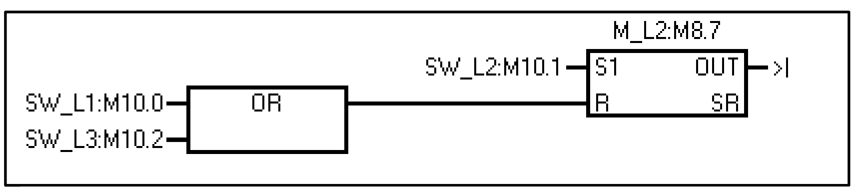


Figure 3.14: Memories the cabin current position

M_Li where $1 \leq i \leq 4$ is used to set the outputs BCD0, BCD1 and BCD2 according to the table:

Table 3.2: The position of the cabin and its BCD representation.

M_L4	M_L3	M_L2	M_L1	BCD4	BCD2	BCD1	BCD0
0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	0

0	1	0	0	0	0	1	1
1	0	0	0	0	1	0	0

Note: BCD4 is connected to the ground.

The BCD signals is connected to BCD to 7-segment IC.

3.6.8 Elevator-Movement Mechanism

The control system should provide a suitable acceleration or deceleration time depending on the length of the journey taken by the elevator to reach the desired destination floor. Figure 3.15 Summarize the speed operation of the elevator. The linear encoder returns the cabin position to the controller and based on it the controller sends an analog signal $(0V \sim 10V)$ to the VFD that sets the speed of the hoist motor.

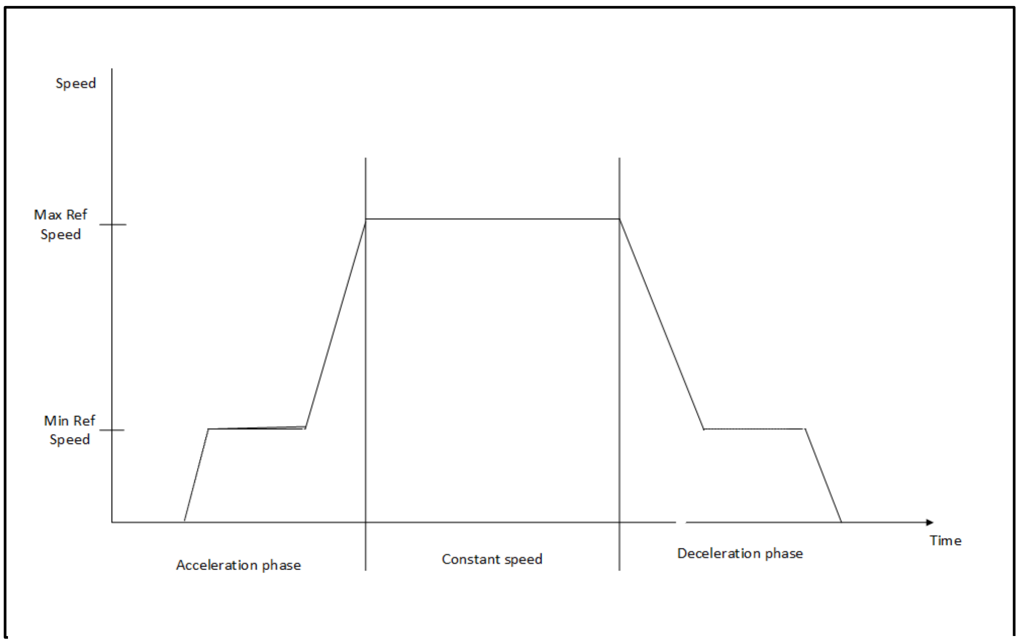


Figure 3.15: The speed operation of the elevator system

In the programming side, UP-DOWN counter is used, it counts up when the cabin moves in up direction and it counts down when the cabin moves in down direction. Figure 3.16 illustrates the counting operation:

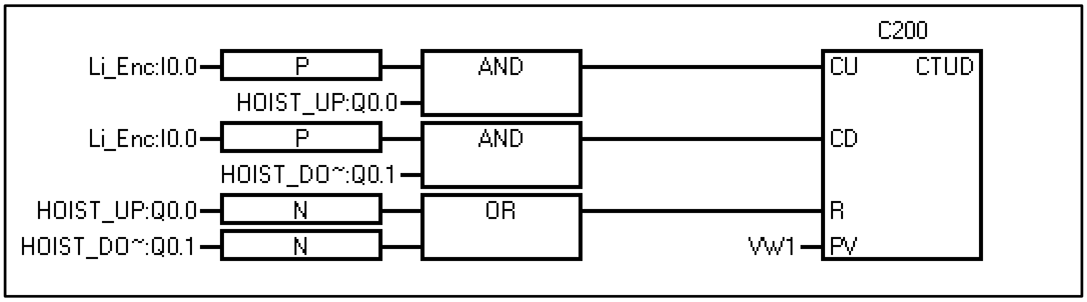


Figure 3.16: The Up/Down Counter conditions

Here VW1 register is used to set the counter setpoint.

