DESIGN AND IMPLEMENTATION OF AN AUTOMATIC CHANGEOVER SYSTEM WITH CONTACTOR AND AUTOMATIC VOLTAGE REGULATOR (AVR) TO MANAGE SOLAR POWER SYSTEM AT HOME

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FACULTY OF ENGINEERING
UNIVERSITY OF BENIN

OCTOBER, 2025

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A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE BACHELOR OF ENGINEERING (B.ENG.)

DEPARTMENT OF ELECTRICAL / ELECTRONICS ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITY OF BENIN

OCTOBER, 2025

CERTIFICATION

This is to certify that the group members listed below, carried out this project in partial fulfillment of the requirements for the award of the Bachelor of Engineering (B.Eng.) in Electrical/Electronic Engineering at the University of Benin.

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DEDICATION

This project is dedicated to our beloved parents, whose unwavering love, sacrifices, and prayers have been the foundation of our academic success. Your encouragement and belief in our potential have inspired us to aim higher and achieve more. We also dedicate this work to our lecturers and friends, whose constant support, guidance, and motivation have been invaluable throughout our journey. To all who continue to inspire innovation and excellence in the field of electrical engineering, this project stands as a reflection of your influence and inspiration.

ACKNOWLEDGEMENT

We give all glory to Almighty God for His divine guidance, wisdom, and grace, which made it possible for us to successfully complete this project and our academic journey. His strength and inspiration were our greatest source of endurance, motivation, and success throughout this work.

Our profound appreciation goes to our project supervisor, **Engr. Dr. O. M. Edohen**, for his patient guidance, technical support, and constructive criticism throughout the course of this research. His mentorship and expertise in Electrical Power Engineering greatly contributed to the quality and successful completion of this project.

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We also express our heartfelt gratitude to our parents and family members for their unwavering support, encouragement, prayers, and sacrifices throughout the course of our studies. Their constant motivation and understanding played a significant role in the successful completion of this project.

ABSTRACT

This project focuses on the design and implementation of an automatic changeover system integrated with contactors and an Automatic Voltage Regulator (AVR) for efficient management of a home solar power system. The system is designed to automatically transfer load supply between the solar inverter, utility grid, and generator in the event of power failure or voltage instability, ensuring uninterrupted power delivery to essential household appliances. The control unit employs electromechanical contactors to achieve seamless source selection, while an AVR maintains stable voltage output to prevent damage to sensitive equipment. A timer/delay relay is incorporated to coordinate the switching process, minimize transient currents, and delay the operation of the alarm siren to prevent false triggers during short interruptions. The project also integrates protective circuit breakers to safeguard the system from overloads and short circuits, improving safety and reliability. The overall design emphasizes efficiency, automation, and simplicity, eliminating the need for manual intervention during power transitions. Testing and evaluation were carried out under various load conditions to verify performance. Results confirmed that the system achieves reliable source transfer, stable voltage regulation, and reduced downtime during source changeovers. The project demonstrates a practical and cost-effective solution for domestic solar power management, promoting energy efficiency and dependable power supply in areas with unstable grid systems.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The stability and reliability of electrical power supply are fundamental to modern society, impacting residential, commercial, and industrial activities alike. However, in many developing nations, for example Nigeria, Ghana and other African countries power outages and fluctuations remain a significant challenge. This instability necessitates the use of alternative power sources such as generators, inverters, and increasingly, solar photovoltaic (PV) systems.

Historically, transitioning between the grid network and these backup sources often require manual intervention using changeover switches. Manual changeover processes are not only inconvenient and time-consuming but can also lead to delays, potential hazards, and equipment damage due to improper sequencing or overloading. The evolution of changeover technology has progressed from basic manual switches to more sophisticated automatic changeover system (ACS) utilizing electromechanical relays, contactors, and timer relays. Contactors, being electrically controlled switches with higher current ratings than relays, are commonly employed in automatic changeover system (ACS) to handle significant power loads. Timer relays are incorporated to introduce deliberate delays during switching, preventing unnecessary transitions due to trips, transient voltage dips and ensuring system stability.

With the growing installation of residential solar power systems, often including battery storage, the need for intelligent power management becomes even more critical. Grid-connected solar PV systems generate direct current (DC) which is converted to alternating current (AC) by inverters for household use. Effective changeover mechanisms are essential to prioritize the use of stored solar energy during grid outages and to facilitate a smooth return to grid power when it is restored. Furthermore, introducing automatic voltage regulators (AVRs) into these systems is vital to maintain stable voltage levels, protecting sensitive electronic appliances from potential damage due to voltage fluctuations from either the grid or the solar power system.

Existing research on automatic changeover systems covers several key approaches. Microcontroller-based designs, such as those using the ATmega328p, focus on controlling switching logic and managing power transitions efficiently at a low cost. FPGA-based systems leverage hardware parallelism to deliver higher processing speeds and reliability, making them suitable for demanding industrial applications. Additionally, integrating generator control mechanisms into automatic changeover switches ensures smooth, uninterrupted power transfer during extended outages by coordinating backup power activation seamlessly. However, there is a need for further research on automatic changeover systems (ACS) specifically designed for managing residential solar power systems with battery backup, incorporating both timer and automatic voltage regulators (AVR) operations. This research aims to address this gap by carrying out the design and implementation of the system.

1.2 Statement of the Problem

Despite advancements in automatic changeover technology, effective and seamless management of residential solar power systems, particularly those with battery backup, during grid outages remains a significant challenge. Current manual changeover methods are inefficient, pose safety risks, and lead to undesirable power interruptions. While existing automatic changeover switches address some of these issues, there is a need for systems specifically tailored to the unique characteristics of residential solar power integration, incorporating crucial features such as:

- Automated and prioritized switching to utilize stored solar power during grid failures.

- Controlled switching with a timer mechanism to prevent unnecessary cycling due to brief grid disturbances.

- Integrated Automatic Voltage Regulation (AVR) to ensure a stable power supply to household appliances from both grid and solar.

- Reliable and efficient operation that minimizes power disruptions and maximizes the utilization of renewable solar energy.

The absence of readily available, cost-effective automatic changeover systems that seamlessly integrate a timer and automatic voltage regulator (AVR) specifically for home solar power management creates a need for the design and implementation of such a system. This research seeks to address this problem by developing a solution that enhances the reliability, efficiency, and safety of residential solar power usage.

1.3 Aim and Objectives

Aim

The aim of this research work is to design and implement an automatic changeover system with contactors, an integrated timer and Automatic Voltage Regulator (AVR) to effectively manage a residential solar power system.

Objectives

The following are the objectives of the study:

1. To analyze the design requirements and operational characteristics of residential solar power systems with battery backup and identify the critical parameters for an effective automatic changeover system.
2. To design an automatic changeover circuit that incorporates a timer mechanism to provide a controlled delay in switching between the main grid and the solar power system.
3. To integrate an Automatic Voltage Regulator (AVR) into the changeover system to ensure a stable voltage supply to the connected loads from both power sources.

1.4 Methodology

1. To select and integrate appropriate hardware components, including contactors, relays, timers, AVR, and sensing circuits, for the prototype implementation.
2. To develop and test a prototype of the automatic changeover system under various operating conditions to evaluate its switching performance, reliability, and voltage regulation capabilities input.
3. To identify potential challenges encountered during the design, implementation, and testing phases and propose suitable mitigation strategies.

1.5 Scope of Study

The scope of this research work is limited to:

1. This research project focuses specifically on the design and implementation of an automatic changeover system for managing residential solar power system.

1.6 Justification

The design and implementation of an automatic changeover system with a timer and AVR for residential solar power management is justified by the following significant factors:

- **Ensuring Uninterrupted Power Supply**: The system will provide a seamless transition between the main grid and the home solar power system, significantly reducing power interruptions during grid outages, which are prevalent in many regions.

- **Maximizing Renewable Energy Utilization**: By automating the switch to solar power (with battery backup) during grid failures, the system will optimize the use of stored renewable energy, decreasing reliance on the utility grid and potentially lowering electricity costs for homeowners.

- **Protecting Household Appliances**: The integration of an AVR will stabilize the voltage supply, safeguarding sensitive electrical and electronic appliances from damage caused by voltage surges, sags, and fluctuations originating from either the grid or the solar power system.

- **Enhancing User Convenience and Safety**: Automation of the power source switching process eliminates the need for manual intervention, providing greater convenience and reducing the risk of electrical hazards associated with manual changeover operations.

- **Contributing to Sustainable Energy Adoption**: By facilitating the efficient use of residential solar power, this research supports the broader adoption of renewable energy sources at the household level, contributing to environmental sustainability.

- **Addressing a Specific Technological Need**: There is a growing demand for integrated and intelligent systems that can effectively manage residential solar power installations. This project aims to address this specific need by providing a tailored solution that combines automatic changeover, timed switching, and voltage regulation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Power Management Using Automatic Changeover

The fundamental operation of an Automatic Changeover System (ACS) hinges on its ability to continuously monitor the primary power source (typically the utility grid) and automatically transfer the load to an alternative power source (such as a generator, battery-inverter system, or solar hybrid system) upon detection of a failure or significant voltage drop. When the primary source is restored and meets predefined voltage stability thresholds, the system automatically reverts the load back to the main source. This process is executed with minimal human intervention, ensuring uninterrupted power delivery and enhanced system autonomy.

This project focuses on the design and implementation of an automatic changeover system integrated with contactors and an automatic voltage regulator (AVR) to manage power supply from both the utility grid (NEPA) and a solar inverter system in a residential setting. The system is developed using electromechanical components such as contactors, circuit breakers, auxiliary contacts, and a time-delay relay, without reliance on voltage-sensing circuits or microcontroller-based logic. Its primary objective is to ensure seamless and safe transition between power sources, giving priority to the grid while automatically switching to solar backup during outages. The AVR unit ensures voltage stability before power reaches the load, while visual indicators and a delayed siren enhance user awareness. This configuration offers a cost-effective, reliable, and low-maintenance solution for improving power availability and quality in homes utilizing hybrid energy sources.

2.1 Concepts, Opinions, Ideas from Authors / Experts

These are diverse range of concepts, opinions, and ideas contributed by various authors and experts in the field of ACS technology.

Johnson (2020) carried out a work on user-friendly designs for automatic changeover system (ACS). The research argued that the complexity of many automatic changeover system (ACS) interface can lead to user errors, especially in emergency situations. The research called for simplified interfaces and intuitive controls that could be easily understood by non-experts. The studies showed that user-friendly designs not only reduced the likelihood of errors but also improved the overall adoption rate of automatic changeover system (ACS). It was also highlighted the importance of clear instruction manuals and training programs to ensure users can operate the systems effectively.

Lee (2021) carried out research which focused on the economic benefits of using multifunction timer relays in changeover system (ACS). The study pointed out that these relays offer significant advantages in terms of flexibility and precision in timing functions. Lee's studies demonstrated that multifunction timer relays can lead to substantial cost savings, both in terms of initial installation and long-term maintenance. By integrating these relays, systems can achieve more accurate timing control, reducing wear and tear on components and extending the overall lifespan of the system.

White (2022) explored the integration of smart technologies with changeover system (ACS), particularly the use of IoT (Internet of Things) capabilities. Her research indicated that real-time monitoring and remote management can greatly improve the efficiency and responsiveness of ACS systems. White's studies highlighted how IoT integration allows for 14 continuous system monitoring, providing real-time data on system performance and enabling predictive maintenance. This approach not only enhances reliability but also reduces maintenance costs and downtime.

Brown (2023) an advocate for energy-efficient ACS designs. He emphasized the environmental benefits of using energy-efficient components and minimizing energy loss. Brown's research showed that adopting energy-efficient practices can lead to significant reductions in operational costs while also contributing to environmental sustainability. He promoted the use of sustainable materials and innovative designs that minimize energy consumption without compromising system performance.

Osaretin et al. (2016) designed an automatic changeover switch with step loading for renewable energy systems. They highlighted the significance of integrating microcontrollers to manage power transitions seamlessly. Their design ensured that the system can automatically switch between power sources, such as the grid and renewable energy, without human intervention, thereby enhancing reliability and efficiency in power supply.

