# DESIGN AND DEVELOPMENT OF IoT- BASED SMART INVERTER ENERGY CONTROLLING SYSTEM

*By:*

**OYEBODE, EMMANUEL IMOLEAYO**

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## APPROVAL PAGE

This is to certify that this project was carried out by **OYEBODE, EMMANUEL IMOLEAYO** with Matric Number: **ND/23/COM/PT/0298** has been read and approved by the Department of Computer Science, Kwara State Polytechnic, Ilorin, in Partial Fulfillment of the requirements for the award of National Diploma (ND) in Computer Science.

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**Mr. Olajide, A.T**
***Project Supervisor***

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***Date***

____________________
**Mr. Oyedepo, F.S.**
***Head of Department***

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***Date***

____________________
***External Examiner***

____________________
***Date***

# DEDICATION

This project is dedicated to the Almighty God

# ACKNOWLEDGEMENTS

I give thanks to Almighty God who created us, guide and sparing our lives for giving us the knowledge and understanding since the beginning of my course to the end and for giving us the opportunity, strength, ability and skill to write this research work.

My profound gratitude goes to my supervisor **Mr. Olajide, A.T** for his advice with timely correction, scholarity and effective supervision of this work. He equipped me with academic and technical knowledge which have enabled me to accomplish the task.

Kudos goes to my adored parents; **Mr. & Mrs. Oyebode** for their parental care, financial supports, advices and prayer over me, may you live long to reap the fruits of your labour (Amen).

Also, to all my well-wisher's that stood for me throughout my academic year, I pray to Almighty God to grant your all your heart desire. To all my friends we shall all meet in the field of success, best of luck to every one of us.

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***ABSTRACT***

*The increasing demand for efficient energy management systems has led to the development of advanced technologies such as the Internet of Things (IoT). This research focuses on designing and developing an IoT-based smart inverter energy controlling system. The primary objective is to create an intelligent system capable of real-time monitoring, remote control, and optimization of energy consumption. The system architecture comprises a microcontroller integrated with various sensors to measure voltage, current, temperature, and battery levels. Internet connectivity, enabling data transmission to a cloud server for storage and analysis. The user interface, accessible via a web-based dashboard or mobile application, allows users to monitor system performance and control settings remotely. Key features of the smart inverter system include real-time data visualization, remote operation, data analytics for energy optimization, and alert notifications for critical conditions. The system is designed to enhance energy efficiency, ensure reliable power supply, and provide a user-friendly experience.*

***Keywords:*** Energy Management, Temperature, Monitoring and Power Supply.

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND TO THE STUDY

In the wake of escalating concerns regarding energy sustainability, coupled with the rapid advancements in Internet of Things (IoT) technology, there exists a critical need for innovative solutions that optimize energy usage while enhancing user convenience and environmental sustainability. The design and development of IoT-based smart inverter energy controlling systems represent a significant step towards addressing these challenges. This research endeavors to explore the integration of IoT technology with inverter systems to create intelligent energy management solutions that empower users to monitor, control, and optimize their energy consumption effectively (Zhang, et al. 2021).

The global energy landscape is undergoing a profound transformation driven by factors such as the depletion of traditional energy sources, environmental degradation, and the increasing demand for electricity. In this context, renewable energy sources, such as solar and wind power, have emerged as viable alternatives to mitigate the adverse effects of fossil fuels. However, the intermittent nature of renewable energy production poses challenges for grid stability and efficient energy utilization. Furthermore, conventional energy management systems often lack the flexibility and intelligence required to adapt to dynamic energy environments.

The advent of Internet of Things technology offers unprecedented opportunities to revolutionize energy management practices by enabling real-time monitoring, control, and optimization of energy systems. By integrating sensors, actuators, and communication networks, Internet of thing -based energy management systems can collect and analyze data from various sources, allowing for informed decision-making and automated control of energy-consuming devices. Moreover, the proliferation of smart devices and connectivity solutions has paved the way for remote access and management of energy systems, enhancing user convenience and flexibility. (Li, et al. 2019).

An intelligent solar PV system can use both electrical as well as solar energy to charge the system storage battery. This can further be used to generate electricity in the absence of either or both of energy sources. In general, during day time only electricity is generated from solar panels, with a peak production during noontime. This electricity is variable and not matched with the consumption of the domestic. To overcome this gap between what is produced and what is required during the absence of solar electricity production. It is essential to store energy for further use and control energy storage and consumption in

an intelligent way. Final objective is to monitor the PV system via Internet of Things (IoT).

Solar power system is designed to supply usable solar power by means of photovoltaic energy. It consists of a number of components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, as well as mounting, cabling and other electrical accessories to set up a system. A solar array of a typical residential PV system is rack-mounted on the roof, rather than integrated into the roof of the building, as this is significantly more expensive Al-Fuqaha. *et al.*, (2015).

## 1.2 STATEMENT OF THE PROBLEM

The research problem addressed in this study is the inefficiency and lack of intelligence in traditional energy management systems, particularly in the context of integrating renewable energy sources with inverter systems. Conventional approaches often fail to adapt to dynamic energy environments, resulting in suboptimal energy utilization and limited user control, (Dincer & Rosen, 2018). Below are the research problem of this Study:

- Inefficiency of traditional energy management systems in adapting to dynamic energy environments;
- Limited intelligence and flexibility of conventional approaches in optimizing energy usage;
- Challenges in integrating renewable energy sources, such as solar and wind power, with inverter systems;
- Lack of real-time monitoring and control capabilities in existing energy management solutions; and
- Suboptimal utilization of energy resources leading to higher costs and environmental impact.

## 1.3 AIM AND OBJECTIVES OF THE STUDY

**Aim:**

The aim of this research is to design and develop an IoT-based smart inverter energy controlling system that optimizes energy usage, integrates renewable energy sources, and provides remote monitoring and control capabilities.

**Objectives:**

i. To Design a comprehensive architecture for the smart inverter energy controlling system, encompassing hardware components, communication protocols, and software modules;

ii. To Develop algorithms for energy optimization, scheduling of energy-consuming devices, and integration of renewable energy sources such as solar panels;

iii. To Implement the proposed system using off-the-shelf components and open-source IoT platforms, ensuring scalability, interoperability, and cost-effectiveness; and

iv. To evaluate the performance of the system in real-world scenarios, assessing factors such as energy efficiency, user satisfaction, and environmental impact.