The transitions are divided into two categories:

- Category One: regroups all the transitions in UP direction, these transitions are divided into three part:
    - Part one: 1 floor transitions i.e. TR_{12}, TR_{23}, and TR_{34}.
    - Part two: 2 floor transitions i.e. TR_{13}, and TR_{24}.
    - Part three: 3 floor transitions i.e. TR_{14} .
- Category two: regroups all the transitions in DOWN direction, also they are divided into three part:
    - Part one: 1 floor transitions i.e. TR_{43}, TR_{32} and TR_{21}.
    - Part two: 2 floor transitions i.e. TR_{31} and TR_{42}.
    - Part three: 3 floor transitions i.e. TR_{41} .

Each one of these parts has its subroutine, the following figure illustrates the conditions that activate the second-floor transition subroutine in up direction:

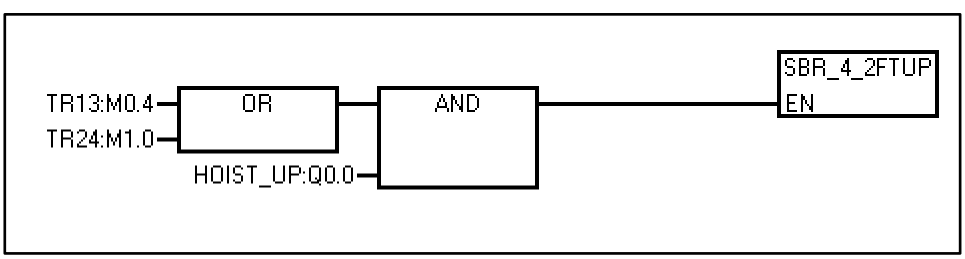


Figure 3.17: The activation of two floor transition speed control Subroutine in the up direction

when TR_{23} or TR_{24} is ON, it activates two floor speed control subroutines, in the subroutine area C200 is compared to a preset value and based on it, a move block is used to set an analog output to the VFD that determines the motor speed.

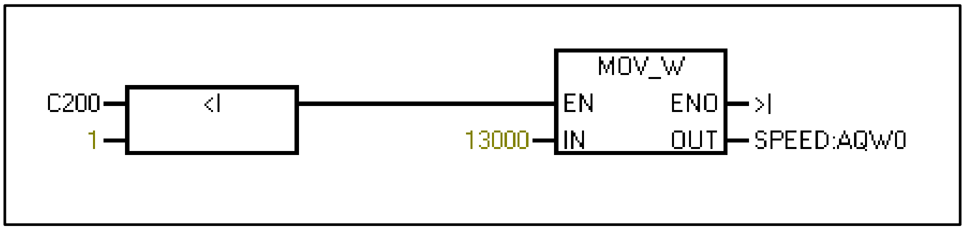


Figure 3.18: setting the acceleration phase

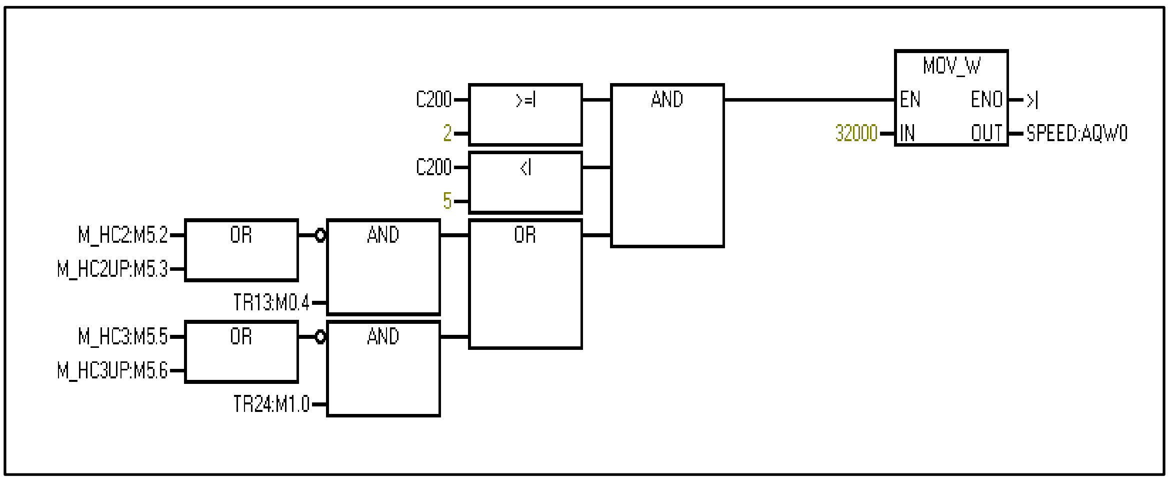


Figure 3.19: The conditions that set the constant speed

The figure 3.19 illustrates the conditions that set the constant speed phase when TR_{13}or TR_{24} is activated, note that among the conditions the Move block activates if there is no request from the second floor when TR_{13} is ON and there is no request from the third floor when TR_{24} is ON. Taking into consideration when a second call is pressed and TR_{13} is ON or when third call is pressed and TR_{24} is ON. The speed changes smoothly to prevent the cogging effect when it is stopped at the second floor or the third floor respectively. To do that a SCR (Sequential Control Relay) is used to activate the speed changes. Figure 3.20 shows the conditions that activate the SCR S0.5 relay.

