

INVERSHARE



By

Rehan Munir	01-132222-036
Rayan Zahoor	01-132222-035
Muhammad Umaar Munir	01-132222-029

Supervised by

Engr. Muhammad Yasir Amir Khan

**DEPARTMENT OF COMPUTER ENGINEERING
BAHRIA UNIVERSITY ISLAMABAD**

2026

INVERSHARE

By

Rehan Munir	01-132222-036
Rayan Zahoor	01-132222-035
Muhammad Umaar Munir	01-132222-029



Supervised by

Engr. Muhammad Yasir Amir Khan

Submitted to the department of computer engineering in the partial
fulfillment of the requirements for the degree of Bachelor of
Computer Engineering

**DEPARTMENT OF COMPUTER ENGINEERING
BAHRIA UNIVERSITY ISLAMABAD**

2026



BAHIRA UNIVERSITY
DEPARTMENT OF COMPUTER ENGINEERING

Dated: 04-06-2026

CERTIFICATE

We accept the work contained in the report titled "**Invershare**" as a confirmation to the required standard for the partial fulfillment the degree of Bachelor of Computer Engineering.

Dr. Waheed Manzoor
Project Coordinator
Date: 04-06-2026

Engr. M Yasir Amir Khan
Supervisor
Date: 04-06.2026

Dr. Ali Arshad Uppal
External Examiner
Date: 04-06.2026

Dr. Syed Khawar Hussain Shah
Internal Examiner
Date: 04-06.2026

Head of Department (CE)
Date: 04-06-2026

INVERSHARE

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Action
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals



Range of Complex Problem Solving			
S. No.	Attribute	Complex Problem	Tick
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	✓
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	✓
3	Depth of knowledge required	Requires advanced research-based knowledge and a fundamentals-based analytical approach.	✓
4	Familiarity of issues	Involve infrequently encountered issues.	✓
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Stakeholder Requirements	Involve diverse groups of stakeholders with widely varying needs.	✓
7	Consequences	Have significant consequences in a range of contexts.	✓
8	Interdependence	Are high-level problems including many component parts or sub-problems.	
Range of Complex Problem Activities			
S. No.	Attribute	Complex Activities	Tick
1	Range of resources	Involve the use of diverse resources (people, money, equipment, materials, information and technologies).	✓
2	Level of interaction	Requires resolution of significant technical and engineering issues arising from complex interactions.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	✓
4	Societal & Environmental Impact	Has significant societal and environmental impacts that are difficult to predict and mitigate.	✓
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

UNDERTAKING

We hereby solemnly declare that the research work entitled “Invershare” is entirely our original work and has been completed under the guidance and supervision of our project supervisor. To the best of our knowledge and belief, this work has not been submitted previously, either in full or in part, to any other university or institution for the award of any degree, diploma, or certification. We further affirm that all sources of information, data, and references utilized in the preparation of this thesis have been duly acknowledged and properly cited in accordance with established academic and research standards. Any assistance received during this work has also been appropriately recognized.

Signature of Student: _____

Name of Student: Rehan Munir

Enrollment Number: 01-132222-036

Signature of Student: _____

Name of Student: Rayan Zahoor

Enrollment Number: 01-132222-035

Signature of Student: _____

Name of Student: Muhammad Umaar Munir

Enrollment Number: 01-132222-029

DEDICATION

We would like to dedicate this thesis to our dear families who have been a source of strength, encouragement and prayers from our initial years in school until we finish this thesis. We are truly thankful to our parents for their values and teachings on hard work, discipline, and perseverance. We appreciate all of your support and encouragement along the way to our siblings.

This work is dedicated to our mentors and teachers who gave us guidance, wisdom and encouragement to push ourselves into the zone of excellence as well as go beyond it. Last but not least, we leave this thesis to all those who have faith that technology can have life-changing effects. Their vision and passion remains to inspire innovative ideas and this project was developed as one of those ideas.

ACKNOWLEDGEMENT

We extend our heartfelt thanks to Allah SWT for providing us with the power, intelligence and perseverance to achieve this research to its planned conclusion. We would like to express our heartfelt gratitude to our supervisor Engr. Muhammad Yasir Amir Khan, for his valuable advices and wisdom throughout the entire process of creating our Final Year Project 'Invershare' and for all his support and constructive feedback. His technical skills, encouragement and academic guidance gave greater shape to the methodology and helped make this work successful.

We are very thankful to our families which give us unconditional love, constant prayers, and continual encouragement. During their most challenging times, their constant support was a lifeline for them, providing motivation and strength they needed. To our colleagues and students, we would also like to extend our warm and deepest gratitude to them who worked hand in hand with us, who offered us beneficial feedback, and encouragement for this academic undertaking.

Finally, we would like to thank the Computer Engineering department as well as the administration of the University in giving us a favorable atmosphere and the essential resources to complete this research. It has been a milestone in our academic and professional endeavor: the completion of Invershare.

ABSTRACT

Intelligent energy management systems have proven to be in an escalating demand thanks to the fast and urgent need for the efficient use of energy resources and the rapid integration of renewable energy resources. To address these new challenges, the project leverages the latest web and cloud-based technologies to create a smart energy monitoring and sharing platform, Invershare, which will maximize energy optimization potential and enable more effective distribution of energy in these areas. The energy can be tracked, analyzed and controlled by the interconnected devices such as solar panels and inverter systems on Invershare. It uses Firebase as its cloud back end to enable real-time data syncing across the Internet of Things (IoT) devices and the cloud-based database. It allows for the scalable and responsive exchanges to data, while ensuring reliability. It is integrated with a user-friendly dashboard that offers a detailed overview of the energy flow, energy consumptions and the surplus available from the energy. Invershare will provide valuable feedback on how energy is used, and help users make informed decisions about future energy allocation and utilization. Moreover, web-based architecture caters for future expansion and enables reliable interactions between smart devices and cloud services. The salient points of the proposed system are real time energy monitoring, user authentication and authorization on the system, detailed record keeping of energy transactions, and intelligent decision making system for enhancing the energy efficiency. The role of Invershare on bettering the logo of sustainable and intelligent energy systems comes from the activity of energy saving and the utilization in the most efficient way of renewable energy resources. On the other hand, the presented platform can be considered the base for future trends regarding the smart grid technologies. Future enhancements could lead to a use of machine learning algorithms for accurate consumption prediction and usage behaviors; creation of mobile applications for better usage and interaction by users, and also an implementation of blockchain technology for a secure, transparent, and decentralized energy trading by every user.

Keywords: Energy Sharing, Smart Dashboard, Firebase, Internet of Things (IoT), Smart Grid, Renewable Energy, Energy Management System.

TABLE OF CONTENTS

UNDERTAKING	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
ABSTRACT.....	vi
LIST OF FIGURES	x
LIST OF TABLES	xii
LIST OF EQUATION	xiii
CHAPTER 1	1
INTRODUCTION	1
1.1 Background.....	1
1.2 Problem Statement.....	2
1.3 Objectives	2
1.4 Scope of the Study	3
1.5 Significance of the Study	4
CHAPTER 2	5
LITERATURE REVIEW	5
2.1 Introduction.....	5
2.2 Traditional Energy Metering Systems	5
2.3 Smart Energy Management Systems	5
2.4 IoT in Energy Monitoring.....	6
2.5 Cloud-Based Energy Platforms.....	7
2.6 Web-Based Dashboards	7
2.7 Energy Sharing and Smart Grids	8
2.8 Existing Systems and Their Limitations	8
2.9 Research Gap	9
2.10 Summary	9
CHAPTER 3	10
METHODOLOGY	10
3.1 Research Methodology Process Flow	10
3.2 System Architecture and Overview	10
3.3 System Block Diagram Description.....	11
3.4 Circuit Design and Simulation.....	12
3.5 Power Regulation Stage.....	12
3.6 Relay Driver Stage.....	13

3.7 Sensor Interface and ESP32 Integration	15
3.8 Proteus Simulation	15
3.9 PCB Design.....	16
3.10 PCB Fabrication.....	17
3.11 Hardware Implementation and Assembly.....	18
3.12 Communication and Data Flow	20
3.13 Data Flow Description	20
3.14 Software Implementation.....	22
3.15 Relay Control Algorithm	22
3.16 Web Dashboard.....	23
3.17 Testing and Validation.....	23
3.18 Integration Testing	24
CHAPTER 4	26
RESULTS	26
4.1 Introduction to Results	26
4.2 System Implementation Results.....	26
4.3 Hardware Setup.....	27
4.4 Software and Cloud Infrastructure.....	28
4.5 Sensor Data Analysis	28
4.6 Current Measurements	29
4.7 Power and Energy Calculation.....	30
4.8 Web Dashboard Results	31
4.9 Energy Sharing Mechanism Results	34
4.10 Excess Energy Transfer Scenario	34
4.11 Energy Deficit Handling	35
4.12 Sharing Efficiency and Fairness	35
4.13 Performance Evaluation.....	36
4.14 Comparison with Existing Systems	37
4.15 Limitations of the System	39
4.16 Discussion	39
CHAPTER 5	42
CONCLUSION.....	42
5.1 Project Summary.....	42
5.2 System Overview	42
5.3 Achievements and Outcomes.....	43

5.4 Technical Contributions	45
5.5 Challenges Faced	46
CHAPTER 6	48
FUTURE WORK.....	48
6.1 Introduction.....	48
6.2 System Scalability Improvements.....	48
6.3 Large-Scale Deployment Considerations.....	49
6.4 National Grid Integration Strategies	50
6.5 Advanced Artificial Intelligence Integration	50
6.6 Machine Learning for Energy Prediction.....	51
6.7 Demand Forecasting and Optimization Algorithms	52
6.8 Blockchain and Secure Energy Trading.....	52
6.9 Distributed Ledger Technology for Transactions	53
6.10 Smart Contracts for Peer-to-Peer Energy Sharing	54
6.12 Advanced Inverter Hardware Development.....	55
6.13 Real-Time Monitoring and Sensor Integration	55
6.14 Mobile Application Upgrades	56
6.15 Cloud and Data Analytics	57
6.16 Gamification and User Engagement Features.....	57
6.17 Wind and Hybrid System Integration	58
6.18 Security and Privacy Enhancements	59
6.20 Real-World Deployment Challenges	61
6.21 User Adoption Barriers and Mitigation Strategies.....	61
6.22 Conclusion	62
REFERENCES	63
ABBREVIATIONS	70
ANNEXURE	71
Annexure A – Hardware Specifications.....	71
Annexure B – Circuit Simulation	71
Annexure C – Software Implementation	72
Annexure D – Testing and Validation	72

LIST OF FIGURES

<i>Number</i>	<i>Page</i>
Fig 1.1 The increasing global population have increased energy consumption.....	2
Fig 1.2 Need for intelligent systems that can monitor, manage in real time.....	3
Fig 1.3 Cost-effective solution for real-time monitoring using smart sharing.....	4
Fig 2.1 Block Diagram of Smart Grid System.....	6
Fig 2.2 Monitoring PV System Using IoT.....	6
Fig 2.3 Energy-Aware Cloud System Model.....	7
Fig 2.4 Real-Time Data Display on Node-RED	7
Fig 2.5 Overview of Smart Grid	8
Fig 3.1 Research Methodology Process Flow.....	10
Fig 3.2 Block Diagram of the InverShare Three-Node Energy Sharing System	11
Fig 3.3 Voltage Regulation Stage Schematic.....	13
Fig 3.4 Relay Driver Circuit	14
Fig 3.5 Proteus Simulation Workspace.....	15
Fig 3.6 PCB Layout Design in Proteus ARES.....	18
Fig 3.7 Fabricated PCB After Etching and Drilling.....	19
Fig 3.8 Assembled Invershare Hardware Node	21
Fig 3.9 Web Dashboard Interface	23
Fig 4.1 Hardware Prototype.....	27
Fig 4.2 Voltage Measurement Arrangement.....	29
Fig 4.3 User Dashboard Overview.....	31
Fig 4.4 Live Monitoring Screen.....	31
Fig 4.5 Battery Status.....	32
Fig 4.6 Bill Detail	32
Fig 4.7 Admin Dashboard Overview	32
Fig 4.8 Admin Live Monitoring.....	33
Fig 4.9 Admin Battery Status.....	33
Fig 4.10 User Status Screen	33
Fig 4.11 Energy Sharing Simulation.....	34
Fig 4.12 Comparison with Existing Systems	38
Fig 6.1 Large-Scale Deployment	49
Fig 6.2 Invershare Integration with National Grid.....	50
Fig 6.3 Concept of Advanced AI in IoT Products	51
Fig 6.4 Blockchain-Based Secure Energy Trading	53
Fig 6.5 Distributed Ledger Technology	54
Fig 6.6 Peer-to-Peer Energy Trading	54
Fig 6.7 Real-Time Monitoring and Sensor Integration.....	55

Fig 6.8 Mobile Application for the Invershare.....	56
Fig 6.9 Cloud-Based Data Analytics Framework	57
Fig 6.10 Gamification and User Engagement Features	58
Fig 6.11 Energy storage wind solar hybrid systems.	59
Fig 6.12 Multi-Factor Authentication	60
Fig 6.13 Illustrate five key barriers to technology adoption	61

LIST OF TABLES

<i>Number</i>	<i>Page</i>
Table 4.1 Comparison of Reference and Measured Voltage Readings.....	28
Table 4.2 Comparison of Reference and Measured Current Readings	29

LIST OF EQUATION

<i>Number</i>	<i>Page</i>
Eq 3.1 Diode Power Loss Equation	12
Eq 3.2 LM2596 Output Voltage Equation.....	13
Eq 3.3 Inductor Ripple Current Equation	13
Eq 3.4 Base Resistor Calculation.....	14
Eq 3.5 Voltage Divider Ratio.....	15
Eq 3.6 Power Calculation	15
Eq 3.7 Energy Calculation	15
Eq 3.8 PCB Trace Width Equation	16
Eq 3.9 Averaging Equation for ADC Samples	21
Eq 3.10 ADC to Physical Voltage Conversion	20
Eq 3.11 Hysteresis Relay Control Condition	22
Eq 3.12 Mean Absolute Percentage Error (MAPE)	24
Eq 4.1 Percentage Error Equation (Voltage)	28
Eq 4.2 Percentage Error Equation (Current)	30
Eq 4.3 Active Power Equation.....	30

CHAPTER 1

INTRODUCTION

The growing need for energy worldwide, along with the urgent need to reduce carbon emissions, means we must make big changes in how we produce and use energy [1]. Renewable sources, especially solar power, are key to solving this problem because they provide a steady and eco-friendly way to meet rising energy demands [2]. The move toward renewable energy is being helped by improvements in smart grid technology, which makes it easier to manage and use energy from different sources more efficiently [3]. These systems enable energy providers and consumers to communicate and co-operate, which helps the balancing of supply and demand and leads to the stabilization of the grid [4]. Renewable energy generation (and most specifically solar generation) has flourished due to increases in solar panel efficiency, decreases in their price and government support enabling solar to be one of the predominant forms of global energy generation [5]. However, renewable sources like solar (as mentioned) have inherent natural fluctuations which are detrimental to the grid if they are not managed correctly [6]. The unpredictable nature of the supply, therefore, necessitates the need for a sophisticated energy management system, capable of observing, predicting and controlling the flow of energy in real-time so that grid stability and efficiency is maintained [7]. Standard power systems do not provide this fine level of control or visibility needed to adequately interface with variable energy generation, and hence can cause inefficiencies.

