# ET163025_ET163038_EMRI(Automatic power changeover system)_Report

*by* Iiuc Central Library

# DESIGN AND IMPLEMENTATION OF A PLC-BASED AUTOMATIC POWER CHANGEOVER SYSTEM WITH PHASE FAILURE DETECTION

by

MARUF RAHMAN

MD. ALTAFUR RAHMAN

**BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING**

Department of Electrical and Electronic Engineering
INTERNATIONAL ISLAMIC UNIVERSITY CHITTAGONG

SEPTEMBER 2021

# DESIGN AND IMPLEMENTATION OF A PLC-BASED AUTOMATIC POWER CHANGEOVER SYSTEM WITH PHASE FAILURE DETECTION

by

MARUF RAHMAN

MD. ALTAFUR RAHMAN

A project
submitted as partial fulfilment of the requirement for the degree of

**BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING**

Department of Electrical and Electronic Engineering
INTERNATIONAL ISLAMIC UNIVERSITY CHITTAGONG

SEPTEMBER 2021

## CERTIFICATE OF APPROVAL

The project entitled as "**Design and Implementation of a PLC-based Automatic power changeover system with phase failure detection**" submitted by **Maruf Rahman**, bearing Matric ID. **ET163025** and **Md. Altafur Rahman**, bearing Matric ID. **ET163038** of session **Autumn 2020**, to the Department of Electrical and Electronic Engineering, International Islamic University Chittagong, has been accepted as satisfactory in partial fulfilment of the requirements for the degree of Bachelor of Science in Engineering and approved for the examination held on the **3rd September, 2021**.

______________________________

Supervisor
Engr. Md. Rashidul Islam
Assistant Professor
Department of Electrical and Electronic Engineering
International Islamic University Chittagong.

# DECLARATION

It is hereby declared that this work has been done by us and no portion of the work contained in this project has been submitted elsewhere for the award of any degree or diploma.

____________________

Maruf Rahman

____________________

Md. Altafur Rahman

# ACKNOWLEDGMENT

All praise and thanks to Allah, the Lord of the world, the Most Beneficent, the Most Merciful. To begin with, we are grateful to Almighty Allah for providing us with quality and intelligence throughout our lifetime.

We would like to express our sincere appreciation to our honorable supervisor, Engr. Md. Rashidul Islam, Assistant Professor, Department of EEE, IIUC, who provided us with valuable proposals and feedback during the entire work process. His invaluable support with significant remarks and ideas throughout the experiment and project has led to the successful implementation of our project.

We are grateful to our family for providing us with inspiration and we thank them for their ethical and financial support. Last but not least, we want to thank our teachers, friends, classmates, seniors, and lab assistants, who have provided us with constant support and help in every way. We are extremely fortunate to have nice people like them in our midst.

Authors

# ABSTRACT

We live in an age of science and invention, and one of the most significant factors is automation. Automation includes increased production rates and efficiency, more efficient material utilization, far superior item quality, improved safety, shorter workweeks for work, and decreased factory lead times. Automation is a requirement in Bangladesh's industries, where PLC is widely used. So, in order to stay familiar with this technology, we decided to work on a PLC-based project. We learned from our industrial visits that delays in production result in a significant financial loss. Because power outage is an issue in Bangladesh, moving to a different power source is a method to reduce this loss. So we created a project that would overcome the problem of manual switching of power sources as well as the problems of automatic switching, and this idea symbolizes an approach that involves quickly connecting electrical users to a backup electric power source. The basic concept behind this project is to feed electricity from multiple sources, which we have successfully implemented by utilizing three power sources: main supply, generator, and battery source. As a result, In the event of a primary power source failure or interruption, the system will quickly switch to the next available power supply, using the parameters specified by programming. Since it is automated it reduces the cost of the manually switching and improves the reliability of the system. It also detects phase failure which increases the protection of system.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| PLC | Programmable Logic Controller |
| MCB | Miniature Circuit Breaker |
| NO | Normally Opened |
| NC | Normally Closed |
| MC | Magnetic Contactor |
| I/O | Input / Output |
| CPU | Central Processing Unit |

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

By the meaning of automatic changeover we know refers to the process of switching the entire load from one power source to another. There are three types of power source in our project, they are: grid, generator, and battery. We suppose the service provider source to be the main supply to load. When service provider source fails to provide supply to the load then automatically changeover switches power to the generator and If generator fails somehow then it automatically switches power to the battery source. For doing this we took the help of programmable logic controller (PLC). A PLC is a computer-controlled system that keeps track of the status of input devices and sends commands to change the state of output devices depending on decisions made by the program. It is ready for numerous input and output configurations, wide temperature ranges, electrical noise immunity, and vibration and impact resistance. Nowadays, PLCs are widely used in a variety of heavy and light sectors, including oil refineries, manufacturing lines, conveyor systems, and so on. Whenever equipment management is required, the PLC provides a flexible approach to 'soft wire' the various components together. The CPU's fundamental units are used to run a program that controls a variety of various inputs and logically manipulates outputs to produce the correct amount of electricity. In comparison to conventional control systems, they are lightweight, highly reliable (no software crashes or mechanical failures), and cost-effective in the manner they may be constructed. PLCs are basically relay control systems in a compact size. This implies that a single PLC functions as a collection of relays, counters, timers, data storage places, and a few other components, all in one compact box.

In this project the purpose of PLC is to automatic changeover of power supply. When it sense that the main supply is failed it changes the supply to another sources. Moreover it also detects if there is any phase failure in line. When the PLC sense the power in service provider is back then it automatically switches load to the main supply.

## 1.2 BACKGROUND

In Bangladesh automation is a must in the industries, where we see the vast use of PLC. So to remain familiar with this technology we have chosen to do a project based on PLC.

As we have done some industrial visit we have come to know that the delay in production tends to increase a huge loss of money. Since power outage is a problem in Bangladesh, switching to another power source is solution to decrease this loss and when a power outage is a possibility, most companies, businesses, and academic institutions have a generator on hand to provide backup power. The generator must be manually regulated to turn on and off, which means that any error might result in a significant financial loss. To minimize the loss due to this delay we have chosen to do this project.

## 1.3 MOTIVATION

People are more intrigued by technology in the twenty-first century. Our country is not meant to lag behind in technology since our country is developing country. We must design our technology with this goal in mind, and we must bear in mind that technology should be readily available. We have set up a project where we may learn a few fundamental PLC operations. Nowadays, it is quite important to know a few essential thoughts about PLC that may be extremely beneficial in the future. Aside from that, PLC offers a few advantages over analog systems. That is why we decided to create a PLC-based project. Furthermore, the majority of our country's factories and businesses are dependent on PLC and automation. That is why we must have at least fundamental understanding of the subject.

## 1.4 OBJECTIVES

The objectives of this project are given below:

- To develop a program to automatically changeover of power source
- To remove analog and manual system in changing power source and to eliminate the continuous manual switching operation.
- Improving industrial and commercial performance
- Developing easily controllable power system
- To increase speed of operation in the system which can improve reliability.

## 1.5 REPORT OUTLINE

Six chapters have been covered in the design and construction of this project. The chapters and their material are as follows:

- **Chapter 1** (Introduction): This chapter providing the outline, motivation and purpose of the project.
- **Chapter 2** (Literature Review): This chapter explored previous work or study related to this project.
- **Chapter 3** (Components): The components of this project has been addressed in detail in this chapter.
- **Chapter 4** (System Design): This section covers experimental setup of this project.
- **Chapter 5** (Implementation and Results): Discuss the execution of the project and the performance of the project.
- **Chapter 6** (Conclusion): The overview of this project is explored in more depth in this Chapter. The advantage of the project, the benefit and the possible future work of the project are addressed.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 INTRODUCTION

A PLC is like an industrial computer which employs hardware and software to operate machines or processes. It's intended for numerous I/O configurations, broad temperature ranges, and immunity to electrical noise; it's also vibration and impact resistant [1]. PLCs are real-time systems because the output of the system they regulate is dependent on the conditions of its input. As a result, since 1968, it has evolved into the brain of industrial automation and control systems [1].

A PLC based automatic changeover system of power source can be seen as an important part of a system where it can increase the system's stability and operation speed. In terms of protection of a system we need to add phase failure detection for improving a system's protection. Therefore this project contains the basic concept of phase failure detection.

## 2.2 REVIEW OF PREVIOUS WORK

In this current period, research is planning to include a variety of up-to-date ways for PLC & automation and modern innovations to update our system on everyday basis. With that view different changed methods are accessible within the field of PLC and automation system and there are numerous more within the study prepare. The below sections will discuss a review of the work which is done before:

### *2.2.1* PLC Based Automatic Changeover Switch

The project is kind of similar to us but here the author chooses to changeover only one source whereas we have shown the changeover of multiple sources and also added phase failure function to our project. Here the author has developed a design of ladder diagram for PLC based automatic changeover switch and they have used a block diagram to show how internal functions work.

Whenever the service provider supply is ON in this project, the PSR checks the presence and absence of the main supply and gives the service provider instructions. Assuming affirmative, the obligation will fall on the service provider to keep the supply flowing [2]. Otherwise, the PLC provides feedback to the DG to get things going. DG will turn on when the battery is connected. When this occurs, the contact or service provider de-energizes and the DG contact or receives energies, and the contactor switches from service provider to DG and vice versa [2]. **Fig.2.1** is the flowchart of PLC-based automatic changeover switch.

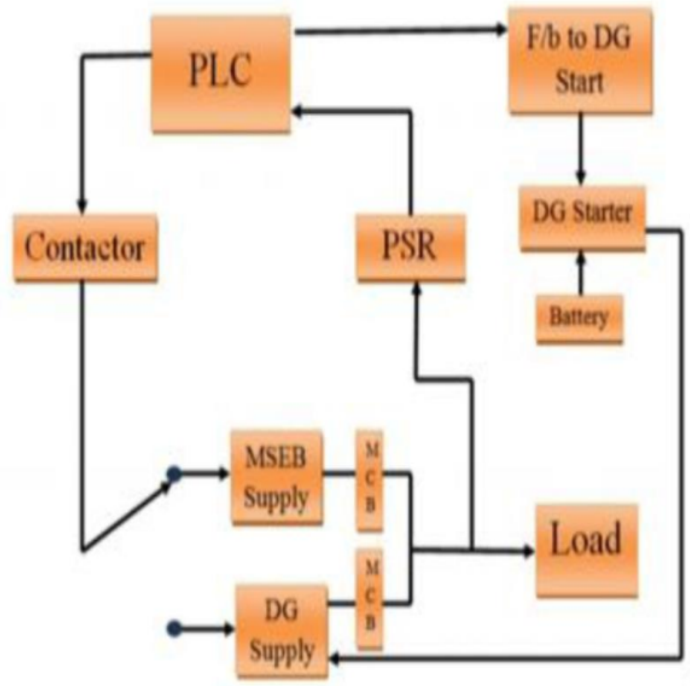


**Fig.2.1:** flowchart of PLC-based automatic changeover switch [2].

And the components which the author used are

- PLC
- MCB
- Selector switch
- Push button
- Emergency switch
- Indicator

**Fig.2.2** illustrates ladder diagram of PLC-based automatic changeover switch and the ladder diagram is as follows:

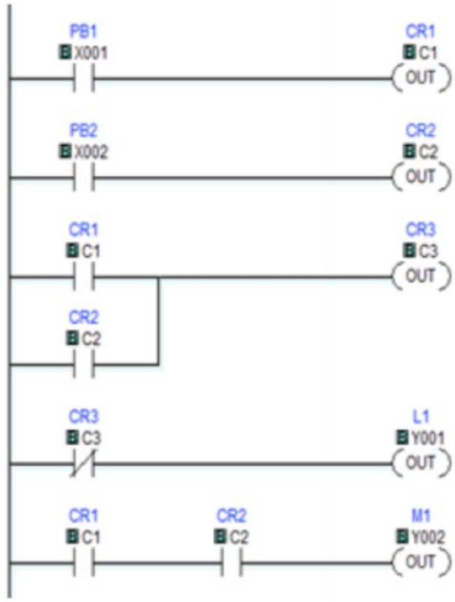


**Fig.2.2:** Ladder diagram [2].

### *2.2.2* Automatic Transfer Switch (ATS) Using Programmable Logic Controller (PLC)

This study showed how to use a programmable logic controller to design and build an automated transfer switch. To increase student talents and deepen their understanding of modern manufacturing technology applied to industrial engineering applications, the suggested set-up was created at the Arab Academy for Science and Technology. In general, the method was found to be easy and successful for usage in a variety of educational, commercial, and industrial settings [3].

In this article, diverse loads, such as residential, commercial, and industrial sectors, are fed through low-voltage distribution systems based on their needs and importance. Some loads can only be supplied from the main source, while others can be fed from many backup sources. As shown in **Fig.2.3**, a distribution system with several sources of supply is used [3].

Here the different load distribution is given in the diagram:

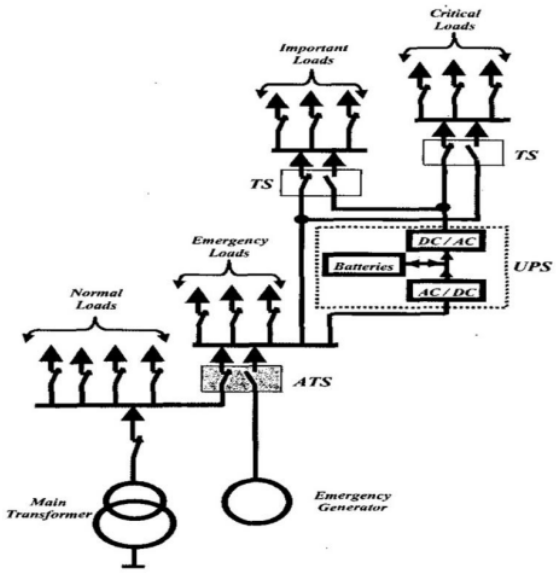


**Fig.2.3**: Distribution of loads [3].

The power circuit connections are depicted in **Fig.2.4**, where the three-phase loads can be fed from the main or the emergency generator through the contactors and circuit breakers [3]. To complete the procedure the author has developed connection of power circuit and control circuit and also the ladder diagram, which are given below:

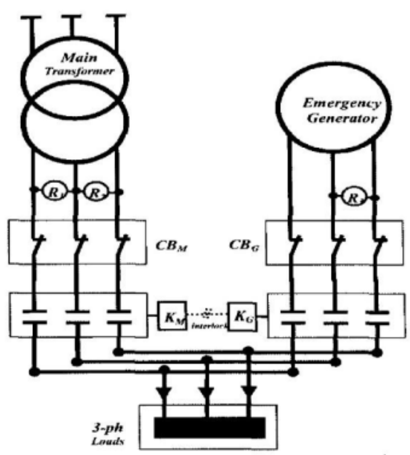


**Fig.2.4**: connection of power circuit [3].

The system is controlled by a PLC to meet the criteria. **Fig.2.5** shows the connections between the PLC and all sensors and actuators.