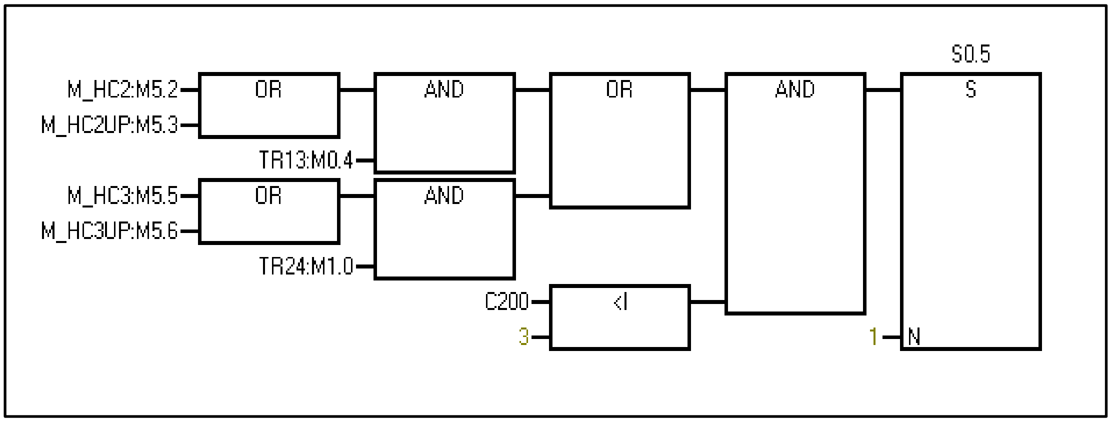


Figure 3.20: The activation conditions of the SCR

In the same manner the construction of the other operations and the same philosophy is used to implement the other floor transitions.

3.6.9 The door control:

In the automatic mode, when the elevator cabin reaches the destination floor, the door cabin opens and waits 10 seconds unless the close door PB is pressed, then it is supposed to close. in the CLOSE state, it can be reopening by:

- Press open door PB.
- A presence of an obstacle in the doorway.

In the case of an overload, the door remains open and the cabin lamp flashes ON and OFF.

In the manual mode, the operator has full control of the door operation, the following flowchart illustrates more details about the door operation.