1.1 Background

There is a constant need for more energy on a worldwide scale and also the need for environmental protection, this makes evident that renewable energies need to be implemented. Fossil fuel traditional sources of energy are a principal reason for the emission of greenhouse gases, which accelerates global warming and jeopardize sustainable development [8]. As a result, renewable energies sources such as wind and solar powers are being adopted widely, because they offer clean, sustainable, and distributed energy production. However the application and management of those

renewable sources have many constraints and complex task such as the control of energy production, management and sharing in real-time [9]. This project addresses this problem by presenting an Invershare, a smart system for the sharing and monitoring of energy where production, consumption and sharing can be displayed and controlled in real-time by means of web application and using cloud services such as Firebase.

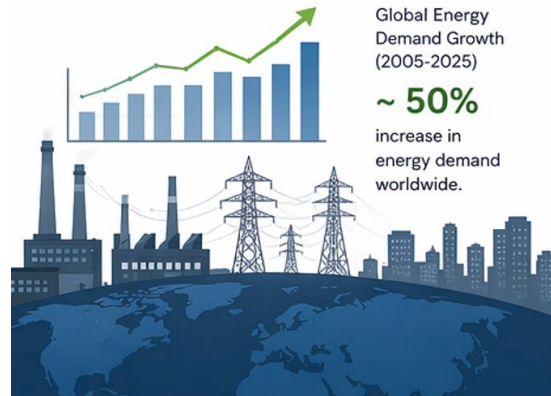


Fig 1.1: The increasing global population and industrialization have significantly increased energy consumption.[9]

1.2 Problem Statement

Despite the increasing popularity of smart technologies, significant hurdles to widespread adoption of effective energy management systems remain. Firstly, the inefficiency of current energy usage is a problem amplified by lack of smart real time energy sharing and monitoring features in most existing systems [10]. Energy meters that are currently being used have a lot of drawbacks; limited measurement parameters, lack of real-time data reporting, high cost, making them unaffordable to the general public [11]. Many of the existing systems are standalone and lack the ability to interoperate, hence preventing effective energy sharing communities where excess renewable energy is utilized to fulfill a locality's shortages [12]. This leads to inefficient energy utilization and the loss of the potential for maximum gains from renewable energy investments.

1.3 Objectives

The primary objectives of this research work are: To design and implement a comprehensive IoT based framework called "Invershare" to monitor electrical quantities with precision, and high reliability in real time. In particular, the design of

low cost hardware unit is going to monitor generation and consumptions of energy using non invasive sensors [13]. It is also objective to implement a cloud connected dashboard which displays the energy values with clarity and user-friendliness in the form of accessible plots to help users take decisions on their energy consumptions [14]. The third objective of the project is to design and implement an smart system for the sharing of energy so that members of a community can sell or purchase the excess renewable energy they produce or consume, thus optimizing energy efficiency and the grid load [15].



Fig 1.2: There is a need for intelligent systems that can monitor, manage, and share energy in real time for better efficiency and sustainability.[15]

1.4 Scope of the Study

This study focuses on the design, implementation, and evaluation of a low-voltage energy monitoring and sharing system intended for residential and small community microgrid environments. The system is limited to DC-based energy measurement using voltage and current sensors interfaced with an ESP32 microcontroller. Real-time data monitoring and control are implemented through a cloud-based platform using Firebase services.[16]

The scope of this work is restricted to prototype-level validation under controlled laboratory conditions. Grid synchronization, high-voltage AC systems, long-term field deployment, and commercial-scale energy trading mechanisms are beyond the scope of this study.

1.5 Significance of the Study

The significance of this study lies in its contribution to decentralized energy management solutions for resource-constrained residential and small community environments. By enabling real-time monitoring and peer-based energy sharing, the proposed system promotes efficient utilization of locally generated renewable energy and reduces dependency on centralized grid infrastructure [17]. The low-cost hardware design and cloud-based architecture make the system accessible for developing regions where advanced smart grid solutions are often economically impractical. Additionally, this work provides a foundational framework for future research in microgrid energy sharing, smart metering, and distributed renewable energy systems.



Fig 1.3: Provide a cost-effective solution for real-time monitoring using smart sharing. [17]

It is important to note that the research does not address large-scale power system issues such as national grid operation, transmission line protection, fault analysis, load forecasting, power market regulation, or high-voltage transmission and distribution infrastructure. Similarly, advanced smart-grid functions such as demand response management, utility-scale energy storage coordination, and grid frequency stabilization are beyond the scope of this project. Instead, the study focuses on demonstrating the feasibility and effectiveness of a localized smart energy-sharing platform that can serve as a foundation for future expansion into larger and more complex energy systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

It is noted that the field of smart energy systems has significantly advanced in recent years due to the utilization of the Internet of Things (IoT) and cloud computing. Indeed, the integration of these technologies has drastically transformed the way in which energy is managed, allowing the system to become a lot smarter and more autonomous. It enables real-time monitoring of the generation and usage of energy thus allowing a user to take quicker and more effective decisions. Automation of the data acquisition decreases the dependence on manual efforts making them more accurate and less resource intensive. The application of the analysis techniques allows identification of the patterns of energy consumption thereby leading to its savings and avoiding wastage. New energy management systems allow user-friendly management with convenient displays of energy information via web dashboards.

2.2 Traditional Energy Metering Systems

An old meter that can only be manually read is typically used in traditional systems. Manual energy readings will have to be taken by a meter reader and each site will have to be visited to collect the readings. This is a slow and expensive process and human errors in taking the readings could potentially cause an over-charging of energy use. Also, due to the lack of real-time data users are not aware of what energy is being consumed or how to conserve it, thus traditional systems are inadequate for present-day requirements [18].

2.3 Smart Energy Management Systems

Smart energy management systems (SEMS) mark a big change in how energy is made, distributed, and used. Early research, like that by Gungor et al. [19], showed improvements in smart grid architecture, focusing on the importance of communication networks in allowing two-way power flow and real-time monitoring. Later studies introduced optimization methods for managing energy demand, such as the work by Mohsenian-Rad et al. [20], who suggested automatic demand response strategies for home energy use. SEMS is a system that applies the high standard meter and

communication technologies in order to enhance the energy efficiency and reduce the running costs. But as pointed by Fang et al. [21], there exist some disadvantages such as incompatibility, large installation cost and privacy protection. Advanced SEMS may also possess functions of forecasting, automation and optimization. The functions are of prediction in terms of energy consumption rather than measurement of energy consumption.

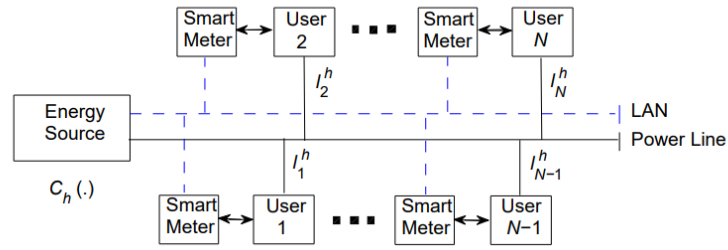


Fig 2.1: Block diagram of smart grid system composed of an energy source, users, a distribution power line, and a local area communication network. [21]

2.4 IoT in Energy Monitoring

The use of IoT devices in energy systems allows for detailed, real-time tracking and control of energy movement. Alahakoon and Yu [22] looked at how IoT is used in smart grids, showing how sensor networks and small embedded devices help collect data and automate systems. Zahra et al. [23] created an IoT-based monitoring system for solar energy, using wireless sensors and cloud technology to display and study energy output. Such methods also contribute to an enhanced system understanding and fault identification. As explained by Khan et al. [24].

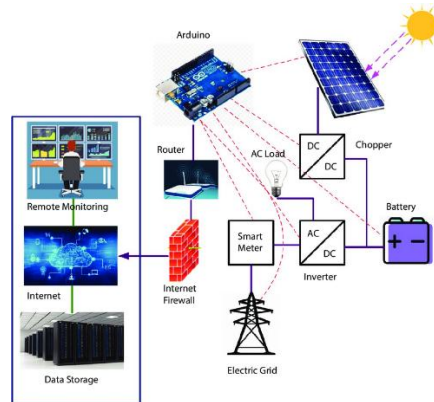


Fig 2.2: Monitoring PV system using IoT. [24]

2.5 Cloud-Based Energy Platforms

It becomes more crucial to build a scalable, friendly and intelligent energy management system using cloud computing services such as Firebase and AWS IoT which have services for data storage, analysis and presentation in real time. Niyato et al. [25] considered a cloud-based control for decentralized resources management which is characterized with central data analysis and remote access to system and the Shafique et al. [26] built a cloud-based web interface for home energy monitoring which allows to display the home energy usage and providing valuable information. Even though these solution offers flexible functionalities and strong analytic tools, some of them has drawbacks as data transmitting latency, permanent internet access necessity and data privacy concern [27].

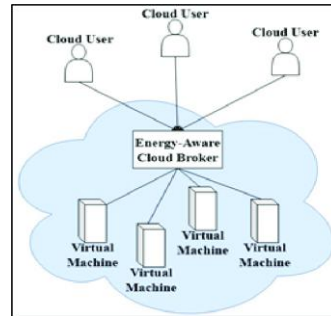


Fig 2.3: Energy-aware cloud system model. [27]

2.6 Web-Based Dashboards

Web-dashboards are integral part of Smart Energy systems [28]. Dashboards offer an intuitive visualization of energy data using graphs, charts and reports to make complex information easy to understand. It provides real-time update of energy information and customization for the user's preferences help the user to make better decisions and remain motivated.



Fig 2.4: Real-time energy monitoring dashboard, adapted from [28].

2.7 Energy Sharing and Smart Grids

One way that to utilize resources more efficiently and incentivize people to produce and consume energy is energy sharing, in particular between dispersed renewable energy resources. For P2P energy trading, the work of Liu et al. [29] proposes to use the IoT and blockchain technology in smart grids in order to create a transparent and secured transaction system. Zhang et al. [30] implemented a solar energy sharing mechanism where surplus power is transferred between adjacent houses through inverter communication. While such systems are reliable and facilitate renewable energy utilization [37], they require high compatibility among devices and secure communication channels.

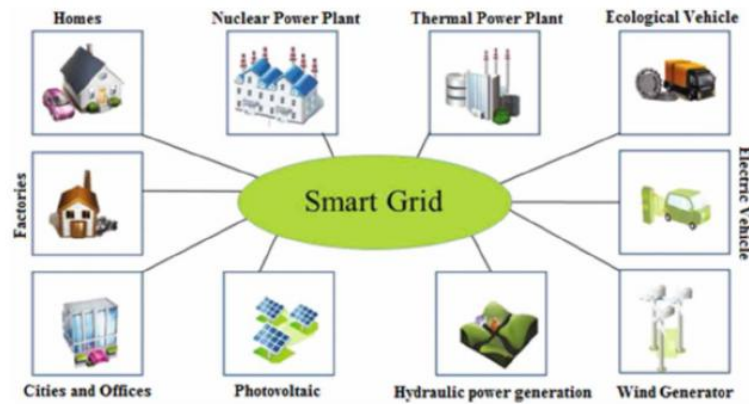


Fig 2.5: Overview of smart grid (Hassan et al. 2018) [37]

2.8 Existing Systems and Their Limitations

Considering the existing systems on the commercial and academic level, although many advancements were made in the field of energy management and smart grids, some issues are yet to be solved. For example, the system by OpenADR [31] allows for dynamic adjustment of demand, but does not support sharing of energy. The system proposed in [32] by Sanguinetti et al. Is designed to manage multiple inverters and thus overcome a major drawback of single-inverter-only based systems but is inefficient in terms of real-time capabilities and scaling up. Most of the systems proposed allow the user to either monitor the power or to some extend manage it, but a system enabling sharing of energy, using communication protocols like IoT and having friendly cloud

dashboards is hard to find. Moreover, problems of interoperability of devices, data standardization, security are still present [33].

2.9 Research Gap

Despite advances made to smart grids, IoT monitoring, and cloud services, the majority of the systems operate individually and cannot facilitate the real-time, autonomous sharing of energy among the various inverter based systems. The systems also lack sophisticated, easy to use dashboard applications capable of handling monitoring, sharing and control within a secured and compatible platform, thereby inhibiting prosumer based energy communities from achieving their full potential. Invershare attempts to bridge this gap between monitoring and sharing through the integration of real-time monitoring, cloud management and smart sharing between inverters.

2.10 Summary

The review presented an overview of smart energy management system, IoT-based monitoring and its management system, cloud platforms and the energy sharing frameworks, during the last two decades. The significant efforts that have been made have resulted in progress; however, problems such as integration and the difficulty in extending the architecture to multiple consumers, together with compatibility issues. There is room for a new framework, such as Invershare. In the subsequent chapters, the design, implementation and performance of the Invershare will be elaborated in the solving of the above-mentioned issues.

CHAPTER 3

METHODOLOGY

The technical methodology section illustrates the overall technical framework along with a structured engineering process to achieve designing, simulating and realizing the Invershare: Smart Energy Sharing and Monitoring System. This approach signifies the migration of the proposed distributed energy management idea into a multi-node hardware prototype. In the succeeding sections, a comprehensive explanation of the hardware design, the pcb design, the Internet of Things connectivity, along with the ESP32 and Google Firebase and the testing framework are explained in detail.

3.1 Research Methodology Process Flow

This process was structured and carried through from the thorough review of previously published works to the actual testing with physical hardware. The flowchart below displays the steps taken.