Onah and Kpochi (2023) developed an automatic changeover switch incorporating a generator trip-off mechanism. Their system utilized relays, integrated circuits, transistors, and electromechanical devices to ensure safe and efficient power transitions. The inclusion of a generator trip-off mechanism prevented potential damage to the generator during power restoration, highlighting the importance of protective features in ACS designs.

Amoran et al. (2021) research focused on designing a low-cost automatic single-phase transfer switch using an Atmega8 microcontroller. Their approach emphasized affordability and reliability, making ACS technology more accessible for residential applications. The microcontroller-based system ensured quick switching between power sources, enhancing the resilience of power supply in areas with frequent outages.

Obasi et al. (2015) implemented a microcontroller-based programmable power changeover system. Their design allowed for customizable switching parameters, enabling users to set preferences based on specific needs. This flexibility in ACS design caters to diverse user requirements and promotes efficient energy management.

Agbetuyi et al. (2011) designed an automatic transfer switch for single-phase power generators. Their work underscored the importance of integrating switchgear control systems to facilitate automatic switching between public utility supply and generators. This integration ensured uninterrupted power supply, particularly in regions prone to frequent outages.

National Renewable Energy Laboratory (NREL) (2016) developed a handbook that addressed challenges associated with high-penetration PV integration, particularly concerning voltage regulation equipment. They discussed scenarios where voltage regulators may experience "runaway tap changer" issues due to power flow reversals in solar PV systems. The handbook recommended modifying control settings or implementing new voltage regulation schemes to maintain system stability.

2.2 Magnetic Contactor

A magnetic contactor is a crucial electromechanical device used in high power electrical systems, particularly within Automatic Changeover Systems (ACS). It functions as an automatic operated switch, engineered to handle high-current and high-voltage loads safely and efficiently. Unlike conventional switches, magnetic contactors are actuated by an electromagnetic coil, which, when energized, pulls a movable core to close (or open) the contact terminals, thereby initiating or interrupting the current flow through the load circuit.

In the architecture of an ACS, magnetic contactors serve as the core switching elements, enabling automatic transition between primary and secondary power sources typically from the grid (main supply) to a generator or inverter without requiring human intervention. This automatic transition is essential in critical installations such as hospitals, data centers, and industrial automation systems, where power continuity is non-negotiable.

Their robust design, characterized by arc suppression chambers, insulated contacts, and spring-loaded mechanisms, ensures long operational life, high switching frequency, and reliable performance under load surges. Additionally, magnetic contactors can be integrated with auxiliary contacts and timers to support control logic, feedback mechanisms, and interlocking schemes further enhancing the safety and intelligence of the ACS.

Figure 2.1: Magnetic Contactor

2.3 Multifunctional Timer Relay

A multifunctional timer relay is a specialized form of electromagnetic relay equipped with timing control capabilities that enable it to delay, repeat, or sequence operations within a circuit based on configurable time parameters. In the context of an Automatic Changeover

System (ACS), this device plays a pivotal role in orchestrating the timing and logic behind the transition between power sources, such as shifting from the utility grid to a generator or solar power and vice versa.

Unlike standard relays that respond instantaneously to input conditions, timer relays incorporate programmable delay features including on-delay, off-delay, interval, and cyclic functions allowing for controlled and deliberate switching actions. This mitigates the risks associated with transient conditions, such as momentary voltage drops or brief power interruptions, which could otherwise cause unnecessary or premature source switching.

Functionally, the timer relay contributes to the intelligent behavior of the ACS. For instance, upon detecting a power outage, the timer may introduce a pre-set delay before initiating generator startup ensuring that only sustained outages trigger the backup system. Similarly, upon power restoration, it can enforce a stability wait-time before re-engaging the main supply, thereby avoiding rapid fluctuations or false switching caused by unstable mains.

Additionally, by providing electrical isolation between the control logic and the high-power switching circuitry, the multifunctional timer relay enhances safety and system integrity. It enables low-voltage control signals to manage high-voltage operations without direct electrical connection, reducing the risk of damage to sensitive control components.

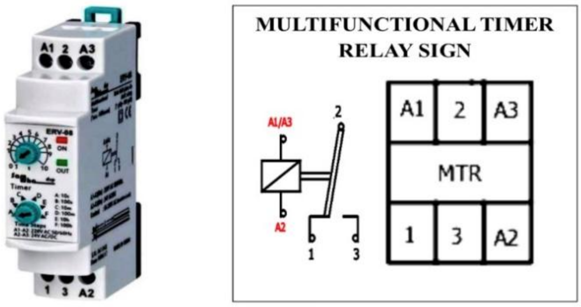


Figure 2.2: Multifunctional Timer Relay

2.4 Digital Voltage Regulator

A digital voltage regulator (DVR) is an intelligent electronic device designed to maintain a consistent and stable output voltage, regardless of fluctuations in the input supply or variations in load demand. Unlike traditional analog regulators, the digital variant utilizes microcontroller-based control logic and pulse-width modulation (PWM) techniques to achieve precise voltage regulation, improved efficiency, and real-time adaptability.

In the context of an Automatic Changeover System (ACS) particularly those interfaced with solar photovoltaic (PV) system’s voltage instability is a common challenge. Solar-generated voltage can vary significantly due to changes in irradiance, shading, and temperature. These variations, if not properly managed, can result in under-voltage or over-voltage conditions, which may degrade or even damage connected loads such as appliances, control systems, or communication devices.

The digital voltage regulator addresses this challenge by constantly monitoring the output voltage and dynamically adjusting its internal parameters to maintain the desired voltage level. It acts as a stabilizing buffer between the fluctuating supply and the load, ensuring that critical equipment operates within safe voltage tolerances.

Beyond regulation, many DVRs incorporate diagnostic, protection, and communication features, such as over-voltage protection, under-voltage cutoff, surge suppression, and digital displays for monitoring system parameters. This makes them especially valuable in modern ACS setups where power quality, safety, and smart integration are paramount.

Figure 2.3: Digital Voltage Regulator

2.5 Timer

A timer is an essential control device that introduces a deliberate delay in electrical operations, allowing my system actions to occur only after a predefined interval. In the framework of an Automatic Changeover System (ACS), the timer's role is both strategic and protective it ensures that power source transitions are executed in a controlled, non-abrupt manner, thereby safeguarding both the system and the connected loads.

One of the key functions of a timer in ACS is to prevent instantaneous switching between the utility supply and alternative sources (e.g., generator or inverter) during a power disturbance. By delaying the activation of the backup source for a few seconds or minutes, the timer verifies whether the outage is temporary or sustained. This delay not only prevents unnecessary generator startups, which can cause mechanical wear, fuel wastage, and noise pollution, but also avoids relay chatter and voltage spikes that can occur with rapid or erratic switching.

Ultimately, the timer is a protective buffer within the ACS a programmable safeguard that enhances system reliability, preserves equipment lifespan, and ensures that the changeover process occurs with precision and stability, regardless of fluctuations in power availability.

Figure 2.4: Timer

2.6 Digital Voltage Indicator

A Digital Voltage Indicator is an electronic measurement device designed to display the real-time voltage level of an electrical source using a digital numeric display, typically LED or LCD-based. It offers a precise, continuous, and easily readable visualization of voltage, making it a critical diagnostic tool in low-voltage power systems.

The digital voltage indicator is typically rated for AC voltage ranges (0–300V) and draws minimal power, making it ideal for continuous operation. It is connected in parallel across the input terminals after the circuit breakers but before the contactors, ensuring it reads supply voltage regardless of the load connection status. Its compact design, low maintenance requirement, and ease of integration make it a valuable addition for operational transparency, safety, and user awareness in the overall power management system.

Figure 2.5: Digital Voltage Indicator

2.7 Siren

The siren in an Automatic Changeover System (ACS) function as a critical audible alert mechanism, designed to provide immediate and unmistakable notification of significant system events. Unlike visual indicators, which require direct observation, a siren delivers alerts that can be heard across wide areas, ensuring that operators and users are promptly informed even when they are not in close proximity to the system panel.

Siren alerts are typically triggered by predefined fault conditions or operational events, such as power outages, changeover failures, generator faults, low fuel warnings, phase imbalance, or unauthorized access attempts to the control unit. In each of these scenarios, the siren acts as a first-line safety mechanism, drawing immediate attention to the need for human intervention.

Furthermore, the siren enhances the overall reliability, responsiveness, and safety of the ACS by reducing the likelihood of undetected faults or delayed responses. It plays a particularly important role in industrial, commercial, and off-grid environments, where uninterrupted power is critical and real-time fault acknowledgment is essential for operational continuity.

Figure 2.6: Siren

2.8 3-Way Distribution Metallic Box

The 6-way distribution metallic box is a vital component in the physical infrastructure of an Automatic Changeover System (ACS), serving as a centralized enclosure for circuit protection and power distribution. Designed to accommodate up to six circuit breakers or fuse units, this enclosure enables the segmented distribution of electrical power to various load circuits, ensuring both operational orderliness and enhanced system safety.

Constructed from durable, corrosion-resistant metal, the enclosure provides mechanical protection for internal wiring and components, shielding them from dust, moisture, physical impact, and other environmental hazards. This is particularly important in installations exposed to outdoor conditions or harsh industrial environments, where electrical integrity must be preserved over long operational lifespans.

In the context of an ACS, the 6-way metallic box facilitates neat and systematic wiring, reducing clutter and the risk of short circuits, ground faults, or accidental disconnections. By hosting individual circuit breakers or fused lines, it ensures selective protection, meaning that a fault in one circuit will not necessarily disrupt the entire system an essential feature for fault isolation and continuity of service in critical applications.

Figure 2.7: Three-Way Distribution Metallic Box

2.9 Auxiliary Contact

An auxiliary contact is a secondary switching element mounted on a contactor, relay, or switchgear device. It operates in conjunction with the main contact but does not carry the primary load current. Instead, it is used for control and interlocking functions within an electrical system. Auxiliary contacts are typically classified as Normally Open (NO) or Normally Closed (NC), based on their default state when the main device is de-energized.

In this project, the auxiliary contact plays a critical role in enforcing source priority and safe switching logic. Specifically, the NC auxiliary contact of the NEPA (grid) contactor is wired in series with the coil of the inverter contactor, ensuring that both contactors cannot be energized simultaneously. This configuration prevents backfeeding, which could lead to equipment damage or hazardous faults. Since the project does not use any voltage sensing or microcontroller, the mechanical interlocking logic provided by the auxiliary contact forms the core decision-making element of the changeover operation. Its reliability, simplicity, and independence from external control circuits make it ideal for hardware-based automation in low-complexity residential systems.

Figure 2.8: Auxiliary Contact

2.10 Circuit Breaker

A circuit breaker is an electromechanical protection device designed to automatically interrupt the flow of electrical current in the event of an overload, short circuit, or other fault condition. It serves as both a protective and isolation device, safeguarding equipment, conductors, and users from electrical hazards.

In this project, Miniature Circuit Breakers (MCBs) are installed on the input lines of both the utility grid and inverter sources. Their primary function is to ensure that only fault-free, stable current is allowed to pass into the contactor switching unit. In the absence of voltage sensing circuits, the breakers act as first-line protection, effectively filtering out dangerous electrical conditions such as short circuits or sustained overcurrent before they can reach the contactors or AVR. Additionally, the breakers allow manual disconnection during maintenance, making the system more serviceable. The selection of breaker ratings is based on load analysis and source capacity, ensuring thermal and magnetic tripping thresholds are well-aligned with the system's operational limits.

Figure 2.9: Circuit Breaker

2.11 Pin Base

A pin base, also referred to as a base relay socket or terminal base, is a modular support component used to mount electrical devices such as relays, timers, and contactors. It provides a standardized interface for plugging and securing control modules without the need for direct wiring to the internal terminals of the device. The pin base contains multiple metallic contacts arranged in a defined pin configuration that matches the layout of the corresponding device.