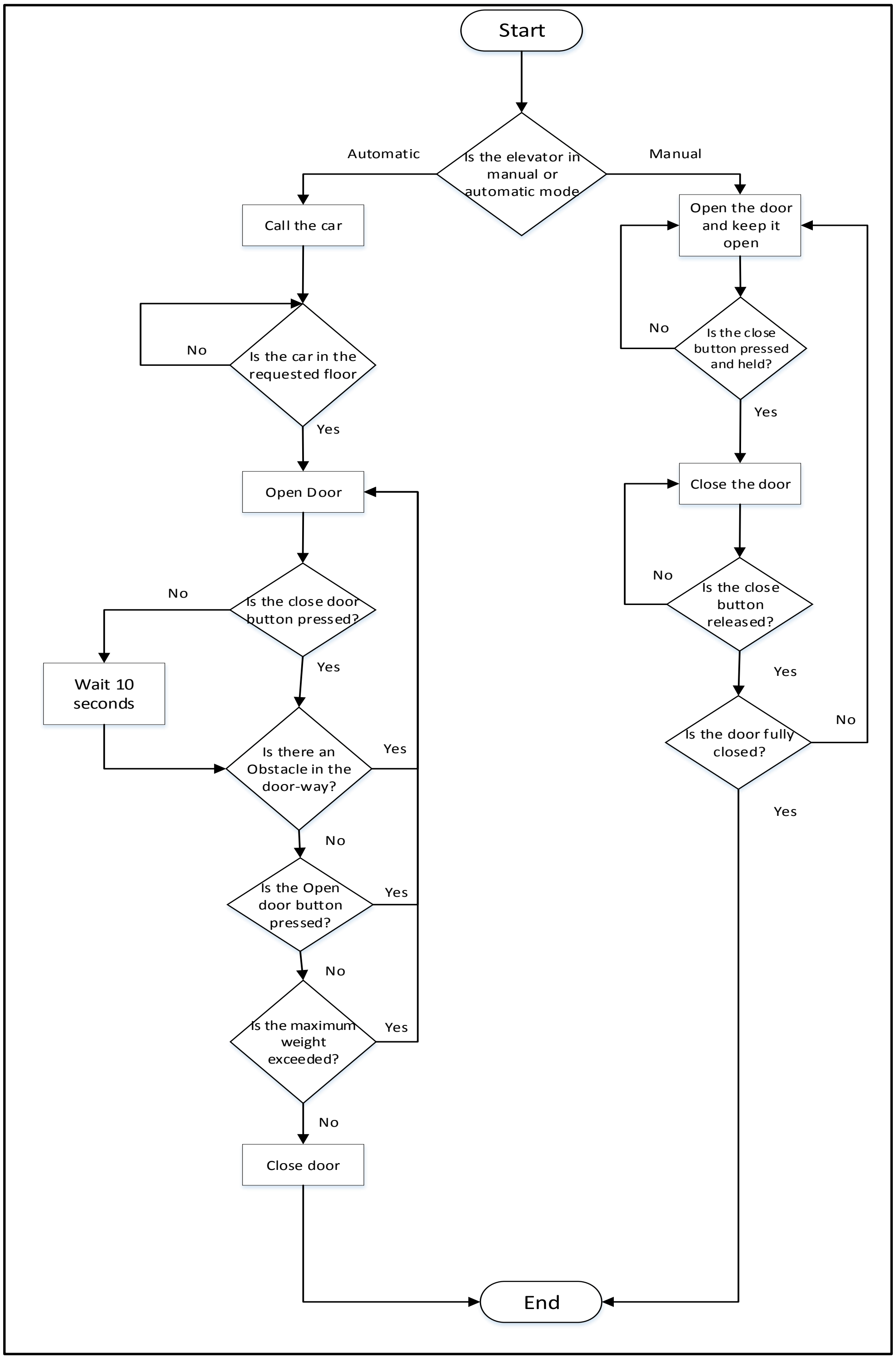


Figure 3.21: The door control Flowchart

3.8 <u>Conclusion</u>

This chapter introduced the control policy and the software design of the elevator, which is based on the first-come first-served basis with the exception for some priority cases, as explained above, made not only to ensure a smooth ride of the lift, but also to reduce the energy consumption. The program is written in FBD language is divided into many networks to ensure better functionality.

Chapter Four

Implementation and Testing

4.1 Introduction

After the elevator design components, both electrical and mechanical aspects, the next step is to assemble those separate parts into one unit. this chapter explains how exactly this elevator is put together, the connections between the different sub-systems, the PLC, the VFD, the AC Motor and the detecting and tracking elements, in addition to the mechanical design that is chosen for this implementation.

4.2 Mechanical description

The mechanical aspect of an elevator is of as much importance as the electrical system in ensuring a smooth and safe operation of the system. Three major parts are considered, the first one is how the AC motor is going to drive the elevator car and that is achieved using a gearbox which will reduce the rotation speed but provide more torque, the gearbox is then connected to a pulley that moves the traction cables. Next is the car and counterweight system, and for that there are several configurations to be considered, the one chosen in this design is quite simple where the car is directly connected to the counterweight using the traction cables that lie on the pulley situated at the top as the Figure 1.3 illustrates.

The last thing considered is the guiding system where rails are used to keep the elevator care stable in one perpendicular path and prevent it from swinging.

4.3 Setting the VFD parameter

4.3.1 Oversized VFD:

Using an oversized VFD i.e. 4kW with lower motor i.e. 500W make the VFD tripping. To treat this problem, OPL (Output Phase Loss) command must be disabled.

The motor thermal protection will not be provided by the drive since the motor's nominal current is lower than 80% of the drive's nominal current. Therefore, adding a thermal relay between the drive and the motor to provide thermal protection.

4.3.2 Parameters setting

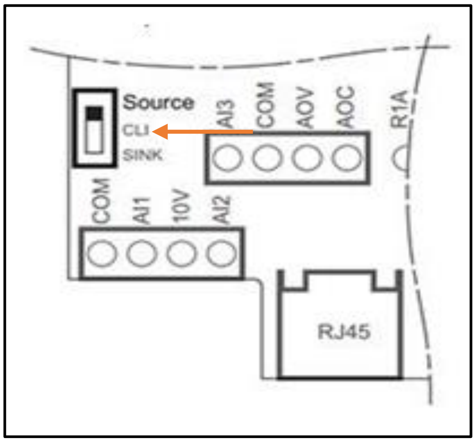
When we powered the drive, the drive display rdY (ready) command, rotate the JOG dial to enter a parameter setting:

Table 4.1: The setting of the VFD parameters

MENU	CODE	Setting
Flt (**Fault management**)	OPL (Output Phase Loss)	No
drC (**motor control**)	bFr (standard motor frequency	50Hz
	unS (nominal motor voltage	220V Δ connection
	FrS (nominal motor frequency)	50 Hz
	nCr (nominal motor Current)	2.3A
	nSP (nominal motor speed in Rpm)	2750 Rpm
	CoS (motor Power factor)	0.83 Pf
tCC (**2/3 wire control**)	2C (2 wire control; Li1: Forward Li2: Reverse	Press the jog dial for 2 Sec to confirm
Fr1 (**Reference Channel 1**)	AI1 (Analog Input 1)	Press the jog dial

4.3.3 Interface the PLC and VFD

To interface the PLC with the drive, switch the logic configuration switch to CLI (Logic input common) position as the following figure illustrates:



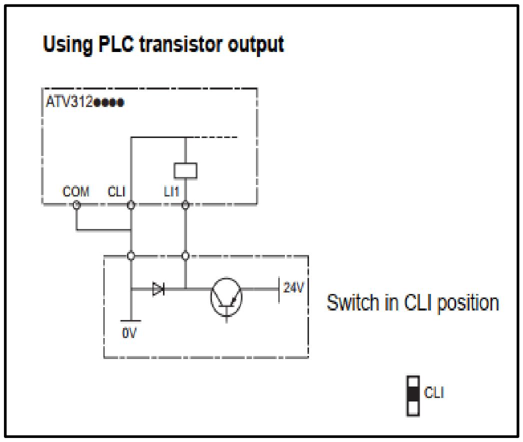


Figure 4.1: Interface the PLC with the VFD

4.4 The Power circuit

Figure 4.2 illustrates the power circuit of the elevator system

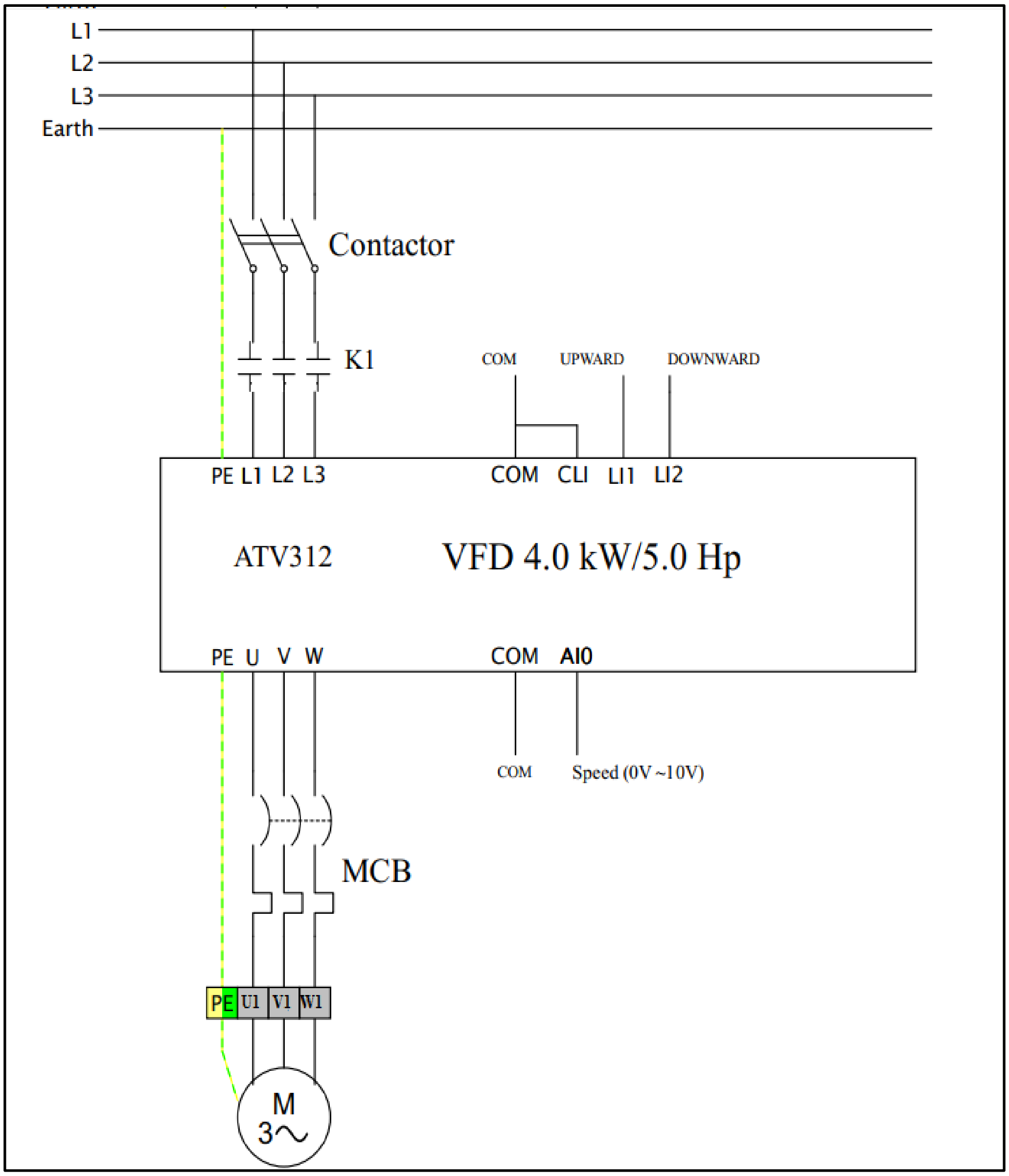


Figure 4.2: Electrical diagram of the VFD connection

4.5 <u>The control circuit:</u>

4.5.1 <u>Relay logic circuit:</u>

Due to the uses of all the PLC inputs and outputs, the starting and the stopping operation is implemented in logic relay as the figure 4.3 illustrates.