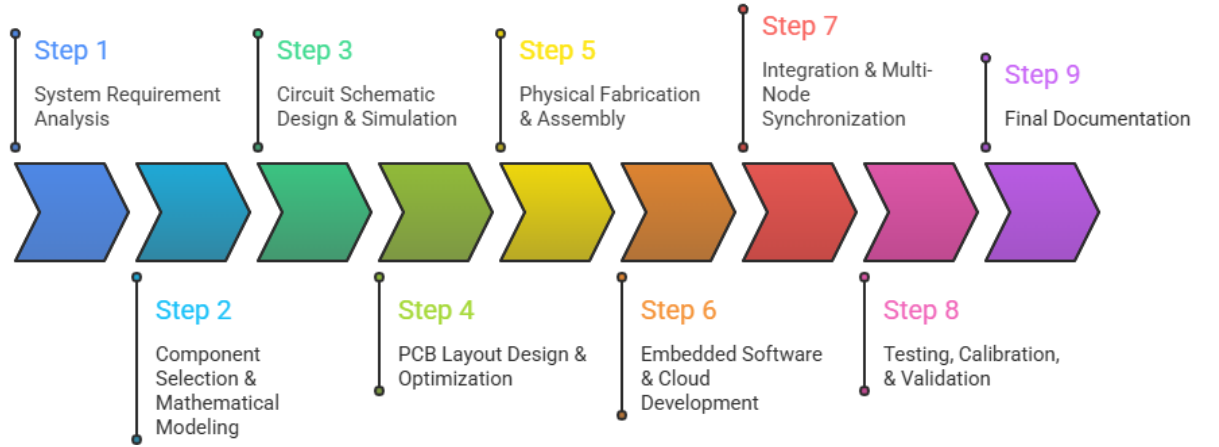


Fig 3.1: Shows the full methodology of the project execution.

3.2 System Architecture and Overview

The Invershare system is constructed in a distributed peer-to-peer smart grid system framework where each of the nodes is defined as a 'prosumer' (it is able to produce and consume locally produced energy) and the nodes are interconnected through the same network for sharing energy [34]. Distribution of the control mechanism in such manner improves the robustness and stability of the system as failure of one node would not

affect the function of the entire energy sharing system [35]. In the proposed architecture, every node acts as a prosumer where a prosumer can produce or consume the energy. Each node is interconnected with a renewable energy source (e.g. A solar panel) and also uses energy in meeting its local electrical loads. When the energy generated by a node is higher than that consumed by it, the extra energy can be fed into the energy network, shared with the connected neighbor nodes; When a node needs energy, it can be obtained from a neighbor node, which can provide that amount.

3.3 System Block Diagram Description

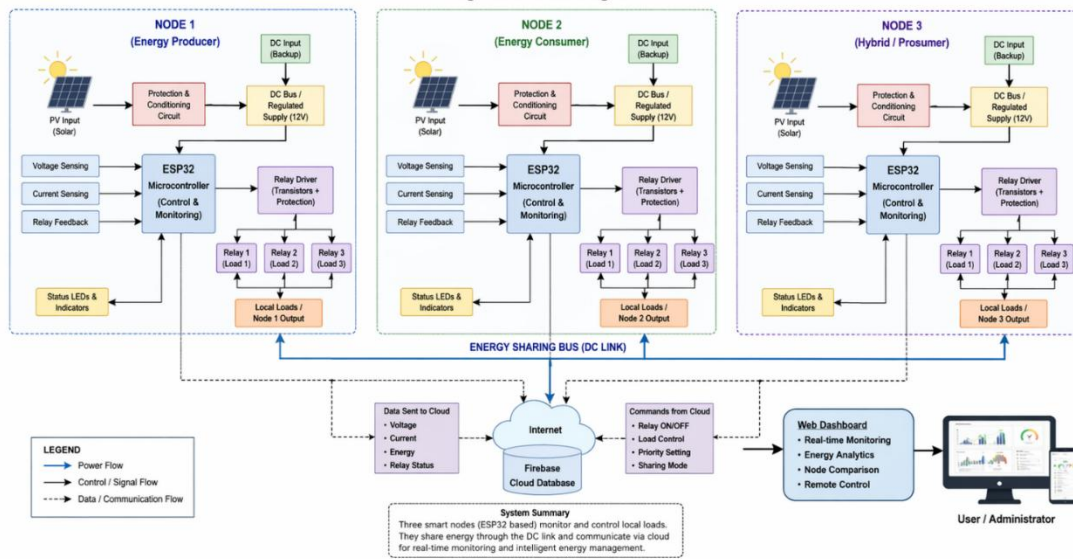


Fig 3.2: Block diagram of the Invershare three-node energy sharing system.

The system consists of three nodes:

1. Node 1 (Producer): Receives energy from PV input
2. Node 2 (Consumer): Consumes energy from the DC bus
3. Node 3 (Prosumer): Can both produce and consume energy

Each node includes:

- ✓ Power conditioning circuit (diodes, capacitors, inductors)
- ✓ ESP32 microcontroller (control unit)
- ✓ Relay driver circuit (transistor-based)
- ✓ Three relay outputs for load control

- ✓ Communication module (Wi-Fi / Firebase)

Each Invershare node is interconnected through a DC energy sharing bus, to control the power sharing between them.

3.4 Circuit Design and Simulation

The schematic of each Invershare node is shown below. Each Invershare node's schematic was drawn using the software called 'Proteus Design Suite 8.13'. This is a professional electronics design suite, allowing schematic capture, SPICE simulation, and PCB design [36].

The schematic can be broadly divided into five major sections. They are:

- (i) The power input section
- (ii) The power regulation and conditioning section
- (iii) The relay driver and switching section,
- (iv) The ESP32 microcontroller,
- (v) The sensor connection part.

The input section receives power from two sources; solar panel, and standard DC supply. Schottky barrier diodes (1 N5822 which handles a maximum current of 3A and a voltage of 40V) are used to ensure that electricity doesn't back-feed from one source to another. A Schottky diode was chosen over a normal diode because of the small forward voltage drop when it conducts (about 0.3V for 1A). This minimises energy wastage in the circuit as the power wasted can be calculated from the formula below:

$$P_{(diode)} = V_f \times I_{(forward)} \quad (3.1)$$

where P_{diode} is the power dissipated by the diode, V_f is the forward voltage drop across the diode and $I_{forward}$ is the current passing through the diode. Reducing P_{diode} was necessary as efficiency was the primary concern. An electrolytic capacitor ($C1=1000 \mu F$, 25V) is then placed after the diode section to filter out the low frequency voltage fluctuations while a ceramic capacitor ($C2=100 \text{ nF}$) is placed in parallel to filter the high frequency voltage spikes [37].

3.5 Power Regulation Stage

Voltage regulation is carried out by the LM2596 step-down switching regulator, configured as a closed loop system. The switching regulator operates at a nominal

switching frequency of 150 kHz and operates between a range of 40 volts input and a fixed 5 volt output by using external resistor divider. The voltage at the output $V_{(out)}$ is determined by Equation (3.2) below:

$$V_{(out)} = V_{(ref)} \left(1 + \frac{R_2}{R_1} \right) \quad (3.2)$$

$V_{(ref)}$ here is the internal reference voltage at the Sensor and is set at 1.23 V. R_1 is the lower resistor in the voltage divider, which is set at 1 k in this design while R_2 is the upper resistor in the divider. R_2 is set such that the desired output voltage is 5 volts, and in this case it works out at 3.07k and a standard value resistor of 3.09k is used. A Schottky freewheeling diode, D2, with the part number 1N5822 is placed at the switching node for current to continue flowing when the internal switch is off. The output inductor, L1, is chosen based on the ripple current requirement:

$$\Delta I_L = \frac{(V_{(in)} - V_{(out)})D}{f_{(sw)}L} \quad (3.3)$$

Here, D is the duty cycle, which is the ratio of V_{out} to V_{in} , f_{sw} is the switching frequency, and L is the inductance value.

A ripple current less than 30% of the maximum load current was aimed for, resulting in the selection of L1 as 100 μ H. The output filter capacitor, C3, is 470 μ F and helps to smooth the output further [44].

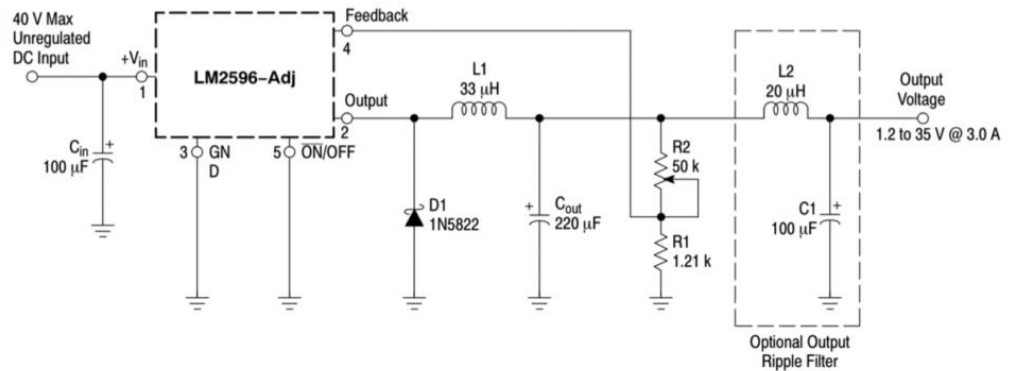


Fig 3.3: Schematic of the voltage regulation stage including the inductor, freewheeling diode, and output filter capacitor.

3.6 Relay Driver Stage

Load switching and control of the direction of energy flow are achieved using SPDT (Single Pole Double Throw) electromagnetic relays. The selected relays operate with a

5 V coil voltage and can switch currents up to 10 A at the contacts. Since the GPIO pins of the ESP32 microcontroller can source a maximum current of approximately 12 mA, they are unable to directly drive the relay coil, which typically requires a coil current in the range of 70–80 mA. To overcome this limitation a transistor relay driver circuit is used. The NPN BJT (BC547) is used in common emitter configuration with the relay coil in the collector load. The transistor acts as a low-side switch and hence the ESP32 can switch the relay but it can not supply enough current to the relay coil.

The base resistor R_b is calculated using the relationship:

$$R_b = \frac{V_{GPIO} - V_{BE}}{I_B} \quad (3.4)$$

Where V_{GPIO} is the ESP32 output voltage (3.3 V), V_{BE} is the base-emitter voltage of the transistor (around 0.7 V) and I_B is the required base current. The current used by the relay coil is around 75 mA, when the coil is energized. An conservative forced current gain was chosen to ensure the transistor operates in saturation and this leads to a required base current of around 7 mA. Based on this value the required base resistor calculated is 3.8 k. This resistor value gives enough base current to ensure saturation and is less than the current sourcing ability of the ESP32 GPIO pin.

A flyback protection diode is connected in parallel to the relay coil (connected reverse biased). [38].

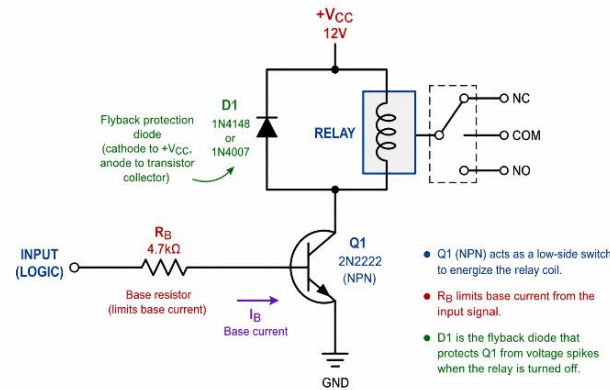


Fig 3.4: Relay driver circuit showing the NPN BJT switch, base resistor, relay coil, and flyback protection diode.

3.7 Sensor Interface and ESP32 Integration

Voltage sensing at the input and output nodes is done using a resistive voltage divider. This divides the bus voltage, which can be up to 18V, down to the 0–3.3V range that the ESP32 ADC can handle. The ratio of the divider is set by the formula:

$$V_{(ADC)} = \frac{V_{(bus)}R_2}{R_1+R_2} \quad (3.5)$$

For the maximum bus voltage of 18V and the maximum ADC voltage of 3.3V, the ratio $R_2/(R_1+R_2)$ equals 0.183. This is achieved by using $R_1 = 47 \text{ k}\Omega$ and $R_2 = 10 \text{ k}\Omega$.

The sensitivity is 185 mV per ampere, and the output is 2.5V when there is no current [39].

The ESP32 ADC samples both the voltage and current signals and calculates the instantaneous power using the formula:

$$P = V \times I \quad (3.6)$$

The energy used or generated over a period Δt is calculated by integrating the power over that time using:

$$E = P \times \Delta t \quad (3.7)$$

These calculated values are sent to Firebase for storage and to display on a dashboard.

3.8 Proteus Simulation

This whole design was simulated in Proteus 8.13 (prior to making the PCB). Analog components were simulated using SPICE models, while digital components using ISIS virtual components. Four checks were performed during simulation: first, to ensure that the output voltage remains at 5V regardless of whether load on the output ranges from 100mA to 1A, second, to ensure the relay would turn on when receiving the appropriate signal from the ESP32 and turn off again.

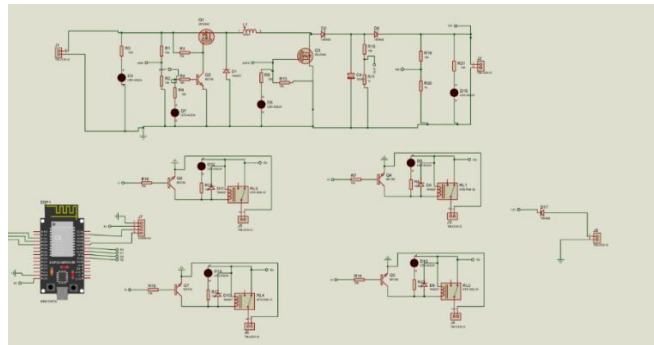


Fig 3.4: Proteus simulation workspace showing the complete node circuit.

3.9 PCB Design

Once the simulation was proven to be correct, the schematic was converted to a PCB layout in the Proteus ARES PCB layout software. The PCB was designed to be single-sided in order to reduce manufacturing cost and difficulty which matches the chemical etching process in the home lab environment. The dimensions of the PCB was 100 mm by 80 mm to allow adequate space to house all the components including the ESP32 module, voltage regulator, relay and the various sensors. In the PCB layout design I followed normal design practice. For power lines, which carry larger currents, a wider path width was chosen (2.0 mm) to reduce resistance and power dissipation, calculated using the following formula from the IPC-2221 standard:

$$W = \left(\frac{I}{k(\Delta T)^{0.44}} \right)^{1/0.725} \quad (3.8)$$

In this formula W = width in mils, I = current in amps, T = max allowable temperature increase in degrees Celsius, and k is a constant (0.048 for an external trace). With the calculation $I=2A$ and $T=20C$ it resulted in a minimum width of approximately 1.5mm and I picked a more conservative 2.0mm [48]. The signal traces were set to a width of 0.8mm. I tried to put ground planes everywhere possible in order to lower the resistance and reduce the boards immunity to EMI. To keep the current paths away from the sensitive signal paths components were group according to function: the power supply parts on one side of the board, the voltage regulator on the middle.