2.12 Wires

In an Automatic Changeover System (ACS), the selection of appropriate wire gauge is crucial for ensuring safe, efficient, and reliable electrical performance. Commonly used sizes such as 1.5mm² and 2.5mm² are specifically chosen based on current-carrying capacity, voltage drop considerations, and the nature of the load or control circuit.

The 1.5mm² wire is typically employed in low-current control circuits, such as connections between relays, timers, and indicator lights, where the current demand is modest. Its smaller diameter allows for flexible routing within compact control panels while maintaining sufficient mechanical strength and insulation integrity.

Figure 2.10: Wires

2.13 Solar Panel Types

2.13.1 Monocrystalline Panel

A monocrystalline solar panel is a type of photovoltaic (PV) module manufactured from a single, continuous crystal structure of high-purity silicon. Recognizable by its uniform dark blue or black color and rounded or curved cell edges, the monocrystalline panel is widely regarded as the most efficient and technologically advanced among commercially available solar technologies.

The production process involves the Czochralski method, wherein a single silicon crystal is grown into an ingot and then sliced into thin wafers. This method uses fresh, high-grade semiconductor material, which enhances the panel’s ability to convert sunlight into electricity with superior energy efficiency typically ranging between 18% and 22% under standard test conditions.

One of the key advantages of monocrystalline panels is their excellent performance in low-light conditions, such as cloudy weather or shaded environments. This makes them particularly suitable for hybrid or off-grid Automatic Changeover Systems (ACS), where consistent energy harvesting is essential for charging batteries and maintaining power availability in the absence of grid supply.

However, this high performance comes at a premium cost, due to the complexity of the manufacturing process and the quality of raw materials used. Despite the higher initial investment, monocrystalline panels offer longer service life, better space efficiency, and higher output per square meter, which often justify their cost in long-term energy applications.

Figure 2.11: **Monocrystalline Panel**

2.13.2 Polycrystalline Panel

The polycrystalline solar panel is a type of photovoltaic module composed of multiple silicon crystal fragments melted together, typically derived from recycled or excess monocrystalline semiconductor material. It is visually distinguished by its bright blue hue, grainy texture, and rectangular cell shape.

Unlike monocrystalline panels, polycrystalline panels lack a uniform crystal structure, resulting in more boundaries between crystals, which in turn reduces electron mobility and slightly lowers energy conversion efficiency typically ranging between 15% and 17%. This structural difference also means polycrystalline panels are less effective in low-light conditions, such as early mornings, overcast days, or shaded environments.

Despite the lower efficiency, polycrystalline panels are favored for their cost-effectiveness and simpler manufacturing process. The reduced production complexity translates into a lower market price, making them an attractive option for budget-conscious projects or installations with ample space where panel size is less of a constraint.

In the context of an Automatic Changeover System (ACS) integrated with solar power, polycrystalline panels can serve as a reliable and economical energy source, especially in regions with strong, consistent sunlight. They may be less suitable, however, in high-demand or space-limited scenarios where maximizing output per square meter is critical.

Figure 2.12: **Polycrystalline Panel**

2.13.3 Thin Film Panel

The thin-film solar panel represents the most flexible and lightweight category of photovoltaic technology. Unlike monocrystalline and polycrystalline panels, which are rigid and bulky, thin-film panels are created by depositing ultra-thin layers of photovoltaic material such as amorphous silicon (a-Si), cadmium telluride (CdTe), or copper indium gallium selenide (CIGS) onto a flexible substrate like plastic, glass, or metal.

A defining characteristic of thin-film panels is their bendable and adaptable form factor, which enables integration into non-traditional surfaces and portable applications. These panels are commonly used in solar-powered bags, mobile charging stations, backpacks, tents, and even textiles, where conventional panels would be impractical or impossible to install. This flexibility opens up innovative possibilities for wearable solar technology and off-grid charging solutions.

While thin-film panels offer excellent form adaptability and aesthetic integration, they generally have lower conversion efficiency typically ranging between 10% and 12% and may require larger surface areas to produce equivalent power compared to crystalline panels. Additionally, they tend to degrade faster and have a shorter lifespan, especially in harsh environmental conditions.

However, in the context of an Automatic Changeover System (ACS) where portability, space constraints, or unconventional installations are considered such as temporary power setups, emergency kits, or mobile units thin-film panels offer unique advantages in flexibility, weight, and ease of deployment.

Figure 2.13: **Thin Film Panel**

2.13.4 Solar PV Array

A Solar Photovoltaic (PV) Array is an integrated system comprising multiple solar panels that are electrically interconnected to collectively generate sufficient electrical power for practical applications. While each photovoltaic (PV) panel contains individual solar cells that convert sunlight into electricity, a single panel typically produces a limited amount of power insufficient for most residential, commercial, or industrial energy demands. Therefore, multiple panels are wired together to form a larger system known as a solar array.

In an Automatic Changeover System (ACS) that incorporates solar power, the PV array serves as the primary energy generation unit, supplying renewable electricity either directly to the load or through a storage system (e.g., battery bank). The total power output of the array is determined by both the number of panels and the configuration of their connections:

Series connection increases the system voltage, which is useful for matching higher input requirements of inverters or charge controllers. Parallel connection increases current output, allowing for greater overall power delivery.

This modular structure enables system designers to scale the array based on load demand, environmental conditions, and available space. Moreover, the orientation, tilt angle, and surface area of the array significantly influence its efficiency and energy yield. The larger the array's total surface area exposed to sunlight, the more solar electricity it will generate.

A complete PV array, when combined with inverters, charge controllers, wiring, protective devices, and mounting structures, forms a photovoltaic power system capable of autonomously powering loads or serving as a primary or backup energy source in an ACS. This configuration is especially important in off-grid or hybrid systems, where consistent and reliable power delivery is crucial.

2.13.5 Solar Array Connection:

Solar panel can be connected in following ways;

- Series connection
- Parallel connection

- Series-Parallel connection

2.13.5.1 Series Connection

In a series connection, solar panels are linked end-to-end by connecting the positive terminal of one panel to the negative terminal of the next, forming a continuous electrical path. This configuration is primarily used to increase the total voltage of the system while the current remains equal to that of a single panel. Mathematically, if each panel produces 24 V at 5 A, then connecting four panels in series yields a total of 96 V (24 V × 4) while maintaining a current of 5 A. This elevated voltage is particularly beneficial when: Matching the input voltage requirements of inverters or charge controllers. Minimizing power losses over long cable runs (since higher voltage allows for lower current, reducing I^2R losses).

In an Automatic Changeover System (ACS) integrated with solar input, series connections are typically used when designing for high-voltage DC inputs required by certain inverter models. However, care must be taken to ensure uniform irradiance across all panels, as the current in a series circuit is limited by the lowest-performing panel (e.g., one affected by shading or dust).

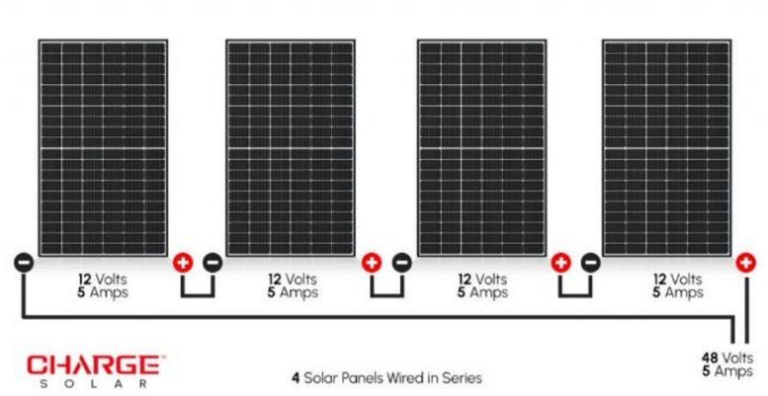


Figure 2.14: **Series Connection**

2.13.5.2 Parallel Connection

In a parallel connection, all the positive terminals of the solar panels are joined together, and all the negative terminals are likewise connected. This configuration is designed to increase the total current output of the system, while the voltage remains equal to that of a single panel.

For instance, if each panel generates 24 V at 5 A, then connecting four panels in parallel will maintain the system voltage at 24 V, but the total current will increase to 20 A (5 A × 4). This setup is especially useful when: The load or inverter requires high current at a fixed voltage. The battery bank voltage must match the panel voltage, but increased current is needed to meet the load or charging demand.

In the context of an Automatic Changeover System (ACS) integrated with solar energy, parallel connections are beneficial when the design prioritizes current availability such as for charging large-capacity batteries or powering high-demand DC loads. Additionally, parallel arrangements enhance system fault tolerance, as shading or failure of one panel has a less pronounced effect on the overall output compared to a series configuration.

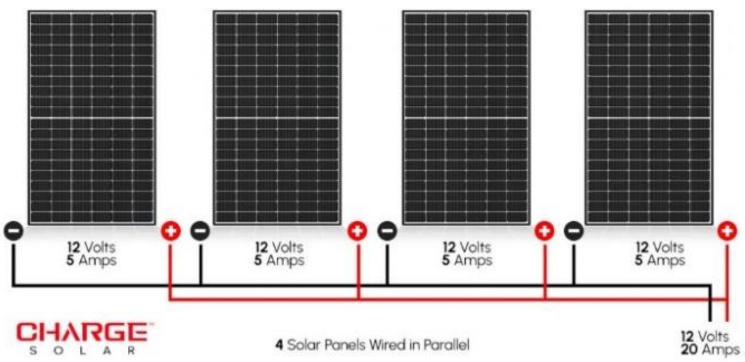


Figure 2.15: **Parallel Connection**

2.13.5.3 Series-Parallel Connection

A series-parallel connection is a combination of both series and parallel connections. It is used to achieve both the desired voltage and current levels by grouping panels in series strings, then connecting these strings in parallel.

2.14 Inverters

A solar inverter is a vital component of a photovoltaic (PV) system that converts the variable direct current (DC) generated by solar panels into alternating current (AC), which is the standard form of electricity used to power most household appliances and feed utility grids. Without this conversion, the DC output from solar panels would be incompatible with conventional AC-powered devices and public distribution networks.

As a core Balance of System (BOS) element, the inverter serves not only as a power converter but also as a smart interface between the PV array and the electrical load or utility grid. In Automatic Changeover Systems (ACS), the inverter plays a dual role: it provides stable AC power during solar availability and works in coordination with other components (like relays and contactors) to switch between power sources as needed.

Advanced solar inverters perform Maximum Power Point Tracking (MPPT) to continuously adjust the voltage and current input from the PV array to extract the maximum possible power, thereby enhancing overall system efficiency. They also support anti-islanding protection, a safety feature that automatically disconnects the inverter from the grid during power outages, preventing energy back-feed that could endanger utility workers.

The selection and sizing of a solar inverter must consider the total PV array capacity, load characteristics, and the type of installation whether grid-tied, off-grid, or hybrid. In residential applications, proper installation ensures seamless power conversion, load balancing, and fault handling.

Figure 2.16: **Inverters**

2.14.1 Types of Inverters

Solar inverters are central to the operation of any photovoltaic (PV) system, and their functionality varies depending on the system configuration and intended use. They are broadly classified into four types, each serving distinct roles in managing power generation, conversion, and distribution. Below is a concise breakdown of each type:

2.14.1.1 Stand-Alone Inverters

Stand-alone inverters are designed for off-grid systems and operate independently from the utility grid. They draw DC power directly from battery banks, which are charged by solar panels. These inverters often include integrated battery chargers that allow for charging the battery using an external AC source (like a generator), when solar power is insufficient.

Key Features:

- Operate without any connection to the utility grid.
- No anti-islanding protection required.
- Suitable for remote or isolated locations.
- Typically used in rural electrification, mobile power units, or backup systems without grid access.

2.14.1.2 Grid-Tie Inverters

Grid-tie inverters are used in on-grid systems, where the solar energy system is connected directly to the utility grid. These inverters synchronize with the grid's voltage and frequency, and feed surplus solar energy back into the grid.