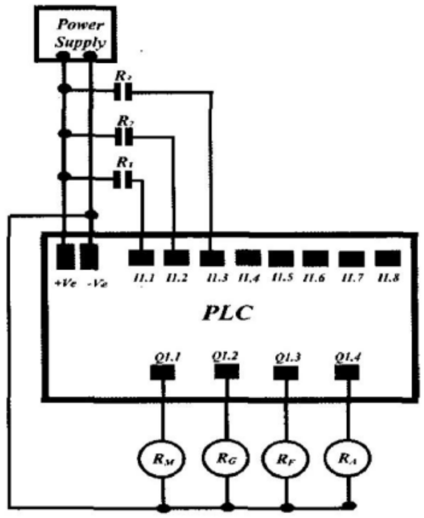


**Fig.2.5**: connection of power circuit and control circuit [3].

**Fig.2.6** shows the ladder diagram of PLC which is given below:

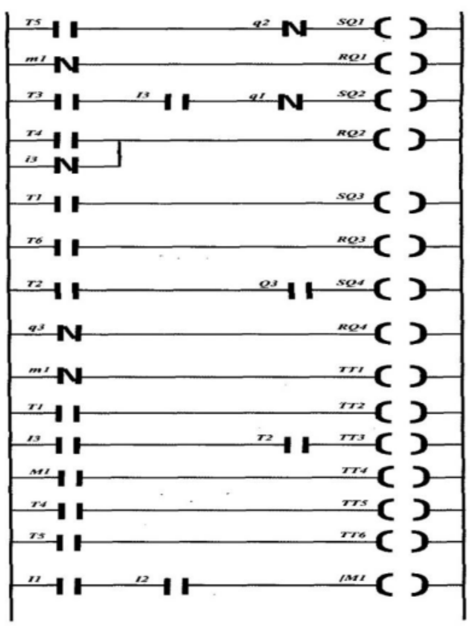


**Fig.2.6**: Ladder diagram of PLC program [3].

### *2.2.3* Automatic Changeover Switch for Power Sources

This paper introduces automatic changeover of power sources by relay logic control (RLC) so this system's hardware components include: a distribution board, contractors, relays, timers, overload sensors, and voltage relays for under and excess voltage.

One of two utilities power supplies will be switched to the standby power supply (generator) and a circuitry will be built which senses power outage and at the same time senses fluctuations in power supplied to the load, in addition to providing maximum protection and safety measures for people. This paper presents an automated solution based on designing and building a system. This will ensure that electricity is always available for critical loads and reduce the number of incidents resulting in fatalities and equipment damage [4].

**Fig.2.7** shows the power connection which is given below:

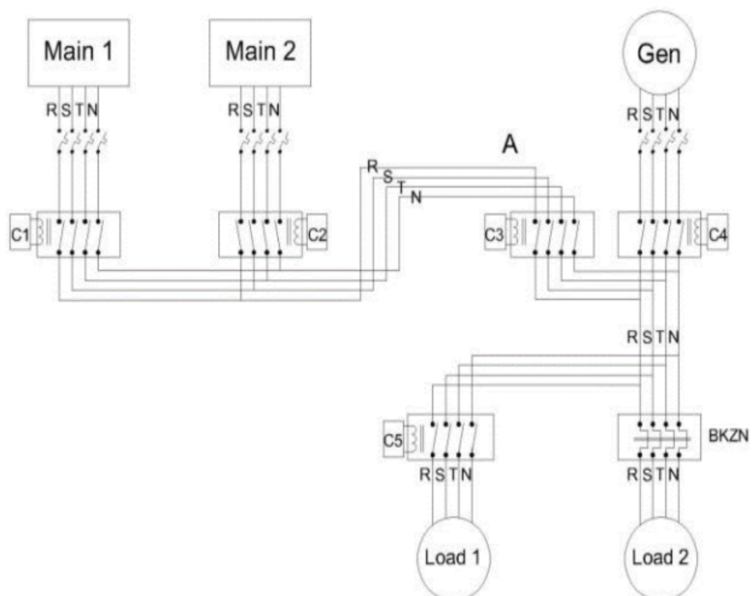


**Fig.2.7**: Power Connection [4].

Major line control, minor line control, and generator line control are the three elements of the control system's design.

The primary circuit breaker with a 2A allowed current is located in the major line control [4].

**Fig.2.8** shows the circuit operation of how major control is done and it is given below:

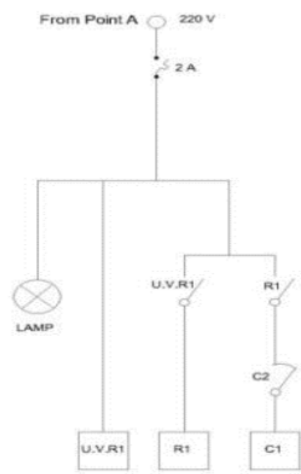


**Fig.2.8**: Major control [4].

When the main power source fails, the minor control kicks in. Minor and major controls operate in the same way, as do the auxiliary closed points from relays (R1 & R2) used to disconnect the generator from control. Generator relay switches on generator contactor if neither source is working. When that happens, the generator will kick on and start working [4]. **Fig.2.9** shows the circuit operation of how minor control is done and it is given below:

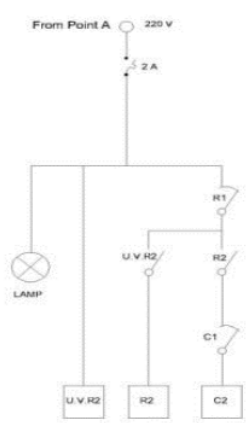


**Fig.2.9**: Minor control [4].

The designed automatic changeover system is showed in **Fig.2.10** which is given below:

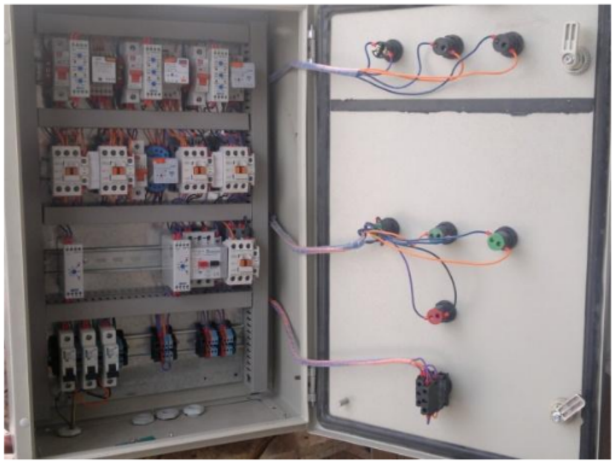

**Fig.2.10**: The designed automatic changeover system. [4].

Here we can see a panel is made for automatic changeover system which is done by relay logic control so relay, timer, magnetic contactor and push buttons are visible. As there is no PLC so the automatic changeover has to be done manually.

# CHAPTER 3
# COMPONENTS

## 3.1 INTRODUCTION

Components are the most essential part of a project, without suitable components, one cannot design an appreciable project. Selecting the suitable components is another important and difficult task. In this section, we will discuss the components that are used in the design of our project. In this section, we will try to discuss hardware descriptions elaborately and also their functions, block diagrams, etc.

## 3.2 LIST OF COMPONENTS

The components that are used in this project are given below:

1. Push Button Switch
2. Electromechanical relay
3. Miniature Circuit Breaker (MCB)
4. Magnetic Contactor (MC)
5. Inverter
6. DC Regulated Power Supply
7. Delta DVP-14SS2 PLC
8. Battery

### 3.3 Push Button Switch

The push-button is a common control interrupter because it may be used to enable and deactivate the control circuit. It is employed in electric automated control circuits to manually transfer control signals to controllers, relays, electromagnetic starters, and more. Because of this, it spends most of the time in the working phase in its initial location in a free state, and only when forced into a second state does it change into the first one (position). The spring-loaded switch returns to its original place after being unplugged. By pressing the button, we may do basic operations including starting, stopping, rotating in the forward or backward direction, changing the speed, and locking in [5].

**Fig.3.1:** Push Button Switch [5].

#### *3.3.1* Push Button Switch Structure:

We can see the push button switch structure in **Fig.3.2.**

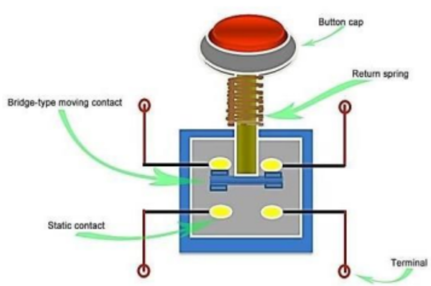


**Fig.3.2:** Push Button Structure [5].

The push-button switch generally consists of

- A button cap,
  A bridge-type moving contact,
- A static contact, a pillar connecting rod, and a shell.

### 3.3.2 Push Button Switch Working Principle

Many control pushbuttons work the same way. Within the button, you have an electromagnetic adsorption kit. The pressure is put on the button or actuator and the contacts at the bottom of the switch are depressed and secure contacts are reached. Either the electrical circuit is opened or closed. As the pressures are repeated, the springwill withdraw and change the attachment to the pushbutton. The button toggles and switches the symbol accordingly between 2 states (sound on/off) [6].

## 3.4 The Electromechanical Relay

Relay is a generic word that describes a device that, in response to the application of a control signal, makes an electrical connection between two or more locations. The electromechanical relay, often known as the EMR, is the most commonly used and most common form of electrical relay [7].

**Fig.3.3:** Electromechanical relay [7].

### *3.4.1* An Electrical Relay

A device's most basic control is whether or not it can be turned on or off. To disrupt the electrical supply, simply use switches. Switches are useful for controlling things, but they can have drawbacks. The most significant drawback is that they must be switched "ON" or "OFF" manually (physically) [7].

A low voltage electrical control signal applied across the relay terminals, either AC or DC, generates a magnetic flux that electromechanical relays translate into a pulling mechanical force that activates the electrical contacts within the relay. Electromechanical relays commonly use a "primary circuit," which is a coil of energizing wire coiled around a permeable iron core [7].

The iron core is made up of a fixed component called the yoke and a spring-loaded movable section called the armature. The armature closes the air gap between the fixed electrical coil and the moveable yoke to complete the magnetic field circuit. To move freely within the magnetic field, the armature is hinged or pivoted to close the electrical contacts that are connected to it. It's common for a spring (or springs) to be connected between the relay's yoke and armature to "reset" the contacts to their initial rest position when the relay's coil is "de-energized," that is, turned "OFF." [7].

### *3.4.2* Electromechanical Relay Construction

There are often two sets of electrically conducting contacts on a device. Relays can be set to "Normally Open" or "Normally Closed," depending on the application. If one set of contacts is classified as Normally Open, the other set is classified as Normally Closed (NC), which means they establish or break connections. Normally open switches have contacts that are only closed when the field current is "ON" and they are being pushed towards the inductive coil [7]. The Electromechanical Relay's Building is seen in **Fig.3.4** below:

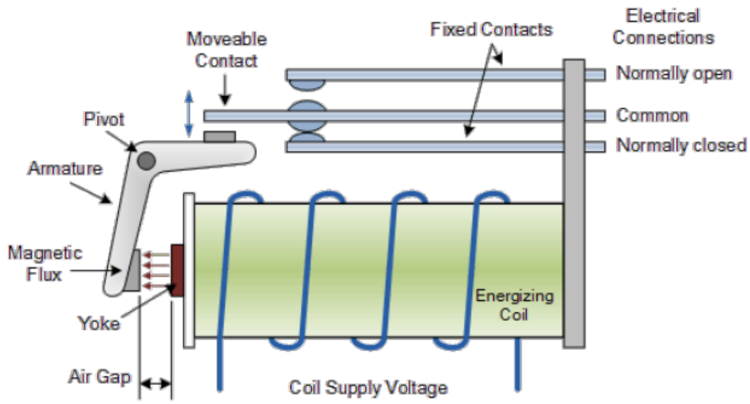


**Fig.3.4:** Construction of Electromechanical Relay [7].

When the field current is turned "OFF," the switch contacts revert to their usual position, leaving the contacts permanently closed in the typically closed position. The words "Normally Closed" and "Make and Break Contacts" refer to the condition of the electrical contacts when the relay coil is "de-energized," i.e., no supply voltage is connected to the relay coil. Make-or-break contact components can have a single or double make-or-break design [7].

In **Fig.3.5** an example of this arrangement is given:

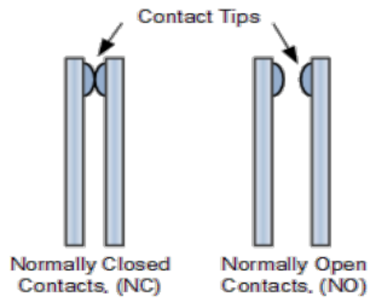


**Fig.3.5:** Energized and de-energized condition of relay [7].

Like a switch, the contacts of a relay are electrically conductive metal pieces that come together to complete a circuit and allow circuit current to flow. When the contacts are open, the resistance between them is extremely high (in the Mega-Ohm range), resulting in an open circuit and no circuit current flow.

In theory, when the contacts are closed, the resistance between them should be zero, creating a short circuit. When a relay's contacts are closed, they have a specific amount of "contact resistance," which is referred to as the "On-Resistance" [7].

### *3.4.3* Electrical Relay Contact Types.

Relay contact arrangements can be classified by their actions in addition to the conventional definitions of Normally Open (NO) and Normally Closed (NC) used to describe how the contacts are linked on the relays. There might be one or more separate switch contacts in an electrical relay, and each one of them is known collectively as a "pole". By activating the relay coil, all of these contacts or poles can be linked or "thrown" together, leading to the definition of contact types as follows:

SPST – Single Pole Single Throw

SPDT – Single Pole Double Throw

DPST – Double Pole Single Throw

DPDT – Double Pole Double Throw

with the contacts' activity being specified as "Make" (M) or "Break" (B). If a basic relay has just one set of contacts, it may be described as "Single Pole Double Throw – (Break Before Make)" or SPDT – (B-M)

Below are a few examples of electrical relay contact type diagrams commonly used to identify relays in circuit or schematic designs, although there are countless more configurations that may be utilized [7].

The contact configurations for an electrical relay is shown in **Fig.3.6.**

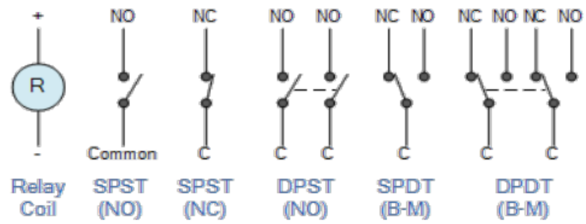


**Fig.3.6:** Contact Configurations of an Electrical Relay [7].

Where:

- C is the Common terminal
- NO is the Normally Open contact
- NC is the Normally Closed contact [7].

### 3.5 Miniature Circuit Breaker (MCB)

A Miniature Circuit Breaker (MCB) is an electrical switch used to safeguard low voltage electrical circuits from damage caused by excessive current from an overload or a short circuit. MCBs have a maximum current rating of 125 A, have no changeable trip characteristics, and can operate thermally or thermally-magnetically [8]. In **Fig.3.7** miniature circuit breaker is shown.