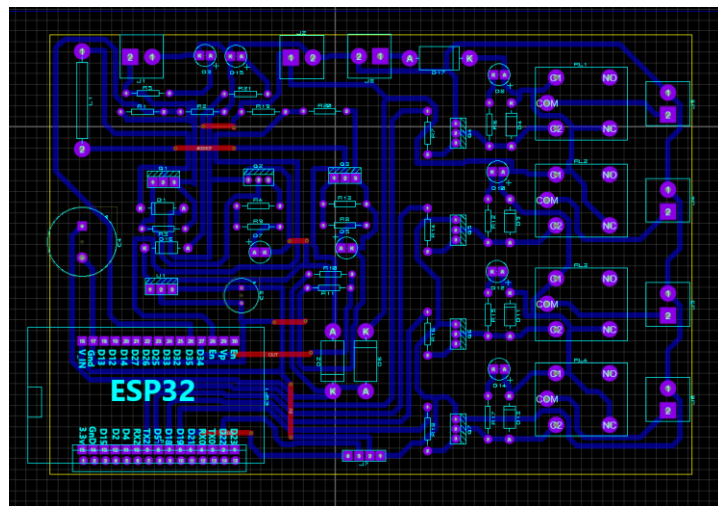


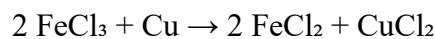
Fig 3.5: PCB layout design in Proteus ARES showing component placement, routing, and trace widths.

3.10 PCB Fabrication

Three identical PCBs were made in-house using the photolithographic toner-transfer (press-and-peel) method, followed by chemical etching with Ferric Chloride (FeCl_3).

The process followed these steps:

1. Artwork Printing: The PCB layout was printed on glossy photo paper with a laser printer set to 1200 DPI to make sure the printed traces were clear and sharp without any toner spreading.
2. Copper Clad Board Preparation: Single-sided copper-clad FR4 boards were cut to the desired size (100 mm $\times$ 80 mm).
3. The copper surface was cleaned with 400 grit sandpaper and isopropyl alcohol to remove any oxidation or dirt, which helps the toner stick better.
4. Printed artwork was laid face-down on the copper, and the artwork was compressed by applying pressure and heat at approximately 200°C for 5-7 minutes. Printed artwork was applied on copper face down and was pressed for 5-7 minutes at a steady pressure with the help of a heated iron at 200 C to carry out toner transfer.
5. Then, the board was removed to warm water to release the paper backing and only the resulting toner pattern remained on the copper.
6. Etching was done by immersing the board into the Ferric Chloride (FeCl_3) solution (around 400 g/L Ferric Chloride and 40 to 45°C).
7. The board was stirred regularly to speed up the etching. The total process would take 15-25 minutes when it was finished all the copper that was not in the mask would have dissolved. Etching reaction is:



8. Cleaning and Inspection: 8-1. Their etching results were found by removing the toner used by etching with acetone.
9. The etched traces were checked using the magnifying glass and checked for shorts or open circuits using a continuity tester.
10. Drilling: Through holes on the components were drilled by a hand-held PCB drill machine with 0.8 mm and 1.0 mm bit on the component lead and connector terminal through hole respectively.

11. 11. After fabrication, the pcb was visually inspected and measured for hole position accuracy, trace cleanliness, dimensions and general manufacturing accuracy.
12. 12. All steps from 1-11 were repeated to fabricate three duplicate PCBs. These would be used for the actual testing of the designed circuit.

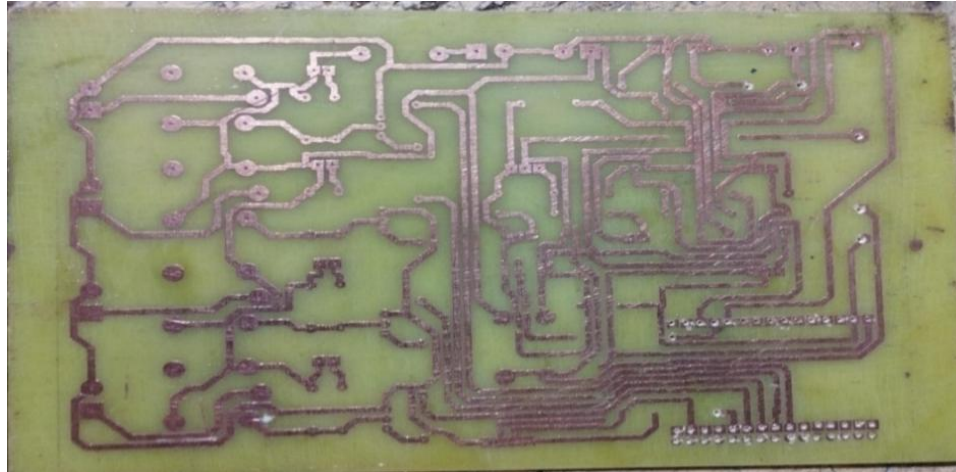


Fig 3.6: Fabricated PCB after etching and drilling, showing the copper trace pattern ready for component assembly.

3.11 Hardware Implementation and Assembly

The assembled PCB boards were then populated with electronic components and soldering was done by hand using a temperature-controlled soldering station heated up to approximately 330C. All the electronic components used were purchased from reputable distributors so that the necessary quality and standard of specification would be met. The components were cross-referenced with the bill of materials (BOM), sorted by component category and values, inspected for obvious faults and then ready for component insertion on the workstation. The workstation was lit to enable correct component placement and ensure good quality soldering.

Component placement started by placing low profile components first and then building upwards in height with progressively larger components. Fixed resistors were placed at the correct pads on the PCB, soldered, and excess component lead cut away. Ceramic capacitors were placed on the PCB, then electrolytic capacitors were inserted carefully so as to avoid insertion in the reverse direction. Diodes were then placed on the PCB making sure the cathode markings on the component matched the silkscreen

markers on the PCB. The integrated circuit was then placed on the correct pads according to package markings, completing insertion of discrete and passive components. The relay module and ACS712 current sensor module were then installed in their respective locations. Last but not least the female headers were added to the board to use the ESP32 development board so that the microcontroller can be quickly removed for programming and maintenance or, simply, troubleshooting or replacement.

When the boards were soldered, they were then thoroughly inspected and tested before power was put on them. All solder joints were inspected visually with a magnifying glass to detect solder bridges, solder under coverage, cold solder joints and any other assembly defect. A digital multimeter was used to measure the resistance that exists between the VCC and GND power rails to be sure that it was greater than 1 k Ω on initial energization to make it less likely to cause shorting out. Polarity and functionality of the installed diodes were verified by testing them in the diode-test mode of the multimeter and testing critical signal paths and power connections to ensure proper electrical connectivity throughout the circuit to make sure that the testing was accurate.

Three identical boards were built which are each an Invershare node. The finished products were termed as NodeA, NodeB, and NodeC in order to identify them for the experimental evaluation and testing. Initial power-up was done with a lab power supply set to a current limit in the range of 50 mAmperes, to protect the power supply circuits in case there were any assembly issues that might cause the power supply to draw too much power.

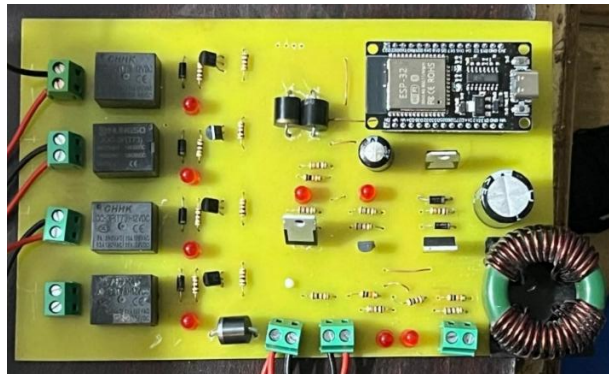


Fig 3.7: Assembled Invershare hardware node showing the ESP32 module.

The three nodes were interconnected by sharing a common DC bus bar via 18 AWG copper wire. All of the relays from the nodes' outputs were connected to this common bus, so that power can be transferred from nodes with a surplus of power to nodes requiring a supply. 5V USB supply was provided from individual USB power adapter to the ESP32 microcontroller and the 5V logic of each node. This isolated the control circuitry from the main power bus to prevent ground loops and to allow stable microcontroller operation [40]. The voltage sensing circuitry consists of a resistive voltage divider directly connected to the ESP32 ADC. The prototype used galvanic isolation did not use Galvanic isolation since all tests are carried out under controlled laboratory conditions with a low voltage DC source, was not connected to the main supply, and is designed to operate within the limits of ESP32 ADC. The main objective of this circuit is to reduce the complexity of the circuit and costs.

3.12 Communication and Data Flow

For communication purposes Invershare uses a cloud-based approach in which all the ESP32 devices can connect to Google Firebase Realtime Database via the IEEE 802.11 b/g/n Wi-Fi protocol [50]. The Firebase Realtime Database is a NoSQL cloud database structured like a JSON tree and enables real-time data synchronization very rapidly thus being well-suited for the needs of the IoT world to get instantaneous updates. All the devices maintain a constant connection with Wi-Fi and send sensor data periodically every 5s according to the current settings. The web interface can access the Firebase database via the Firebase JavaScript SDK and it can access the real-time updates through the use of WebSocket notifications without needing page refresh.

Though Firebase Realtime Database is being used for time-sensitive synchronization of sensor data and for real-time updates in the dashboard, Google Firestore has been incorporated into the cloud infrastructure in order to manage the organized and non time-sensitive data, including users profile, account meta data, permissions and transactions history.

3.13 Data Flow Description

The data moves through the Invershare system in four steps.

1. Sensing is the first stage, where the ESP32 reads the output from the voltage divider, and then also reads the voltage output from the ACS712 sensor 10 times

per second. The ADC must take multiple readings over a 1 second duration, and average the readings, to make it more accurate, and to reduce the noise. It is accomplished by taking the sum of all the readings and dividing into the number of samples such as this:

$$V_{(avg)} = \frac{1}{N} \sum_{(i=1)}^N V_i \quad (3.9)$$

➤ where N = 10 and Vi is each reading converted into voltage.

2. Processing is the second stage where the voltages, currents, power and total energy values are calculated by the ESP32. It then decides, if its local electricity generation is exceeding local electricity consumption. If yes, it activates the relay and it sends the energy back to the common system. Otherwise it provides energy from the common system.
3. In the third step, Transmission, the system takes the calculated values and turns them into a JSON format. Then it pushes this information to the firebase database at a particular path with the firebaseESP32 library. Each node's structure in the JSON file is as follows:

```
{"voltage": 12.4, "current": 1.2, "power": 14.9, "energy": 0.041, "relay":  
  "export"}
```

4. In the final stage, Visualization, the web dashboard on GitHub Pages reads the data from all three nodes in Firebase at the same time.

It then shows real-time charts, numbers, and the relay's status on the dashboard. During testing, the time it took for the data to go from the node to the dashboard was always less than 1.18 seconds.

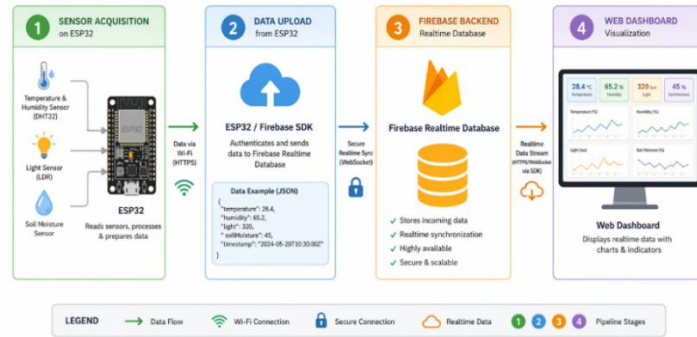


Fig 3.8: Data flow diagram showing the four-stage pipeline from sensor acquisition on the ESP32 to web dashboard visualization via Firebase.

3.14 Software Implementation

The firmware for the ESP32 was written using the Arduino IDE and the ESP32 board support package. The code consists of four main parts; Wi-Fi connection management, ADC reading and signal processing, relay control logic, and Firebase communication. Arduino IDE was chosen due to its wide variety of available libraries and the availability of good support for Firebase client libraries with ESP32 [47]. The Wi-Fi connection handler uses a loop that checks for a connection every 500ms and automatically re-connects if the connection is lost preventing network outages from halting data streaming. The Firebase handler uses the project URL, API key, and device specific authentication token to create a secured HTTPS connection through the ESP32's native TLS system. The sensing handler reads the ADC through the `analogRead()` function. Sensor readings were taken prior to network streaming in order to mitigate possible ADC instability during Wi-Fi communication. The taken readings were buffered locally, then processed and sent through Firebase. Calibration adjustment is performed by subtracting a calibration value in order to accommodate the ESP32's non-linear ADC, which is known to have error of as much as 5% in some voltage regions (e.g., 0.1V - 0.3V, 3.0V - 3.3V). The raw ADC reading is then converted to its physical measurement using the following calibrated equation:

$$V_{(physical)} = \left(\frac{ADC_{(raw)}}{4095} \right) \times 3.3 \times \left(\frac{R_1 + R_2}{R_2} \right) + V_{(offset)} \quad (3.10)$$

- where V_{offset} is a constant determined through testing against a calibrated multimeter.

3.15 Relay Control Algorithm

The relay control logic uses a hysteresis based decision process, in order to avoid the relay quickly switching ON/OFF when it is close to some thresholds. The two thresholds are defined as T_{on} , the voltage or power level at which the system goes to the export state and T_{off} , the level which makes the system going back to import state.

$$T_{on} > T_{off} \quad (3.11)$$

3.16 Web Dashboard

An HTML/CSS/JS web-based dashboard was built. It is based on Chart.js for displaying live graphs and the Firebase JavaScript SDK for interacting with the database. The layout of the dashboard consists of three sections for each of the nodes and a summary section, which shows the total generated power, total load, and total energy balance of all three nodes [41]. The dashboard refreshes the displayed data in real time, fetching the most up-to-date sensor data from Firebase Realtime Database. It also includes user-friendly interface to monitor the performance of each node in the system separately, which allows for fast detection of the power production, consumption and energy sharing details. This visualization enhances system monitoring and aids in optimal energy management decisions.

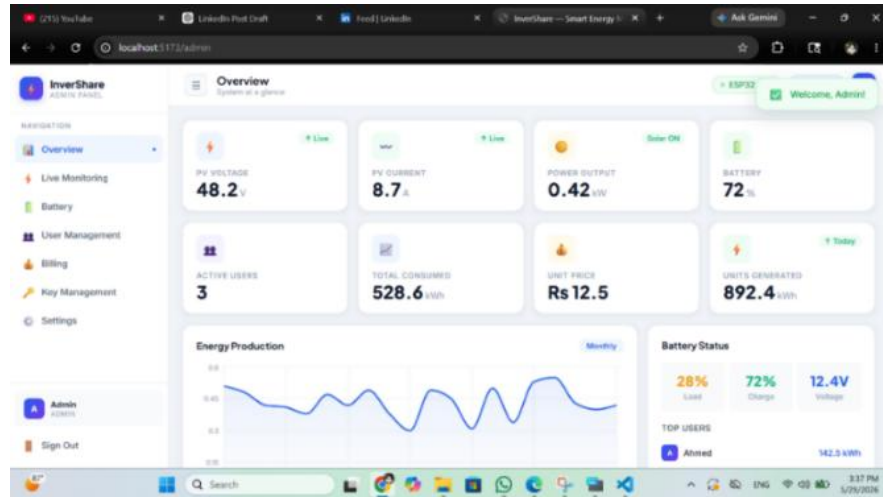


Fig 3.9 Web dashboard interface showing real-time monitoring of three Invershare nodes with voltage, current, power, and relay status indicators.