Key Features:

- Include anti-islanding protection for safety during outages.
- Do not supply power when the grid is down.
- Maximize energy export and enable net metering.
- Ideal for urban installations focused on reducing electricity bills.

2.14.1.3 Battery Backup Inverters

These inverters combine the functionalities of stand-alone and grid-tie systems. They draw power from a battery and can supply power to critical loads during outages while still exporting excess energy to the grid during normal operation.

Key Features:

- Include onboard chargers to manage battery health.
- Provide uninterrupted power supply (UPS) capabilities.
- Feature anti-islanding protection.
- Useful in regions with frequent blackouts or unstable grids.

2.14.1.4 Intelligent Hybrid Inverters

Hybrid inverters are advanced, multifunctional systems capable of managing solar panels, battery storage, and grid input within a single unit. They are designed for flexibility, functioning in stand-alone, grid-tied, or backup modes as needed.

Key Features:

- Integrated energy management systems (EMS).
- Optimize self-consumption and reduce grid dependency.
- Allow time-of-use optimization, smart load prioritization, and remote monitoring.
- Preferred in modern installations where energy independence and smart control are prioritized.

2.15 Charge Controllers

A charge controller is a vital component in a solar power system, particularly in systems integrated with battery storage. Its primary role is to regulate the voltage and current flowing from the solar photovoltaic (PV) panels to the batteries, ensuring the battery bank is safely charged and protected from conditions that could reduce its lifespan or damage the system.

Without a charge controller, the unregulated DC output from solar panels can lead to overcharging, over-discharging, and even short circuits, all of which can severely degrade battery performance and reduce the efficiency of the overall system. In the context of an Automatic Changeover System (ACS), where batteries are often essential for backup or energy storage, the charge controller plays a protective and performance-enhancing role.

The fundamental working principle of a charge controller is to monitor battery voltage levels and control the charging current accordingly. When the battery reaches a predefined voltage threshold, the controller either disconnects or limits the input from the PV array to prevent overcharging. Early charge controllers used mechanical relays to open or close the circuit, whereas modern versions now employ solid-state electronics for precision and efficiency.

In most small to medium-scale solar installations, 12 V battery systems are common. However, solar panels often output higher voltages (e.g., 18–20 V for a 12 V system) to ensure efficient energy transfer. The controller steps this voltage down while maintaining optimal charging currents. This enables the system to reduce charging time, improve battery health, and operate at maximum power levels more consistently.

Additionally, charge controllers allow the use of higher-voltage transmission from the panels to the controller, which reduces I^2R (resistive) losses in the wires due to lower current. This feature enhances system efficiency, especially in installations where the panels are located far from the battery bank.

Another critical function is reverse current protection. At night or during low sunlight conditions, there's a risk of current flowing from the batteries back to the panels, which can cause power loss or even damage the panels. Charge controllers are equipped with blocking mechanisms (typically diodes or transistors) to prevent such reverse current flow.

2.14.1 Types of Charge Controller

Charge controllers are indispensable in solar photovoltaic (PV) systems, serving to regulate the voltage and current supplied to the battery bank, thereby protecting against overcharging, over-discharging, and reverse current flow. Depending on the control strategy and system efficiency requirements, charge controllers can be broadly classified into three main types:

2.14.1.1 PWM (Pulse Width Modulation) Charge Controllers

PWM charge controllers operate by gradually reducing the amount of power sent to the batteries as they approach full charge. Instead of sending a constant stream of energy, the controller rapidly switches the charging circuit on and off (pulse modulation), maintaining the battery at a safe voltage level.

Advantages:

- Cost-effective and simple design.
- Well-suited for small-scale solar applications.
- Extends battery life with controlled charging.

Limitations:

- Not efficient for larger systems or for PV arrays producing voltages significantly higher than the battery voltage.
- Less effective in extracting maximum power under varying sunlight conditions.

- PWM controllers are best used when panel voltage closely matches battery voltage, such as in 12V or 24V standalone systems.

2.14.1.2 MPPT (Maximum Power Point Tracking) Charge Controllers

MPPT charge controllers are highly efficient and technologically advanced. They constantly monitor and adjust the operating point of the PV panels to match the maximum power point (MPP) the voltage and current combination that yields the highest power output.

Advantages:

- Can improve system efficiency by up to 30% or more, especially in cold or cloudy conditions.
- Allows use of higher voltage PV arrays with lower voltage battery banks, reducing cable losses and system costs.
- Ideal for larger, professional, or hybrid solar systems.

Limitations:

- More expensive than PWM controllers.
- Requires a more complex design and installation process.
- MPPT controllers are optimal for systems where maximizing energy harvest is a priority, particularly in Automatic Changeover Systems (ACS) with high power demands or battery storage.

2.14.1.3 Shunt Charge Controllers

Shunt controllers' function by diverting excess current away from the battery once it reaches full charge, often dissipating the energy as heat through a resistive load. This method was common in earlier solar systems but has largely been replaced by more efficient techniques.

Advantages:

- Simple and reliable in small-scale, low-current systems.
- Historically used in solar lighting or water pumping applications.

Limitations:

- Inefficient due to energy wastage.
- Not suitable for modern high-capacity battery systems.
- While rarely used in contemporary systems, shunt controllers may still find application in legacy setups or ultra-low-cost off-grid applications.

2.15 Battery

Purpose of Battery in PV:

In photovoltaic (PV) systems, batteries play a central role in energy storage, system stability, and power reliability, especially in off-grid or hybrid setups. They act as electrochemical storage units, capturing surplus solar energy for delayed consumption, particularly during non-generating periods such as nighttime or inclement weather. The core function of a battery is to store energy when production exceeds demand, and to release it when demand exceeds production.

Energy Conversion and Functionality

Batteries convert chemical energy into electrical energy through redox reactions. In rechargeable batteries, the reverse is also true electrical energy from the PV system is converted into chemical energy during charging. This dual-conversion process allows batteries to be reused across numerous charge-discharge cycles.

In solar PV systems, the battery performs multiple critical functions:

- Storing excess daytime energy for later use.
- Providing backup power when generation is low or zero.
- Balancing voltage levels, particularly for auxiliary DC components such as charge controllers, relays, and sensors.

Operational Logic in a Solar Day Cycle

During the Day:

- The PV system generates electrical power.
- The controller evaluates the real-time household demand.
- Surplus energy is diverted to charge the battery.
- If the battery is full, excess energy is exported to the grid (in grid-tied systems).

At Night or During Low Irradiance:

- The PV panels generate little or no electricity.
- The system draws power from the charged battery to meet the load.
- If the battery is fully discharged, the system switches to the grid to ensure continuity of power supply.

Benefits and Design Considerations

Batteries allow for greater energy autonomy by enabling users to maximize the consumption of self-generated power. They are particularly valuable in:

- Off-grid applications, where no utility grid is available.
- Hybrid systems, where grid reliability is poor.
- Critical infrastructure, where uptime is non-negotiable.

However, batteries represent a significant capital investment, and their inclusion must be carefully designed and economically justified. Key factors include:

- Battery type (e.g., lithium-ion, lead-acid, gel, flow batteries).
- Capacity (Ah or Wh) and depth of discharge (DoD).

- Cycle life, charging speed, and temperature sensitivity.

2.15.1 Types of Batteries

Solar batteries are a critical component in photovoltaic (PV) systems, enabling energy storage and delayed usage. They ensure continuous power supply even when solar generation is unavailable, such as at night or during cloudy periods. Selecting the right battery type involves balancing factors such as initial cost, efficiency, lifespan, depth of discharge (DoD), energy density, and maintenance needs. The four primary types of batteries used in solar applications include:

2.15.1.1 Lead-Acid Batteries

Lead-acid batteries are the oldest and most widely used storage technology in solar systems. They come in two main variants:

Flooded Lead-Acid (FLA):

- Requires regular maintenance, such as checking electrolyte levels and ventilation.
- Offers low upfront cost, making it a common choice for budget-constrained off-grid systems.
- Shorter cycle life and lower DoD (~50%) compared to newer technologies.

Sealed Lead-Acid (SLA):

- Includes AGM (Absorbent Glass Mat) and Gel batteries.
- Maintenance-free and safer due to sealed design.
- Slightly more expensive than flooded types but with longer service life and better handling.
- Still relatively bulky and heavy.

2.15.1.2 Lithium-Ion Batteries

- Lithium-ion batteries have become the industry standard for modern solar installations, particularly in residential and commercial settings.
- High energy density, meaning more storage capacity in a compact size.
- High DoD (up to 90% or more), allowing more usable capacity per cycle.
- Long lifespan, often exceeding 10 years or 6000+ cycles.
- Low maintenance, with advanced Battery Management Systems (BMS) for protection and monitoring.

2.15.1.3 Nickel-Based Batteries

- Nickel-Cadmium (Ni-Cd) and Nickel-Metal Hydride (NiMH) batteries are less common in solar PV systems but are sometimes used in industrial or specialty applications.
- High tolerance to extreme temperatures and deep discharges.

- Ni-Cd batteries are robust and durable, making them ideal for remote or rugged conditions.
- Environmental concerns due to cadmium toxicity.

2.15.1.4 Flow Batteries

- Flow batteries store energy in liquid electrolytes contained in external tanks and are known for their scalability and long cycle life.
- Ideal for large-scale, long-duration energy storage.
- Virtually unlimited DoD and cycle life (over 10,000 cycles).
- Slow response time and low energy density, making them unsuitable for small residential use.

2.16 Technological Approaches to Acs Design

Over time, various design architectures have emerged, each with its trade-offs in terms of cost, complexity, and performance:

a. Sequential Logic-Controlled Systems

These systems are based on discrete digital logic components such as logic gates and flip-flops to perform basic power sensing and switching operations. While effective in simple installations, many early designs lacked full automation, often requiring manual startup of the generator or inverter. Modern versions have improved with digital timers and improved sensing mechanisms.

b. Field Programmable Gate Array (FPGA-Based Systems)

Field Programmable Gate Arrays (FPGAs) enable highly parallel hardware-level processing, making them suitable for real-time, high-speed control in power systems. FPGA-based ACS can monitor multiple input parameters simultaneously and provide ultra-fast switching with high reliability. However, the cost and complexity associated with FPGA programming and hardware integration often limit their application to critical infrastructure or industrial-scale ACS deployments.

c. Relay-Based Systems

Electromechanical relays are widely employed for physically isolating and switching between power lines. They offer robustness and ease of implementation but require careful design to avoid back feeding or arcing issues. These systems are often augmented with:

- Logic gates or transistors for switching control.
- Opto-isolators to decouple high voltage from sensitive control electronics.
- Timers and voltage sensors to enhance automation.

Although simple, relay-based systems can effectively support fully automatic changeovers when integrated with logic modules or microcontrollers.

d. Microcontroller-Based Systems

Microcontroller-based ACS solutions represent the most flexible and scalable approach, especially for smart or hybrid power systems. Microcontrollers such as the Arduino ATmega328P, ESP32, or STM32 can:

- Continuously monitor voltage levels from the grid, inverter, and battery.
- Execute conditional logic for changeover decisions based on real-time data.
- Control relay drivers, PWM generation, and LCD/user interfaces.
- Interface with timers, sensors, and protection devices for holistic system control. The programmability and low cost of microcontrollers make them ideal for domestic and commercial ACS, particularly when integrated with solar PV systems.

2.16.1 Integration of Solar Power Systems in ACS

With the increasing adoption of renewable energy sources, ACS systems are being adapted to manage solar PV arrays, especially in hybrid configurations. In such systems:

- Photovoltaic (PV) modules generate DC electricity, which is converted to AC using a solar inverter for load compatibility.
- A battery backup system stores excess energy generated during peak sunlight periods for use during outages or at night.
- Charge controllers are essential to regulate the voltage and current flowing to the battery, preventing overcharging and deep discharging, which could compromise battery lifespan.
- Grid-tied systems may utilize net metering to export excess energy back to the grid; however, these systems generally shut down during a power outage to prevent back feeding.

In integrated systems, the ACS intelligently orchestrates transitions between:

- Grid power
- Inverter (from solar + battery)
- Generator (if present)

This coordination ensures energy efficiency, load prioritization, and uninterrupted power supply.