**Fig.3.7:** Miniature Circuit breaker [9].

### 3.5.1 Working Principle Miniature Circuit Breaker

A miniature circuit breaker has two ways of operating. A thermal overcurrent effect, one, and an electromagnetic overcurrent effect both exist. When a continuous overcurrent flows through the MCB, a bimetallic strip heats up and bends, allowing the circuit breaker to operate thermally [8].

A mechanical latch is released as a result of the bimetallic strip bending. When the mechanical latch on the working mechanism is released, the contacts on the miniature circuit breaker are opened. However, under short circuit situations, the rapid rise in current induces the electromechanical displacement of the MCB plunger connected with the tripping coil or solenoid. Upon striking the trip lever, the latch mechanism is released, allowing the circuit breaker contacts to be opened immediately. This was a basic explanation of how a miniature circuit breaker works [8].

### 3.5.2 Operating Mechanism of Miniature Circuit Breaker

Using the miniature circuit breaker's operating mechanism, users may manually open and close the circuit breaker. It has three settings, "ON," "OFF," and "TRIPPED." If the MCB trips owing to an over-current, the external switching latch will be in the "TRIPPED" state [8].

When the MCB is manually switched off, the switching latch is in the "OFF" position. An MCB's switch is set to "ON" when the device is shut down. When the switching latch is in the closed, tripped, or manually off state, it's possible to tell if the MCB is working properly [8].

### 3.5.3 Trip Unit of Miniature Circuit Breaker

The trip unit is the most important component, since it ensures the effective operation of the micro circuit breaker. MCB offers two primary types of trip mechanisms. Overload and short-circuit protection are provided via a bimetal and electromagnet, respectively [8].

A trip circuit safeguards the equipment in the event of a circuit malfunction. Breaker tripping devices are critical in protecting equipment from faults such as overload, earth fault, short circuit, and so on. To safeguard the circuit breaker tripping coil/system protection device [8].

### *3.5.4* Operation of Miniature Circuit Breaker

To turn it off, a single miniature circuit breaker is equipped with three mechanisms. We can see in the illustration below that there is basically one bimetallic strip, a trip coil and a single on/off lever that is controlled with one hand. Here's how a miniature circuit breaker's electric current flows through it. The left-side power terminal comes first, followed by the bimetallic strip, the current coil or trip coil, the moving contact, the fixed contact, and finally the right-side power terminal. All the connections are arranged in series [8]. In **Fig.3.8** the internal mechanism of MCB is shown:

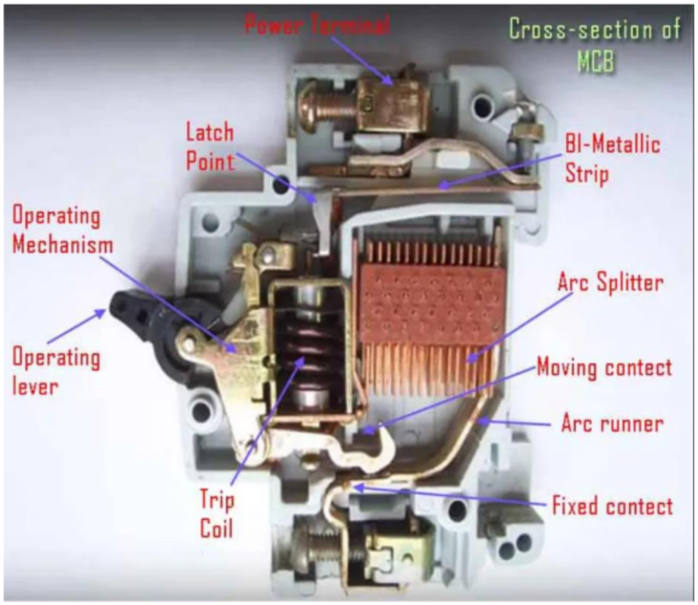


**Fig.3.8:** mechanism of MCB [8].

Bimetallic strips heat up and distort when circuits are overloaded for an extended period of time. The latch point is displaced due to the bimetallic strip deforming. The MCB's moving contact is set up with this latch point such that a little displacement of the latch triggers the release of the spring and allows the moving contact to move in order to open the MCB. This is done by using spring pressure. The current coil or trip coil is positioned in such a way that during a short circuit fault, the magneto-motive force (MMF) of that coil forces its plunger to strike the same latch point and move the latch. Consequently, the MCB will operate in the same manner [8].

Once more, if the MCB's working lever is manipulated by hand, the identical latch point is shifted, resulting in the moving contact and fixed contact being separated in the same manner. There is no difference in latch point displacement or deformed spring release depending on how it operates – whether it is due to the bimetallic strip deformation, increased MMF of the trip coil, or manual operation. Ultimately, this is in charge of causing the moving contact to move in any way. Arcing is more likely when the moving contact is cut off from the stationary contact. The arc then travels up the arc runner, via the arc splitters, and is ultimately extinguished at the end. When an MCB is turned on, the displaced operational latch is reset to its prior on position, and the MCB is ready for another switch off or trip operation [8].

### 3.6 Magnetic Contactor

Related to electrical relays found in some electric motors, are magnetic contactors. In electric motors, magnetic contactors are used to balance the difference in frequency of the motors or the motor state, which can be named ON and OFF motor switches. The microcontroller is like a relay that has a greater current capability and thus an additional power supply. The sturdy variant of the relay is a magnetic contactor. For its small connections, Relay can take little power, but magnetic contactors can handle high power. This security unit can also be used in a power circuit. An external signal such asa relay may not be activated or controlled by a magnetic contactor [10].


**Fig.3.9:** Magnetic Contactor [10]

### *3.6.1* Construction of Magnetic Contactor

A contactor has three main parts;

1. Coil or Electromagnet

2. Enclosure or Frame

3. Contacts

**Fig.3.10** shows the internal construction of a magnetic contactor.

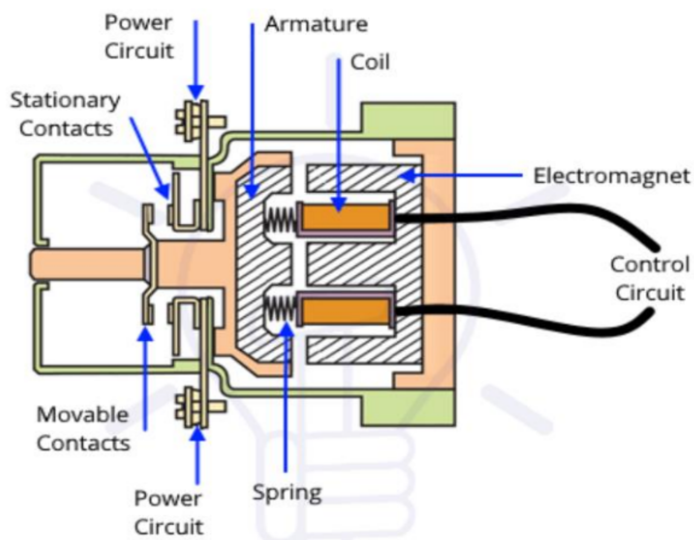


**Fig.3.10:** Construction of magnetic contactor [11].

#### *3.6.1.1* Coil or Electromagnet

The coil is wrapped around an electromagnetic core and acts as an electromagnet. There are usually two components to it: one is permanent and the other is moveable. Between the two pieces is a spring-loaded connector. As a result, a spring-loaded return mechanism has been incorporated. The moving component is attached to the rod. An armature or a rode are both terms for the same thing. Coil forces exceed spring forces, and both contacts are linked; conversely, when spring forces exceed coil forces, both contacts are removed from one another [11].

It just takes a tiny amount of current from the supply or control circuit to activate the electromagnet's core. To decrease eddy current in alternating current (AC) applications, the electromagnetic core is composed of laminated soft iron. Eddy current isn't a concern in DC applications since the core is solid steel [11].

#### *3.6.1.2* Enclosure or Frame

The enclosure is utilized to safeguard the contactor's interior components. It is composed of plastic, nylon 6, ceramic, or Bakelite. It houses the electromagnet and the connections. It protects the contacts from dust, oil, weather, and other explosive risks by acting as an insulator between them and the outside world. When activated, it prevents users from making direct contact with it [11].

#### *3.6.1.3* Contacts

This is the only part from which the whole load current will flow. As a result, it's a crucial part of the contactor. There are three types of contacts: power contact, auxiliary contact, and contact spring. Stationary and moveable power contacts are both types of power contacts. The contacts are made of a material with a steady arc resistance and a high weld resistivity. These materials must be able to endure mechanical stress, erosion, and arc. Because the whole load current will travel via the contacts, the resistance of this material must be as low as feasible. Silver cadmium oxide and silver nickel are used for low current applications, whereas silver tin oxide is used for high current and DC current. The electromagnet's armature is attached to the moving contact by a wire. Since an electromagnet moves the moving contact, it may connect and detach with the fixed contact as necessary [11].

### *3.6.2* Magnetic Contactor Working Principle

Electricity flowing through an electromagnetic coil generates an electromagnetic field. The movable contact of the contactor is linked to the armature (metal rod) of an electromagnet, as demonstrated in the design. When an electromagnetic field is generated, the armature feels the force and is drawn towards the fixed contact. The coil generates more force than the spring. Until the coil is de-energized, the contacts will stay in this state. Once the coil is de-energized, the electromagnetic force is nullified, and the armature begins to retract owing to the pull of the spring. And then things will go back to normal (OFF position). The contactors are made to operate quickly from ON to OFF [11].

The contactor coil's input can be either AC or DC, or the universal coil can be utilized as an electromagnetic coil. The universal coils can be used with either direct current (DC) or alternate-current (AC). An economizer circuit reduces the loss caused by a tiny amount of power lost via the contacts [11]. In **Fig.3.11** we can see the working principle of magnetic contactor.

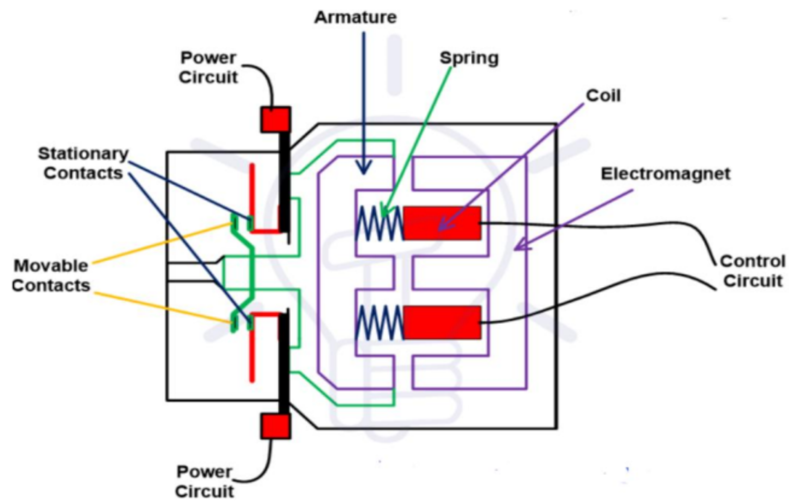


**Fig.3.11:** Working principle of magnetic contactor [11].

When contacts are formed and broken, an arc is created between them. Because it raises the temperature of the contactor's contacts, this arc has the potential to shorten their lifespan. Harmful gases such as mono-oxide are generated as a result of an electric arc. As a result, many techniques are employed to manage and extinguish arcs.

The contactors are chosen according to the load current and voltage, the voltage control range, and the application according to the usage category. You may use an ohm-meter to see if the contacts are open or closed. Simply connect your digital multimeter to the input and output connections and check if the readings are infinite or zero [11].

### 3.6.3 NO and NC Contact points on Magnetic Contactor

The job of the magnetic driver is to attach or sever an electrical circuit and on a magnetic driver there are two kinds of touch points,

- NO (Normally Open)
- NC (Normally Closed)

### 3.6.4 NO (Normally Open)

If the magnetic contactor is not equipped with electrical voltage, the pole will be detached, so when a magnetic contactor coil is supplied, the voltage will be attached to the pole (closed) [11].

### 3.6.5 NC (Normally Closed)

When a magnetic connection does not have an electric voltage, NC (Normally Closed) is attached to the Pole, which means that when the Magnetic is given a tension, the Pole is detached and separated [11].

## 3.7 Power Inverter

An inverter (sometimes known as a power inverter) is a power electronics device that converts DC electricity to AC voltage. Most domestic equipment, however, is powered by AC rather than DC. DC is only utilized in small electrical gadgets. As a result, an effective method of converting DC power to AC power is required [12].

The inverter is a piece of equipment that remains in place. It's capable of converting between several types of electrical power. However, it is unable to produce any kind of electric power. Hence, an inverter is a device that converts voltage, not a machine that produces electricity [12].

Solar power or back-up electricity for household appliances can be utilized as a stand-alone device. An inverter is a device that transforms DC electricity (from batteries) to AC (alternating current) when there is a power outage. A power inverter is a device that converts large amounts of DC electricity to AC power and integrates it into the power system. The receiving end of an HVDC transmission line would have this. A grid-tie inverter is the technical term for this inverter [12].

### 3.7.1 Working principle of power inverter

Let's use an example to show how an inverter works. One battery-powered light. It creates a short, direct route. As a result, electricity will flow through the light bulb. A and B are the bulb's two terminals. The battery's positive and negative terminals are linked to the

'A' and 'B' terminals, and the bulb will illuminate as a result. One difference is that the alternating current (AC) flows in the opposite direction here. IGBT and MOSFET switches are used in the inverter. The number of switches is determined on the type of inverter used [12].

There are a total of four toggles to be found here. A DC supply that's connected to the switches and load. There will be a positive flow of current through the load if switches 1 and 2 are on and 3 and 4 are off. It produces an alternating current (AC) output with a half-cycle that is half-positive. Switches S3 and S4 are now on, but S1 and S2 are still off. The polar opposite of the stream. It generates an alternating current (AC) with a half-cycle that is counter-clockwise. The output frequency is determined by how long the switches are turned on and off for. The inverter generates a square wave as its output. The sine wave is made using filters [12]. In **Fig.3.12** we can see the types of inverter.

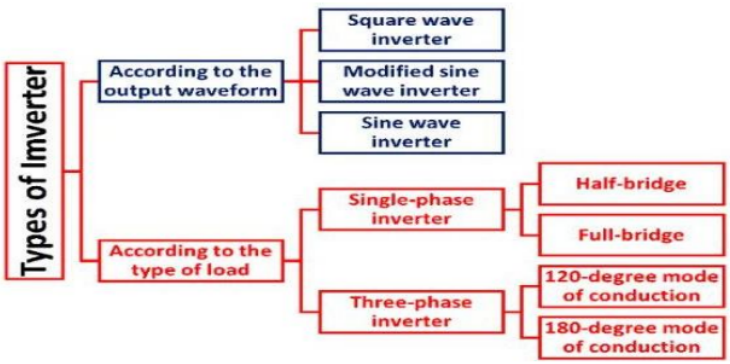


**Fig.3.12:** Types of inverter [12].

### 3.7.2 Types of Inverter According to the Output Waveform

There are three types of inverters.