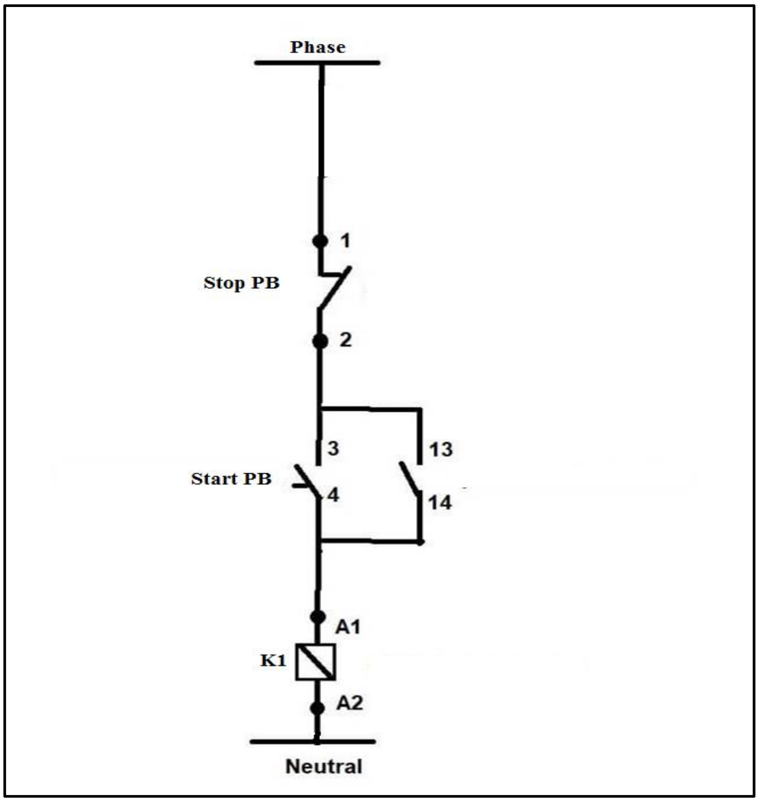


Figure 4.3: The logic relay schematic of the start and the stop operation.

4.5.2 PLC I/O interfacing

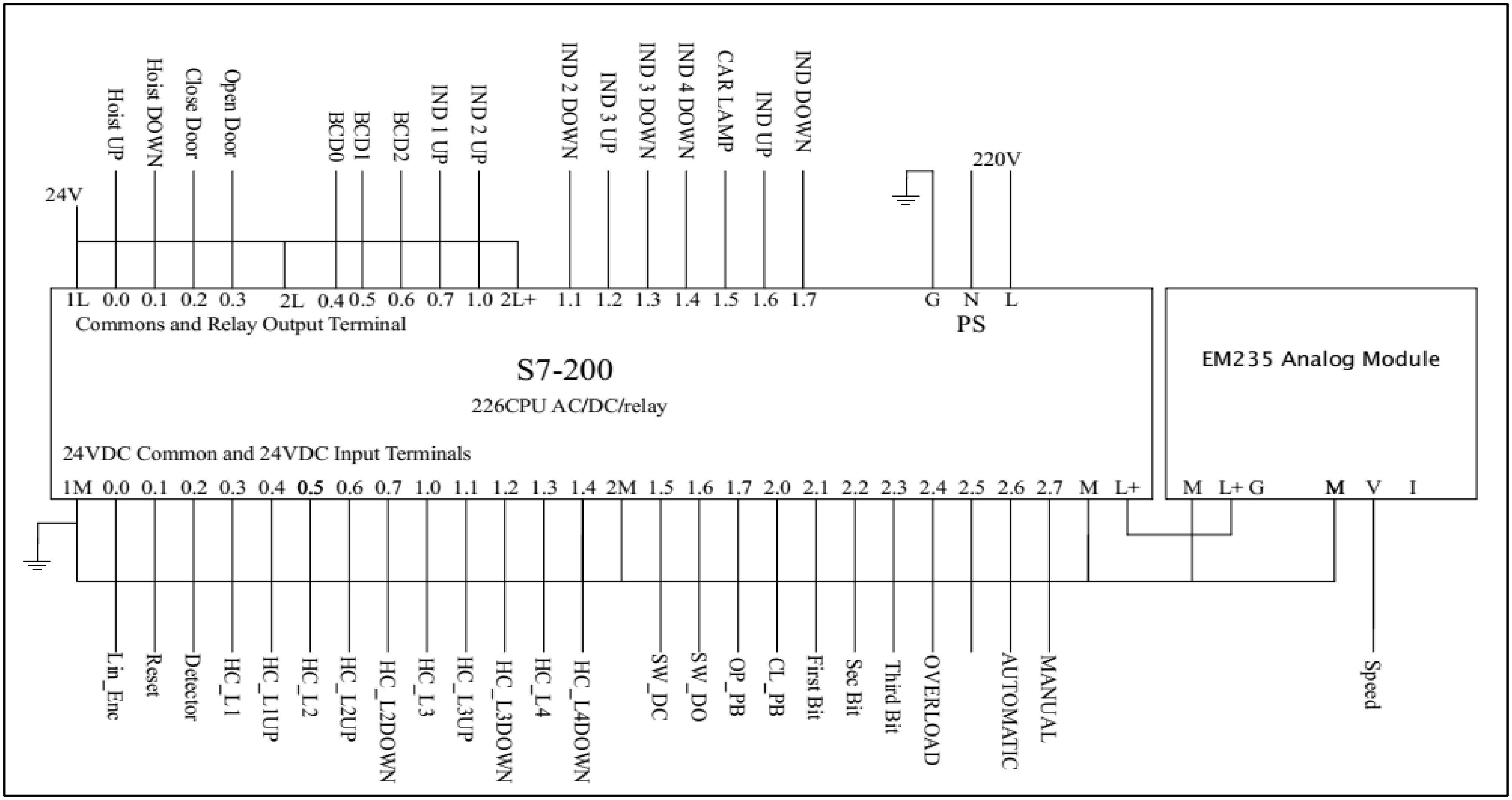


Figure 4.4: PLC I/O interfacing

4.6 Implementation and Testing

First, each component integrated within the elevator system was tested individually, starting from the interfacing between the PLC and the VFD, then, several tests were carried on the floor detection circuits and linear encoder to establish the threshold voltage. Also, the 7-segment display circuit was tested with the PLC and it worked perfectly. The same thing for the door operation, where the H-bridge that controls the door operation interfaced with the PLC, the door mechanism showed a poor performance in the closing due to the small torque of the DC motor used.