2.16.2 Role of Timer and Automatic Voltage Regulator (AVR)

a. Timer

A programmable timer or delay relay is vital for introducing a buffer period before executing changeover actions. This delay:

- Prevents false triggering during temporary grid voltage dips or fluctuations.
- Reduces unnecessary wear on mechanical switching devices.
- Ensures that backup sources (like generators) are fully stabilized before being loaded.

Timers can be implemented via:

- Analog circuits (e.g., NE555 timer-based delay modules),
- Digital relays with configurable time settings,
- Or software timers in microcontrollers for greater precision and control.

b. Automatic Voltage Regulator (AVR)

The AVR plays a pivotal role in stabilizing the output voltage of the generator or inverter. Its inclusion is critical in solar-inverter setups where irradiance variations can cause voltage instability. The AVR:

- Maintains steady voltage output despite load variations or input fluctuations.
- Protects sensitive appliances from overvoltage or undervoltage conditions.
- Enhances overall system reliability and longevity.

CHAPTER THREE

DESIGN APPROACH AND SYSTEM ARCHITECTURE

3.1 Design Approach

The design of the Automatic Changeover System with Contactor and Automatic Voltage Regulator (AVR) was approached methodically using a structured engineering workflow. This workflow ensured that each stage of the design, conceptualization, component selection, circuit development, prototyping, and testing, was logically sequenced and guided by real-world constraints, particularly those applicable to Nigerian residential power environments.

The stages of the design approach are outlined below:

3.1.1 Problem Definition:

The core challenge was to ensure seamless switching between power sources (solar inverter and Grid) with protection against low/high voltage using an AVR, while allowing for delay-based switching and alert notifications.

3.1.2 Requirements Analysis:

Critical requirements included:

- Automatic detection of power availability and voltage quality.
- Automatic transfer switching without manual intervention using Contactors and auxiliary.
- Voltage regulation to ensure appliance protection.
- voltage level indication (LEDs and siren).
- Safety via circuit protection devices.

3.1.3 System Partitioning:

The design was divided into modular sub-systems:

- Power Input breakers for both Solar and grid input
- Control Module auxiliary contactor control)
- AVR Module (for automatic voltage regulation)
- Changeover Switching Unit (contactors for load transfer)
- Alert/Indicator Unit (LEDs and siren)

3.2 System Architecture

The system architecture consists of interconnected functional units working together to manage power selection, switching, and regulation. A functional block diagram helps visualize this architecture. This automatic changeover system is designed for residential applications using solar and utility grid as dual sources. It automatically switches the load between these sources based on availability using contactors with auxiliary interlocking, breakers, and an AVR for voltage regulation. The design is intentionally kept electromechanical, excluding voltage sensors or microcontroller logic to reduce cost, complexity, and susceptibility to failure in harsh environments.

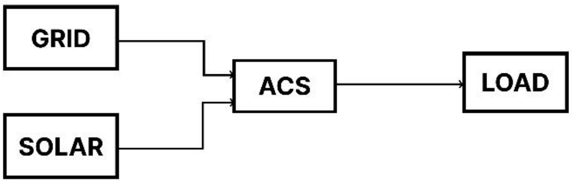


Figure 3.1

Below are the In-Depth Technical Explanation of Subsystems in an Automatic Changeover System with AVR. The components were selected based on reliability, electrical performance, availability in local markets, safety, and compatibility with Nigerian residential solar installations

3.2.1. Power Sources

3.2.1.1 Utility Grid Supply (NEPA/PHCN)

The utility grid is the default and preferred power source. It is routed through a dedicated circuit breaker, which provides basic protection against short circuits and overloads. The output of the breaker is connected to the NEPA contactor, which is configured as the priority contactor.

The 60Amp contactor is energized directly when grid power is available. Through the use of normally closed auxiliary contacts (mounted on the NEPA contactor), the solar contactor is held in a de-energized state whenever NEPA is present. This implements a simple but effective interlocking logic, ensuring that the grid always takes precedence.

3.2.1.2 Solar Inverter System (Battery + PV)

The inverter system serves as the standby source. It receives power from batteries charged via solar panels and/or grid. Similar to the grid line, the inverter output passes through a circuit breaker for safety before reaching the solar contactor.

The solar contactor only energizes when the NEPA contactor is de-energized, and Grid power is unavailable (as inferred passively). No sensing or measurement of voltage occurs, the system relies on mechanical state detection via the auxiliary contact on the NEPA contactor. This passive interlocking ensures that source conflict or back feeding is physically impossible, enhancing safety.

3.2.2 Circuit Breakers and Protection Devices

Each power source (NEPA and solar inverter) is protected using miniature circuit breakers

(MCBs) rated according to the expected load. These breakers serve multiple purposes:

- Short circuit protection
- Overcurrent protection
- Isolation for maintenance

They are installed before the respective contactors, ensuring the contactors only receive power from a safe, protected line. From a power engineering standpoint, using circuit breakers instead of fuses improves reset-ability, allows for easier system troubleshooting, and conforms to IEC 60898 standards for residential distribution.

3.2.3 Contactor Switching Unit with Auxiliary Interlocking

This is the core logic engine of the changeover system. It uses electromagnetic contactors to automatically select between power sources. Each contactor controls one source:

- Contactor A (NEPA contactor): Priority contactor
- Contactor B (Inverter contactor): Standby contactor

3.2.3.1 Priority Logic Using Auxiliary Contacts

A normally closed auxiliary contact on the NEPA contactor is wired in series with the coil of the inverter contactor. The logic works as follows:

- When NEPA is available, Contactor A energizes, and its Normally close (NC) auxiliary contact opens, preventing Contactor B from energizing.
- When NEPA fails, Contactor A de-energizes, its NC contact closes, and Contactor B is then allowed to energize, connecting the inverter output to the load.

This ensures a fail-safe, automatic switching with no overlap. The two sources are mutually exclusive. All logic is implemented via relay-grade electromechanical hardware with instantaneous response time.

3.2.4 Automatic Voltage Regulator (AVR)

An AVR is positioned after the output of the contactor system and before the load. It stabilizes the voltage being delivered to sensitive appliances, regardless of which source is currently active.

- From GRID: AVR compensates for low voltage or surges, which are common in public supply.
- From Inverter: Some low-cost inverters can experience voltage droop under load. AVR helps maintain stable output.

Although voltage is not sensed or monitored by the system to influence switching, the AVR independently regulates whatever voltage reaches the load, functioning as a line conditioner. It ensures that voltage to the load remains within ±5% of nominal (typically 230V), transients, surges, and sags are smoothed, sensitive equipment is protected from erratic supply behavior. This improves the system’s power quality and enhances the operational life of appliances.

3.2.5 Load (Appliances)

The system is designed to support a range of typical residential appliances, such as:

Lighting, Fans, Refrigerators, Televisions, Routers and chargers

All appliances are supplied through the AVR output. Load sizing is determined based on:

- Total wattage
- Surge current requirements
- Diversity factor

The capacity of contactors, breakers, and AVR are all selected based on these calculations to avoid overload conditions.

3.2.6 Indicators and Siren Unit (Timer-Based)

3.2.6.1 LED Indicators

LED indicators provide immediate visual feedback regarding the source currently powering system switches to inverter power (i.e., NEPA fails), a delay timer activates. After a few seconds (e.g., 10–30 seconds), the siren sounds, alerting the user that the system is now on backup the load. The LEDs are wired through auxiliary contacts of each contactor:

- When GRID contactor is energized, the red LED glows.
- When inverter contactor is energized, a green LED glows.

This provides real-time system status without digital interfaces or monitoring circuits.

3.2.6.2 Siren with Timer Delay

An audible alarm siren is included in the system, controlled via a timer relay module. This delay avoids false alarms due to momentary NEPA dips.

The timer module is a standalone electromechanical or solid-state device, typically operating on 12V or 230V depending on design. This feature enhances user awareness without complicating the switching logic.

3.2.6.3 System Behavior Summary (No Sensing Design)

Table 3.1: **System Behavior Summary Table**

Condition	NEPA Contactor	Solar Contactor	AVR	Siren	LED
Active	On	Off	Energized	Active ON (after delay)	Red
Inactive	Off	On	De-energized	Inactive	No Color

3.2.7 Wiring and Terminal Connectors

The wiring and terminal connectors play a vital role in ensuring safe, efficient, and reliable interconnection between all electrical modules in the automatic changeover system. These components are responsible for carrying power supply from one unit to another, forming the backbone of the electrical distribution within the system.

For this project, a combination of copper-insulated single-core and multi-core cables was used. These types of cables were selected based on their superior conductivity, mechanical flexibility, and long-term durability in domestic power applications. Specifically, 2.5 mm^2 wires were employed for low-current control circuits, such as those connected to the contactor coils, indicators, and the timer module. In contrast, higher current paths, such as those handling the utility grid supply, inverter output, and the load, utilized 4 mm^2 to 6 mm^2 copper cables, depending on the power rating of each line.

In terms of insulation, PVC-coated cables rated up to 300V were predominantly used due to their cost-effectiveness, flame resistance, and adequate thermal protection for indoor installations. For areas expected to experience elevated temperatures or where higher mechanical durability is required, heat-resistant rubber insulation was applied.

Electrical terminations were achieved using a mix of crimp-type and screw-type connectors, selected based on their ability to provide clean, secure, and low-resistance contacts. Crimped terminals were used primarily for connections to control components and small devices, where fast and reliable joints were necessary. Screw-type terminals, on the other hand, were used in busbars, circuit breakers, and contactor terminals, where solid and maintainable connections were required.

The choice of appropriate cable sizes and terminal types is critical for minimizing voltage drops, ensuring thermal stability under load, and preventing fire risks. By employing well-rated and properly terminated cables, the system maintains electrical efficiency, reliability, and safety, even under varying operational conditions. This approach not only aligns with standard wiring practices in residential installations but also meets the performance expectations of a robust, electromechanical changeover system

3.3 Solar Power Connection Subsystem

The solar power subsystem serves as the secondary energy source in the automatic changeover system, providing backup power during grid failure and contributing to energy self-sufficiency for domestic loads. The configuration is carefully designed to meet moderate household demand with a balance of efficiency, reliability, and cost-effectiveness.