- Square wave inverter
- Modified sine wave inverter
- Sine wave inverter

#### *3.7.2.1* Square Wave Inverter

This is the simplest and least common kind of inverter. A square wave emerges from this inverter's output. The sine wave is used in most household appliances and equipment that runs on AC power. It shifts the phase of a DC signal into an alternating current signal.

There is no clean AC signal coming out of it. This is the most affordable model of inverter. More losses occur when using a square wave inverter to connect the equipment. Worst-case scenario: damage to the equipment [12]. **Fig.3.13** shows the waveform of square wave inverter.

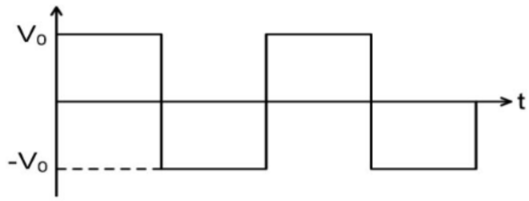


**Fig.3.13**: square wave inverter [12].

#### *3.7.2.2* Modified Sine Wave Inverter

It is also known as a quasi-wave inverter, this device converts electrical energy into electrical waveforms. Using this inverter, a sine wave-like signal is generated. However, it is unable to produce a sine wave with a smooth topology. Before phase shifting, a modified sine wave inverter generates a few pauses. Like a sine wave, it doesn't go from positive to negative all at once. However, this inverter's design is more complicated than the square wave inverter's while being simpler than the sine wave inverter's [12]. **Fig.3.14** shows the waveform of modified square wave inverter.

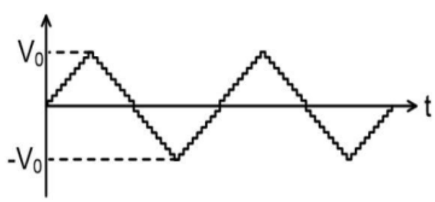


**Fig.3.14**: modified sine wave inverter [12].

#### *3.7.2.3* Sine Wave Inverter

It is the most efficient, but also the most complex of its type. It creates a clean sine wave, which is identical to the grid's power waveform. The sine wave signal is used by all AC devices. Modifying the output waveform of a square wave inverter yields a sine wave. This was the inverter with the lowest net losses. However, this inverter's price is prohibitive. In both home and business settings, this sort of inverter is common [12]. **Fig.3.15** shows the waveform of sine wave inverter.

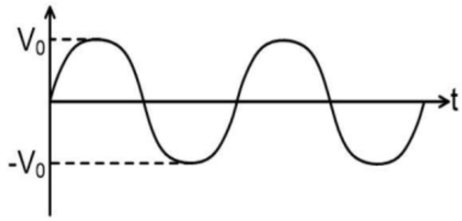


**Fig.3.15:** sine wave inverter [12].

### 3.7.3 According to the Type of Load

Single-phase and three-phase alternating current (AC) are the two kinds of AC electricity. As a result, there are two sorts of load. There are two sorts of inverters, then, based on that, they are:

- Single-phase inverter
- Three-phase inverter

#### *3.7.3.1* Single-phase Inverter

The single-phase inverter is utilized if the load is a single-phase inverter. There are two types;

- Half-bridge inverter
- Full-bridge inverter

#### *3.7.3.2* Single-phase Half-bridge Inverter

The circuit diagram below shows two thyristors (S1 and S2) coupled to two feedback diodes (D1 and D2). The power supply voltage is split in half. The resistive load used as a teaching tool to help students grasp the operating principle [12].

**Fig.3.16** shows the single phase half-bridge inverter which is given below:

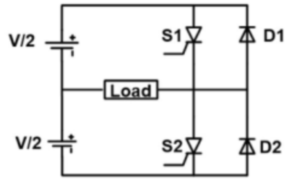


**Fig.3.16:** single phase half-bridge inverter [12].

**Mode-1**

In this state, thyristor S1 is ON while thyristor S2 is off. The present route of flow is V/2-S1-B-RL-A-V/2. The load's current flows in the B to A direction. As well as that, there's a positive voltage of V/2 across the loaded circuit. The output creates a positive cycle when run in this mode [12].

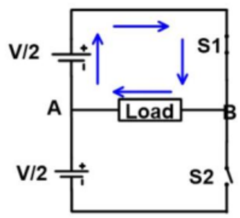


**Fig.3.17:** Mode -1 [12].

**Mode-2**

In this state, thyristor S2 is ON while thyristor S1 is OFF. The present flow route is V/2-A-RL-B-S2-V/2. The A-to-B direction of the current flow via the device's battery. The voltage drop across the load equals -V/2. In this mode, output is generated via a negative cycle [12].

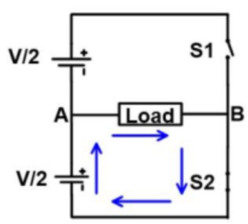


**Fig.3.18:** Mode-2 [12].

### *3.7.3.3* Single-phase Full-bridge Inverter

Four feedback diodes and four thyristors comprise a full-bridge inverter. The circuit only has one DC supply. A half-bridge inverter has one switch conducting at a time. Also, two switches are conducting at once in a full-bridge inverter. [12]. **Fig.3.19** shows the single phase full bridge inverter which is given below:

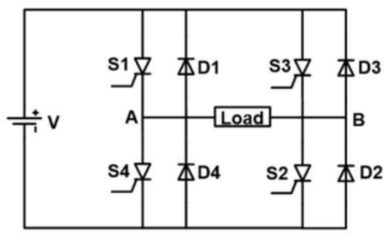


**Fig.3.19:** single phase full bridge inverter [12].

**Mode-1**

Thyristors S1 and S2 are ON, but S3 and S4 are OFF, when the mode is switched to this. The present route of flow is V-S1-A-RL-B-S2-V. A to B is the direction in which the current flows through the load, resulting in a positive half cycle [12].

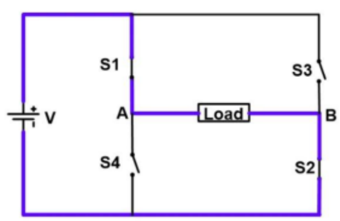


**Fig.3.20:** Mode -1 [12].

**Mode-2**

Thyristor S3 and S4 are ON, but S1 and S2 are off. The present route of flow is V-S3-B-RL-A-S4-V. The load's current flow is from B to A, resulting in a negative half-cycle [12].

In **Fig.3.21** the negative half-cycle of mode-2 is given:

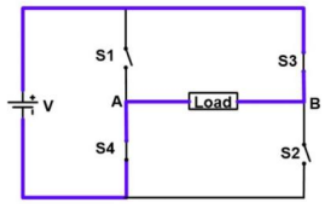


**Fig.3.21:** Mode-2 [12].

#### *3.7.3.1* Three-phase Inverter

Three-phase alternating current (AC) is commonly employed in industry, and the load is three-phase as well. This load was driven by a three-phase inverter in this instance.

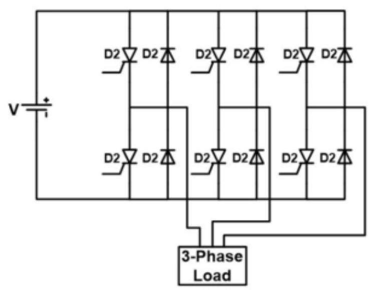


**Fig.3.22**: Three phase inverter [12].

Six diodes and six thyristors are employed in a three-phase inverter. There are two variants of this inverter, based on the thyristor's conduction time;

- 120-degree mode of operation
- 180-degree mode of operation

### 3.8 DC Regulated Power Supply

Unregulated Alternating Current (AC) is converted to a steady Direct Current (DC) by a regulated power source (Direct Current). The use of a regulated power source ensures that the output stays consistent even if the input varies. It's also known as a linear power supply, and it's an embedded circuit made up of a number of different components [13].

**Fig.3.23** shows the visual representation of a power supply which is given below:


**Fig.3.23:** Power Supply [13].

### *3.8.1* Components of DC Regulated Power Supply

The regulated power supply takes an AC input and outputs a steady DC voltage. **Fig.3.24** below illustrates a block diagram of a typical regulated DC power supply.

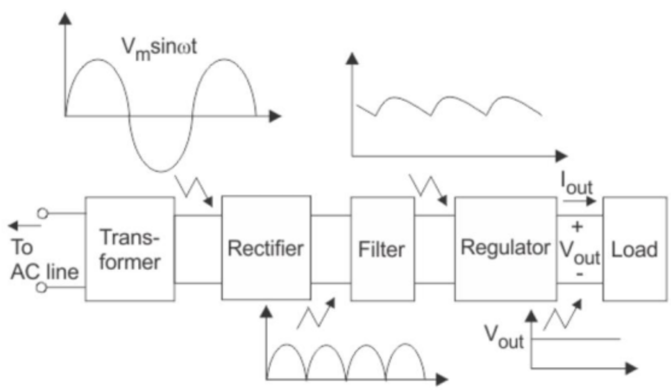


**Fig.3.24:** Basic Regulated Power Supply Components [13]

The following are the fundamental components of a regulated DC power supply:

- A step-down transformer
- A rectifier
- A DC filter
- A regulator

### *3.8.2* Operation of Regulated Power Supply

#### *3.8.2.1* Step Down Transformer

A step down transformer reduces the voltage from the alternating current mains to the desired voltage level. The transformer's turn ratio is changed to get the desired voltage value. The transformer output is used as an input to the rectifier circuit [13].

#### *3.8.2.2* Rectification

A rectifier is an electrical circuit made up of diodes that performs the rectification process. Rectification is the process of turning an alternating voltage or current into a direct current (DC) amount. A rectifier's input is alternating current, and its output is unidirectional pulsing direct current [13].

Although a half-wave rectifier may be utilized, its power losses are substantial when compared to a full-wave rectifier. As a result, a full wave rectifier or a bridge rectifier is needed to rectify both half cycles of the alternating current source (full wave rectification). Figure 3.25 depicts a full wave bridge rectifier:

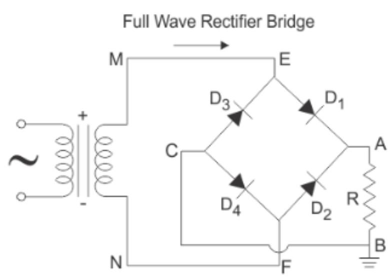


**Fig.3.25:** Full Wave Bridge Rectifier [13]

A bridge rectifier is made up of four p-n junction diodes linked as illustrated above. The voltage induced across the secondary of the electrical transformer, VMN, is positive during the positive half cycle of the supply. As a result, point E is positive in relation to point F. As a result, diodes D3 and D2 are reverse biased, but diodes D1 and D4 are forward biased. Diodes D3 and D2 will operate as open switches (there will be some voltage drop), but diodes D1 and D4 will act as closed switches and will begin conducting. As a result, as illustrated in the first figure, a rectified waveform occurs at the rectifier's output. When the voltage induced in the secondary, i.e. VMN, is negative, D3 and D2 are forward biased while the other two are reverse biased, resulting in a positive voltage at the filter's input [13].

### *3.8.2.3* DC Filtration

In the case of a rectifier, the output voltage is a pulsing DC voltage with a significant amount of ripple. But that's not what we're looking for; instead, we'd want a ripple-free DC waveform. As a result, a filter is utilized. Filters of many sorts are employed, such as capacitor filters, LC filters and choke input filters [13]. The **Fig.3.26** below shows the output waveform after connecting a capacitor filter to the rectifier's output:

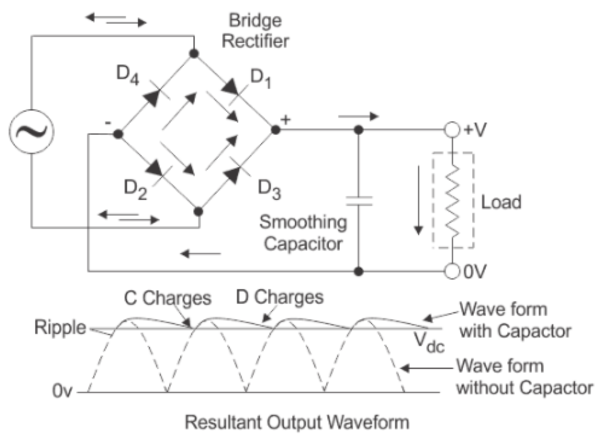


**Fig.3.26:** Resultant output waveform [13].

As the instantaneous voltage rises, the capacitor charges up until the waveform reaches its highest point. Capacitor discharges exponentially and slowly as the instantaneous value falls, causing the load to increase (input of the regulator in this case). As a result, a DC value with virtually constant ripple content has been achieved [13].

### *3.8.2.4* Regulation

The regulated DC power supply concludes with this final block. When the input voltage or current from the ac mains changes, or because the load current at the regulated power supply's output changes, or because of other variables like temperature changes, the output voltage or current will alter or fluctuate. Using a regulator will solve this issue. Even if the input voltage or frequency fluctuates, a regulator will keep the output steady. Depending on the application, a transistor series regulator, fixed or variable IC regulator, or a zener diode operating in the zener region can be employed. Fixed output voltage levels are produced using ICs such as the 78XX and 79XX [13].

We may set the output voltage to a consistent value by using ICs like the LM 317 or the 723. The LM317 voltage regulator is seen in the picture below. In order to alter the output voltage, change the resistance values R1 and R2. For input noise and output transients, coupling capacitors of around 0.01F to 10F are commonly used at the output and input [13]. **Fig.3.27** shows the output voltage.

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$

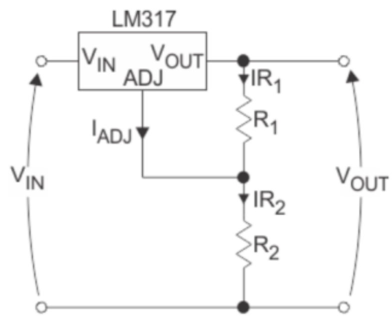


**Fig.3.27:** circuit of a regulated +5V DC power supply [13].

The circuit for a controlled +5V DC power supply is depicted in the diagram above.

### 3.9 Delta DVP-14SS2 PLC

The DVP-SS2 series slim type PLC's second generation retains the fundamental sequential control features of the DVP-SS series PLC, but with quicker execution speed and improved real-time monitoring capability [14].


**Fig.3.28:** Delta DVP-14SS2 PLC [14].

### *3.9.1* Specifications

- MPU points: 14 (8DI + 6DO)
- Max. I/O points: 494 (14 + 480)
- Program capacity: 8k steps
- COM port: Built-in RS-232 & RS-485 ports, compatible with Modbus ASCII/RTU protocol. Can be master or slave.
- High-Speed Pulse output: It Supports 4 points (Y0 ~ Y3) of independent high-speed (max. 10kHz) pulse output
- Supports PID Auto-tuning : DVP-SS2 saves parameters automatically after the PID auto temperature tuning is completed.
- Built-in High-Speed Counters

### *3.9.2* Applications

Spinning machine, conveyer belt (rotation speed control), winding machine (tension control) [14].

### *3.9.3* Product Profile and dimensions

The model name of this delta plc is DVP-14SS2. The dimension of this product is given below in **Fig.3.29**.