After wiring the PLC and the associated components according to the schematic shown in section 4.5, a number of tests ware carried on both modes (manual and automatic).

In the automatic mode, several tests were carried:

- **Case One**: a series of simple tests were carried where the PLC controller answered correctly to the inner and outer requests according to the first come first served basis.
- **Case Two**: a sequence of simultaneous requests was carried, an up hall call pressed on the third floor and followed by a hall call from the second floor, the cabin was on the first floor and on its way to the third floor, it stopped at the second floor and then continued its journey to the third floor. The speed changed accordingly before reaching the second-floor form constant speed to deceleration phase to stop on the second floor as the control policy specified in chapter three.
- **Case Three**: the elevator was moving down from the third floor to the first floor, an outside request on the second floor to go up, the controller ignored it temporary and the elevator kept moving to the first floor and then went to the second floor, which confirms that the elevator is operating according to the control strategy.

The same cases used in the manual mode, and it worked as desired.

General Conclusion

General Conclusion

In this report of our work, we have described the design and the implementation of four level Elevator based on the PLC and the VFD controllers. We developed the program in Function Block Diagram (FBD) language to control the different functionalities of the Elevator system. The designed program is based on a control strategy that is based on a first come first served basis except when the controller has priority cases i.e. multiple requests, instantaneous requests … etc.

Most of the efforts and time were spend on the software design and fixing its bugs as well as the hardware problems, the fact that we have used breadboards to implement 7-segment display, position sensors and linear encoder caused us plenty of problems due to the bad wire connection, one more problem we have faced was the door mechanism which showed a poor performance in the closed state due to the small torque of the DC motor.

Although, the system was implemented and tested successfully. It can be developed and improved by working on other aspects, we can suggest the following:

- Redesign the door mechanism and use a suitable DC motor.
- Off-chip circuitry can be implemented on PCBs instead of breadboards.
- Expand PLC inputs and outputs or use two controllers which are connected through a communication network such as Modbus protocol where the first controller is responsible for collecting inputs and send it to the main controller that processes these inputs and produces outputs.
- The interfacing between the PLC and the VFD can be done using a communication network instead of electrical wiring. This offers better functionality and provides more details about the motor and the VFD status.
- Use a rotary encoder instead of a linear encoder that we designed. It offers an accurate position of the cabin elevator.
- The control strategy can be modified to use smart techniques like a PID controller.

- Use Human Machine Interface (HMI) inside the cabin instead of pushbuttons and LEDs.

References

[1]: Abdelkarim Ahmed Eltahir Ali, Zhang Jiang Min, “Design of Five Floors Elevator with SCADA System Based on S7200 PLC”, International Journal of Science and Research (IJSR), Volume 5 Issue 4, April 2016.

[2]: https://en.wikipedia.org/wiki/Elevator , 02-09-2019

[3]: Kalemla SRIKANTH, “Design of Elevator Controller Using VERILOG HDL”, Department of Electronics and Communication Engineering, VA RDHA MA N COLLEGE OF ENGINEERING, 2012.

[4]: “Energy Efficient Elevators and Escalators”, ISR-University of Coimbra (Portugal). March 2010.

[5]: http://elevation.wikia.com/wiki/Traction_elevators. 02-09-2019

[6]: Platform lift company article: “Traction versus Hydraulic Lifts: Advantages and Disadvantages”

[7]: “National Elevator Industry, Inc. Regenerative Drives”, http://www.neii.org/regenerative.cfm, 02-09-2019.

[8]: Lubomir Janovsky, “Elevator Mechanical Design Textbook 3rd Ed”, Page 3 and Page 4.

[9]: NEMAT HASSAN Ahmed, EL-HASSAN, “A 4-Stories Building Elevator Control System”, NO. 064086

[10]: “Elevator Controller and Relay Repair, Types of Elevator Controllers” https://coloradoelevatorsolutions.com/elevator-controller-relay-repair-colorado/,02-09-2019

[11]: L.A BRAYAN, E.A BRAYAN, “Programmable Controllers Theory and Implementation Second Edition 1997”, ISBN 0-944107-32-X.