3.3.1 Solar Power System Circuit Diagram

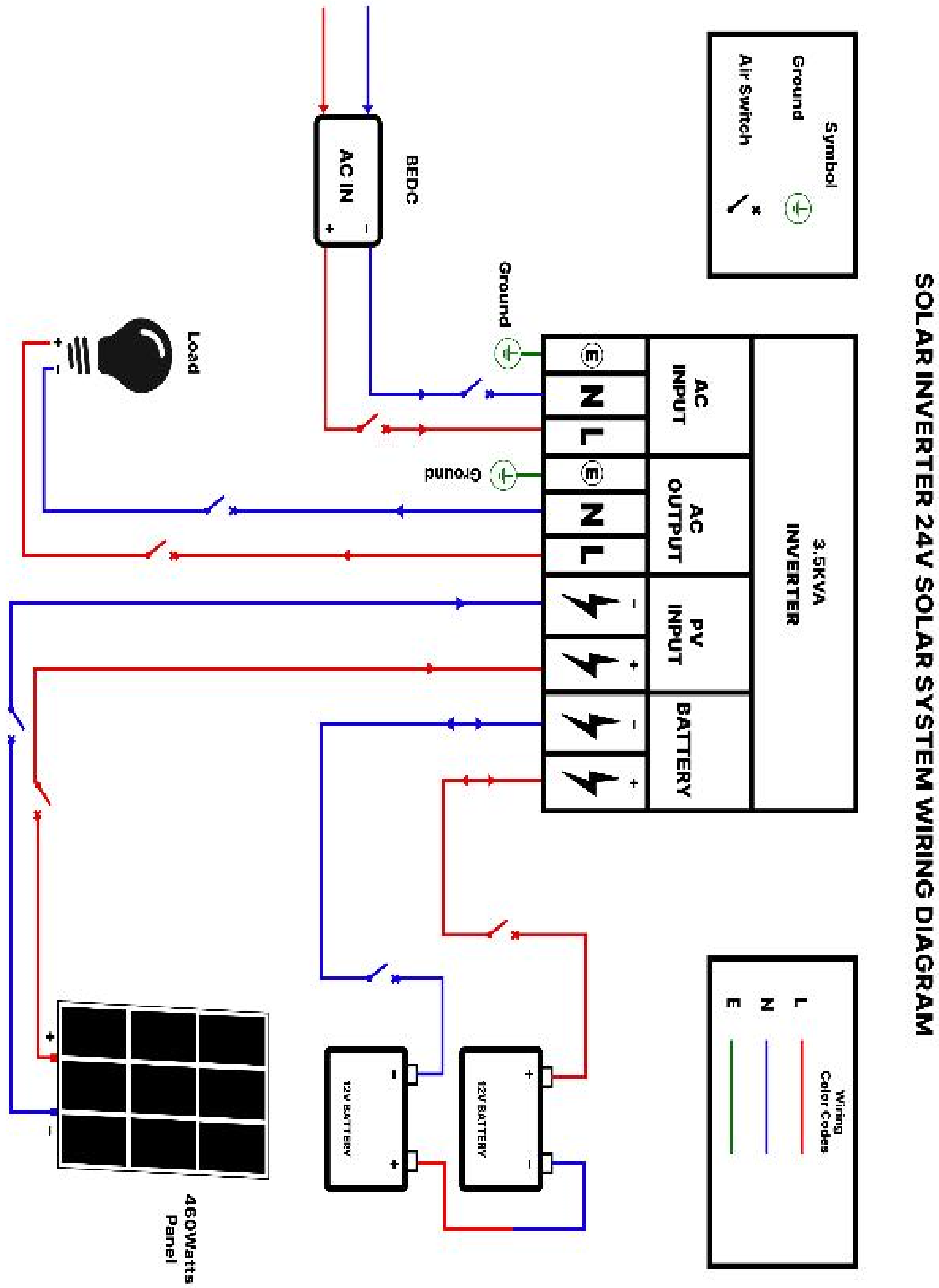


Figure 3.2: **Solar Power System Circuit Diagram**

3.3.2 Solar PV Module

The system utilizes a single 460W monocrystalline solar panel, known for its high conversion efficiency and excellent low-light performance. The module typically operates at a maximum power voltage (Vmp) of approximately 42–46V and maximum power current (Imp) around 10–11A, depending on the manufacturer. This panel is mounted on a tilted frame to optimize solar irradiance based on the geographical location.

3.3.3 Inverter – 3.5kva Hybrid Type

At the heart of the solar subsystem is a 3.5kVA hybrid inverter, which integrates three major functionalities: inversion, battery charging, and automatic source switching. The hybrid nature of the inverter allows it to accept both solar and grid input for charging the batteries and powering the load.

The inverter converts the DC output from the solar panel and battery bank into 230V AC, synchronized with the grid voltage standard. It also contains a built-in MPPT (Maximum Power Point Tracking) charge controller, which optimizes the panel's energy harvesting under variable sunlight conditions. When grid power is unavailable, the inverter seamlessly transitions to battery-supplied AC output without user intervention, ensuring uninterrupted power supply to critical appliances.

3.3.4 Battery Bank – Two Tubular Lead-Acid Batteries

Energy storage is handled by two deep-cycle tubular batteries, each rated at 12V and approximately 200Ah. The batteries are connected in series to provide a 24V DC bus, which aligns with the inverter's input requirement. Tubular batteries are chosen over flat plate types due to their higher durability, deeper discharge tolerance, and longer cycle life, making them well-suited for daily charge-discharge cycles typical in solar applications.

Together, the batteries provide a usable energy capacity of roughly:

$Energy\ (Wh) = 24v \times 200ah = 4800h = 4.8Wh$

Assuming a depth of discharge (DOD) of 50–70% for battery health, the usable energy lies between 2.4kWh and 3.3kWh, which can comfortably support essential household loads (lights, fans, low-power electronics) during short to moderate grid outages.

3.3.5 Electrical Integration and Safety

The solar inverter output is connected to the changeover panel via a dedicated MCB (Miniature Circuit Breaker), ensuring protection against overcurrent and fault conditions. The contactor switching system is configured such that the inverter is only engaged when grid supply is unavailable, controlled mechanically through auxiliary contacts without voltage sensing.

Charging status, voltage levels, and power availability from the solar system can be visually monitored using built-in indicators on the inverter and external digital voltage displays on the panel.

3.4 Automatic Changeover Circuit and Control Logic Design

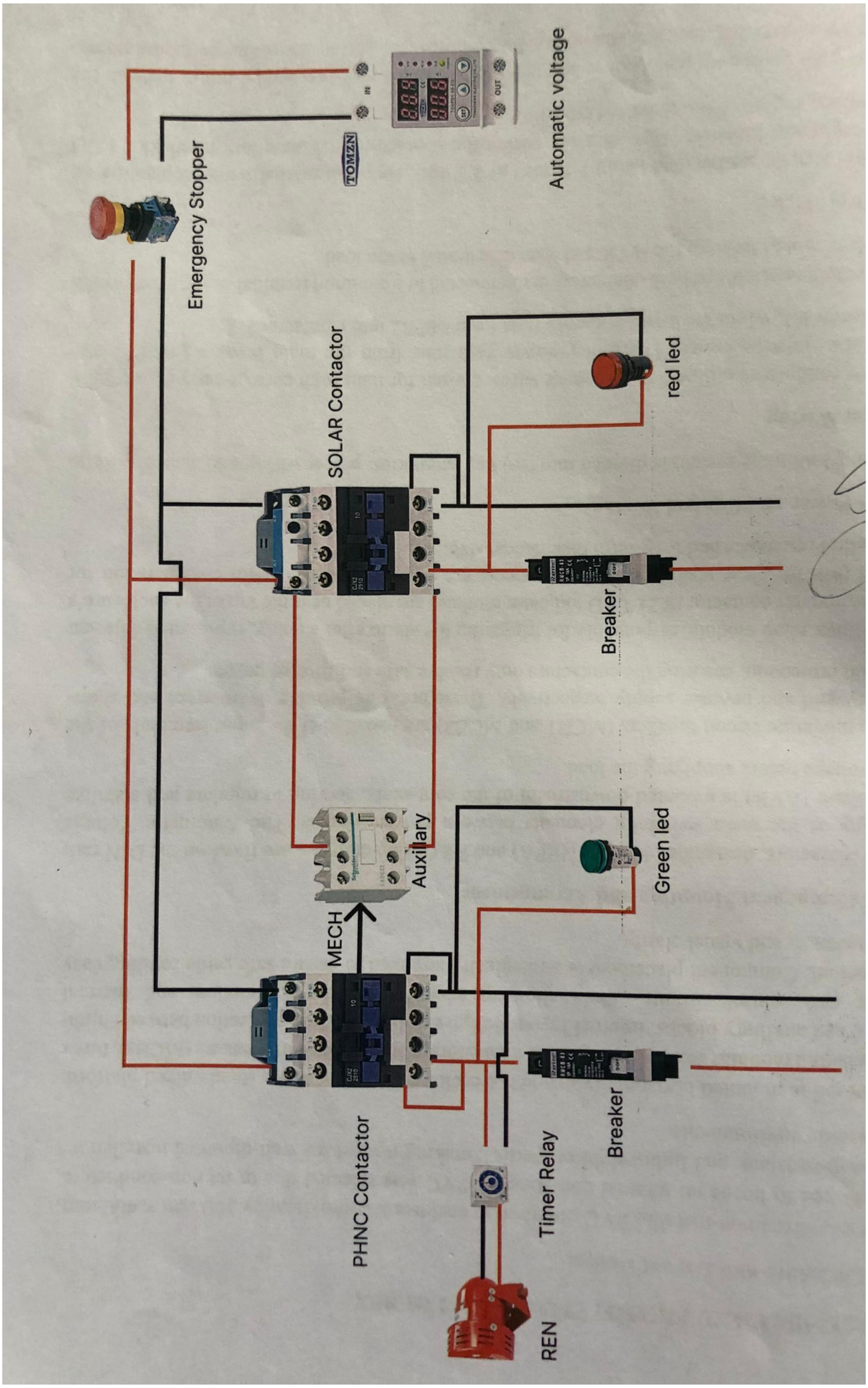
3.4.1 Single-Line Diagram (Functional Schematic)

A single-line diagram simplifies the representation of the electrical flow between the core parts of the system. It shows the high-level connection between:

- Power sources (Mains & Solar/Inverter)
- Auxiliary
- Timer/Delay Module
- AVR (Automatic Voltage Regulator)
- Contactors (Changeover Switches)
- Load
- Alarms and Indicators

3.4.2 Wiring Diagram of solar input (Detailed Circuit Layout)

The wiring diagram shows physical interconnections and control signals.


Emergency Stopper
TOMZN
IN
OUT
Automatic voltage
SOLAR Contactor
red led
Breaker
MECH
Auxiliary
Green led
PHNC Contactor
Timer Relay
Breaker
REN

3.5 Assembly and Prototyping Procedures

3.5.1 Enclosure and Layout Design

A medium-sized non-metallic PVC distribution enclosure, approximately 300 mm × 400 mm, is employed to house all internal components. PVC was selected due to its non-conductive, corrosion-resistant, and lightweight properties, making it ideal for wall-mounted installations in domestic environments.

A DIN rail is mounted horizontally inside the enclosure to serve as the standardized platform for installing modular components such as contactors, miniature circuit breakers (MCBs), timer relays, and auxiliary blocks. Internal layout design emphasizes clear separation between high-power and control circuits, while allowing adequate spacing for airflow and thermal dissipation. Component placement is strategically arranged to ensure safe cable routing, easy maintenance, and visual clarity.

3.5.2 Component Mounting and Arrangement

Two contactors, designated K1 (for NEPA) and K2 (for inverter) — are fixed on the DIN rail, serving as the main switching elements between power sources. The Automatic Voltage Regulator (AVR) is mounted downstream of the contactors, serving to regulate and stabilize the voltage before supplying the load.

Two miniature circuit breakers (MCB1 and MCB2) are installed at the input terminals of the utility grid and inverter supply respectively. These breakers provide overcurrent and short-circuit protection, ensuring the contactors only receive safe and filtered power.

The timer relay module, responsible for triggering the alarm after a delay, is mounted adjacent to the inverter contactor (K2). LED indicator modules are placed near the top of the enclosure's front face for clear visibility. All components are securely fastened, with consideration for vibration resistance and long-term mechanical stability.

3.5.3 Power and Control Wiring

Wiring within the system is divided into two key categories: power wiring and control wiring.

Power Wiring

Power conductors utilize 6 mm^2 copper wires, chosen for their high current-carrying capacity and low resistive losses. The utility power path runs from the main breaker (MCB1) into Contactor K1, while the inverter supply runs from MCB2 into Contactor K2.

The output terminals of both contactors are connected to a common terminal block, from which power is routed through the AVR and then distributed to the load.

Control Wiring

Control signals are handled using 1.5 mm^2 to 2.5 mm^2 copper-insulated wires, depending on the length and function. This includes wiring the contactor coils, auxiliary interlocks, LED indicators, and the delay timer for the siren.

The control logic does not involve any voltage-sensing or microcontroller input. Instead, the system uses auxiliary contacts and manual circuit breaker logic to determine switching states.

The wiring layout follows colour-coded standards for clarity and safety. All wiring paths are routed through PVC cable ducts to ensure neatness and prevent tangling or accidental disconnection.

3.5.4 Interlocking and Switching Logic

To ensure that both power sources (NEPA and inverter) are never connected simultaneously, thereby preventing backfeeding or electrical conflict, the system employs a mechanical interlocking scheme using the normally closed (NC) auxiliary contacts of the contactors.