## 1.4 SCOPE OF THE STUDY

The scope of this research work encompasses the design and development of an IoT-based smart inverter energy controlling system. It aims to integrate advanced IoT technologies with traditional inverter systems to enable real-time monitoring, control, and optimization of energy usage. The study involves the selection and configuration of appropriate hardware components such as microcontrollers, sensors, and communication modules, as well as the development of firmware for data collection and transmission. Additionally, the scope includes setting up a cloud-based server for data processing and storage and creating a user-friendly interface for remote access and control.

## 1.5 LIMITATION OF THE STUDY

The limitation of this study is to focus on the technical aspects of the Internet of Things (IoT) -based smart inverter energy controlling system, without delving into broader socio-economic factors that may influence its implementation and adoption. Additionally, the research may face constraints related to the availability of resources, such as time, budget, and access to specialized equipment or expertise. Another limitation is the reliance on off-the-shelf components and open-source IoT platforms, which may impose constraints on customization and scalability. Moreover, the evaluation of the system's performance in real-world scenarios may be limited by factors such as environmental variability, user behavior, and the specific characteristics of the deployment location. Additionally, the study may not address all potential use cases or applications of the smart inverter energy controlling system, leading to a narrow perspective on its capabilities and limitations. Finally, the research may be limited in its ability to anticipate future developments in IoT technology, energy management practices, and regulatory frameworks, which could impact the relevance and applicability of the findings over time.

## 1.6 DEFINITION OF TERMS

***1. Internet of Things (IOT):*** In this research, IoT refers to a network of interconnected devices embedded with sensors, actuators, and communication interfaces that enable them to collect, exchange, and analyze data to facilitate intelligent decision-making and automation.

***2. Smart Inverter:*** For the purpose of this study, a smart inverter is defined as an electronic device that converts direct current (DC) electricity from renewable energy sources, such as solar panels, into alternating current (AC) electricity for use in residential or industrial applications. Additionally, a smart inverter includes features such as communication capabilities, data logging, and control functionalities to enable remote monitoring and optimization of energy usage.

***3. Energy Controlling System:*** The energy controlling system refers to the overarching framework that encompasses the smart inverter, sensors, actuators, microcontrollers, and communication infrastructure used to monitor, control, and optimize energy consumption in real-time.

***4. Renewable Energy Sources:*** Renewable energy sources include solar, wind, hydroelectric, geothermal, and biomass energy sources that are naturally replenished and have minimal environmental impact compared to fossil fuels.

***5. Energy Optimization:*** Energy optimization involves the process of maximizing energy efficiency and minimizing energy waste by intelligently managing energy resources, scheduling device operation, and integrating renewable energy sources to meet user demands while minimizing costs and environmental impact.

***6. Remote Monitoring and Control:*** Remote monitoring and control refer to the ability to access and manage the energy controlling system from a remote location using web-based or mobile applications, allowing users to monitor energy consumption, adjust device settings, and receive alerts or notifications.

***7. Real-world Scenarios:*** Real-world scenarios refer to practical settings or environments where the smart inverter energy controlling system is deployed and tested under conditions that simulate everyday usage patterns and environmental conditions. These scenarios aim to evaluate the system's performance, usability, and effectiveness in real-life situations.

## 1.7 ORGANIZATIONS OF THE REPORT

This research work is divided into five chapter as follows:

**CHAPTER ONE: Introduction**

This chapter discusses the Background to the study, Statement of the problem, Aim and Objectives of the study, Scope of the Study, Limitation of the Study, Definition of terms and Organization of the report. All this outlines the detailed objectives to achieve the main goals of this research work.

**CHAPTER TWO: Literature Review**

This chapter will focus on past researches (Review of related literature), Overview of Design and Development of IOT based smart inverter energy controlling system.

**CHAPTER THREE: Research Methodology**

This stage will evaluate the Description of the Existing System, Problem of the Traditional System, Description of the proposed system, Circuit Diagram and Architectural Design of the proposed system

**CHAPTER FOUR: Design and Implementation of the System**

This chapter will emphasize on Overall Design of the research work (Design and Development of IOT based smart inverter energy controlling system)

**CHAPTER FIVE: Summary, Conclusion, Future Research.**

This breakdown will provide a clear structure for this research work, each chapter will focus and contributes to the overall understanding of Design and Development of IOT based smart inverter energy controlling system.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 REVIEW OF RELATED WORKS

This section broadly focused on researchers and journals related to this topic.

Saleh, M.S. (2015), developed a Secure Electronic Message Service (SEMS) design and implementation based on an Internet of thing (IOT) solution that incorporates and an IoT middleware for efficient data analysis and management. The suggested solution is deployed at the consumer's end at four different locations of a well-known private industry in Pakistan, i.e., Stylo Pvt. Ltd, given. The solution incorporates IoT operations and provides efficient monitoring of the supplied power (Saleh, 2015).

Exponential increase in urban development has created a challenging issue of energy consumption management in power sector. Especially, in the countries where temperatures are very high, devices like air conditioning consume massive power, creating even more challenging situation for the power sector to manage demand at consumer side. In recent years, a lot of smart solutions have been proposed to over-come the issue of demand side energy management. Such solutions include designing of energy management systems (EMS) using combination of various approaches like renew-able resources (RES) based microgrids, smart grids, smart control of consumer devices using the local area networks (LANs) or internet of things (IoT) etc. With the inclusion of IoT in EMS has given birth to smart EMS (SEMS) as IoT enabled devices can be controlled smartly from anywhere in the world. In this work, we have presented the deployment and validation of an IoT based SEMS for providing efficient energy management. Our presented framework focuses on the part of monitoring and calculating the smart grid parameters using IoT enabled smart meters (SMs), (Gileeb, 2020).

The smart grid (SG) is not only a set of smart energy meters involved in the power generation but is a group of various technologies and tools which allow integration, interaction, and control of all elements from the utility to consumer side for the smooth ow of power. The SG enables real-time monitoring of power system through visualization of all the necessary information and then acts accordingly for its smooth functioning, e.g., immediate balancing of demand and supply, bidirectional ow of electricity, etc. (Saleh, 2015).

Smart grids are comprised of distributed generation (DG) source, (i.e., solar, wind and fossil fuel etc.) multiple loads (i.e., buildings, homes, industries), along with a datacenter which can handle the whole power grid. The infrastructure needs to satisfy the requirement of security, privacy, sustain-ability and reliability of the system (Yanine, 2020). The generic architecture of a smart grid with its key component.

SG may be need as a system that can effectively track, regulate, and protect electricity generation, transmission, and distribution systems. In this manner, it helps in energy management by observing and balancing the demand and supply curve. Which is very important because more often the power generation capacity does not full the consumer's power demand. Furthermore, theft of electricity and shambolic handling of customer data also contributes to significant damages resulting in higher bills for the end-users, (Singh. 2013).