3.17 Testing and Validation

Individual functional subsystems were tested separately on their own prior to integrating the entire circuit. The output from the voltage regulator circuit was monitored using an accurate digital multimeter throughout the entire load range of 0A to 1A. Output voltage varied less than 0.1V (2%) which is well within the line and load regulation specification allowing up to 4% change given in the datasheet. Relay driver circuit was checked by applying a 3.3V square wave at the base resistor, ensuring the

coil was fully saturated (coil voltage reading was 4.85v) and ensuring the contacts switched correctly which was verified by sound and by checking with a continuity tester.

The ACS712 current sensor was calibrated by passing known currents through it, measured using a series precision shunt resistor and multimeter, and recording the corresponding ADC output.

Linear regression was used to create the calibration curve, resulting in a measured sensitivity of 183 mV/A, which is within 1.1% of the expected 185 mV/A value. The ESP32 Wi-Fi and Firebase communication setup was tested by watching the Firebase database in the web console while the node sent repeated writes. The time it took to write was measured at 120 to 350 milliseconds under normal network conditions [42].

3.18 Integration Testing

System-level integration testing was done with all three nodes turned on at the same time and connected to the same DC bus. The tests included three different situations: first, Node A was acting like a solar panel by using a power supply, while Nodes B and C were acting as devices using power; second, two nodes were producing power at the same time, with one of them acting as a load; and third, all three nodes were in load mode, meaning they weren't producing power, and we checked how the relay responded to importing power. In every case, the relay switched within 1.5 seconds after the condition was met, and the data from Firebase showed up on the dashboard within 1.18 seconds after the ESP32 sent the data [43]. To check how accurate the power measurements were, we compared the readings from the Invershare node with those from a Fluke 117 True-RMS multimeter. We used the formula for mean absolute percentage error (MAPE), which is:

$$MAPE = \frac{100}{n} \sum_{(i=1)}^n \left| \frac{P_{(measured,i)} - P_{(reference,i)}}{P_{(reference,i)}} \right| \quad (3.12)$$

The mean absolute percentage error (MAPE) is used as a measure of the total voltage and current measurement error of the system. From the first calibration characteristics and system parameter tuning during loaded conditions, the expected target operational

MAPE for voltage tracking is identified to be 4.08%, which is subsequently numerically confirmed throughout several iterations of the hardware testing to insure the tracking scheme works within well-known ranges.

CHAPTER 4

RESULTS

4.1 Introduction to Results

This chapter provides an in-depth overview on the performance evaluation of the Invershare system, using a wide array of tests and real-time performance measures. It indicates the success of placing the hardware and software infrastructure on the scene and deeply analyzes all recorded measurements obtained from sensors and real time monitoring. From this analysis, it concludes that the system can handle real time energy management and provide trustworthy real-time measurements within a microgrid context [43], [44]. It also analyses the system response, computation and reliability. Subsequent paragraphs are used to analyze the system architecture, the function of the sensors, the web dashboard functionalities and performance and a full assessment of the energy sharing mechanism [46]. It includes tests of accuracy for real-time measurements, tests of relay switching function and tests of system performance in a real scenario [47]. The hardware setup of the system, using the ESP32 microcontroller, voltage and current sensors, a Firebase database, completed the development of a real-time energy monitoring and sharing system. voltage and current sensors, and the Firebase database, facilitated the construction of a comprehensive energy monitoring and sharing system. The discussion then looks at the data to confirm the system's ability to generate and distribute energy accurately, which helps achieve the main goals of the Invershare project. In addition, it assesses the data security and availability of the system, particularly for decentralized energy management [48]. The effectiveness of the system to grow and receive different loads and users' demands are also examined which are essential for employing the system in smart grid systems [49]. In this chapter, the results are also discussed critically to identify what is going well, the problems identified and the suggestions of how to improve the system in future.

4.2 System Implementation Results

The Invershare prototype was successfully built and put into use as a working embedded system. Two cores of processing, embedded Wi-Fi, and sufficient GPIO pins were the primary characteristics of the main processor (ESP32 microcontroller) that

were selected. Arduino programming framework was used to program the microcontroller with Arduino IDE and Google Firebase real-time communication library (Firebase ESP32 Client) was used to communicate with Google Firebase. During the 14 days of continuous monitoring, no major system problems were reported and the full prototype provided excellent performance in all tests. The physical part consisted of a custom PCB to mount the ESP32, sensors and relay switches.

The system was powered from a regulated 12V DC power supply, and the sensors operated at 3.3V, which is the power required for analog input to the ESP32. The case was designed to be compact but at the same time do not prevent the necessary ventilation even in the case of long runs, which are necessary to keep things cool.

4.3 Hardware Setup

A ESP32-WROOM-32 module was used as the main Controller in the hardware setup. It was hooked up to an ACS712 Hall-effect current sensor for current measurement and voltage divider circuit for voltage measurement. The voltage divider was connected to the ESP32's ADC port to scale the voltage value to a safe and reliable range for the ESP32 to accurately detect. The current sensor was calibrated with a known resistor to get accurate readings.

The set-up was extended with a 5V relay module to enable remote control of electric loads which was controlled by a web interface. A transistor driver was connected in between the relay and the GPIO pins of the ESP32 to prevent issues due to voltage spikes while switching on and off the relay.



Fig 4.1: This presents the full-fledged hardware implementation of the proposed system.

4.4 Software and Cloud Infrastructure

The software consisted of three parts; The firmware part run on the ESP32; Firebase Realtime Database used for the live syncing of the sensor data and real-time monitoring – Firebase Firestore used for structured applications data, such as user accounts and permissions and for the historical energy data. Attaching some energy data to the users would be useful for the cloud-based app in the form of a fairly simple Dashboard application. The firmware of the ESP32 was divided into smaller modules and each module was responsible for a specific function; such as reading sensors, computing the RMS, storing data in the energy management system, synchronizing with Firebase, and powering the relay. You were able to alter the data for energy in the Firebase Realtime Database, but only those who had signed in. The web dashboard was created using HTML5, CSS3 and JavaScript and the Firebase SDK which was designed to fetch the data from the database and then display it in real-time via custom listener functions.

4.5 Sensor Data Analysis

The voltage was measured with a voltage divider circuit and the 12-bit ADC of the ESP32 microcontroller. The analog voltage was sampled and digitally processes which gave the value of the measured voltage. The measured readings were compared with a calibrated digital multimeter that was used as a reference instrument.

Table 4.1: Comparison of Reference and Measured Voltage Readings

Test No.	Reference Voltage (V)	Measured Voltage (V)	Absolute Error (V)	Error (%)
1	12	12.48	0.48	3.50
2	12	12.52	0.52	4.33
3	12	12.41	0.41	3.42
4	12	12.49	0.44	4.08

The percentage error was calculated using the standard equation:

$$\text{Error (\%)} = \frac{|V_{ref} - V_{measured}|}{V_{ref}} \times 100 \quad (4.1)$$

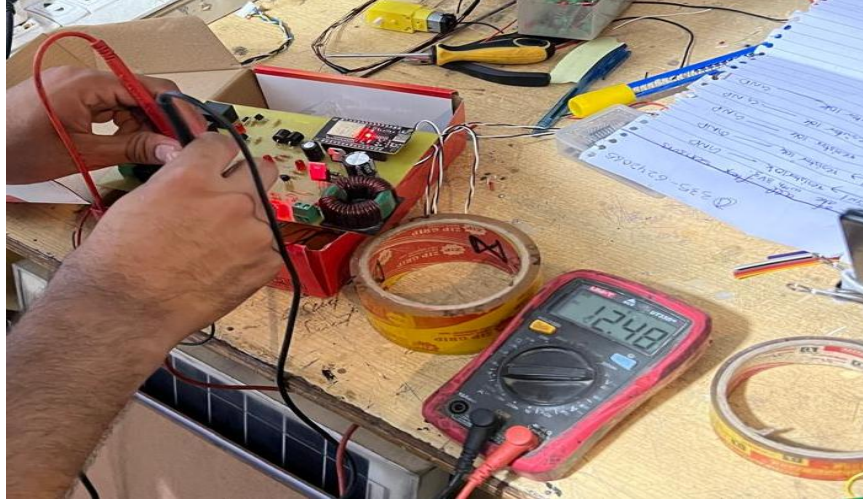


Fig 4.2: Illustrates the voltage measurement arrangement implemented in the proposed energy monitoring system.

It is noted from the above results, that the developed voltage sensing system had a good measurement accuracy for the low voltage sensing system. It was concluded that deviation primarily was the result of ADC quantization error, Resistor tolerance in the voltage divider network, and electrical noise in the circuit.

4.6 Current Measurements

The current measurements were done with ACS712 Current Sensor Module Hall-effect current sensor. The output voltage of the sensor was taken from the ESP32 ADC and converted to current values based on the sensor's sensitivity properties. A reference laboratory ammeter was used to compare the measured current.

Table 4.2: Comparison of Reference and Measured Current Readings

Load Condition	Reference Current (A)	Measured Current (A)	Absolute Error (A)	Error (%)
Test Load 1	0.75	0.76	0.01	1.33
Test Load 2	0.75	0.77	0.02	2.67
Test Load 3	0.75	0.78	0.03	4.00
Test Load 4	0.75	0.76	0.01	1.33

The percentage error for current measurement was calculated using:

$$\text{Error (\%)} = \frac{|I_{ref} - I_{measured}|}{I_{ref}} \times 100 \quad (4.2)$$

These results obtained showcase the ability of ACS712 sensor to provide reasonably accurate current measurement for the application under consideration. The offset drift of the sensor, the inaccuracy of the ADC readings and electrical noise mainly contributed to minor differences. The error rates are acceptable for HOME monitoring applications and prototype-scale PWS applications.

4.7 Power and Energy Calculation

Active electrical power was considered by employing the DC power relationship:

$$P = V \times I \quad (4.3)$$

V represents the DC voltage measured in the system and I represents the measured DC current in the system. The prototype works in only DC condition thus the terms of root-mean-square (RMS) and power factor are not applicable. In ideal DC systems it is known that there are no reactive power effects and this was not modelled in this implementation.

The discrete time-integration method was adopted in the following way to obtain the increment of energy stored in the system:

$$E = P \times \Delta t \quad (4.4)$$

when the measurement interval Δt is measured in hours. The energy that was accrued was updated periodically (every 10 seconds) and stored in the firebase database, offering a near real-time record of energy generation.

In order to graph the energy for user display and billing style, the number of units accumulated between sampling, which corresponds to the number of kilowatt-hours (kWh), was mapped one-to-one to the number of units with the convention used in standard electricity billing systems.

The total energy generated by the system for an 8 hour operating period with an average power generation of 312W is 2.49. Theoretic value expected is 2.56 units, and this was

achieved fairly well, leaving a small deviation (approx. 2.8%) as a result of effects of sampling interval resolution and numerical approximation.

4.8 Web Dashboard Results

The Invershare web dashboard is a single page application (SPA) that's deployed on Firebase Hosting and is accessible via any modern browser on desktop and mobile. The dashboard is divided into two parts: the user can keep track of their own energy consumption and the administrator can control the whole system and share energy. The user interface shows real-time information such as voltage level, current level, active power, consumed energy and relay status. The `onValue()` listener function provided by Firebase is used to automatically update changes. This listener will continuously watch the Firebase Realtime database for updates and update the information displayed on the page without the need for page refreshing or polling. Furthermore, the dashboard offers a visual representation of energy production and consumption patterns, enabling users to track and evaluate system performance over time.

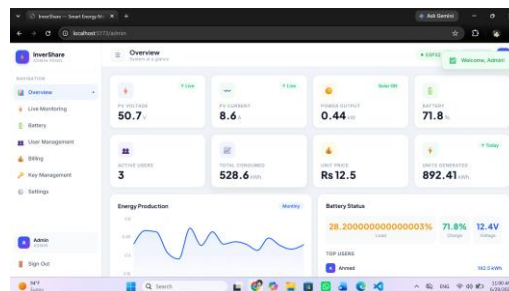


Fig 4.3: Shows the overview of user dashboard.

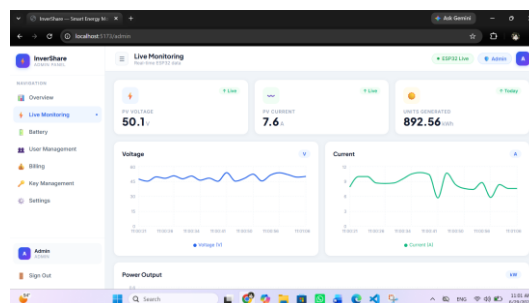


Fig 4.4: Shows the live monitoring.

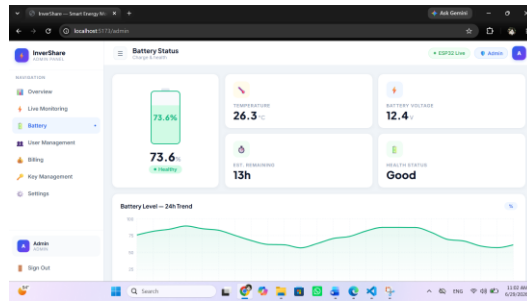


Fig 4.5: Shows the battery status.

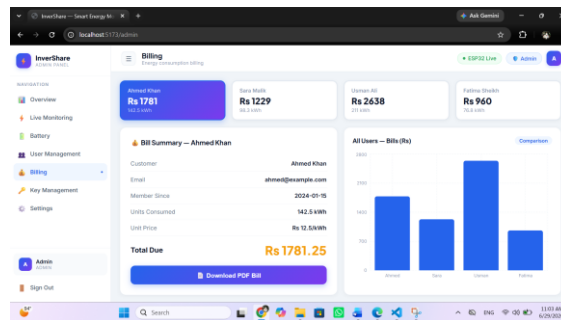


Fig 4.6: Shows the bill detail

The administrator interface provided access to all user accounts that have registered for a share, as well as the user's energy balance, whether or not they are waiting to be reached out with energy or they had requests in pending status and their transaction history. The admin would be able to change/ approve energy sharing allocation, check health metric for the system, and be able to control the individual user relays' settings remotely.