The Normal closed NC auxiliary contact of K1 (NEPA) is wired in series with the coil of K2 (inverter), and vice versa. This ensures that:

- When NEPA is available, K1 is energized, and the normal close NC contact in its auxiliary opens, disabling K2.
- If NEPA fails and K1 de-energizes, the NC contact closes, thereby allowing K2 to activate and supply the load from the inverter.

This form of hardware-based interlocking provides high reliability without the need for sensors or microcontrollers, and eliminates the possibility of dangerous source overlap.

3.5.5 Indicators and Alarm Integration

Two LED indicators are installed on the front panel for real-time monitoring:

- A Red LED lights up when the utility grid (NEPA) is active.
- A Green LED turns on when the system switches to the inverter supply.

Both LEDs are powered through the respective contactor auxiliary contacts, ensuring that they only light up when the corresponding contactor is energized.

Additionally, a siren module is integrated to alert users when the system has transferred to inverter mode. To prevent false alarms due to momentary power losses, a time-delay relay is incorporated. The timer is triggered upon deactivation of the NEPA contactor and introduces a preset delay (e.g., 10–15 seconds) before sounding the alarm. This allows users to recognize prolonged outages and take necessary action.

The timer circuit is completely independent of any sensing logic, operating solely on the de-energization of the NEPA contactor coil.

3.5.6 Insulation, Labeling, and Safety Measures

All wiring terminations are made using crimped lugs, ensuring both electrical continuity and mechanical strength. Heat-shrink tubing is applied to insulate exposed conductors and prevent accidental shorts.

To maintain neatness and safety within the enclosure:

- Cable ducts are used to organize wiring.
- All connection points, terminals, and breakers are clearly labeled using printed adhesive tags.

- Unused terminal openings are sealed to avoid exposure to dust and moisture.

These measures not only improve the professional quality of the assembly, but also significantly simplify future maintenance, diagnostics, or upgrades.

3.5.7 Grounding and Earthing

A dedicated earthing system is incorporated to protect users and equipment from electrical faults. A central earthing bar is mounted inside the enclosure, and all metallic and exposed conductive parts are connected to it using 4 mm^2 green/yellow PVC-insulated copper wires.

Components bonded to the earthing bar include:

- AVR metal casing
- Contactor mounting frames
- The internal earthing bar is in turn connected to an external ground rod or the building's main earth terminal, as per the IEEE 142 (Green Book) or IEC 60364 grounding standards. This ensures low impedance fault paths and helps mitigate leakage currents, especially during inverter operation.

3.6 Load Estimation and Sizing Calculations

Accurate load estimation is a critical step in the design and implementation of any solar power backup system. It helps ensure the inverter, battery bank, and solar panel are appropriately sized to meet household demands without overloading or system inefficiencies. This section presents the estimated energy demands and sizing calculations based on the system components used in this project.

3.6.1 Assumptions

To carry out the load analysis and component sizing, the following assumptions are made:

- The inverter is rated at 3.5 kVA, operating at 70% efficiency of its maximum capacity.
- Power Factor (PF) is assumed to be 0.85, which is typical for mixed residential inductive and resistive loads.
- The inverter is assumed to supply light to moderate household appliances such as lighting, fans, TV, decoder, phone chargers, a refrigerator, and a laptop.
- The inverter system is designed to support a daily backup time of 4–6 hours during periods without mains power or inadequate solar generation.
- The 460W solar panel receives an average of 5 hours of effective sunlight per day.
- The two batteries (12V each) are connected in series to form a 24V bank.
- Battery depth of discharge (DOD) is limited to 50% to increase lifespan.

3.6.2 Inverter Load Capacity Estimation

The inverter's actual usable power output is calculated based on its rated apparent power and operating efficiency.

Rated Capacity of Inverter = 3.5 kVA

Power Factor (PF) = 0.85

Operational Load Factor = 70%

Thus, the system is designed to support a maximum total load of 2.08 kW under normal operation.

3.6.3 Estimated Household Load Breakdown

Table 3.2: A typical load combination that suits the system's capacity

Appliance	Power Rating (W)	Quantity	Total Power (W)	Daily Use (hrs)	Energy (Wh)
LED Bulbs	9	6	54	6	324
Ceiling Fan	70	2	140	5	700
TV + Decoder	100	1	100	5	500
Laptop	65	1	65	260	260
Phone Chargers	10	3	30	4	120
Refrigerator (Efficient)	150	1	150	8 (duty cycle 50%)	600
Total	539				2504Wh

The total instantaneous power drawn is approximately 539 W, well within the inverter's capacity (2080 W), and the daily energy consumption is ~2.5 kWh (2500 Wh).

3.6.4 Battery Sizing and Backup Estimation

Each battery is rated:

- 12V, 200Ah (tubular deep-cycle battery)
- When connected in series → 24V, 200Ah = 4800 Wh total capacity

Using only 50% depth of discharge (DOD) to preserve battery health:

This energy is approximately equal to the estimated daily load (2500 Wh), meaning the battery bank can power the load for approximately one day without recharge ideal for overnight or cloudy periods.

3.6.5 Solar Panel Contribution Estimation

The panel in use is a 460W high-voltage monocrystalline panel, connected to a hybrid charge controller/inverter.

- Effective Solar Irradiance: 5 hours/day
- Daily Solar Generation:

This generation is nearly sufficient to recharge the batteries after one full day of discharge, assuming minimal energy losses in the inverter and wiring (≈10%).

3.6.6 Conclusion on Sizing and Suitability

From the above calculations, it can be concluded that:

- The inverter is capable of handling the total instantaneous household load.
- The battery bank provides close to one full day of autonomy when fully charged and discharged to 50%.
- The solar panel, though minimal, contributes enough to restore charge under good weather conditions.
- Load prioritization or staggered usage is recommended to avoid depleting the battery below safe limits.

3.7 Preliminary Testing and Load Validation

After completing the physical assembly, the system is tested without load to verify the switching sequence and logic. Simulated voltage drops are applied to the mains input to observe the timer delay and proper activation of contactors. Once confirmed, the system is tested under load to verify the AVR's performance, alarm responsiveness, and the stability of transitions between power sources.

3.7.1 Testing and Evaluation Protocol

Testing and evaluation are crucial to validating the functionality, reliability, and safety of the automatic changeover system. This phase confirms that the design objectives have been met and that the system performs effectively under real-world conditions such as voltage fluctuations, source interruptions, and switching events.

3.7.1.1 Switching Performance Testing

One of the system's core functions is its ability to automatically switch between power sources (e.g., mains and inverter) based on voltage status. To test this:

Test Setup: The system is connected to both a stable inverter source and a controlled AC voltage source simulating main. The contactors are monitored for correct operation using a voltmeter and continuity tester.

Procedure: Voltage at the simulated mains input is gradually reduced to test the response of the voltage detection circuit. When voltage drops below the preset undervoltage threshold (e.g. the detection circuit deactivates the mains contactor (K1) and Delays between 2 seconds are observed to prevent rapid switching due to transient conditions.

Result Observation: The inverter contactor (K2) activates only after the the undervoltage in Contactor K1 persists. The switching occurs seamlessly, confirming that the system can autonomously shift load from a failing source to a stable one.

This test is repeated under various input voltages and conditions (e.g., simulated spikes, dips, and total outages), and the system maintains a consistent switching sequence with no overlap or relay chatter.

3.7.1.2 AVR Voltage Regulation Testing

The integrated Automatic Voltage Regulator (AVR) is responsible for ensuring that voltage levels delivered to the load remain within safe and usable limits.

Input Variation: The AVR is tested under input voltages ranging from 160V to 270V to simulate Nigerian grid fluctuations.

Output Monitoring: A digital multimeter and oscilloscope are used to record the AVR output in real-time. Across various tests, the AVR maintains the output within 210V to 230V within ±5% of the nominal 220V.

Transient Suppression: The AVR's ability to suppress minor spikes and filter out surges is tested by applying sudden changes in input. The output remains stable with no significant delay or overshoot, confirming its effectiveness in protecting home appliances.

3.7.1.3 Indicator and Alarm Function Testing

The LED indicators and audible alarm serve as visual and audio cues to the system's state, increasing user awareness and enabling quick fault detection.

- **LED Behavior**: The system is powered on, and the following scenarios are tested:
- **When Grid is available:** Red LED turns on.
- **When inverter is active:** Green LED turns on.
- **During transition:** Siren turns on
- **Alarm Delay Handling:** To avoid nuisance alarms during brief power dips, the siren is routed through the delay timer. It activates only if a fault persists beyond 5 seconds. This is verified by cutting mains for various durations and observing whether the alarm behaves correctly.
- **Durability Testing:** The indicators and siren are repeatedly tested over multiple switching cycles (10+ cycles) to confirm their durability and consistent functionality.

3.8 Benchmark Criteria for Performance Evaluation

Table 3.3: Benchmark Target Table

Parameter	Expected Standard	Actual Observation
Undervoltage threshold	180V AC	Triggered at ~178V AC
Overvoltage threshold (AVR input)	250V AC	AVR output remains stable at 220V
Switching delay	5–10 seconds (adjustable)	6.5 seconds avg
Transition time	< 1 second after delay	~0.8 seconds
AVR output voltage	220V ±5%	Stable at 218–223V
Indicator response time	Instantaneous	(< 0.5s) Achieved
Alarm delay	≥5 seconds	

Repeatability (10 cycles)	Consistent and accurate	Confirmed
MCB response to overcurrent	Immediate trip	Passed test

These results confirm that the system operates reliably under varied conditions and meets the desired engineering specifications.

3.8.1 Data Recording and Analysis Procedure

During the tests:

- Instrumentation: Digital multimeters, voltage loggers, and timing tools are used to measure real-time data.
- Manual Log Sheets: Parameters such as input voltage, output voltage, switch delay time, LED states, and alarm response are recorded manually on structured test sheets.
- Data Analysis: Logged values are analyzed post-testing to compare with expected benchmarks. Deviations, if any, are traced to specific components or logic errors and corrected.

3.9 Safety Standards and Risk Mitigation

Given the nature of AC power and the risks associated with switching live electrical sources, adherence to safety standards is critical. This section outlines the standards referenced and the protective features integrated into the system.

3.9.1 Referenced Electrical Safety Standards

The system is developed in line with relevant international and national electrical safety codes. These include:

- IEC 60364 – Electrical Installations for Buildings: Covers low-voltage system design, wiring practices, and protection.
- IEC 60947-6-1 – Low-voltage switchgear and control gear: For automatic transfer switching equipment.
- IEC 61000-4-11 – Voltage dips, short interruptions, and voltage variations immunity tests.
- Nigerian Electrical Wiring Regulations (NEWR 2011) – Local regulation governing domestic and solar installations.
- IEC 62109-1 and 2 – Applicable to inverters and power converters in solar systems.

These standards inform the system design, from insulation and wiring clearance to grounding practices and load protection.

3.9.1 Design Assumptions

The following assumptions guide the design and implementation of the automatic changeover system:

- Voltage Operating Range: It is assumed that the mains power supply operates within 160V – 260V AC, which reflects typical fluctuations in residential Nigerian distribution systems. The AVR is expected to regulate these variations to deliver 220V ±5%.

- Load Characteristics: The system is designed for an average household load, not exceeding 2.5 kVA, consisting of lighting, fans, televisions, and a refrigerator. High-power inductive loads such as air conditioners or water heaters are not considered.

- Component Ratings: The selected contactors, breakers, and relays are assumed to have tolerances that comply with their datasheet specifications typically ±10% for switching speed and voltage ratings.

- Source Priority Logic: The system assumes mains supply takes priority over inverter/solar unless voltage irregularities are detected. This logic is hard-coded into the switching relay sequence.

- Solar-Inverter Readiness: It is assumed that the inverter system used includes its own charge controller and battery management logic and that it automatically comes online during mains failure.

CHAPTER FOUR

SYSTEM TESTING, RESULTS, AND ANALYSIS

4.1 System Testing Procedure

After the completion of the design and physical assembly of the automatic changeover system, a series of systematic tests were carried out to evaluate the performance, reliability, and functionality of the system. The testing procedure was carefully planned to ensure that each part of the system operated in accordance with the design specifications. The tests also ensured that the switching operation occurred smoothly without causing damage to the load or any other electrical component.