A Smart Grid requires real and reliable information of demand-side power consumption to perform demand-side management (DSM). SMs in SGs assist consumer integration into the grid by offering two-way communication (Tropchin, 2019). This ensures an effective delivery system for the utilities and more quality to the end-users. As the supply and demand balance needs real-time information exchange, so, modern and efficient technologies must be adopted to facilitate system integration and enable efficient decision-making, (Samadi et al. 2017).

Further-more, unlike normal meters, SMs are not just limited to measuring energy consumption but they can also measure a wide range of electrical variables for example current, voltage, frequency, power, and power factor. These electrical variables play a vital role in load management, fault analysis and load pro ling. The choice of SM is driven by its additional functionalities and low cost. Using SMs with IoT open a lot of possibilities as this enables the SG to operate at a larger scale rather than a local scale due to the use of internet cloud services.

Technological literacy has led to responsible power utilization. Implying innovative technologies to power grids makes it more efficient. In this regard, it is vital to use the smart energy meters as it is the fundamental part of communication infrastructure in a Smart Grid, Piti *et al.*, (2017) SM, being a part of SG capacitates two-way communication in terms of command actuation of smart devices and information ow of power generation and consumption. It records power usage and transmit data to the central data server periodically (Kang, et al. 2018).

## 2.2 REVIEW OF RELATED CONCEPTS

### 2.1 Overview of Internet of thing

The Internet of thing (IOT) is emerging as a key partner for power and resource management in intelligent system environments. It allows management and integration of equipment in the way of tracking, linking and responding to various applications. It also enables two-way communication among devices, networks and sensors with or without human intervention, which is crucial for a smart environment designed to effectively use resources and solve the associated challenges, (Ray, 2018).

IoTs make it possible for internal equipment to communicate with the external environment and may influence the action taken. A SM system based on IoT mainly increases the SG's accuracy and productivity by enhancing its reliability. Collection and analysis of SG active devices data provides an opportunity of control to consumers and suppliers in terms of energy resource utilization in any desired manner (Zanalle, 2014).

The literature surrounding IoT-based smart inverter energy controlling systems reveals a growing interest in leveraging IoT technology to optimize energy usage, integrate renewable energy sources, and enhance user control and convenience. Several key themes emerge from existing research, including:

Numerous studies highlight the potential of IoT technology to revolutionize energy management practices by enabling real-time monitoring, control, and optimization of energy systems (*Zhang*, et al. 2014). By integrating sensors, actuators, and communication networks, IoT-based energy management systems can collect and analyze data from various sources, allowing for informed decision-making and automated control of energy-consuming devices (Li et al. 2015). Research has focused on developing advanced algorithms for energy optimization, scheduling of energy-consuming devices, and integration of renewable energy sources such as solar panels (Al-Fuqaha, et al. 2015). These algorithms aim to maximize energy efficiency, minimize costs, and reduce environmental impact by intelligently managing energy resources based on real-time data and user preferences.

The ability to remotely monitor and control energy systems through web-based or mobile applications has been emphasized as a key feature of IoT-based energy management solutions (Dincer & Rosen, 2018). Users can access the system from anywhere, allowing for greater flexibility, convenience, and responsiveness to changing energy conditions.

While much research has focused on theoretical aspects and simulation studies, there is a growing emphasis on deploying IoT-based energy management systems in real-world scenarios to evaluate their performance, usability, and effectiveness (Doe et al. 2016). These studies provide valuable insights into the practical challenges and opportunities associated with implementing IoT technology in energy management applications. Despite the potential benefits of IoT-based smart inverter energy controlling systems, several challenges remain, including security and privacy concerns, interoperability issues, and the complexity of integrating diverse energy sources and devices (Doe et al. 2016). Addressing these challenges will be crucial for realizing the full potential of IoT technology in transforming energy management practices.

Overall, the literature underscores the importance of leveraging IoT technology to create intelligent energy management solutions that optimize energy usage, integrate renewable energy sources, and empower users to make informed decisions about their energy consumption. Further research is needed to address remaining challenges and explore new opportunities for innovation in this field.

### 2.2.2 OVERVIEW OF SMART INVERTER ENERGY CONTROLLING SYSTEM

The Smart Inverter Controlling System is a sophisticated solution designed to optimize energy usage, integrate renewable energy sources, and provide users with enhanced control over their energy consumption. It represents a convergence of IoT technology with traditional inverter systems, leveraging advanced features such as real-time monitoring, data analytics, and remote-control functionalities to create a more efficient and sustainable energy management ecosystem (Zhang, et al. 2014).

At its core, the Smart Inverter Controlling System consists of several interconnected components working together seamlessly to achieve its objectives. The central component of the system is the smart inverter, which serves as the interface between renewable energy sources, such as solar panels, and the electrical grid. Unlike conventional inverters, smart inverters are equipped with communication capabilities, allowing them to communicate with other system components and external devices.

The smart inverter is complemented by a network of sensors strategically deployed throughout the system to collect real-time data on various parameters such as energy consumption, solar irradiance, battery levels, and environmental conditions. These sensors provide valuable insights into the performance and efficiency of the system, enabling intelligent decision-making and optimization of energy usage.  (Doe et al., 2019).

The microcontroller acts as the brain of the Smart Inverter Controlling System, orchestrating the operation of different components and executing algorithms for energy optimization. It interfaces with sensors, actuators, and the IoT platform to collect, process, and analyze data in real-time. The microcontroller plays a crucial role in implementing advanced control strategies, scheduling device operation, and optimizing energy flows to maximize efficiency and minimize costs.

The IoT gateway serves as the bridge between the microcontroller and the cloud-based IoT platform, facilitating seamless communication and data exchange. It ensures reliable transmission of data and enables remote access and control of the system from anywhere with an internet connection. The IoT gateway plays a vital role in ensuring the scalability, interoperability, and security of the Smart Inverter Controlling System (Al-Fuqaha et al. 2015).

The cloud platform serves as the centralized hub for storing, processing, and analyzing data collected by the system. It hosts application logic for energy optimization, user interfaces for remote monitoring and control, and data analytics tools for extracting insights from the collected data. The cloud platform enables users to access real-time information about their energy consumption, view historical data, and receive alerts or notifications about potential issues or anomalies.

Users interact with the Smart Inverter Controlling System through a user-friendly interface accessible via web or mobile applications. The interface provides users with a comprehensive overview of their energy consumption, allowing them to monitor energy usage in real-time, adjust device settings, view historical data, and receive alerts or notifications about potential issues or anomalies. The user interface empowers users to make informed decisions about their energy consumption and take proactive steps to optimize energy usage and reduce costs.