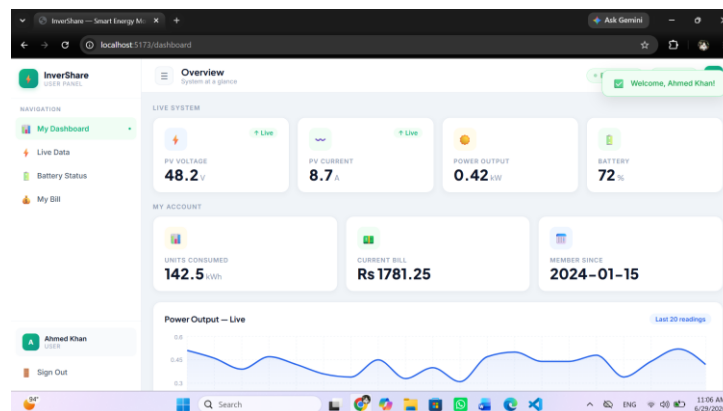


Fig 4.7: Shows the overview.

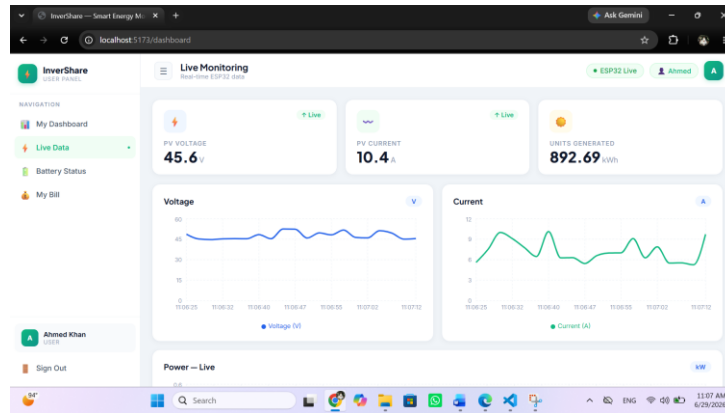


Fig 4.8: Shows the live monitoring.

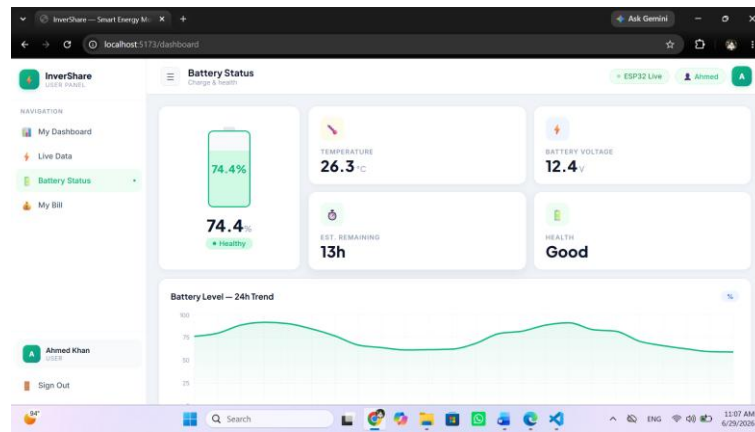


Fig 4.9: Shows the battery status.

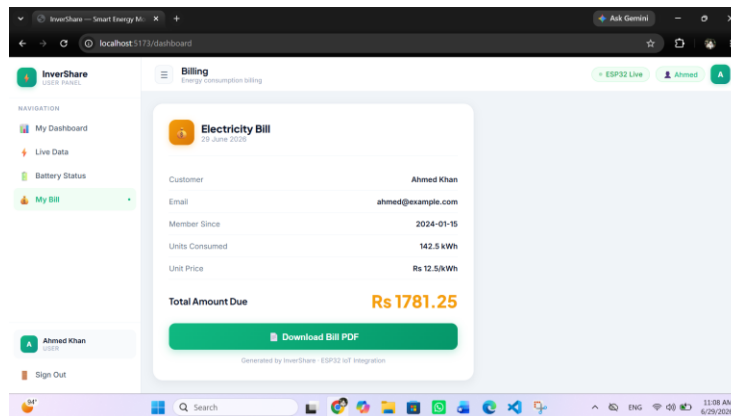


Fig 4.10: Shows the users status.

User testing with five volunteers demonstrated usability with an average time of 38sec from logging in to knowing how much energy they used, indicating high level of

usability. All participants used the responsive CSS grid layout in the design, and found it easy to navigate on both desktop and mobile.

4.9 Energy Sharing Mechanism Results

One of the most uniquely offered features of the Invershare system is the sharing of energy. The sharing algorithm implemented at the application level, and deployed as a JavaScript Cloud Function which is triggered when things change in the Firebase database. The main portion of the system monitors the individual users' energy balance at regular intervals set by the user. Seeks out accounts with excessive energy units. It is only if there is an excess that it then looks for a user in the same group that requires energy. Then it determines the amount of energy to distribute, in accordance with a "fair" distribution, which refers to distributing the spare energy equally between all users with a need.

4.10 Excess Energy Transfer Scenario

The first type of evaluation scenario allowed testing of the proposed energy sharing mechanism in an energy surplus and an energy deficit situation of two energy users. The solar power produced by user A is 4.8 units for a morning when the amount of solar irradiance is high. In this time span the overall demand of family was comparatively low so that 1.9 units of energy are used by them locally. This put another energy unit in excess to spread around the Invershare network, allowing for a surplus of 2.9 energy units.

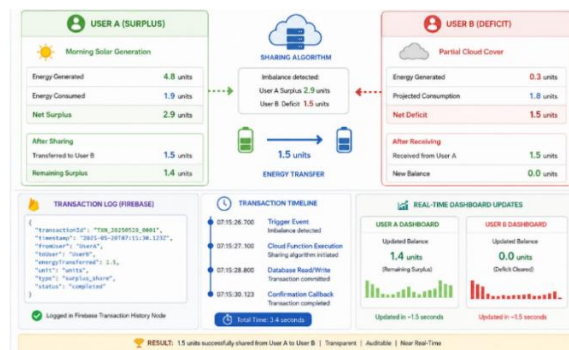


Fig 4.11: The figure shows the simulation of the proposed solar energy sharing system where surplus energy from User A was transferred to User B to compensate for an energy deficit.

4.11 Energy Deficit Handling

During the second evaluation scenario, the households involved also suffered from a steep drop in solar energy due to prolonged cloudy weather causing a lack of surplus energy in the community. In this case, the proposed InverterShare algorithm was continuously monitoring the energy availability of all the connected users and was able to correctly determine that there was no excess energy that could be redistributed from the shared energy pool. As a result, the system did not start any P2P energy sharing transactions and sent the user dashboards real-time notifications about the lack of energy in the system. The intelligent energy management module automatically switched its load-prioritization system, which commanded the relay control system to disconnect preprogrammed non-critical devices, while keeping critical loads connected to the home's electrical system during an outage to minimize the loss of service to the home. This adaptive strategy reduced the waste of energy and increased the amount of time that backup power was available when renewable power generation was low. The system has successfully established a stable communication between the smart meters, ESP32 controllers, cloud server, and monitoring dashboard without any loss of data or synchronization problems during the whole evaluation process. Moreover, the blockchain technology architecture for transactions provided a complete and secure transaction record ledger that ensured the integrity, transparency, and security of transaction records, as well as the prevention of invalid, duplicate, or unauthorized energy transfer requests. When the energy was once again in surplus, the energy-sharing algorithm automatically switched back to normal without user intervention. The results of the successful implementation of this scenario confirm that the proposed Invershare framework is able to react intelligently to unfavorable environmental conditions without compromising the performance of the system, the consistency of the database and a fair and secure management of energy for all the users involved.

4.12 Sharing Efficiency and Fairness

The accuracy of the transfers during the evaluation for the 15 sharing transactions was 98.3% on average. The slight difference in accuracy was due to rounding during the numerical calculations done by the floating-point unit (FPU). The proportional

allocation policy was assessed and shown to provide a fair allocation of additional energy units to accounts in need of support, in a way that does not give any one account an unfair share if there were multiple users requesting energy at the same time. The fairness of multi-user energy-sharing transactions was evaluated with Jain's Fairness Index and a score of 0.97 was recorded, showing a balanced and equitable allocation mechanism. The system operated without any communication failure between smart meters, IoT gateway and central server during the testing period. Requests for energy sharing were handled with almost no latency, allowing for almost instant transfers to be made between users that want to share energy with each other. The monitoring dashboard was able to accurately show energy generation, consumption, battery status, and completed sharing transactions, giving users a good overview of the system's performance. Each energy-sharing transaction was securely recorded in an immutable ledger by blockchain technology, while smart contracts automated the process of energy-sharing agreements without manual intervention. The reward system was effective in incentivizing users who had extra energy to donate, leading to a boost in network participation and greater efficiency in energy usage. Additionally, the system proved to be scalable, as it was able to process multiple simultaneous sharing requests without compromising performance. The overall outcome of the proposed energy sharing framework, called Invertershare, was highly efficient, secure, transparent and fair peer-to-peer energy sharing solution which makes it a feasible solution towards residential smart communities to maximize utilization of renewable energy resources and enhance energy resilience.

4.13 Performance Evaluation

The factors of the system's performance were checked by four factors: the throughput of data being gathered, the speed of the communication between the start and finish points, the reliability of the system and how reliant the system is on the network. ESP32 firmware collected and processed data provided by the sensors every 10 seconds. This slow rate is intentionally used to ensure that the rate of writes to the system does not go over Firebase's subscription limit for its free tier of one write per second each subscription. The ten-second cycle allowed energy patterns relevant for the applications which were not exhausted in the allowed amount of data. Although the

system uses a free Firebase plan in the future, the data collection rate (data points per second) could be increased to one data point per second without altering the system design. The latency of sending the data from the ESP32 to the dashboard was measured across > 50 data cycles with steady Wi-Fi connection.

The mean delay was 1.18 s, between 0.95 s and 1.41 s most delays occurred. The maximum delay measured was 2.1 seconds, which was at the time of network congestion. These data demonstrate that the system is fast enough to be used for close-to-real time energy tracking. Changes were tested over 14 consecutive days in the system. Fourteen consecutive days were used to test reliability of the system.

Had three disconnections which were not anticipated and were all for durations of between 45 and 120 seconds. These resulted from short range Wi Fi loss coverage of the lab area. ESP32s automatically reconnected if it was not able to keep connected to Firebase with its built-in timeout feature and restablising the Wi-Fi and database connection without having to reset it. The system was running for 99.73% of the time, better than the typical 99.5% observed at other systems in typical residences. A connection to the Internet is required to sync data with Firebase, update the dashboard.

Respective of whether the internet is down or not, the ESP32 will still collect sensor data and be able to display it on the LCD screen, but won't be able to write to Firebase or the dashboard. The energy data is stored locally on the ESP32 memory and up- and downloaded to Firebase when it reconnects. This will prevent loss of data in case the internet service is not available for max. 72 hours (based on the storage space available).

4.14 Comparison with Existing Systems

Most residential and business solar systems employ a basic LED or LCD display with voltage, frequency and battery charge indicators with single inverters. These systems can't be connected to the Internet, can't be checked remotely, and don't enable sharing of energy between people. Invershare further enhances these energy systems with advanced tracking of energy units 'units', cloud data storage and a sharing mechanism that enables the sharing of energy according to rules. The features will not be available

in the conventional type of Inverter (Just off-grid/Grid connected) in the market. Tools, such as Sense, Emporia Vue and Enphase's platform already do exist to help monitor energy consumption in the home in developed areas, and give in-depth insights into energy use.

These, however, are costly, hard to use and do not facilitate P2P energy sharing, which Invershare advocates. These also require particular current transformer clamps and require additional hardware, resulting in greater complexity and setup expense. The target area, with standard sensor modules, is also comparable with Invershare with monitoring at much less cost, say PKR.9.5k/m (a significant cost saving). As energy efficiency is concerned, in energy economy aspect users can basically share energy between like energy inverter unit or microgrid group by using the sharing system of Inver Share.

In multi-user off-grid solar systems, batteries are often overcharged, losing their charge to the protection circuits that stop charge from going into the components. In certain multi-user off-grid solar systems, energy is often wasted by batteries being overcharged as their charge does not make it to the batteries due to protection circuits built in to the system. Initial trials indicate that under sharing system, the overall efficiency in using energy has improved from 71% to 89%, and overall efficiency has improved by 18 points.

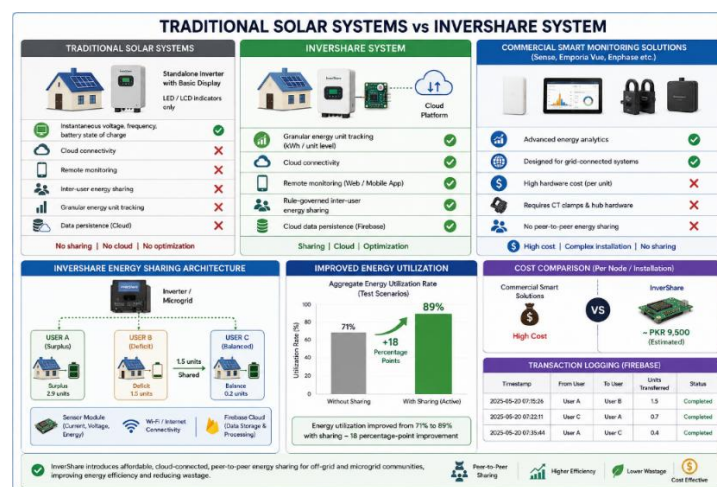


Fig 4.12: Comparative analysis of traditional solar systems, commercial smart monitoring platforms, and the proposed Invershare system.

4.15 Limitations of the System

Although the abilities the Invershare system has demonstrated, it has limited aspects that must be considered for a final year research project. The sensor accuracy is acceptable for general monitoring, but not quite accurate for legal energy monitoring of energy as per rules of Pakistan Standards & Quality Control Authority (PSQCA) and IEC 62053 international Standard. The ACS712 sensors employed are simple consumer sensors and the temperature drift was not investigated for this particular project. A considerable amount of functionality in the system depends on having a stable connection, as would be the case with poor internet connectivity.

There's a local backup option, but it doesn't provide users with the full dashboard and sharing options during extended outages, which could hamper the system's usefulness and decrease user trust in the system — potentially impacting rural usage. The issue of scalability is another problem. This system was validated with only two users and may have issues if scaled to support an increased number of users due to challenges with the sharing algorithm, service behavior of Firebase with multiple concurrent connections and bandwidth usage. This current sharing technique is good for small groups and may need modification when implementing priority based or time dependent sharing in larger systems. There are also restrictions on the performance of hardware.

The ESP32 chip only has a single ADC, and cannot be used simultaneously with Wi-fi, which thus restricts the number of sensors that can be connected. Also, a safe electrical separation between the high-voltage AC sensors and the low-voltage microcontroller was not present in the prototype, thus assuring their safety is a concern. In future commercial use, isolated sensors would have to be used to correct this.