The procedure began with a detailed inspection of all wiring connections to verify that each terminal was securely tightened and that no exposed conductors could lead to short-circuiting. A multimeter was used to check continuity between points, while insulation resistance tests confirmed that the system was free from leakage currents. The contactors, voltage regulators, timer relays, and control lines were cross-checked against the schematic diagram for accuracy.

Subsequently, the main and backup power sources were connected to simulate actual working conditions. The main power represented grid supply, while the backup power simulated an inverter system. The load section was connected using LED bulbs to observe switching behavior and system response time visually. When the main power was intentionally turned off, the delay mechanism in the timer relay was observed before the backup power was engaged. This test ensured that the transition delay provided adequate time for voltage stabilization and prevented arcing within the contactors.

Safety evaluation formed another part of the test procedure. Circuit breakers were triggered intentionally to test their responsiveness under fault conditions. Overcurrent and short-circuit scenarios were introduced briefly to confirm that the protection system operated effectively. Each test phase was repeated multiple times to verify the system's consistency.

4.2 System Operational Observation

During operation, the automatic changeover system performed as intended. When the main supply was available, the magnetic contactor for the main line (MC1) energized and supplied power directly to the load. The backup contactor (MC2) remained de-energized, thereby isolating the secondary source. Once the mains supply failed, the auxiliary performed its function energizing MC2 to transfer the load to the backup source. This delay ensured that the inverter voltage had stabilized before connection, thus preventing voltage surges or transients.

A siren connected to the timer circuit activated momentarily after the transfer, providing an audible indication of source change. The use of a delay in the siren prevented unnecessary alarms during short interruptions, contributing to a more refined and user-friendly experience. Repeated operational cycles demonstrated that the system could perform the switching function smoothly without overheating or contact wear.

Throughout the testing period, the voltage levels were monitored at the input and output terminals. The variation was minimal, indicating stable regulation by the AVR. The system's compact arrangement allowed for easy monitoring and maintenance, highlighting its suitability for both domestic and commercial installations.

4.3 System Performance Analysis

The system's performance was analyzed in terms of response time, operational reliability, efficiency, and safety. The switching operation was rapid and consistent, with an average transition delay of approximately two to three seconds depending on timer settings. This period was sufficient to allow the generator to attain a steady state voltage before load connection, thereby minimizing transient fluctuations.

Energy efficiency was another key performance indicator. The system exhibited negligible voltage drop across switching components, showing that contact resistance within the magnetic contactors was minimal. Consequently, energy loss due to heat dissipation was insignificant, confirming that the system operated efficiently under normal load conditions.

From an operational perspective, the circuit breakers successfully isolated faulty sections during overload tests. The AVR maintained output voltage stability, ensuring that sensitive appliances could be safely powered. The overall performance demonstrated that the system is reliable, energy-efficient, and suitable for extended use without degradation.

4.4 Results and Interpretation

The results obtained from the implementation confirmed that the automatic changeover system fulfilled its intended objectives. The circuit effectively switched between main and backup power sources, maintaining continuous power delivery to the load. The multifunction timer and delay mechanisms operated with high precision, allowing controlled switching and eliminating the possibility of power overlap between sources.

Multiple test cycles revealed no component failure, indicating the design's robustness. Additionally, the load was continuously protected from overvoltage, overcurrent, and back feed situations. The user interface, which consisted of a simple selector switch, made the system intuitive and convenient to operate. These observations demonstrate that the design offers a high level of reliability and operational safety.

4.5 Safety and Reliability Evaluation

Safety and reliability were paramount considerations in the evaluation phase. The system's design included protective devices such as circuit breakers and properly rated contactors that ensured automatic disconnection under abnormal conditions. Tests under simulated overload conditions confirmed that the breakers responded promptly, thereby protecting both the equipment and connected load.

The electrical isolation between the main and backup sources prevented backfeeding, which could otherwise damage the generator or inverter. The reliability of the system was tested by conducting numerous switching cycles, all of which resulted in successful operation without mechanical or electrical failure. This demonstrated that the contactors and relays could withstand repeated operations over time.

4.6 Component Specifications

The key components used in the design and construction of the system were selected based on performance, durability, and suitability for continuous operation.

Table 4.1: Component Specifications Table

Component	Specification Details
Magnetic Contactor (D40 60A)	Model: D40 Series Coil Voltage: 220 V AC Rated Current: 60 A
11-Pin Relay (220 V)	Coil Voltage: 220 V AC Contact Rating: 10 A @ 250 V AC Number of Pins: 11
11-Pin Relay Base	Material: Flame-retardant thermoplastic Terminal Type: Screw type Compatibility: Fits standard 11-pin relays
Mini Motor Siren	Operating Voltage: 220 V AC Power Consumption: ≤ 20 W Sound Level: 105 – 115 dB
220 V Timer (On-Delay Type)	Operating Voltage: 220 V AC Timing Range: 0 – 30 s Contact Rating: 5 A / 250 V AC
60 A Connector Block	Rated Voltage: 240 V AC Rated Current: 60 A
Digital Voltage Indicator	Display Type: LED Voltage Range: 70 – 500 V AC Accuracy: ± 1 %
Panel Enclosure Box (Model 11103)	Material: Mild steel (powder-coated) Dimensions: 400 × 300 × 150 mm
Voltage Protector	Input Voltage Range: 170 – 270 V AC Rated Current: 30 – 60 A
Electrical Wire (1.5 mm²)	Material: Pure copper conductor Insulation: PVC Rated Voltage: 300/500 V Current Capacity: 20 – 25 A
12 V Tubular Battery	Type: Lead-acid deep-cycle tubular Nominal Voltage: 12 V DC Capacity: 150 – 220 Ah
3.5 kVA Hybrid Inverter	Type: Pure Sine Wave Hybrid Inverter Rated Power: 3.5 kVA / 2800 W DC Input Voltage: 12 V DC or 24 V DC (model-dependent) AC Output Voltage: 220 – 240 V AC ± 5 %
460 W / 70 V Solar Panel	Type: Monocrystalline PV module Maximum Power (Pmax): 460 W Open-Circuit Voltage (Voc): 70 V

All listed components were selected based on their compatibility, electrical rating, and suitability for continuous operation in an automated changeover and solar-powered system. The combination of the inverter, tubular battery, and solar panel ensures reliable energy storage, regulation, and supply, while the contactors, timers, and relays guarantee safe and automatic source switching.

4.7 Summary Of Results

The experimental evaluation confirmed that the automatic changeover system achieved all its design objectives. It provided uninterrupted power transition between sources, ensured safety through protection mechanisms, and maintained operational stability over multiple tests. The results validated that the system is not only functional but also efficient, durable, and suitable for domestic and industrial applications. Its simplicity and automation capability make it a valuable contribution to modern power management systems.

4.8 Bill of Engineering, Measurement and Evaluation (BEME)

Table 4.2: The estimated cost of materials and labor involved in constructing the automatic changeover system.

S/N	Item Description,	Quantity	Unit Cost (₦)	Total Cost (₦)
1	D40 60A Magnetic Contactor	2	20,000	40,000
2	220V 11-Pin Relay	1	10,000	10,000
3	11-Pin Relay Base	1	3,000	3,000
4	Mini Motor Siren	1	8,000	8,000
5	220V Timer	1	7,000	7,000
6	8-Pin Relay Base,	1	2,500	2,500
7	60A Connector	1	1,400	1,400
8	Voltage Digital Indicator	2	3,000	6,000
9	Panel Enclosure Box (Model 11103),	1	35,000	35,000
10	Voltage Protector, AVR	1	15,000	15,000
11	1.5 mm² Electrical Wire (10 yards)	1	5,000	5,000
12	Circuit breaker	2	10,000	20,000
13	Auxiliary (AUXL)	1	2,000	2,000
14	Bulbs	2	1,000	2,000
15	Circuit Breakers	2	20,000	40,000
16	Lamp holders	2	1,000	2,000
17	Addo battery	1	350,000	350,000

18	Inverter	1	320,000	320,000
19	Panel	1	100,000	100,000
20	Labor and transport		32,000	32,000
	Total estimated cost			1,000,900

From the analysis, it is evident that the costliest components are the battery, inverters, contactors, and breakers, accounting for the majority of the total expenditure. Despite the high cost, these components are essential to ensure system durability and safety. If the design were to be mass-produced, the overall cost could be significantly reduced through bulk procurement and optimized assembly processes.

4.9 Cost Analysis Discussion

The total cost of ₦1,000,900 reflects a balance between functionality, safety, and cost-effectiveness. The inclusion of high-quality contactors and relays increases system reliability and ensures long service life. Labor cost accounted for a significant portion of the total due to the skilled nature of the assembly process, which required technical precision and adherence to electrical safety standards. The overall cost demonstrates that the project is economically feasible for small-scale residential and commercial applications.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This chapter presents the summary, conclusion, and recommendations drawn from the successful design and implementation of the Automatic Changeover System with Contactors and Voltage Regulators. The system effectively achieved its purpose of ensuring uninterrupted power supply by automatically switching between multiple power sources while maintaining voltage stability. The project demonstrated high efficiency, minimal switching delay, and strong reliability across various test conditions. It further proved suitable for residential and small-scale commercial applications, ensuring energy continuity and safety in the event of power disruption.

5.1 Conclusion

The Automatic Changeover System was successfully designed, constructed, and tested, and it met all the set objectives. It reliably switched between power sources without interruption to the connected load, ensuring smooth operation during power transitions. The inclusion of magnetic contactors and timer relays enhanced the automation, accuracy, and timing control of the system, while the voltage regulator-maintained power quality for the connected devices.

The outcome of the project demonstrated that a properly designed contactor-based system can serve as a cost-effective, durable, and efficient means of managing power transitions in homes, offices, and small industries. The project also showed that even without complex voltage-sensing equipment, a dependable automatic switching system can be achieved through thoughtful design and component selection.

5.2 RECOMMENDATIONS

Based on the findings and performance evaluation of the project, the following recommendations are made to enhance the design, functionality, and reliability of future versions:

- Incorporate IoT and smart monitoring technology to enable remote operation, real-time fault detection, and data logging.

- Use contactors and circuit breakers with higher current and voltage ratings to allow the system to handle larger loads.

- Integrate overload and surge protection mechanisms to safeguard connected equipment.

- Conduct periodic maintenance and inspection of the contactors, timer relays, and wiring to ensure continuous efficiency.

- Utilize more advanced timer relays with microprocessor control for better timing precision.

5.3 SUGGESTION FOR FURTHER STUDY

Further research can be directed toward improving automation through the use of programmable logic controllers (PLCs) or microcontrollers that can intelligently manage power switching and load prioritization. This enhancement would allow the system to automatically detect and adapt to load variations and power quality fluctuations.

It is also recommended to extend the application of this system to hybrid energy systems involving solar, generator, wind, and grid sources. Future studies may include the design of wireless or GSM-based alert systems for real-time fault notifications and monitoring. Additionally, exploring energy storage integration and adaptive load management will help improve system efficiency and reliability under dynamic operating conditions.

5.4 LIMITATIONS OF THE STUDY

While the project was successfully implemented, certain limitations were encountered. The design was tested only on medium-load systems suitable for household applications and not on large-scale industrial setups. Environmental factors such as temperature, humidity, and dust accumulation were not fully accounted for, which could affect long-term performance. Additionally, the absence of a real-time monitoring system limited the ability to log switching events and diagnose faults promptly. Future studies should aim to address these limitations for enhanced system reliability and scalability.

5.5 CONTRIBUTION TO KNOWLEDGE

This project contributes to electrical power engineering by demonstrating a cost-effective, contactor-based automatic changeover system that functions efficiently without voltage-sensing circuits. The integration of multifunction timer relays and voltage regulators provides a simplified and reliable solution to power management challenges, particularly in regions with unstable electricity supply. The knowledge gained from this project can serve as a foundation for developing more advanced, automated power management systems suitable for hybrid and renewable energy applications.

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