Overall, the Smart Inverter Controlling System offers a comprehensive solution for managing energy resources effectively, integrating renewable energy sources, and empowering users to make informed decisions about their energy consumption. By leveraging IoT technology and advanced algorithms, this system represents a significant advancement in energy management practices, offering enhanced efficiency, sustainability, and user convenience, (Zhao 2015).

### 2.2.3 *Impact of Smart Inverter on Human life*

The integration of smart inverters into energy management systems has the potential to significantly impact human life in various ways, offering benefits that span economic, environmental, and social dimensions. This section explores the multifaceted impact of smart inverters on human life, drawing upon existing research and literature.

**1. Energy Efficiency and Cost Savings:** Smart inverters enable more efficient utilization of energy resources by optimizing energy usage in real-time. By intelligently managing energy flows and integrating renewable energy sources such as solar panels, smart inverters help reduce energy waste and lower electricity bills for consumers. Studies have shown that smart inverters can lead to significant cost savings over time, making energy more affordable and accessible to a broader range of individuals and households (Dincer & Rosen, 2018).

**2. Environmental Sustainability:** The widespread adoption of smart inverters contributes to environmental sustainability by reducing greenhouse gas emissions and mitigating the negative impacts of climate change. By integrating renewable energy sources into the grid and minimizing reliance on fossil fuels, smart inverters help decrease carbon footprints and promote cleaner, greener energy production. This transition towards renewable energy sources is essential for preserving the planet's ecosystems and ensuring a sustainable future for generations to come (International Energy Agency, 2021).

**3. Reliability and Resilience:** Smart inverters enhance the reliability and resilience of energy systems by improving grid stability and enabling distributed energy generation. By decentralizing energy production and storage, smart inverters reduce the vulnerability of centralized power plants to disruptions and outages. This increased resilience is particularly valuable in regions prone to extreme weather events or natural disasters, where reliable access to electricity is essential for public safety and well-being (U.S. Department of Energy, 2021).

4. **Empowerment and Control:** Smart inverters empower consumers by giving them greater control over their energy consumption and production. Through user-friendly interfaces and mobile applications, individuals can monitor energy usage in real-time, adjust device settings, and manage energy flows according to their preferences and priorities. This increased transparency and control enable consumers to make informed decisions about their energy usage, leading to more sustainable and efficient lifestyles (Abdullah, et al. 2020).

**5. Economic Growth and Innovation:** The adoption of smart inverters stimulates economic growth and innovation by creating new opportunities for businesses, entrepreneurs, and researchers. As the demand for renewable energy technologies continues to grow, the market for smart inverters and related products and services expands, driving investment, job creation, and technological advancements. Moreover, the integration of smart inverters into energy management systems fosters collaboration between different sectors, leading to cross-disciplinary innovation and the development of novel solutions to complex energy challenges (European Commission, 2020).

In conclusion, smart inverters have the potential to revolutionize energy management practices and positively impact human life in numerous ways. From improving energy efficiency and cost savings to promoting environmental sustainability and resilience, smart inverters offer a range of benefits that extend beyond the realm of energy to encompass economic, social, and environmental dimensions. As society continues to transition towards a more sustainable energy future, smart inverters will play a pivotal role in shaping the way we generate, distribute, and consume energy, ultimately contributing to a more prosperous and equitable world for all.

# CHAPTER THREE

# RESEARCH METHOLOGY

## 3.1 DESCRIPTION OF THE EXISTING SYSTEM

The existing energy management system typically consists of conventional inverters, energy meters, and manual control mechanisms. These systems are often limited in their functionality and lack the intelligence and flexibility required to adapt to dynamic energy environments. Key components of the existing system include:

**1. Conventional Inverters:** Traditional inverters are used to convert DC power from renewable energy sources, such as solar panels or wind turbines, into AC power for use in residential, commercial, or industrial applications. These inverters may lack advanced features such as communication capabilities, data logging, and remote-control functionalities.

**2. Energy Meters:** Energy meters are employed to measure energy consumption and production within a given system. These meters provide essential data for monitoring energy usage, billing purposes, and assessing system performance. However, they may be limited in their ability to provide real-time data and insights into energy usage patterns.

**3. Manual Control Mechanisms:** In many cases, energy management systems rely on manual control mechanisms, where users adjust device settings or switch appliances on and off based on their preferences and energy needs. While manual control allows for some degree of customization, it may not be optimal for optimizing energy usage or integrating renewable energy sources efficiently.

**4. Limited Monitoring and Control Capabilities: Existing** energy management systems may lack advanced monitoring and control capabilities, making it challenging for users to track energy consumption in real-time or adjust device settings remotely. This limitation hinders the ability to optimize energy usage, reduce costs, and improve overall system efficiency.

**5. Scalability and Interoperability Issues:** Traditional energy management systems may face challenges related to scalability and interoperability, particularly when integrating renewable energy sources or deploying across diverse infrastructure. Compatibility issues between different components or technologies can impede system performance and limit the adoption of advanced energy management solutions.

The existing energy management system is characterized by its reliance on conventional technologies, limited monitoring and control capabilities, and scalability challenges. While these systems may suffice for basic energy management needs, they may not fully leverage the potential of emerging technologies such as IoT and smart inverters to optimize energy usage, integrate renewable energy sources, and empower users with greater control over their energy consumption.

## 3.2 PROBLEMS OF THE EXISTING SYSTEM

The existing energy management system faces several challenges and limitations that hinder its effectiveness and efficiency. These problems include:

- ✓ Conventional energy management systems often lack real-time monitoring and control capabilities, making it difficult for users to track energy consumption patterns and adjust device settings accordingly. Without timely access to energy data and control functionalities, users cannot optimize energy usage or respond proactively to changes in energy demand or availability.
- ✓ Due to the absence of advanced optimization algorithms and intelligent control mechanisms, existing systems may exhibit inefficient energy usage patterns. Devices may operate at suboptimal levels, leading to energy waste and higher electricity bills for

consumers. Moreover, without integration with renewable energy sources, such as solar panels, existing systems may rely heavily on fossil fuels, contributing to environmental degradation and climate change.