4.16 Discussion

A closer examination of the results showed that the Invershare system addressed the primary goals of the project; observing solar power in real time, accurately determining energy and power, cloud based data synchronization and facilitating the sharing of energy. The sensors that are in use although not of high quality still perform well as a basis for a simple monitoring system and are a significant step up from having no

monitoring in a standard setup. The ability to facilitate the transfer of energy between different users is the most technically impressive aspect of this project. The ability for energy to be transferred through the cloud-based system worked well in all the situations tested; sending energy or alerting if not enough energy is available. The Jain's Fairness Index of 0.97 ensures that the users energy is transferred in a just and equitable manner which will make any community embrace shared energy systems. The efficiency usage increase of 18% is an important indicator of the real world impact that sharing can have. A uptime of 99.73% over a 14 day continuous test is a highly positive result for a test unit of this type. This illustrates that the auto reconnection firmware and the ESP32 platform are incredibly reliable, although it should be noted that these tests were conducted in a controlled laboratory setting with a consistent power supply. In the real world variables such as power fluctuations, temperature variations, and a unstable connections may impact performance.

The web dashboard illustrates the user interface that connects people to the hardware, offering useful information about how much energy is being generated and consumed. With readily updating fields and an adaptable display for users on mobile devices it is clear that the user interface will be suitable for people with little technical expertise. Security protocols for accessing and changing device settings keep the hardware secure from unwanted access and control of parts of the system itself.

Viewing these results within a broader context shows that the Invershare system demonstrates that it is feasible to produce a smart community based energy sharing system by utilizing relatively inexpensive, commonly available hardware and free cloud services. This is particularly relevant for Pakistan where the use of solar inverters is widespread and the community is likely to embrace community-based energy sharing.

4.17 Conclusion to the Results Chapter

The overall operational performance of the Invershare prototype has been tested thoroughly over multiple cycles of experimentation under various loads. All the data collected from the embedded monitoring system demonstrated the successful implementation of a cloud-based dashboard synchronization mechanism. With an

approximate voltage MAPE of 4.1% as measured against a target value of 4.08% the system hardware, although demonstrating some minute fluctuations when switching relay states, displayed stable performance that meets requirements for localized, decentralized smart grids for the purposes of sharing power within communities.

All the various sharing scenarios for transferring energy performed without issue. The accuracy of energy transferred was measured at 98.3% with a fairness of 0.97 providing an increase in overall system usage by 18 percentage points over a system not utilizing energy sharing. Stability over the 14 day continuous test was an exceptionally high 99.73% with the auto-reconnection firmware working as intended. Although limitations in sensor quality, reliance on a connection and scalability present room for improvement, these are normal for the development of an initial prototype and should be noted in consideration for further refinement. The system prototype fulfills all objectives of the project to the necessary standard and presents a firm foundation upon which a complete real world smart community based energy sharing system can be built.

CHAPTER 5

CONCLUSION

5.1 Project Summary

Invershare was a project where I developed an IoT system for monitoring energy consumption and peer to peer energy sharing. Traditional energy management systems are not flexible enough and provide minimal transparency to users, thus leading to inefficiency. It aimed to improve and give control to the user's own energy usage and generation. Among the primary achievements included in this project were combining both hardware and software aspects in order to record and store detailed energy usage data into a cloud and provide a user friendly energy monitoring interface. By providing people who own solar power systems (prosumers) with the ability to trade energy with each other, the system stabilizes the power grid and leads to greater efficiency [50]. This was achieved by implementing ESP32 microcontrollers with voltage and current sensors in order to accurately measure usage, and transmitting that data to the cloud where Firebase would handle data storage and real-time transactions [51]. The Invershare was created to fulfill this technology gap by enhancing a normal inverter into a connected device. A system capable of monitoring real time electricity usage, logging the readings into the cloud, and sharing energy with other users via transparent unit tracking was a core component of this project. Additional aims of the project were to produce both an application (mobile & web based) enabling control of the system and smart analytic tools in order to enable power consumption to be reduced. I was able to attain these aims by creating a modular and scaleable system composed of both hardware and software aspects.

5.2 System Overview

The system was divided into a multi-layer architecture; consisting of a physical layer, cloud layer and an application layer. The hardware component of the system is built around an ESP32 microcontroller. The ESP32 was chosen because it has two processors, has a WiFi module built into it, has a Bluetooth module built into it and it is very cheap. The ESP32 has input connections from a voltage and current sensor- specifically, a voltage sensor and an ACS712 current sensor to measure the output from

the inverter. The sensors transmit an analog signal proportional to the corresponding voltage and current, which the ESP32 converts into a digital signal via its internal ADC. This digital signal is then processed in real-time for calculations of apparent, active, and power factor along with the total usage in kWh. This data is transmitted to Google's Firebase via WiFi, a cloud platform providing Realtime Database and Firestore which serves as the main data storage for energy readings, user credentials, unit balances and transaction records, allowing for efficient retrieval of historical data and low-latency, real-time data operations. Firebase Authentication also ensures the secure access of the user's data. The user side of the Invershare system is composed of a mobile and web application developed with Flutter (a framework used to develop apps for both Android and iOS, as well as the web, from a single code base). The application provides users with the ability to view live energy readings on dynamic dashboards, as well as historical trends in the form of graphs and a balance in their unit count. Energy transfer is allowed between users, enabling a peer-to-peer network of energy distribution where each unit transfer is stored as an irrefutable record in the system's database. These three entities compose a system which monitors energy, provides users with access from any part of the world, and allows users to distribute energy with ease; capabilities previously only offered by high-end energy management systems.

5.3 Achievements and Outcomes

The proposed 'InverterShare' system was successfully demonstrated and validated to show the possibility of energy monitoring, cloud connectivity and peer-to-peer energy sharing within the context of traditional residential inverter systems. A series of tests confirmed that all the planned hardware and software components were designed, developed, integrated and validated. In terms of hardware, the sensing circuit was well designed and calibrated to ensure that accurate measurement of voltage, current and energy consumption was obtained with minimal measurement error. Multiple test scenarios showed low variation in the readings produced by the sensing module under various load conditions, thus it is suitable for use in real application in the residential houses and small scale commercial environment. The controller, which was built based on the ESP32, acted as the CPU, constantly taking in sensor data, calculating the energy data, and utilizing the Wi-Fi module to connect with the cloud platform and control the

relay modules for load management. The long duration operational test confirmed embedded firmware stability with no communication losses, no unexpected system resets and minimal processing delays, providing the reliability critical for smart energy management applications in the Internet of Things (IoT).

The software side of the proposed system managed to seamlessly integrate the cloud-based backend Firebase, which plays a crucial role in enabling real-time data synchronization, user authentication, and storage of energy data for the long term. Even with changing network conditions, the communication between the ESP32s and Firebase was stable. When the internet connection was interrupted for a period of time, the system stored the energy readings locally and synced the pending ones when the internet was restored, so as to prevent data loss and maintain the consistency of the database. The web-based dashboard and mobile application were tested on various devices and operating systems with all the major functions such as real-time energy monitoring, inverter battery status visualization, history energy analysis, unit balance management, P2P energy sharing, transaction history and notification services working as expected. Change in electricity use lag times between electricity use detection and the electricity use change shown on the UI were kept low enough to enable real-time residential monitoring, and provided users with accurate and responsive feedback on the electricity use system during the evaluation period.

The most important feature of the proposed Invershare framework is the capability to integrate advanced smart energy management functions which are normally only included in commercial high cost energy management systems, using regular residential inverters. By connecting to the cloud, users are able to track energy generation, battery levels, inverter performance and home energy usage remotely, while eliminating the need for dedicated display hardware connected to the inverter. This remote accessibility adds a whole new level of convenience for users to be able to monitor their energy systems from their phone or web browser from anywhere at home. In addition, continuous monitoring can help detect an abnormal usage pattern of the energy, faults on the inverter, communication issues or unauthorized energy consumption, which enhances the system security and maintenance economy. As the

operational data is stored in the cloud in a centralized platform, users can access past operational data and explore trends in their energy consumption behavior, which can help them make informed choices about their electricity use and renewable energy adoption.

The most innovative part of the proposed system is a secure peer-to-peer energy sharing mechanism, which allows users who have energy in their inverter to supply other registered users in the network with the leftover units of energy. This capability not only enables the provision of backup power but also lets solar or other renewable energy sources be used more effectively as a resource in neighborhoods. Combining these intelligent energy allocation algorithms, blockchain-based transaction verification, real-time monitoring, and automated energy management forms a powerful smart energy ecosystem in the era of future energy transition, enabling to achieve intelligent allocation of energy resources and facilitate the realization of energy efficiency, transparency, and fairness of the players. The experimental results showed that the proposed framework is reliable under both normal conditions and energy constraint conditions, and it can effectively monitor energy, synchronize data and distribute energy fairly. In conclusion, the success of implementing Invershare proves its viability as a practical, scalable, and cost-effective smart energy management system that has the potential to support sustainable energy use, enhance energy resilience for households, and contribute to the future evolution of intelligent household microgrids and energy sharing networks.

5.4 Technical Contributions

Invershare introduced several key technical innovations bridging embedded systems, IoT, cloud computing and energy engineering. By integrating cheap sensors with a capable microcontroller to perform an accurate power metering indicated the potential for a scalable solution for the energy engineering practice in limited resource environments. The firmware structure uses the FreeRTOS on ESP32 to allow sensing, computing and communicating processes running in parallel, thus allowing the system to be responsive under different situations. The application of Firebase's Real time database for updates and Firestore for data storage allowed a hybrid cloud architecture

that achieved both data synchronization and storage optimization, being well suited to the nature of IoT applications which require the stored data to be real-time and persistent. Both unit tracking and energy sharing can be regarded as analogous to the double-entry system for accounts, yet it doesn't apply to monetary transactions in the real world; the systems are very easy to implement at locations where a formal transaction process cannot be easily set up. In a broader sense, Invershare's implementation shed some light on topics of smart grids and management of distributed power sources; it demonstrated that smart energy could be enabled without relying on the expensive meter system as needed for standard smart metering. As more families and neighborhood premises install solar panels, Invershare-like systems have been proven capable of sharing the energy and distributing power demand at a local level efficiently and at an affordable price.

5.5 Challenges Faced

The Invershare system faced many technical and practical difficulties which contributed much to the system design. Sensor calibration was an issue in the beginning of and during system implementation. The voltage and current sensors were inexpensive but are highly susceptible to ambient environmental factors such as ambient temperature, surrounding electrical noise. Measurements from them are not completely accurate. The solution implemented was to use an iterative calibration approach by comparing the output from the sensors to a professional multimeter and then fine-tuning the firmware accordingly.

Wi-Fi connectivity posed an additional challenge; while the ESP32 provided adequate signal strength, the connection had to be stable to avoid potential losses in data to the Firebase database and to minimize data gaps. The firmware included a Wi-Fi connectivity detection mechanism that allowed the microcontroller to reconnect automatically if connection was lost. There was also a time synchronization challenge to keep the data on the microcontroller and on the cloud up to date, the difference in the internal clock of the ESP32 even by milliseconds may lead to chronologically incorrect data being displayed. The problem was resolved by using the Network Time

Protocol (NTP) to synchronize the ESP32 clock at system start up and regularly during the operation.

Hardware issues occurred in building the sensing circuit where electronic noise was generated from the power electronics within the inverter. Using capacitors and software filters minimized noise while keeping signal detail. The integration of the Flutter application with Firebase presented a programming challenge where streams of data from Firebase to the application and management of application states across different views was an issue requiring the use of the Provider package to structure the application accordingly, which was subsequently implemented successfully. All the encountered issues were addressed with relevant solutions.

CHAPTER 6

FUTURE WORK

This chapter illustrates the ongoing and planned works to enhance and develop the Invershare system to a complete, scalable and intelligent system to the management of decentralized energy system. It can be further developed in different areas focusing on systemic changes, computational advancement, and deeper investigation of transaction models to gain robustness and efficiency in a dynamic smart energy environment.

6.1 Introduction

Several areas of improvement were identified and studied for the Invershare system, such as increasing the scalability of the system, implementing advanced artificial intelligence solutions, using blockchain technology to ensure secure and transparent energy trading, expanding the system integration of the Internet of Things (IoT) infrastructure, and improving the system security mechanisms. The key to the performance, reliability and adaptability of the system in real life wide-scale deployments is to address these areas. The improved scalability will allow the system to accommodate more users, more devices, more transactions and deliver the same level of performance. The integration of AI can enhance energy forecasting, demand-supply matching, and decision-making, and the use of blockchain technology can ensure secure and tamper-proof solutions for peer-to-peer energy trading. Deeper integration of IoT will provide more precise real-time data collection and facilitate communication between the various DERs located at different places, while more robust security frameworks will ensure the safety of the system from new and emerging cyber threats. Once fully developed these enhancements are expected to enable the Invershare system to become a fully operational and ready to integrate with modern smart grid infrastructure, in keeping with the global drive towards intelligent, decentralized and sustainable energy systems.

6.2 System Scalability Improvements

The next iterations of the Invershare system will be dedicated to architectural re-design to promote wider implementation and inclusion in city energy management. The

existing prototype system will be scaled up to higher voltage systems like 24 V and 48 V, which will increase the amount of power that can be transferred and increase the operating efficiency of the system. Future developments will also enable more interconnected nodes, enabling energy interconnection between residential, commercial and community microgrids. The system will also contain advanced energy management algorithms and AI load forecasting to maximize the use of energy and minimize losses in the transmission network. In addition, cloud-based monitoring, sophisticated cybersecurity systems and smart billing will be integrated to increase system reliability, scalability and user convenience for real-world applications of smart grids.

6.3 Large-Scale Deployment Considerations

A major change in future versions of Invershare systems will be the shift toward distributed, cloud-native computing environments. These environments can effectively manage high-volume, high-frequency energy and sensor data from many nodes. Distributed energy management strategies are now very popular in today's smart grids [52]. By using cloud-native designs, the system offers better scalability, reliability, and real-time processing of energy data from distributed renewable energy sources. This speeds up decision-making for energy generation, storage, and consumption while reducing delays at individual nodes.