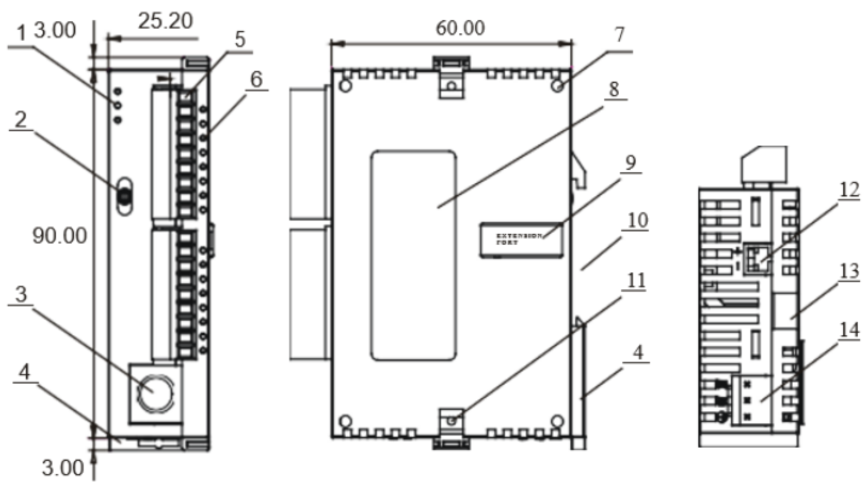


**Fig.3.29:** Product profile and dimensions of DVP-14SS2 [14].

The Pin description of DVP-14SS2 PLC module is shown in **Table 3.1**.

**Table 3.1:** Pin description of DVP-14SS2 PLC module:

| | |
|---|---|
| 1. POWER, RUN, ERROR indicator | 8. Nameplate |
| 2. RUN/STOP switch | 9. Extension port |
| 3. I/O port for program communication (RS-232) | 10. DIN rail mounting slot (35mm) |
| 4. DIN rail clip | 11. Extension unit clip |
| 5. I/O terminals | 12. RS-485 communication port |
| 6. I/O point indicator | 13. Mounting rail for extension module |
| 7. Mounting hole for extension module | 14. DC power input |

### 3.9.4 Electrical specification of Delta PLC model

The Electrical specification of DVP-14SS2 PLC module is shown in **Table 3.2**.

**Table 3.2:** Electrical specification of DVP-14SS2 PLC module

| DVP Model Item | 14SS211R |
|---|---|
| Power supply voltage | 24VDC (-15% ~ 20%) (with counter-connection protection on the polarity of DC input power) DVPPS01(PS02): input 100-240VAC, output 24VDC/1A(PS02: 2A) |
| Inrush current | Max. 7.5A24VDC |
| Fuse capacity | 1.85A/30V DC, Poly switch |
| Power consumption | 1.8W |
| Power protection | With counter-connection protection on the polarity of DC input power |
| Operation environment | Free of corrosive gas |
| Installation position | Inside the control box |
| Pollution rating | 2 |

| DVP Model Item | 14SS211R |
|---|---|
| Grounding | The diameter of terminals L and N (All DVP units should be grounded directly to the ground pole). |
| Operation storage | Operation: 0°C ~ 55°C (temp.), 5 ~ 95% (humidity), no condensation. Storage: -25°C ~ 70°C (temp.), 5 ~ 95% (humidity), no condensation. |
| Vibration shock resistance | International standards: IEC61131-2, IEC 68-2-6 (TEST Fc)/IEC61131-2 & IEC 68-2-27 (TEST Ea.) |
| Atmospheric pressure | Operation: 1080 ~ 795hPa (Equivalent to -1000 ~ 2000 feet above sea level)<br>Storage: 1080 ~ 660hPa (Equivalent to -1000 ~ 3500 feet above sea level) |
| Weight (g) | 97g |
| Insulation resistance | > 5MΩ (all I/O point-to-ground: 500VDC) |
| Protection rating | IP20 |
| Over voltage tolerance limit | 1,500VAC (Primary-secondary), 1,500VAC (Primary-PE), 500VAC (Secondary-PE) |

### 3.9.5 Power supply of DVP-14SS2 PLC

The power supply of PLC is as followed

- DVP-SS2 accepts a DC power supply as an input. The following considerations should be kept in mind while using DVP-SS2.
- There are two terminals for connecting the electricity. 24V DC and 0V, with a power range of 20.4 - 28.8V DC. The PLC will shut down, all outputs will be off, and the error indication will begin blinking if the power voltage is less than 20.4 V DC.
- The PLC's functionality is unaffected by a power outage lasting less than 10ms. [15].

### 3.9.5 Input and output configuration of DVP-14SS2 PLC

The Input and output configuration of DVP-14SS2 PLC module is shown in **Table 3.3**.

**Table 3.3:** Input and output configuration of DVP-14SS2 PLC module

<table>
<tr><td colspan="2" rowspan="2">DVP Model Items</td><td colspan="2">Input Point (single common port input)</td></tr>
<tr><td colspan="2">14SS2</td></tr>
<tr><td colspan="2">Input No.</td><td colspan="2">X4 ~ X7</td></tr>
<tr><td colspan="2">Input type</td><td colspan="2">DC (SINK or SOURCE)</td></tr>
<tr><td colspan="2">Input Current (± 10%)</td><td colspan="2">24VDC (-15% ~ 20%),5mA</td></tr>
<tr><td colspan="2">Input impedance</td><td colspan="2">4.7kΩ</td></tr>
<tr><td colspan="2">Max. frequency</td><td colspan="2">10kHz</td></tr>
<tr><td rowspan="2">Action level</td><td>Off-On</td><td colspan="2">> 15VDC</td></tr>
<tr><td>On-Off</td><td colspan="2">< 5VDC</td></tr>
<tr><td colspan="2">Filter time</td><td colspan="2">X0 ~ X7 adjustable within 0 ~ 20ms by D1020 (Default: 10ms)<br>X10 ~ X17 adjustable within 0 ~ 20ms by D1021 (Default: 10ms)</td></tr>
<tr><td colspan="2">Specific Items</td><td colspan="2">Output Point</td></tr>
<tr><td colspan="2" rowspan="2">Output No.</td><td colspan="2">Relay</td></tr>
<tr><td colspan="2">Y0 ~ Y7, Y10 ~ Y13</td></tr>
<tr><td colspan="2">Max. frequency</td><td colspan="2">1Hz</td></tr>
<tr><td colspan="2">Working voltage</td><td colspan="2">250VAC, < 30VDC</td></tr>
<tr><td colspan="2" rowspan="3">Max. load</td><td>Resistive</td><td>1.5A/1 point (5A/COM)</td></tr>
<tr><td>Inductive</td><td>#2</td></tr>
<tr><td>Lamp</td><td>20WDC/100WAC</td></tr>
<tr><td colspan="2" rowspan="2">Response time</td><td>Off-On</td><td rowspan="2">Approx. 10ms</td></tr>
<tr><td>On-Off</td></tr>
</table>

### 3.10 Lead Acid Battery

In solar systems, lead acid batteries are by far the most prevalent. Despite their low energy density, mediocre efficiency, and high maintenance needs, lead acid batteries have a long lifespan and inexpensive cost when compared to other battery types. As the most widely used battery type for most rechargeable battery applications (such as starting vehicle engines), lead acid batteries have a well-established, mature technical foundation, which is one of its main advantages [16].


**Fig.3.30:** Lead Acid Battery [16].

### *3.10.1* Construction of Lead Acid Battery

If we see how do lead acid batteries work we find lead acid battery becomes lead, acid, and battery if the name is shattered. Chemically, lead is an element (symbol is pb and the atomic number is 82). It's pliable and supple. We know what acid is, and when it reacts, it can either give or take a proton and an electron pair. As a result, a battery made of lead and anhydrous plumbic acid (incorrectly referred to as lead peroxide) is known as a lead acid battery. [17].

### *3.10.2* Internal construction

Here **Fig.3.31** shows the internal parts of a lead-acid battery:

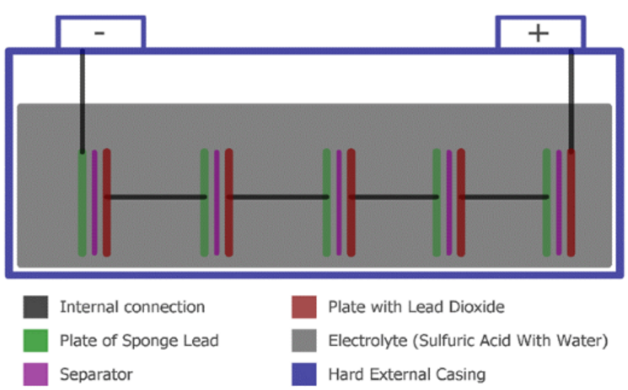


**Fig.3.31:** Lead Acid Battery Internal Diagram [17].

Plates, Separator, and Electrolyte make up a Lead Acid Battery, which is housed in a hard plastic container with a firm rubber seal. Positivity and negativity are represented by the plates in batteries. Lead dioxide makes up the positive one, whereas Sponge Lead makes up the negative one. A separator, which is an insulating substance, is used to separate these two plates. With the exception of the electrolyte, everything is stored in a durable plastic casing. Water and sulfuric acid are used as electrolytes [17].

One cell contains the hard plastic casing. 2.1 volts is the usual voltage stored by a single cell. A 12V lead acid battery has six cells, each supplying 2.1V, therefore the total voltage produced is usually 12.6V. [17].

### *3.10.3* Charge storage capacity

The amount of active material (Electrolyte) and the size of the plate have a big impact on this. mAh or milliamp-hour rating is used to indicate lithium battery storage capacity; however, with a Lead Acid battery the unit of measurement is amp hour. This will be explained in more detail in the next section. [17].

### *3.10.4* Working of Lead Acid Battery

It's fascinating to learn about the chemistry behind how a lead acid battery works. When a Lead Acid battery is being charged or discharged, a large number of chemical reactions occur. When sulfuric acid H2SO4 dissolves in water, the molecules separate into two halves. It will produce positive ions like 2H+ and negative ones like SO4-. Anode and cathode are linked as plates, as previously explained. The negative ions are caught by the anode, while the positive ions are drawn to the cathode. Sulfuric acid diluted in water, SO4- and cathode bonding exchanges electrons with H2O or water (sulfuric acid diluted in water) [17].

The battery has two states of chemical reaction:

- Charging
- Discharging.

### *3.10.5* Lead Acid Battery Charging

A voltage larger than the terminal voltage is required to fully charge a battery, as we know. As a result, a 13V supply may be used to recharge a 12V battery. The same chemistries are at work as previously. When the battery is connected to the charger, the sulfuric acid molecules break down into two ions: two positive ions, 2H+, and two negative ions, $SO4^-$. Hydrogen exchanges electrons with the cathode to create hydrogen, and this hydrogen combines with the $PbSO_4$ in the cathode to form sulfuric acid ($H_2SO_4$) and lead (Pb). $SO4^-$, on the other hand, exchanges electrons with the anode and transforms into the radical $SO_4$. The $SO_4$ interacts with the anode's $PbSO_4$ to produce the peroxide of lead $PbO_2$ and sulfuric acid ($H_2SO_4$). Gravity increases and cell potential voltage increases are used to store energy [17].

The following chemical processes occur at the anode and cathode during charging, as previously described:

At cathode:

$PbSO_4 + 2e^- \Rightarrow Pb + SO_4^{2-}$

At anode:

$PbSO_4 + 2H_2O \Rightarrow PbO_2 + SO_4^{2-} + 4H^- + 2e^-$

When the two equations above are combined, the final chemical reaction will be:

$2PbSO_4 + 2H_2O \Rightarrow PbO_2 + Pb + 2H_2SO_4$

**Fig.3.32** illustrates the lead acid battery charging:

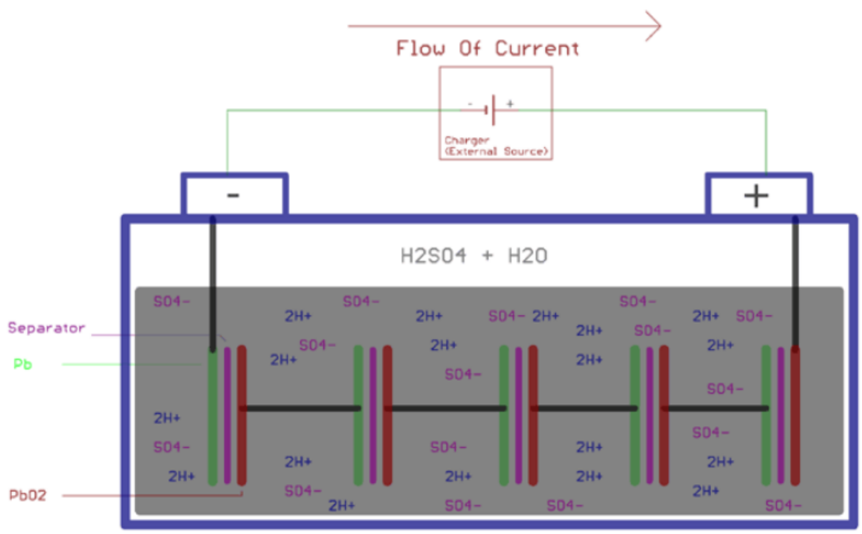


**Fig.3.32:** Lead Acid Battery Charging [17].

The lead-acid battery may be charged via a variety of techniques. Each technique can be used to a certain type of lead-acid battery depending on its intended purpose. The charging technique used in certain applications is constant voltage, whereas the charging method used in others is constant current. Typically, battery manufacturers will offer instructions on how to charge certain lead-acid batteries. Lead acid battery charging doesn't usually use constant current charging [17].

The most popular charging technique for a lead acid battery is the constant voltage charging method, which saves time by charging the battery quickly. Charge voltage is constant during the whole cycle and current decreases with increasing battery charge level. [17].