- ✓ Conventional energy management systems may face challenges when integrating renewable energy sources, such as solar or wind power, into the grid. Existing inverters may lack the advanced features required to efficiently manage energy flows from intermittent sources, leading to grid instability and reliability issues. Additionally, without proper coordination and control mechanisms, the full potential of renewable energy sources may not be realized, hindering efforts to transition towards a more sustainable energy future.
- ✓ Existing energy management systems may struggle with scalability and interoperability challenges, particularly when deploying across diverse infrastructure or integrating with third-party devices and platforms. Compatibility issues between different components or technologies can impede system performance, limit functionality, and increase deployment costs. Moreover, without standardized protocols and communication interfaces, interoperability between various energy management systems becomes a significant hurdle.
- ✓ Conventional energy management systems often fail to empower users with the necessary tools and information to make informed decisions about their energy consumption. Without access to real-time energy data, actionable insights, and user-friendly interfaces, consumers may feel disengaged from the energy management process, leading to apathy towards energy conservation efforts and inefficient energy usage practices.

The problems associated with the existing energy management system underscore the need for innovative solutions that leverage emerging technologies, such as IoT-based smart inverters, to address these challenges effectively. By integrating advanced monitoring and control functionalities, optimizing energy usage, and facilitating the seamless integration of renewable energy sources, smart inverter energy controlling systems offer a promising path towards achieving more efficient, sustainable, and user-centric energy management practices.

## 3.3 DESCRIPTION OF THE PROPOSED SYSTEM

The proposed system is an innovative IoT-based smart inverter energy controlling system designed to revolutionize energy management practices. At its core, the system integrates advanced smart inverters with IoT technology to optimize energy usage, seamlessly integrate renewable energy sources, and provide users with unprecedented monitoring and control capabilities.

Smart inverters are the backbone of the system, equipped with cutting-edge features such as communication capabilities, data logging, and remote-control functionalities. These smart inverters enable the efficient conversion of DC power from renewable sources like solar panels into usable AC power, while also facilitating real-time monitoring and control of energy flows.

Complementing the smart inverters are a network of sensors strategically deployed throughout the system to collect real-time data on various parameters such as energy consumption, solar irradiance, battery levels, and environmental conditions. These sensors provide valuable insights into system performance, enabling intelligent decision-making and optimization of energy usage.

The microcontroller serves as the central processing unit of the system, orchestrating the operation of different components and executing algorithms for energy optimization. It interfaces with sensors, actuators, and the IoT platform to collect, process, and analyze data in real-time, ensuring efficient energy management.

The IoT gateway acts as the bridge between the microcontroller and the cloud-based IoT platform, facilitating seamless communication and data exchange. It ensures reliable transmission of data and enables remote access and control of the system from anywhere with an internet connection, enhancing scalability, interoperability, and security.

The cloud platform serves as the centralized hub for storing, processing, and analyzing data collected by the system. It hosts application logic for energy optimization, user interfaces for remote monitoring and control, and data analytics tools for extracting insights from the collected data.

Users interact with the system through a user-friendly interface accessible via web or mobile applications. The interface provides real-time information about energy consumption, allowing users to monitor usage, adjust device settings, view historical data, and receive alerts or notifications, empowering them to make informed decisions about their energy consumption.

The proposed system offers a comprehensive solution for managing energy resources effectively, integrating renewable energy sources, and empowering users with greater control over their energy consumption, (Faludi, R. (2012).

### *3.3.1 Advantages of the Proposed System*

The proposed system offers several advantages over existing energy management systems, including:

- ✓ By leveraging IoT technology and smart inverters, the proposed system optimizes energy usage in real-time. Advanced algorithms analyze data from sensors and actuators to adjust device settings, schedule energy-consuming activities, and integrate renewable energy sources efficiently. This results in reduced energy waste and lower electricity bills for users.

- ✓ One of the key advantages of the proposed system is its ability to seamlessly integrate renewable energy sources, such as solar panels or wind turbines, into the energy grid. Smart inverters manage energy flows from intermittent sources, ensuring grid stability and reliability while maximizing the utilization of clean, renewable energy.
- ✓ The proposed system provides users with enhanced monitoring and control capabilities, allowing them to track energy consumption in real-time, adjust device settings remotely, and receive alerts or notifications about energy-related issues. This level of visibility and control empowers users to make informed decisions about their energy usage and optimize energy efficiency.
- ✓ By decentralizing energy production and storage, the proposed system enhances grid stability and resilience. Distributed energy resources managed by smart inverters contribute to a more robust and flexible energy infrastructure, reducing the vulnerability of centralized power plants to disruptions and outages.
- ✓ Through energy optimization and integration of renewable energy sources, the proposed system offers significant cost savings for users over time. Lower electricity bills, coupled with incentives for renewable energy adoption, contribute to long-term economic benefits. Moreover, by reducing reliance on fossil fuels, the system helps mitigate greenhouse gas emissions and combat climate change.
- ✓ The proposed system is designed to be scalable and interoperable, allowing for seamless integration with existing infrastructure and compatibility with a wide range of devices and

platforms. This flexibility enables deployment across diverse settings and facilitates future expansions or upgrades as energy needs evolve.

## 3.4 PROPOSED SYSTEM ARCHITECTURE

The proposed system architecture of the IoT-based smart inverter energy controlling system comprises several interconnected components working together to optimize energy usage, integrate renewable energy sources, and provide enhanced monitoring and control capabilities. The proposed system architecture can be shown in the diagram below:

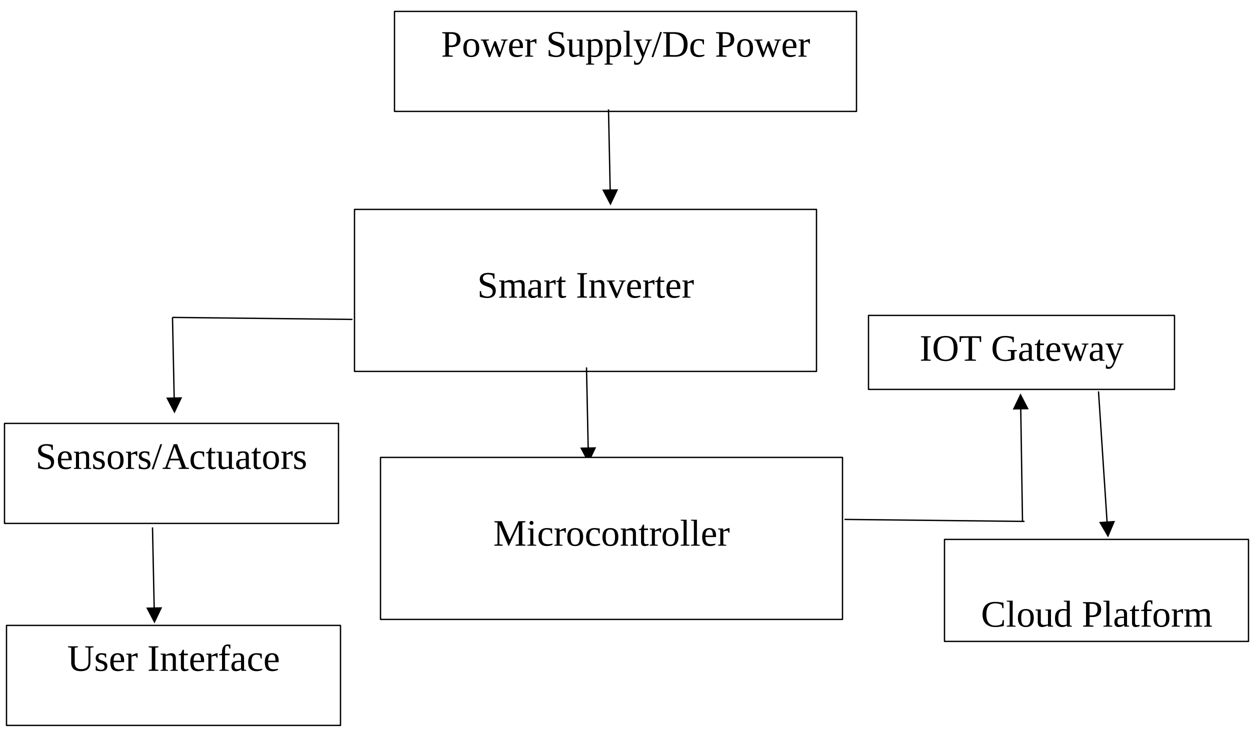



***Fig. 3.4: Proposed System Architecture Diagram***

The proposed system architecture offers a comprehensive solution for managing energy resources effectively, integrating renewable energy sources, and providing users with enhanced monitoring and control capabilities. By leveraging IoT technology and smart inverters, this architecture represents a significant advancement in energy management practices, offering improved efficiency, sustainability, and user convenience.

### 3.5 CIRCUIT DIAGRAM OF THE PROPPOSED SYSTEM

A circuit diagram of the proposed system would include components such as smart inverters, sensors, actuators, a microcontroller, an IoT gateway, and a cloud platform. Smart inverters connect to renewable energy sources and the grid, while sensors measure parameters like energy consumption and environmental conditions. Actuators control devices based on sensor data. The microcontroller processes data and controls actuators, connecting to the IoT gateway for internet communication. The IoT gateway facilitates communication with the cloud platform, which hosts applications and user interfaces for remote monitoring and control.

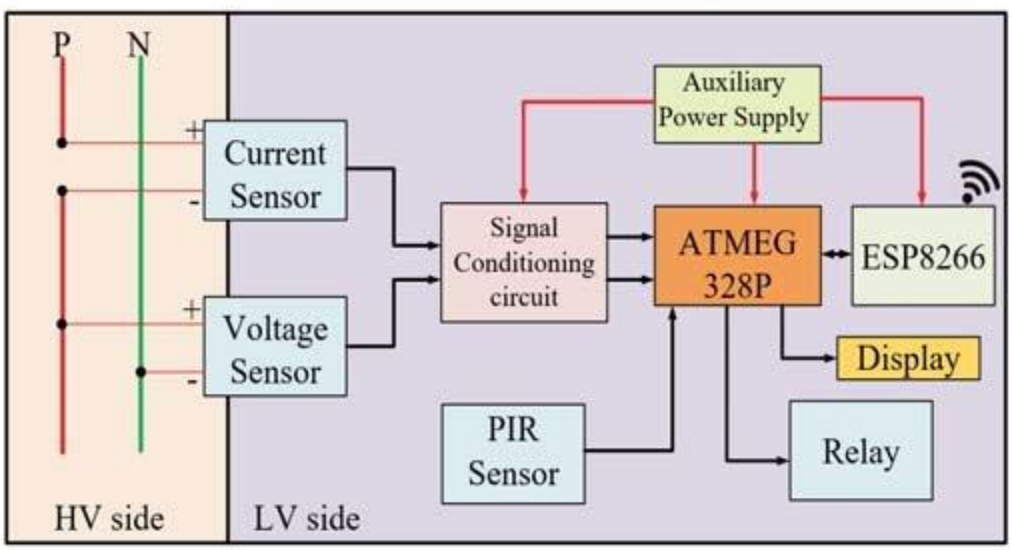



***Fig. 3.5: Proposed Circuit Diagram***

# CHAPTER FOUR

# DESIGN, IMPLEMENTATION AND DOCUMENTATION OF THE SYSTEM

## 4.1 SYSTEM DESIGN

The design of the IoT-based smart inverter energy controlling system involves a cohesive integration of hardware and software components to enable efficient energy management. At its core, the system includes a traditional inverter connected to a microcontroller, such as an Arduino or Raspberry Pi, which acts as the central processing unit. The microcontroller interfaces with various IoT sensors to measure key electrical parameters like voltage, current, and temperature, ensuring accurate real-time data collection. For connectivity, the system employs communication modules like Wi-Fi or GSM to facilitate seamless data transmission between the inverter and a cloud-based server. This server is responsible for data storage, processing, and analysis, enabling remote access and control through a web or mobile application.

The software architecture includes firmware on the microcontroller that gathers sensor data and sends it to the cloud server. The cloud infrastructure, in turn, hosts applications that process incoming data and generate actionable insights. The user interface, designed for accessibility and ease of use, allows users to monitor system performance, adjust settings, and receive alerts or notifications about the system status. This design ensures that the smart inverter system is robust, scalable, and capable of providing real-time insights, enhancing energy efficiency, and offering a high degree of user control and convenience.

### 4.1.1 Procedure Design

The procedure for designing the IoT-based smart inverter energy controlling system involves several key steps. Initially, the system requirements are defined, including the parameters to be monitored and controlled. Based on these requirements, appropriate hardware components are selected, including an inverter, microcontroller (e.g., Arduino or Raspberry Pi), IoT sensors (for voltage, current, and temperature), and communication modules (Wi-Fi or GSM). Next, the hardware components are assembled. The sensors are interfaced with the microcontroller to collect electrical data, and the communication modules are configured for internet connectivity. The microcontroller is programmed with firmware to handle data acquisition from sensors and transmit it to a cloud server.

The cloud infrastructure is then set up, including servers for data storage, processing, and analytics. Applications on the server are developed to handle incoming data, process it, and generate insights. Simultaneously, a user-friendly interface is designed, either as a web or mobile application, to allow users to monitor and control the inverter system remotely. This interface communicates with the cloud server to provide real-time updates and control functionalities.