[12]: Abdelraouf BOUDACHE, Younes HOUAS. “Implementation and design of four level elevator using PLC”, June 2012, IGEE

Appendix A: S7-200 CPU specifications

SIMATIC S7-200 CPU 226 AC/DC/Relay:

The features of CPU 226 AC/DC/Relay are summarized below:

Table A-1: Specification for CPU 226 AC/DC/Relay

Description Order Number	CPU 226 AC/DC/Relay 6ES7 216–2BD21–0XB0
Physical Size	
Dimensions (W x H x D)	196 mm x 80 mm x 62 mm
Weight	660 g
Power loss (dissipation)	17 W
CPU Features	
On-board digital inputs	24 inputs
On-board digital outputs	16 outputs
High speed counters (32 bit value)	
Total	6 High-speed counters
Single phase counters	6, each at 20 kHz clock rate
Two phase counters	4, each at 20 kHz clock rate
Pulse outputs	2 at 20 kHz pulse rate
Analog adjustments	2 with 8 bit resolution
Timed interrupts	2 with 1 ms resolution
Edge interrupts	4 edge up and/or 4 edge down
Selectable input filter times	7 ranges from 0.2 ms to 12.8 ms
Pulse Catch	14 pulse catch inputs
Time of Day Clock (clock accuracy)	2 minutes per month at 25° C 7 minutes per month at 0° C to 55° C
On-board Communication	
Number of ports	2 ports
Electrical interface	RS-485
Isolation (external signal to logic circuit)	Not isolated
PPI/MPI baud rates	9.6, 19.2, and 187.5 kbaud
Freeport baud rates	0.3, 0.6, 1.2, 2.4, 4.8, 9.6, 19.2, and 38.4 kbaud

Power Supply	
Line voltage–permissible range	85 to 264 VAC 47 to 63 Hz
Input current CPU only/max load	40/160 mA at 240 VAC 80/320 mA at 120 VAC
In rush current (maximum)	20 A at 264 VAC
Isolation (input power to logic)	1500 VAC
Hold up time (from loss of input power)	80 ms at 240 VAC, 20 ms at 120 VAC
Internal fuse, not user-replaceable	2 A, 250 V, Slow Blow
Input Features	
Number of integrated inputs	24 inputs
Input type	Sink/Source (IEC Type 1)
Input Voltage	
Maximum continuous permissible	30 VDC
Surge	35 VDC for 0.5 s
Rated value	24 VDC at 4 mA, nominal
Logic 1 signal (minimum)	15 VDC at 2.5 mA, minimum
Logic 0 signal (maximum)	5 VDC at 1 mA, maximum
Output Features	
Number of integrated outputs	16 outputs
Output type	Relay, dry contact
Output Voltage	
Permissible range	5 to 30 VDC or 5 to 250 VAC
Rated value	–
Logic 1 signal at maximum current	–
Logic 0 signal with 10 K Ω load	–
Output Current	
Logic 1 signal	2.00 A

Appendix B: Analog EM235 specifications

Table B-1: Analog EM 235 specifications

General	6ES7 235-0KD22-0XA0
Data word format Bipolar, full-scale range Unipolar, full-scale range	(See Figure A-14) -32000 to +32000 0 to 32000
DC Input impedance	≥ 10 MΩ voltage input 250 Ω current input
Input filter attenuation	-3 db at 3.1 Khz
Maximum input voltage	30 VDC
Maximum input current	32 mA
Resolution Bipolar Unipolar	
Isolation (field to logic)	None
Input type	Differential
Input ranges Voltage Current	 Selectable, see Table A-21 for available ranges 0 to 20 mA
Input resolution	See Table A-21
Analog to digital conversion time	< 250 μs
Analog input step response	1.5 ms to 95%
Common mode rejection	40 dB, DC to 60 Hz
Common mode voltage	Signal voltage plus common mode voltage must be ≤ ±12 V
24 VDC supply voltage range	
Isolation (field to logic)	None
Signal range Voltage output Current output	 ± 10 V 0 to 20 mA
Resolution, full-scale Voltage Current	 11 bits plus sign bit 11 bits
Data word format Voltage Current	 -32000 to +32000 0 to +32000
Accuracy Worst case, 0° to 55° C Voltage output Current output Typical, 25° C Voltage output Current output	 ± 2% of full-scale ± 2% of full-scale ± 0.5% of full-scale ± 0.5% of full-scale
Setting time Voltage output Current output	 100 μS 2 mS
Maximum drive Voltage output Current output	 5000 Ω minimum 500 Ω maximum
24 VDC supply voltage range	

Appendix C: The IP rating

The IP Code or Ingress Protection Marking, classifies and rates the degree of protection provided by mechanical casings and electrical enclosures against intrusion, dust, accidental contact, and water.

Table C-1: Ingress protection classification

Ingress Protection Classification			
First Number		Second Number	
IP	Protection Provided	IP	Protection Provided
0	No Protection	0	No Protection
1	Protected against solid objects up to 50mm e.g. accidental touch by hands	1	Protected against vertically falling drops of water e.g. condensation
2	Protected against solid objects up to 12mm e.g. fingers	2	Protected against direct sprays of water up to 15 degrees from the vertical
3	Protected against solid objects over 2.5mm e.g. tools	3	Protected against direct sprays of water up to 60 degrees from the vertical
4	Protected against solid objects over 1mm e.g. wires	4	Protected against water sprayed from all directions - limited ingress permitted
5	Protected against dust - limited ingress (no harmful deposit)	5	Protected against low pressure jets of water from all directions - limited ingress permitted
6	Totally protected against dust	6	Protected against strong jets of water e.g. for use on ship decks - limited ingress permitted
		7	Protected against the affects of immersion between 15cm and 1m
		8	Protected against long periods of immersion under pressure