### *3.10.6* Lead Acid Battery Discharging

When a lead acid battery is discharged, chemical processes are once again engaged. Sulfuric acid is generally diluted in a 3:1 water to sulfuric acid ratio. When the loads are linked across the plates, the sulfuric acid again breaks down into positive ions 2H+ and negative ions SO4. The hydrogen ions react with the PbO2 to form PbO and water H2O. When PbO reacts with H2SO4, it becomes PbSO4 and H2O. On the other hand, SO4- ions trade electrons with Pb to form a radical SO4, which then reacts with Pb to form PbSO4. Anode and cathode chemical processes during discharge are described above as follows [17]. These reactions are the total opposite of charging reactions:

At cathode:

Pb + SO42- => PbSO4 + 2e-

At anode:

PbO2 + SO42- + 4H- + 2e- => PbSO4 + 2H2O

When the two equations above are combined, the final chemical reaction will be

PbO2 + Pb + 2H2SO4 => 2PbSO4 + 2H2O

**Fig.3.33** illustrates the lead acid battery discharging:

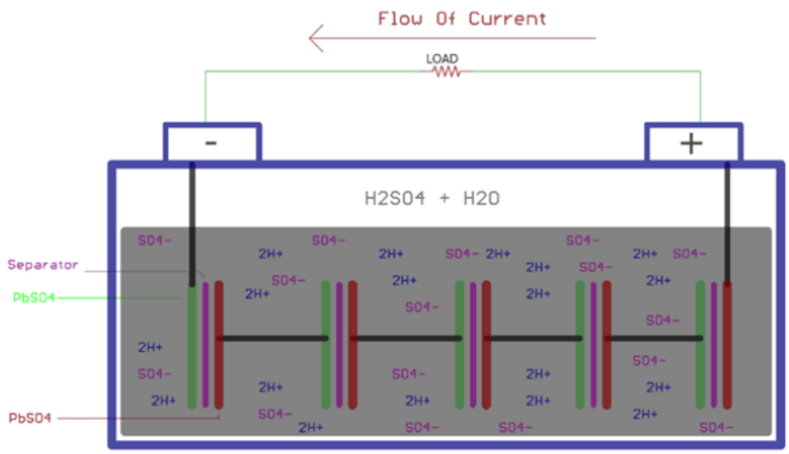


**Fig.3.33:** Lead Acid Battery Discharging [17].

The balance of electrons between the anode and the cathode changes as a result of the electron exchange. A load is connected to the battery, and as a result, electrons travel through the load, discharging the battery. The diluted sulfuric acid gravity decreases as a result of the discharge. In addition, the cell's potential difference decreases at the same moment [17].

# CHAPTER 4
# DESIGN METHODOLOGY

## 4.1 INTRODUCTION

Typically design methodology is the most imperative chapter of any project report. This chapter covers the project's design methodology, including the block diagram and circuit diagram and a brief explanation of how they work. The step by step discussion of this project is given underneath:

## 4.2 BLOCK DIAGRAM

Here we have developed a block diagram which discusses the input and output of PLC that we have used in this project. Here we have used a Delta DVPSS2 PLC which is a relay type PLC. This PLC has port of 8 inputs and 6 outputs. In this block diagram we have just used a logo PLC to discuss about the inputs and outputs that we have conducted in our project. Here, **Fig.4.1** shows the PLC's input and output block diagram for this project.

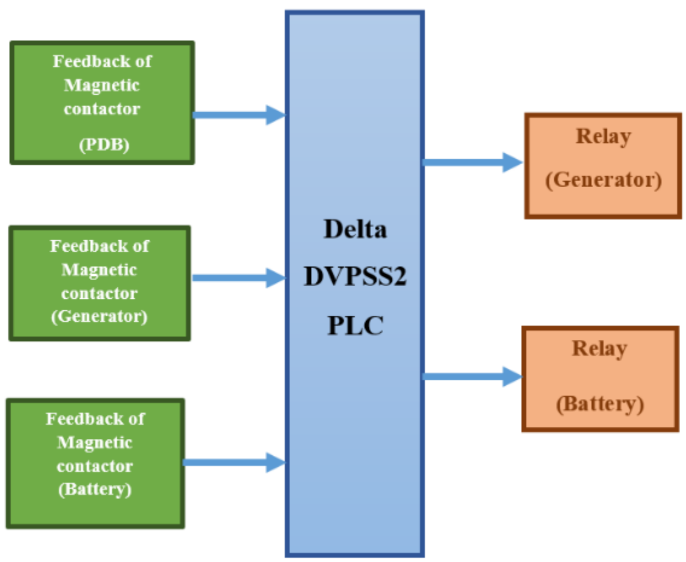


**Fig.4.1:** Block Diagram of PLC input and output

All the PLC's have flash memory which makes a difference to store or remove the programming within the PLC. The main parts of PLC are I/O, CPU, and control supply.

We will see from the **Fig.4.1** is that the portrayed block diagram is separated into 3 parts such as input portion, PLC and output portion.

As input we have used feedback of magnetic contactors from PDB, generator and battery to the PLC. This feedback is given from the NC port of magnetic contactors. Feedback will generate only when a magnetic contactor fails to find any phase on the certain line. As output we have used electromagnetic relays of generator and battery line. It will work following the input feedback given to PLC.

## 4.3 CIRCUIT DIAGRAM

Here we have developed some circuit diagrams using Microsoft Visio, AutoCAD and power point for this project automatic changeover with phase failure by PLC. All the circuit diagrams are given below:

### *4.3.1* CONTROL WIRING CIRCUIT DIAGRAM

Here the control wiring diagram of our project is shown at **Fig.4.2**. As the figure shown there are three MCB which we figured as one is PDB power source, the middle one is generator power source and another one is battery source. Then we have used one AC electromagnetic relay and two others are DC electromagnetic relay. We used the PDB MCB to power the AC relay which energizes the following magnetic contactor (PDB). We used DC relay because the output of PLC is in DC +24V, therefore the DC relay of generator source energizes the magnetic contactor of generator and the DC relay of battery source energizes the magnetic contactor of battery. The magnetic contactors are used for running the loads of different sources.

Firstly, for the PDB part, we have given phase (P) to the relays 13 number pin and the common (C) and also neutral (N) to the relays 14 number pin. From the relays NO pin we have given phase to $A_1$ of magnetic contactor. As we had no generator so to differ the source of PDB from generator we have given an interlock, so the $A_2$ of magnetic contactor of PDB has been taken from NC of generator relay and it came from another common pin which we denoted as $C_2$. In $L_1$ and $L_2$ of magnetic contactor we given phase and neutral respectively so from $T_1$ and $T_2$ of magnetic contactor we have taken the load of PDB.

The figure is drawn below:

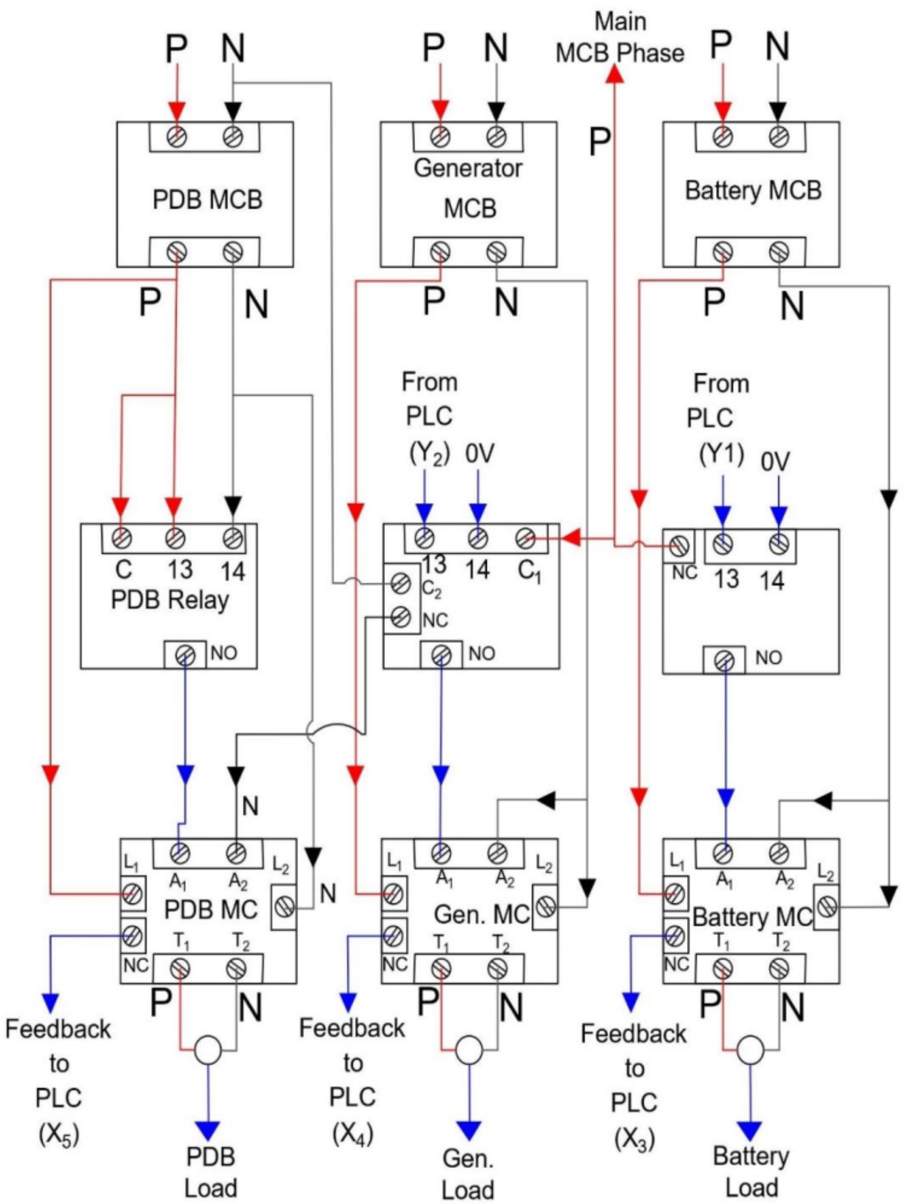


**Fig.4.2:** Control wiring Circuit Diagram

Secondly, for the generator part, we have given 24V to the relays 13 number pin by using output of PLC $Y_1$ and neutral (N) to the relays 14 number pin. From the power supply. Then we have used 220V from main MCB to the common of generator relay. From the relays NO pin we have given phase to $A_1$ of magnetic contactor and the $A_2$ of magnetic contactor from generator (MCB). In $L_1$ and $L_2$ of magnetic contactor we have given phase and neutral respectively from generator (MCB) so from $T_1$ and $T_2$ of magnetic contactor we have taken the load of generator.

At last, for the battery part, we have given 24V to the relays 13 number pin by using output of PLC $Y_2$ and neutral (N) to the relays 14 number pin. From the power supply. Then we have used 220V from main MCB to the common of battery relay. From the relays NO pin we have given phase to $A_1$ of magnetic contactor and the $A_2$ of magnetic contactor from battery (MCB). In $L_1$ and $L_2$ of magnetic contactor we have given phase and neutral respectively from battery (MCB) so from $T_1$ and $T_2$ of magnetic contactor we have taken the load of battery.

Here the magnetic contactors are also used for giving feedback to PLC, from the NC of magnetic contactors we have given feedback to PLC. The feedback will work as inputs of PLC. From the magnetic contactor of PDB gives feedback to the $X_5$ input of PLC and from the magnetic contactor of generator gives feedback to the $X_4$ input of PLC and also from the magnetic contactor of battery gives feedback to the $X_3$ input of PLC.

### *4.3.2* VISUAL REPRESETATION OF CONTROL WIRING CIRCUIT DIAGRAM

Visual representation of control wiring circuit diagram below in **Fig.4.3**. The visual representation of control wiring is done by Microsoft PowerPoint. It is done to visually represent the control wiring circuit diagram and the operation is same as the control wiring diagram. In the visual representation there are also three MCB as denoted and three electromagnetic relay and three magnetic contactor as followed by this project. The feedbacks of magnetic contactors are given as inputs to PLC and the PLC gives input to electromagnetic relay.

The figure is given below:

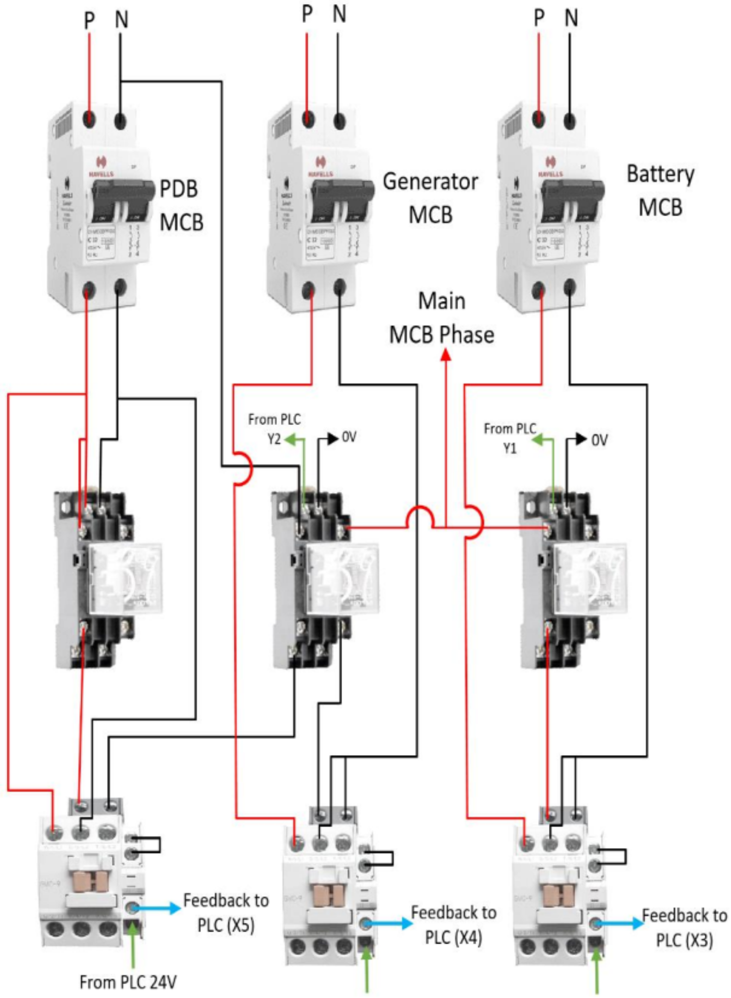


**Fig.4.3:** Visual representation of control wiring circuit diagram

### *4.3.3* PLC WIRING DIAGRAM

As the PLC runs on +24V so we had to use a DC power supply which takes 220V as input and +24V as output. Therefore from main MCB we give phase and neutral respectively to L and N pin of DC power supply. PLC is run by connecting sink source (s/s) pin of PLC to power supply positive (+) and neutral (.) pin of PLC to power supply negative (-). After connecting as followed then we have to push the RUN button of PLC to take it in run mode.

Here we have drawn the wiring diagram of PLC in **Fig.4.4**

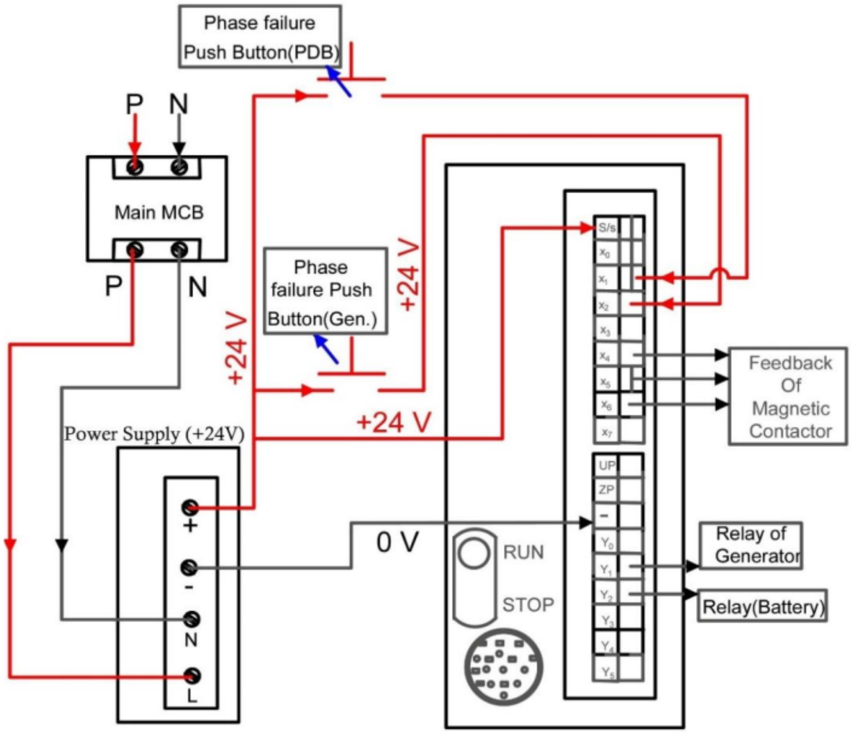


**Fig.4.4:** PLC wiring diagram

To wire the inputs we need push button to give command, so two push button is connected to +24V from the power supply. From phase failure push button (PDB) we gave connection to $X_1$ input pin of PLC and from phase failure push button (Generator) to $X_2$ input pin of PLC. From the magnetic contactor of PDB feedback is given to the $X_5$ input pin of PLC and from the magnetic contactor of generator feedback is given to the $X_4$ input pin of PLC and also from the magnetic contactor of battery feedback is given to the $X_3$ input pin of PLC.