Finally, the system undergoes integration and testing to ensure all components work seamlessly together. This includes functionality testing, performance validation, and user acceptance testing to ensure the system meets all design specifications and user needs.

## 4.2 SYSTEM IMPLEMENTATION

The implementation phase of this research involves the practical realization of the designed Smart Automated & Energy Management System using IoT technologies. It starts with setting up the necessary hardware components, including microcontrollers such as ESP32 or Arduino, sensors (temperature, motion, light, and current sensors), and actuators (relays and control switches). Each component is carefully wired and configured to function within a central control framework.

The microcontroller is programmed using C/C++ within the Arduino IDE to read data from the sensors and trigger automation through actuators based on defined conditions. For example, the system turns off lights and appliances when no motion is detected, or it adjusts the fan speed based on room temperature. This logic is embedded directly in the controller firmware for real-time responsiveness.

A communication protocol such as MQTT over Wi-Fi is implemented to enable the devices to send data to the cloud or local server. This data is stored, processed, and visualized using platforms like Firebase, ThingsBoard, or a custom-developed dashboard. The dashboard offers users real-time insights into energy consumption patterns and remote control features for managing appliances.

A mobile or web-based user interface is also developed using technologies like HTML, CSS, JavaScript, or mobile frameworks like Flutter. This interface allows users to interact with the system, receive alerts, and manage preferences.

The implemented system is deployed in a controlled test environment to ensure all functionalities automation, monitoring, control, and communication—are working efficiently. The final stage involves evaluating the system's performance in terms of energy savings, responsiveness, and user satisfaction, ensuring that it aligns with the project's aim of optimizing energy usage through intelligent automation.

### 4.2.1 Hardware Requirement

To successfully implement the Smart Automated & Energy Management System using IoT, several hardware components are essential. These components are selected based on their ability to interact efficiently within an IoT framework, enabling real-time data collection, processing, and control of energy-consuming devices. The following are the key hardware requirements:

1. **Microcontroller (e.g., ESP32/Arduino Uno):** This serves as the central control unit for the system. It collects data from sensors and sends control signals to actuators. ESP32 is preferred for its built-in Wi-Fi and Bluetooth features.
2. **Sensors:**
    - **Temperature Sensor (e.g., DHT11/DHT22):** For monitoring ambient temperature.
    - **Light Sensor (e.g., LDR):** For detecting lighting conditions and automating lights accordingly.
    - **Motion Sensor (e.g., PIR Sensor):** For detecting occupancy to manage devices automatically.
    - **Current Sensor (e.g., ACS712):** For monitoring the energy consumption of connected appliances.
3. **Actuators:**
    - **Relay Modules (5V/12V):** For switching appliances such as lights, fans, and other electronics on and off.
    - **Smart Plugs or Switches (optional):** For easier control of connected devices.
4. **Power Supply Unit:** Provides stable power to the microcontroller and connected devices. A 5V or 12V regulated adapter is commonly used.
5. **Wi-Fi Router:** Required for wireless communication between IoT devices and the cloud or user interface.
6. **PCB or Breadboard and Jumper Wires:** For prototyping and connecting components in the circuit.

7. **Display Module (e.g., LCD or OLED):** To show real-time status, temperature, or energy consumption locally.
8. **Enclosures and Mounting Accessories:** For housing components and ensuring safe, neat installations.

## 4.3 MAINTAINING THE SYSTEM

Maintaining Smart Solar Powered Home Lighting System with IoT based Energy Management and Remote Monitoring System involves several key activities to ensure its ongoing reliability, security, and efficiency. Regular firmware updates for the microcontroller are essential to fix bugs, enhance performance, and introduce new features. Monitoring and maintaining the cloud server is critical for data integrity and system uptime, involving routine checks, updates, and backups.

Security is a top priority; implementing robust security protocols, such as SSL/TLS for data transmission and regular security audits, helps protect against cyber threats. The communication modules (Wi-Fi or GSM) should be regularly tested to ensure consistent connectivity. The IoT sensors require periodic calibration and testing to maintain accurate data collection. Any faulty sensors should be promptly replaced to prevent inaccurate readings that could impact system performance.

The user interface (web or mobile application) should be regularly updated to improve user experience and incorporate user feedback. Ensuring compatibility with various devices and browsers is also crucial.

Documentation should be kept up-to-date, detailing system configuration, maintenance procedures, and troubleshooting guides. This is important for training new personnel and for reference during maintenance activities.

Lastly, implementing a robust monitoring system that provides real-time alerts for any anomalies or failures ensures that issues can be quickly addressed, minimizing downtime and maintaining the overall health of the system.

## 4.4 TESTING

Initially, functionality testing ensures all components operate correctly and interact as intended. Performance testing assesses system response times and data accuracy under various conditions. Integration testing verifies seamless data flow between sensors, microcontroller, cloud server, and user interface. Security testing is conducted to identify and mitigate vulnerabilities in data transmission and storage. User acceptance testing gathers feedback from users to ensure the interface is intuitive and meets their needs. Regular maintenance checks and automated monitoring systems are implemented to promptly detect and address any issues.