From output of PLC +24V is given to the relays because it needs to be controlled by PLC. Therefore from $Y_1$ output pin +24V is given to 13 number pin of generator relay and from $Y_2$ output pin +24V is given to 13 number pin of battery relay.

### *4.3.4* VISUAL REPRESENTATION OF PLC WIRING DIAGRAM

The visual representation of PLC wiring is done by Microsoft PowerPoint. It is done to visually represent the PLC wiring circuit diagram and the operation is same as demonstrated in PLC wiring diagram. Visual representation of PLC wiring circuit diagram below in **Fig.4.5**.

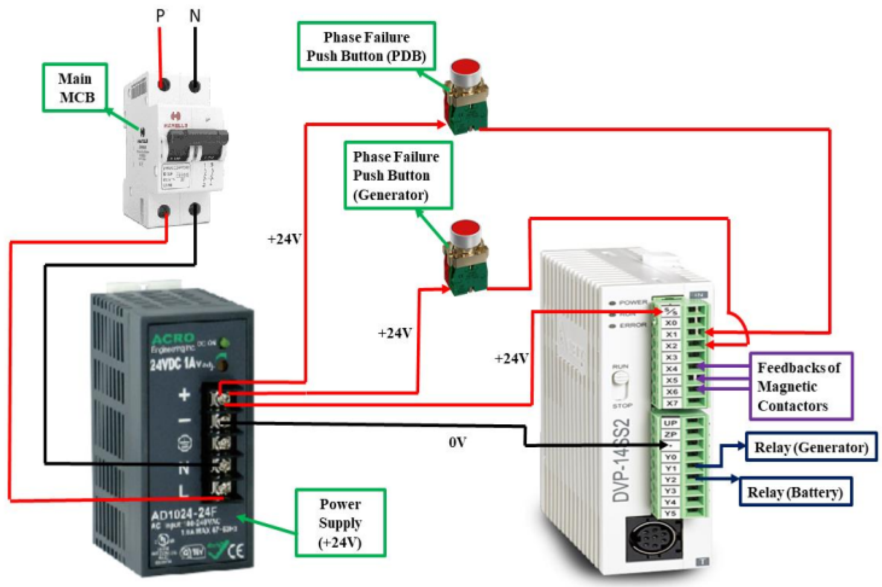


**Fig.4.5:** Visual representation of PLC wiring

### *4.3.3* LADDER DIAGRAM

This ladder diagram is developed by WPLSoft 2.46 software. In this ladder diagram for feedback we have used $X_5$ as PDB feedback and $X_4$ as feedback of generator. For phase failure we have used $X_0$, $X_1$, $X_2$. We used two timers one is $T_0$ which is for generator and another one is $T_1$ which is used for battery. There are four coils $M_0$, $M_3$, $Y_1$ and $Y_2$ which can be energized. Here $M_0$ , $M_3$ are memory unit and $Y_1$, $Y_2$ are battery and generator coil respectively.

First coil is $M_0$ which is the coil of PDB, to energize it the conditions are:

- PDB feedback X5 needs to remain ON.
- Two phase X0 and X2 needs to be ON

The ladder diagram is given below in **Fig.4.6**.

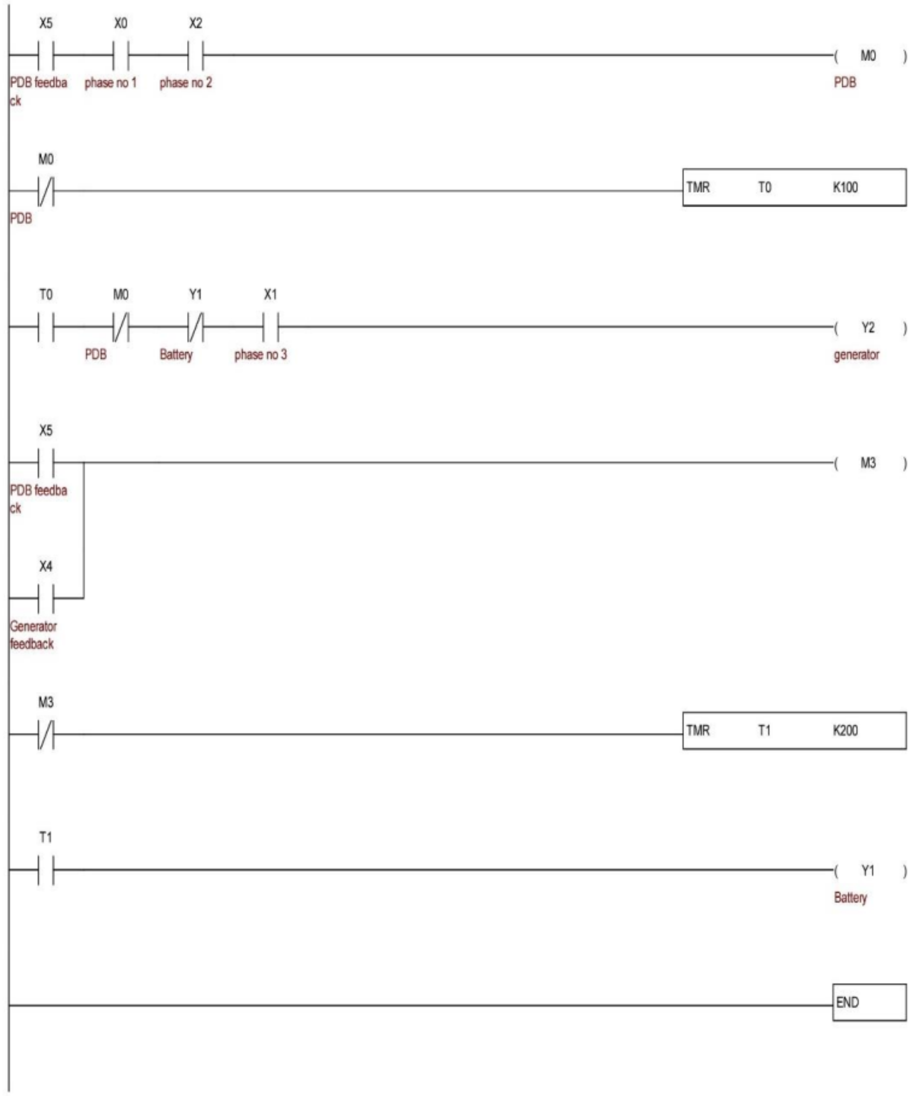


**Fig.4.6:** Ladder diagram

Here X5, X0 and X2 are in series it's like an AND gate, so if PDB phase is missing or other two phase are missed by phase failure then NC of $M_0$ will start timer $T_0$ which will give a feedback to generator coil which is $Y_2$.

Now, to energize generator coil $Y_2$ the conditions are:

- $M_0$ will remain OFF.
- Timer $T_0$ needs to be energized which will give a 10 second delay.
- $Y_1$ should be interlocked so it will remain OFF.

The M3 will energize when it detects any of the feedback of PDB or generator. If it fails to find any feedback then from the NC of M3 it will energize the timer T1 which is for battery coil. So after 20 second delay the battery coil Y1 will energize. In the meantime, if M0 energizes then the connection will automatically make the PDB source ON.

# CHAPTER 5

# IMPLEMENTATION AND RESULT

## 5.1 INTRODUCTION

This project is developed to get familiar with basic PLC. We have used delta PLC because its software WPLSoft 2.46 is very user friendly. We have downloaded the program in PLC and all the components were arranged according to the design procedure. In this chapter, implementation of the system and the obtained result is discussed.

## 5.2 IMPLEMENTATION

In this system all the equipment are fixed in their position according to design. A wooden board has been used to fix all the components which are MCB, power supply, magnetic contactors, electromechanical relay etc. Connectors were used for wiring the connections of PLC and other components.

### *5.2.1* COMPLETE OVERVIEW

Here **Fig.5.1** indicates the complete overview of the system.

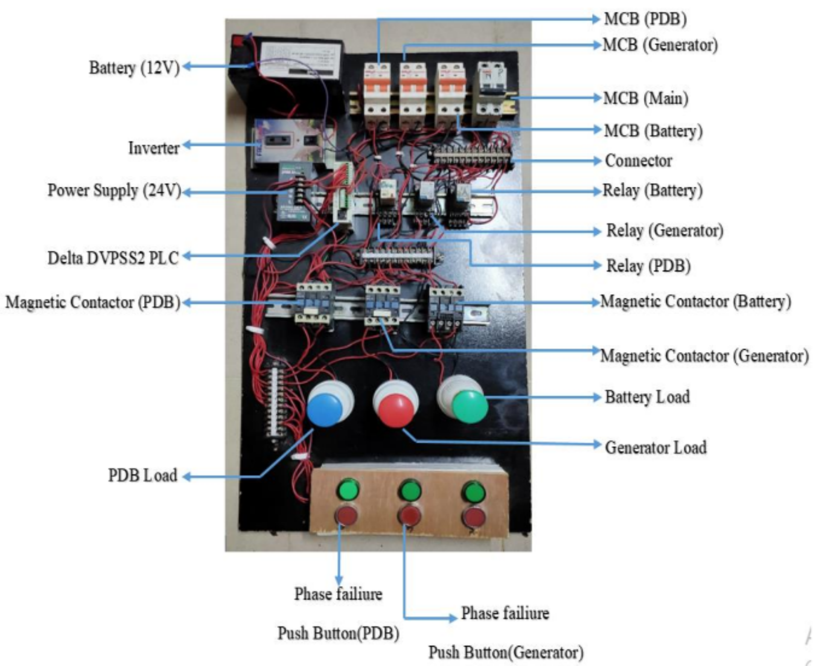


**Fig.5.1:** Total overview of the system

We have used three power source in our project. We have used MCB, two types of electromagnetic relay, a 24V Delta PLC, one power supply for PLC, one inverter, three magnetic contactor, three switch for phase failure, three lamp for load and connecting wires in this project.

### 5.3 PERFORMANCE OF THE SYSTEM

Firstly we have to take the PLC on run mode. Then we have given the power to the MCB from the PDB source then the AC electromagnetic Relay will be energized so the magnetic contactor and load will turn on. When PDB source fails then generator Source will turn on by PLC and DC electromagnetic relay will energize so the magnetic contactor and load will turn on. When generator source fails then Battery source will be turned on by PLC and DC electromagnetic relay will energize so the magnetic contactor and load will be on. When PDB Source become available then the AC electromagnetic relay will energize so the magnetic contactor and load will be turn on.

### 5.4 DEMONSTRATION AND RESULT OF THE PROJECT

Here we will discuss about our obtained result. In **Fig 5.2** we can see that all connections are off. After that when we put the main MCB in ON mode then all other MCB. Then we have to turn the PLC in RUN mode. After that we observe that PDB connection is ON and the load is also on in **Fig.5.3.**

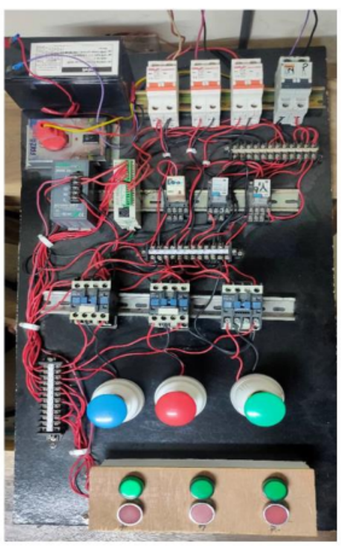

**Fig.5.2:** All connection OFF

**Fig.5.3:** Load of PDB ON

After that generally the PDB connection will remain ON otherwise the PLC detects phase failure or the power source is missing. It can be done by turning OFF the MCB of PDB source or using the phase failure switch. In **Fig.5.4** it is shown by doing phase failure by push button, when it is done PLC will get a feedback so after 10 second delay it will automatically make ON the load of generator source which is showed in **Fig.5.5**.

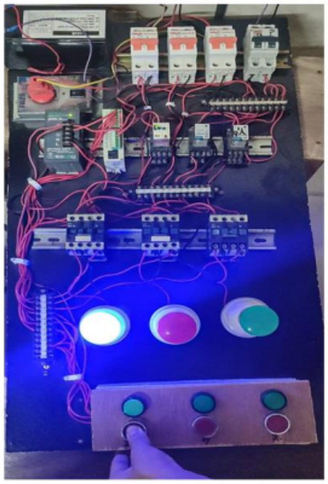

**Fig.5.4:** Phase Failure of PDB source

**Fig.5.5:** Automatic ON of Generator load

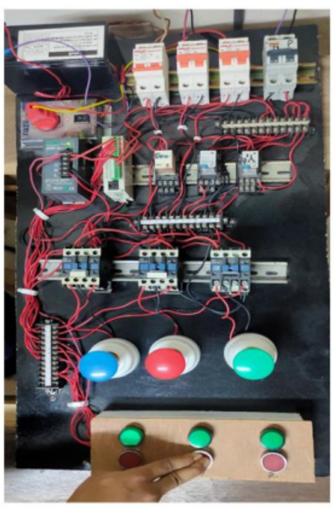

**Fig.5.6:** Phase Failure of Generator source

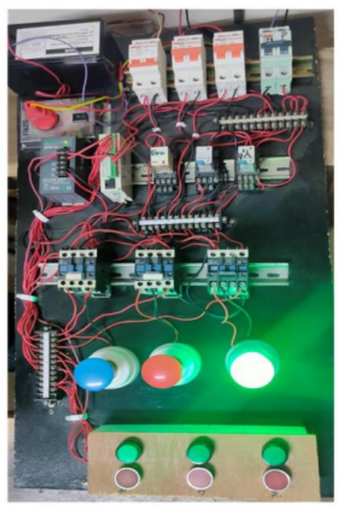

**Fig.5.7:** Automatic ON of Battery Load

After that generally the generator source connection will remain ON until the PLC detects phase failure or the power source is missing. It can be done by turning OFF the MCB of generator source or using the phase failure switch. In **Fig.5.6** it is shown by doing phase failure by push button, when it is done PLC will get a feedback so after 20 second delay it will automatically make ON the load of battery source which is showed in **Fig.5.7.**

In the meantime, if the PLC detects phase or power in the PDB source then it will automatically make the load of PDB ON which is shown in **Fig.5.8.**

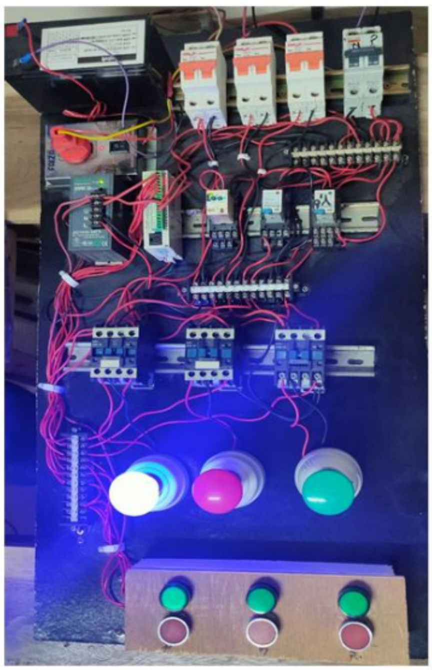

**Fig.5.8:** Automatic ON off PDB when detects phase

## 5.5 TOTAL COST OF THE PROJECT

Our project is costly but it can be used normally used for both industrial and commercial purpose. This project has cost approximately 9860 taka, If we want to reduce the cost, then we need to reduce or replace some equipment. But it will bring down the performance of the project. Since this is the basic idea of using PLC for industrial and commercial purposes, it is important to use good and long lasting equipment. Total cost of this project is shown in **Table 5.1**.