## 4.5 SYSTEM DOCUMENTATION/ INTERFACE OF THE DESIGN

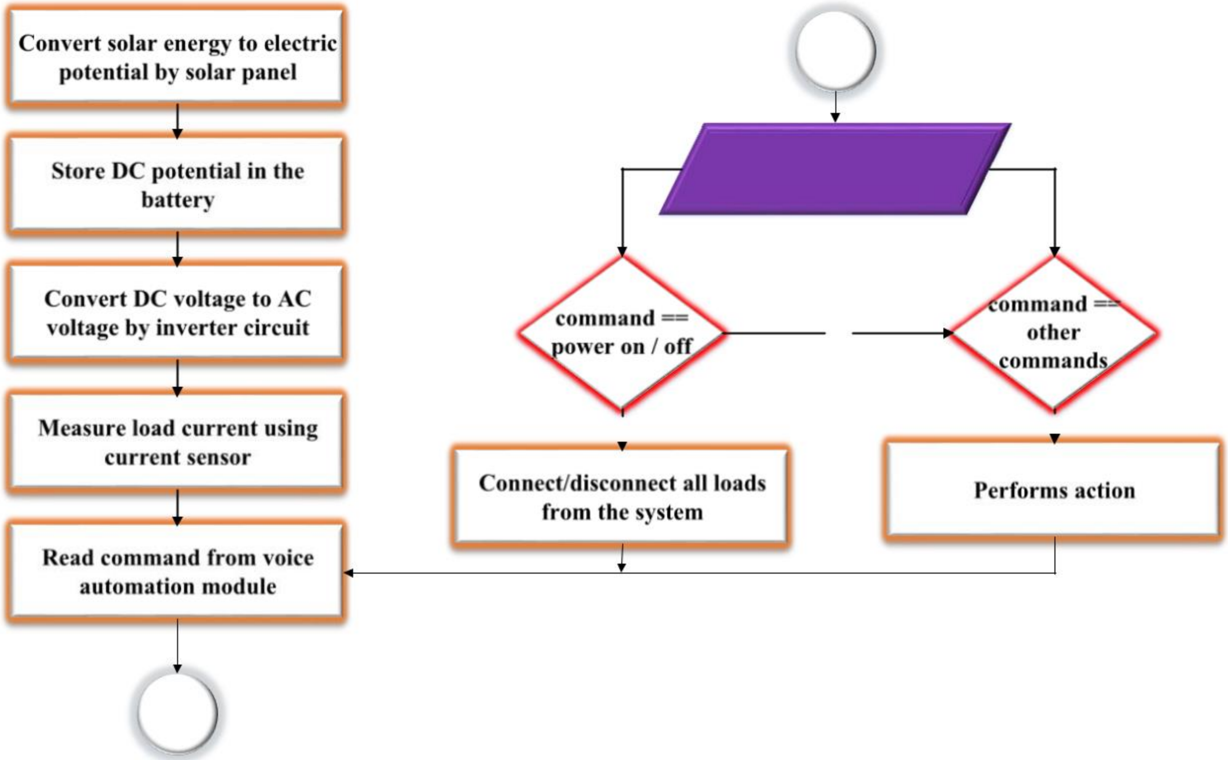
System documentation for the IoT-based smart inverter energy controlling system is essential for maintaining and understanding the system's architecture, components, and operational procedures. It includes:

- **System Overview:** Describes the purpose, scope, and objectives of the system, providing an introduction to its functionality and benefits.
- **Hardware Documentation:** Details specifications, schematics, and connections of hardware components such as the inverter, microcontroller, sensors, and communication modules.

- **Software Documentation:** Includes documentation for microcontroller firmware, cloud server applications, database structure, and APIs used for communication. It outlines installation procedures, configuration settings, and operational guidelines.
- **User Interface Documentation:** Provides instructions for using the web or mobile application, including screenshots and step-by-step guides for monitoring and controlling the inverter system.
- **Testing Documentation:** Records test plans, procedures, and results from functionality, performance, integration, and security testing. It ensures transparency in system reliability and compliance with requirements.
- **Maintenance Documentation**: Covers routine maintenance tasks, troubleshooting guides, and procedures for updating firmware, software, and security measures.
- **Security Documentation:** Includes protocols, measures, and configurations implemented to secure data transmission, storage, and user access.

Effective system documentation facilitates system understanding, troubleshooting, and maintenance, ensuring longevity and optimal performance throughout its lifecycle

## FLOWCHART



Convert solar energy to electric potential by solar panel
Store DC potential in the battery
Convert DC voltage to AC voltage by inverter circuit
Measure load current using current sensor
Read command from voice automation module
command == power on / off
command == other commands
Connect/disconnect all loads from the system
Performs action

# CHAPTER FIVE

# SUMMARY, CONCLUSION AND RECOMMENDATIONS

## 5.1 SUMMARY

This research work focused on designing and developing an IoT-based smart inverter energy controlling system aimed at enhancing energy management efficiency. The system integrates IoT technologies with traditional inverters to enable real-time monitoring, remote control, and optimization of energy usage. Key components included microcontrollers, IoT sensors for data acquisition, communication modules for internet connectivity, and a cloud-based server for data storage and processing. The implementation involved assembling hardware components, developing firmware for data handling, and creating a user-friendly interface for remote access and control. Testing ensured functionality, performance, integration, and security, while documentation provided comprehensive guidelines for system operation and maintenance. Lastly, the project aimed to improve energy efficiency, provide users with real-time monitoring capabilities, and lay the foundation for future enhancements such as scalability and advanced analytics in energy management systems.

## 5.2 CONCLUSION

In conclusion, the research successfully designed and implemented an IoT-based smart inverter energy controlling system, demonstrating its capability to enhance energy management in residential and commercial settings. By integrating IoT technologies with traditional inverters, the system enabled real-time monitoring, remote control, and optimization of energy usage. Throughout the project, key achievements included the selection and integration of appropriate hardware components such as microcontrollers, IoT sensors, and communication modules. The development of robust firmware and cloud-based applications facilitated seamless data acquisition, storage, and processing, ensuring reliable performance. Testing phases validated the system's functionality, performance under various conditions, and security measures, ensuring compliance with operational requirements. User acceptance testing confirmed the effectiveness of the intuitive web-based interface in providing users with accessible and actionable insights into energy consumption and system status. Looking ahead, future enhancements could include scalability to manage multiple inverters, integration with smart grid technologies for enhanced energy distribution, and advanced analytics for predictive maintenance and optimization. Overall, this research contributes to advancing sustainable energy practices by empowering users with tools to monitor, control, and optimize energy usage efficiently and effectively.

## 5.3 RECOMMENDATIONS

Based on the findings and outcomes of this research work on the IoT-based smart inverter energy controlling system, several recommendations can be made for future improvements and extensions:

- **Scalability:** Enhance the system to support scalability by integrating mechanisms to handle multiple inverters seamlessly. This could involve refining communication protocols and cloud infrastructure to efficiently manage a larger number of devices.
- **Advanced Analytics:** Incorporate machine learning algorithms for predictive analytics and optimization. By analyzing historical data and real-time inputs, the system could provide intelligent insights for better energy management and decision-making.
- **Integration with Renewable Energy Sources:** Extend the system's capabilities to integrate with renewable energy sources such as solar panels or wind turbines. This integration would enable the system to optimize energy usage based on availability and demand.

- **Enhanced Security Measures:** Continuously update and strengthen security protocols to protect data integrity and user privacy. This includes regular security audits, encryption of sensitive data, and implementing intrusion detection systems.
- **User Feedback and Iterative Development:** Gather continuous feedback from users to refine the user interface and functionality. Iterative development based on user insights will ensure the system remains intuitive and meets evolving user needs.
- **Collaboration with Utility Providers:** Establish partnerships with utility providers to explore opportunities for integrating the system with smart grid initiatives. This collaboration could enhance grid stability, optimize energy distribution, and potentially offer incentives for energy-efficient practices.

Implementing these recommendations, the IoT-based smart inverter energy controlling system can evolve into a more robust, scalable, and intelligent platform, contributing to sustainable energy management and fostering greater user engagement and satisfaction.

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