**Table 5.1:** Total cost of the project

| Components | Quantity | Cost (BDT) |
|---|---|---|
| 1. Delta DVPSS2 PLC | 1 | 4500 |
| 2. Miniature Circuit breaker | 4 | 700 |
| 3. Power Supply (+24V) | 1 | 1000 |
| 4. Electromagnetic Relay | 3 | 800 |
| 5. Magnetic Contactor | 3 | 1000 |
| 6. Lights | 3 | 150 |
| 7. Holder | 3 | 90 |
| 8. Push Button | 3 | 120 |
| 9. Battery (12V) | 1 | 1000 |
| 10. Inverter | 1 | 500 |
| | **Total** | **= 9860/-** |

**Table 5.1** shows the total cost of this project which is 9860/- BDT. Here we can see the highest expenditure is PLC which costs 4500/- BDT.

### 5.6 COST COMPARISON

As per our perspective, when compared to related projects published in renowned journals and articles, we conclude that this article is — "**PLC Based Automatic Changeover Switch**'' [2] the approximate cost of this project is around **BDT8,085**. The main key feature of this project is design and implement a PLC based automatic changeover switch but it's changeover system for only one source whereas our project shows automatic changeover of multiple source and also we have implemented phase failure detection which is missing on this project. Though our price is slightly higher than theirs we can assure its more effective and have more features. This analysis is also applicable for another paper which is titled as — "**Automatic Transfer Switch (ATS) Using Programmable Logic Controller (PLC)**'' [3] the approximate cost is not less than BDT9,500. The key feature of this project is to automatically changeover to generator source when main supply is missing. We excluded the price of generator here because we didn't use it in our project. This project also lack the feature to changeover multiple sources and missing the phase failure detection system. We would like to discuss about another project titled as — "**Automatic Changeover Switch for Power Sources**'' [4] which is done by relay logic control (RLC). As there was no use of PLC so the price is less again there will be need of more components like timers, overload which will increase the price so we think it's price is approximately BDT7,500. It also didn't show the use of multiple source but if it is done then the circuits will be more complex and will be hard to find any kind of fault if occurs. The author also insisted that it can be done by PLC for better performance in his paper. So overall we find our system more effective and it includes more feature.

# CHAPTER 6
# CONCLUSION

## 6.1 INTRODUCTION

The project report concludes with this chapter. In this chapter, we'll discuss about how the project came to a conclusion. We'll also discuss about the project's limitations, future improvements, applications and advantages.

## 6.2 CONCLUSION

This project demonstrates the design and implementation of PLC based automatic power changeover with power and phase failure detection. Because of its simplicity and effectiveness, the system may be utilized in a variety of settings including education as well as commercial and industrial ones. This project is designed to eliminate manual operation of power source and to decrease the time of operation. It also can increase speed of operation in the system which can improve reliability of the system.

## 6.3 APLLICATIONS

Our project contains some real world applications which are given below:

- Automatic changeover of any power source like emergency generators, uninterrupted power supply (UPS).
- It can be used in any industry where they need speed in operation of changing power supply.
- It will be very effective for the industries which feeds from different substations.
- It can be used in hospital where it contains operation and intensive care rooms.
- It can be used in school or malls where they contain lifts.

## 6.4 ADVANTAGES

Our project have some advantages which are given below:

- Since it is automated, it does not require a separate man power to control the changeover system, only needs to set the program in PLC.
- As the project is automated it reduces the cost of an industry.
- It improves the reliability of system.
- It detects phase failure which increases the protection of system.

## 6.5 LIMITATIONS

Our project have some limitations which are given below:

- As we only have single phase power supply we have designed the three phase system as single phase failure detection.
- As the price of PLC is high, it increases the total cost

## 6.6 FUTURE IMPROVEMENT

We want to make some future improvements which are given below:

- We want to make the phase failure detection system in three phase power supply which will me much more effective.
- We want to make the project more digitalized by adding HMI in the system it will improve the user interface and can be used to remotely control the system.

# REFERENCES


1. Akparibo, Awingot Richard, Albert Appiah, and Oliver Fosu-Antwi. "Development of a Programmable Logic Controller Training Platform for the Industrial Control of Processes." *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)* 15, no. 1 (2016): 186-196.
2. Unaune, Vivek Sanjay, Amit Jangonda Patil, Mahadev Sampatrao Gadiwan, Prashant Sudrashan Tawdare, and Chetan S. Rawal. "PLC Based Automatic Changeover Switch." *Dimensions* 70: 4mm.
3. Ashour, Hamdy. "Automatic transfer switch (ATS) using programmable logic controller (PLC)." In Proceedings of the IEEE International Conference on Mechatronics, 2004. ICM'04., pp. 531-535. IEEE, 2004.
4. Elaydi, Hatem Ali. "Automatic Changeover Switch for Power Sources." *Majlesi Journal of Energy Management* 3, no. 2 (2014).
5. https://www.quisure.com/blog/faq/what-is-the-principle-of-the-push-button-switches.[Accessed:May30,2021]
6. https://uk.rs-online.com/web/generalDisplay.html?id=ideas-and-advice/push-button-switches-guide.[Accessed:May30,2021]
7. https://www.electronics-tutorials.ws/io/io_5.html[Accessed: June01, 2021]
8. https://www.electrical4u.com/miniature-circuit-breaker-or-mcb/[Accessed: June01, 2021]
9. https://www.indiamart.com/proddetail/home-electrical-mcb-15015760448.html [Accessed: June01, 2021]
10. https://diary-of-electric.blogspot.com/2019/10/working-principle-of-magnetic-contactor-and-contact-point-no-nc.html[Accessed: May30, 2021]
11. https://www.electricaltechnology.org/2020/06/electrical-contactor.html [Accessed: June01, 2021]
12. https://www.electrical4u.com/power-inverter/ [Accessed: June01, 2021]
13. https://www.electrical4u.com/regulated-power-supply/ [Accessed: June01, 2021]
14. https://www.deltaww.com/en-us/products/PLC-Programmable-Logic-Controllers/253 [Accessed: June01, 2021]
15. Nanda, Babita. "Automatic Sorting Machine Using Delta PLC." International Journal of Innovative Research in Advanced Engineering 1, no. 7 (2014): 235-242.
16. https://www.pveducation.org/pvcdrom/batteries/lead-acid-batteries [Accessed: June01, 2021]
17. https://circuitdigest.com/tutorial/lead-acid-battery-working-construction-and-charging-discharging [Accessed: June01, 2021]

# ET163025_ET163038_EMRI(Automatic power changeover system)_Report

ORIGINALITY REPORT

| 24% | 20% | 4% | 13% |
|---|---|---|---|
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

PRIMARY SOURCES

| | | |
|---|---|---|
| 1 | www.electrical4u.com<br>Internet Source | 4% |
| 2 | dspace.iiuc.ac.bd<br>Internet Source | 2% |
| 3 | circuitdigest.com<br>Internet Source | 1% |
| 4 | www.deltakaran.com<br>Internet Source | 1% |
| 5 | www.electricaltechnology.org<br>Internet Source | 1% |
| 6 | www.electronics-tutorials.ws<br>Internet Source | 1% |
| 7 | Submitted to Universiti Tenaga Nasional<br>Student Paper | 1% |
| 8 | www.scribd.com<br>Internet Source | 1% |
| 9 | Submitted to Chesterfield College<br>Student Paper | 1% |

| | | |
|---|---|---|
| 10 | scholar.ppu.edu<br>Internet Source | 1 % |
| 11 | Submitted to Fiji National University<br>Student Paper | 1 % |
| 12 | Submitted to Visvesvaraya National Institute of Technology<br>Student Paper | <1 % |
| 13 | Submitted to University of Southern Mississippi<br>Student Paper | <1 % |
| 14 | Submitted to University of Sunderland<br>Student Paper | <1 % |
| 15 | ametex.ru<br>Internet Source | <1 % |
| 16 | www.jpo.go.jp<br>Internet Source | <1 % |
| 17 | H. Ashour. "Automatic transfer switch (ATS) using programmable logic controller (PLC)", Proceedings of the IEEE International Conference on Mechatronics, 2004. ICM '04., 2004<br>Publication | <1 % |
| 18 | Submitted to Durban University of Technology<br>Student Paper | <1 % |

| | | | |
|---|---|---|---|
| 19 | Submitted to St Joseph Engineering College, Mangalore<br>Student Paper | <1 % |
| 20 | Submitted to Cavite State University<br>Student Paper | <1 % |
| 21 | www.quisure.com<br>Internet Source | <1 % |
| 22 | Submitted to Oaklands College<br>Student Paper | <1 % |
| 23 | Submitted to Myanmar Noble College<br>Student Paper | <1 % |
| 24 | www.youtube.com<br>Internet Source | <1 % |
| 25 | www.pantechprojects.com<br>Internet Source | <1 % |
| 26 | Submitted to Middlesbrough College<br>Student Paper | <1 % |
| 27 | www.delta.com.tw<br>Internet Source | <1 % |
| 28 | Submitted to Universiti Teknologi Malaysia<br>Student Paper | <1 % |
| 29 | www.elprocus.com<br>Internet Source | <1 % |
| 30 | www.gmrt.ncra.tifr.res.in | |

Internet Source

<1 %

31 Submitted to Higher Education Commission Pakistan
Student Paper
<1 %

32 downloads.eatoncanada.ca
Internet Source
<1 %

33 Anthony C. Caputo. "Security Integration and Access Management", Digital Video Surveillance and Security, 2010
Publication
<1 %

34 Submitted to Chichester College of Arts, Science and Technology, West Sussex
Student Paper
<1 %

35 www.pveducation.org
Internet Source
<1 %

36 Submitted to Savitribai Phule Pune University
Student Paper
<1 %

37 asrjetsjournal.org
Internet Source
<1 %

38 Submitted to North West University
Student Paper
<1 %

39 Submitted to Purdue University
Student Paper
<1 %

40 Submitted to Limerick Institute of Technology

Student Paper

<1%

| | | |
|---|---|---|
| 41 | www.electronicsforu.com<br>Internet Source | <1% |
| 42 | Christoph Strauß, Armin Vetter, A. Von Felde. "Chapter 313 Biogas biogas Production biogas production and Energy Crops biogas energy crops", Springer Nature, 2012<br>Publication | <1% |
| 43 | Submitted to Swindon College, Wiltshire<br>Student Paper | <1% |
| 44 | www.pmpautomation.com<br>Internet Source | <1% |
| 45 | Submitted to Universiti Malaysia Perlis<br>Student Paper | <1% |
| 46 | Submitted to University of Western Sydney<br>Student Paper | <1% |
| 47 | automationforum.in<br>Internet Source | <1% |
| 48 | www.cogsci.indiana.edu<br>Internet Source | <1% |
| 49 | Submitted to 1611<br>Student Paper | <1% |
| 50 | Submitted to Coleg Gwent<br>Student Paper | <1% |

| | | |
|---|---|---|
| 51 | J.F. WHITFIELD. "SUPPLIES AND PROTECTION", Elsevier BV, 1966<br>Publication | <1 % |
| 52 | Submitted to Sim University<br>Student Paper | <1 % |
| 53 | Submitted to University of Bolton<br>Student Paper | <1 % |
| 54 | www3.hants.gov.uk<br>Internet Source | <1 % |
| 55 | Sedra, Adel. "Microelectronic Circuits 7th Edition, International Edition", Oxford University Press<br>Publication | <1 % |
| 56 | Submitted to Sreenidhi International School<br>Student Paper | <1 % |
| 57 | C.-U. Kim. "Multilevel inverter employing cascaded transformers", IECON 03 29th Annual Conference of the IEEE Industrial Electronics Society (IEEE Cat No 03CH37468) IECON-03, 2003<br>Publication | <1 % |
| 58 | Ken Oldham Smith, John M Madden. "Electrical Safety and the Law", Wiley, 2002<br>Publication | <1 % |
| 59 | Witter, Gerald. "Arcing Contact Materials", Electrical Contacts Principles and Applications | <1 % |

Second Edition, 2014.
Publication

| | | |
|---|---|---|
| 60 | idm-instrumentos.es<br>Internet Source | <1 % |
| 61 | mafiadoc.com<br>Internet Source | <1 % |
| 62 | rfm.zftp.com<br>Internet Source | <1 % |
| 63 | vampirenzmods.wordpress.com<br>Internet Source | <1 % |
| 64 | www.coursehero.com<br>Internet Source | <1 % |
| 65 | www.deltaacdrives.com<br>Internet Source | <1 % |
| 66 | www.electromaticsolar.com<br>Internet Source | <1 % |
| 67 | Katsioulis, Vasileios(Hadjinicolaou, M and Karapidakis, E). "Design of a wireless monitoring system based on the ZigBee protocol for photovoltaic systems", Brunel University School of Engineering and Design PhD Theses, 2011.<br>Publication | <1 % |
| 68 | Haitham Abu‐Rub, Atif Iqbal, Jaroslaw Guzinski. "High Performance Control of AC Drives with MATLAB®/Simulink", Wiley, 2021 | <1 % |

Publication

| | | |
|---|---|---|
| 69 | Hasmukh S. Patel. "", IEEE Transactions on Industry Applications, 5/1973<br>Publication | <1% |

| | | | |
|---|---|---|---|
| Exclude quotes | On | Exclude matches | Off |
| Exclude bibliography | On | | |