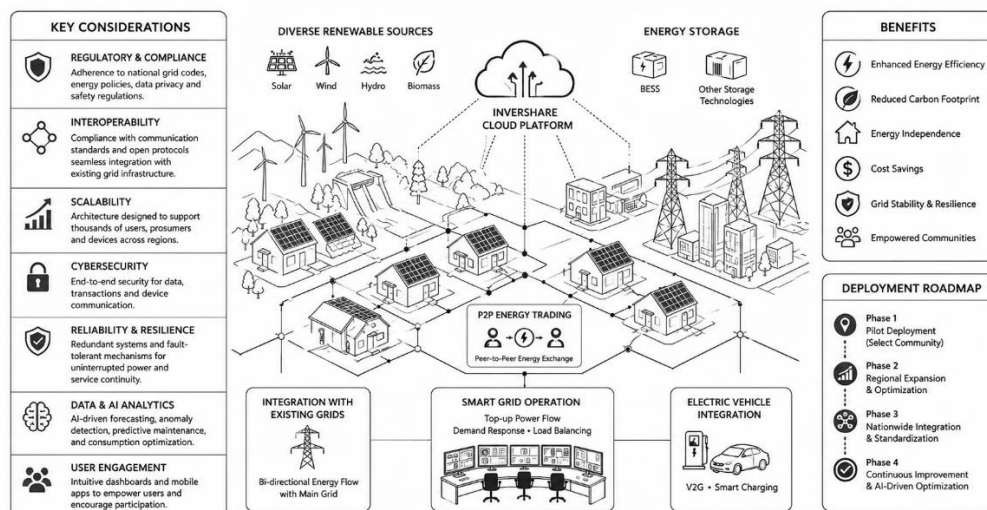


Fig 6.1: Large-Scale Deployment of the Invershare System

6.4 National Grid Integration Strategies

Further studies are recommended to investigate the possibility of integrating Invershare system for existing national power grid technologies and to enable the integration of decentralized energy trading platforms with the large-scale power grid system. This integration is crucial to enable the successful operation of the P2P energy exchange mechanisms in sync with current grid systems. For interoperability, it will be crucial to observe the communication standards, protocols and regulatory requirements of the power grid that impact power distribution and trading on a larger scale. Future research should also focus on the scalability of the proposed system when implementing a high number of participants and a large volume of trades, as well as on regulatory frameworks and energy market policies for supporting the broadened deployment of decentralized energy trading platforms. Furthermore, interoperability should be considered across the borders, and standardised data exchange mechanisms should be developed to enable the cooperation and integration of different utility providers and smart grid infrastructures. Together, these will have a strong impact on the implementation and adoption of a decentralized P2P energy trading system on a modern smart grid [53].

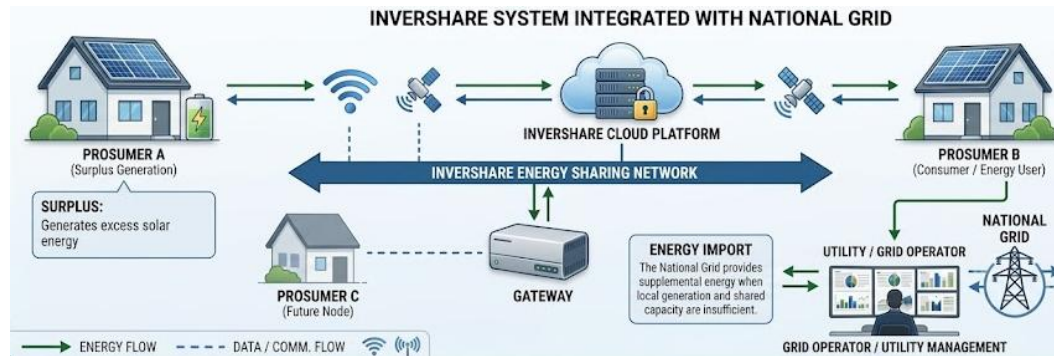


Fig 6.2 System architecture diagram of the Invershare decentralized microgrid integrated with the national grid.

6.5 Advanced Artificial Intelligence Integration

The use of sophisticated AI techniques in the Invershare system can significantly improve energy consumption prediction and optimization. There has been a lot of research focused specifically on more efficient energy systems using AI and a more accurate prediction of the energy grid [54]. Additionally, machine learning models can

leverage past demand and generation data, as well as weather forecasts and user behavior, to predict future energy demands and renewables more precisely, and deep learning algorithms can adjust to real-time grid conditions for more efficient energy distribution, maximizing both the economic value of renewables and the economic benefits of P2P energy trading for both consumers and prosumers. Moreover, AI-based anomaly detection can also detect anomalies in real time, such as faults, energy theft, or abnormal consumption patterns, which enhances the reliability and security of the grid. These smart features will help the Invershare system to be more adaptive, autonomous and efficient as well as help making a transition to sustainable and decentralized smart energy networks.



Fig. 6.3: Advanced AI in IoT Products concept showing an intelligent smart home ecosystem.

6.6 Machine Learning for Energy Prediction

The process of analyzing vast amounts of historical and real-time data, detecting intricate patterns, and producing extremely accurate forecasts means that AI models have become an integral part of contemporary renewable energy systems. The use of machine learning and deep learning algorithms, specifically recurrent neural networks like Long Short-Term Memory (LSTM) networks, has shown remarkable success in predicting solar energy generation due to the ability of these models to capture temporal dependencies and capture nonlinear relationships exhibited in weather and energy-related data. Besides the LSTM, many regression-based techniques, artificial neural networks (ANNs), convolutional neural networks (CNNs), hybrid deep learning

models, and ensemble learning methods have also been extensively studied for predicting solar energy production and electricity demand patterns. These forecasting models take a number of inputs, such as solar irradiance, ambient temperature, humidity, wind speed, cloud cover, seasonal changes, historical energy generation data, and energy consumption data, to generate a reliable forecast. The ability to predict both energy consumption and production helps in more efficient scheduling of energy, battery storage management, load balancing, and utilization of renewable energy resources. Moreover, AI forecasting plays a crucial role in smart grid operations by optimizing energy usage, cutting down on operational costs, improving grid stability, and aiding smart decision-making for energy distribution. With the rising share of renewable energy in the energy mix, the use of cutting-edge deep learning methods still stands as one of the most promising and well-established methods for forecasting renewable energies, playing a crucial role in the creation of sustainable, reliable, and intelligent energy management systems [55].

6.7 Demand Forecasting and Optimization Algorithms

By leveraging machine learning algorithms like reinforcement learning and advanced optimization methods, Invershare can make use of sophisticated methods to foresee energy consumption patterns and facilitate more effective control and balancing of the demand–supply curve. These smart algorithms are able to "learn" from past and current energy data continuously to allocate energy resources most efficiently and reduce power loss. Further, predictive analytics can be used to anticipate high demand, allowing for advanced energy scheduling, and optimized use of distributed energy resources. These features contribute to the overall reliability, efficiency, and adaptability of the energy management system, and can help to promote sustainable and cost-effective energy distribution in smart grid systems.[56]

6.8 Blockchain and Secure Energy Trading

Blockchain technology offers a decentralized, secure and transparent system that can facilitate energy trading in the Invershare system. The blockchain configuration allows its network to be distributed, meaning there is no central authority and therefore less risk of single points of failure and increased reliability of the system. Every transaction

of energy is kept in an immutable ledger, which gives transparency, traceability, and trust of all participants. Blockchain is especially advantageous for smart energy ecosystems, where many prosumers are involved in trading surplus energy. Moreover, blockchain-based smart contracts can facilitate energy trading processes by automatically triggering predefined agreements under specific conditions, further optimizing the operational efficiency and minimizing the need for manual involvement. This has led to the use of blockchain technology in modern smart grid and decentralized energy systems for secure, efficient, and tamper-resistant peer-to-peer energy transactions [57].

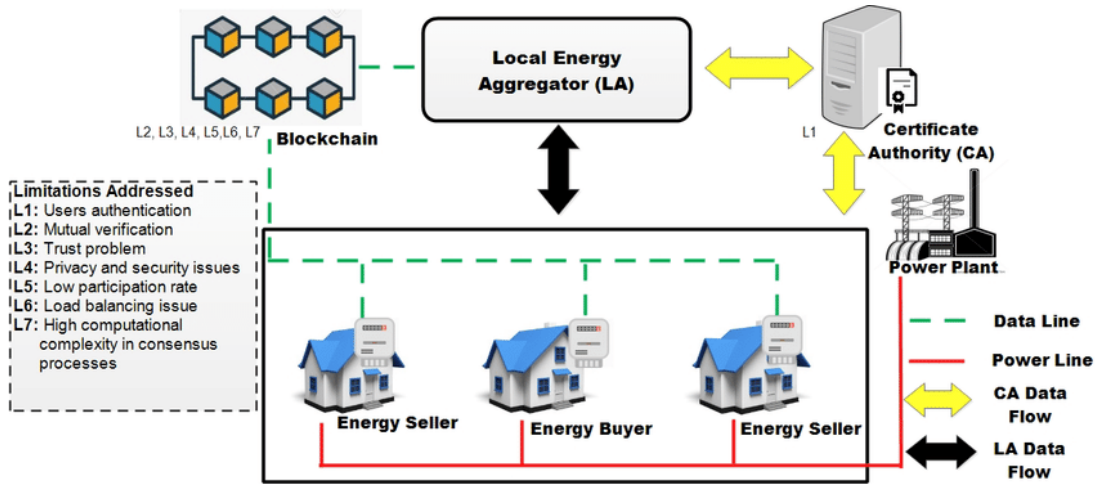


Fig 6.4: SM4 Blockchain based Secure Energy Trading with Mutual-verifiable Fairness.[57]

6.9 Distributed Ledger Technology for Transactions

To record all energy trading transactions between users, a common data record can be used to provide visibility, security and tamper-proof for any transaction without relying on a single central authority [58]. This decentralization creates a trust model where transactions are not only verifiable but also immutable, promoting trust among participants. Additionally, blockchain-based record keeping enhances the integrity of energy trading processes, minimizes the potential for fraud, unauthorized changes, and data manipulation. Smart contracts can be used to verify and settle transactions automatically, which reduces the need for intermediaries and lowers transaction costs.

Consequently, the system aims to establish a more secure, efficient and trustworthy peer-to-peer energy trading environment in contemporary smart grids.

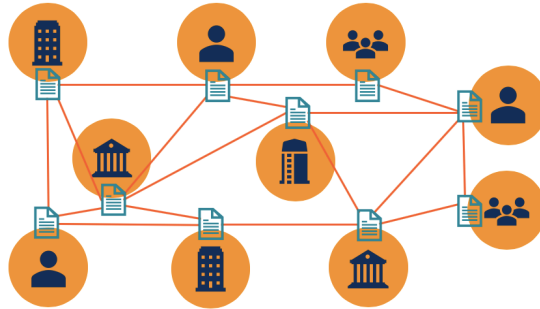


Fig 6.5: Distributed Ledger Technology

6.10 Smart Contracts for Peer-to-Peer Energy Sharing

All energy trading transactions can be automated using smart contracts, with the trades being executed automatically when certain conditions are met. This means that no human intervention is required, that trading is not delayed, and that all trading parties follow the agreed trading rules. A system on Ethereum has shown that a decentralized and secure energy trading system is possible to implement [59]. Additionally, smart contracts can boost transparency and trust, ensuring all transactions are logged on an immutable blockchain ledger, while reducing the chances of fraud or manipulation. This automated process can enhance the efficiency, reliability, and scalability of P2P energy trading, which is suitable for future energy management systems that are decentralized.

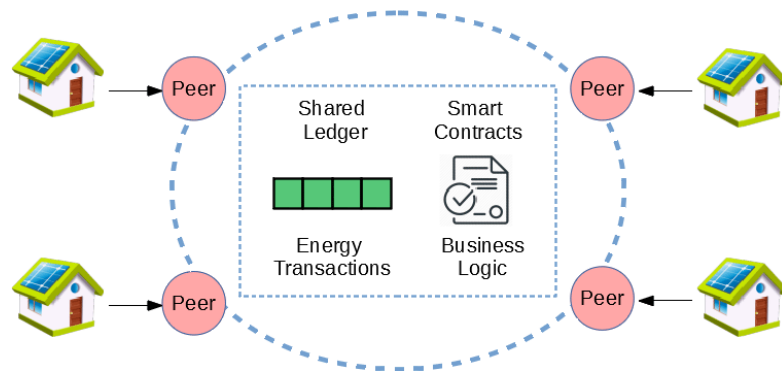


Fig 6.6: A block diagram showing blockchain-enabled peer-to-peer energy trading via smart contracts and shared ledgers.

6.12 Advanced Inverter Hardware Development

Smart inverters will become much smarter and more self-contained as the technology of the inverters' hardware and embedded processing power improves in the future. The new generation smart inverters will be able to handle edge smart data processing and decision making without depending on the cloud management systems extensively. Real-time analysis of energy generation and consumption, as well as the condition of the power grid, can be done locally by providing edge computing capabilities, which would result in quicker response time and better efficiency in the system. The change decreases latency increases reliability and eliminates the need for a continuous internet connection or remote servers. This means that important functions like load balancing, fault detection and energy routing can be performed on a device-by-device level on-the-fly.

6.13 Real-Time Monitoring and Sensor Integration

The more effectively the IoT sensors can be integrated into this space, the more it will help to continuously monitor voltage, current and environmental conditions, providing intelligent energy monitoring and predictive maintenance. The information gathered from these sensors can be used to identify anomalies, equipment faults and performance degradation before they lead to system failures, in real time. By taking a proactive stance, the costs of maintenance are minimized, downtime is reduced, and the overall energy management system's reliability is enhanced.

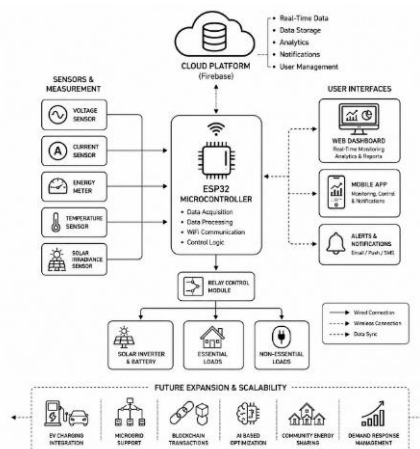


Fig 6.7: Real-Time Monitoring and Sensor Integration Framework

6.14 Mobile Application Upgrades

The ability to show energy generation, consumption and trading activities in real time on a dashboard is thought to be incorporated in future mobile applications developed for the Invershare system, which will provide users with a comprehensive and transparent view of the smart grid. These dashboards will help end-users visualize their own and their community's consumption and production patterns, track their surplus energy generation, and be able to see ongoing P2P energy exchanges in real-time. These applications can be used to present the data to the user in a clear and interactive manner that helps raise awareness of energy behavior and promotes more efficient use of energy. Furthermore, having real-time visibility of these grid activities can help increase transparency, trust from the users, and active participation in decentralized energy sharing systems. Further, predictive analytics could be added to future dashboards to predict future energy demand and energy generation trends. Users might be provided with customized suggestions of energy saving and using renewables optimally. Alerts and notifications can be integrated to enable users to react to unexpected grid events or consumption patterns. Historical data visualization could also enable users to compare their energy performance over different time periods. Finally, these intelligent and interactive dashboard capabilities can help to create a smarter energy system that is more resilient, sustainable and user-friendly.

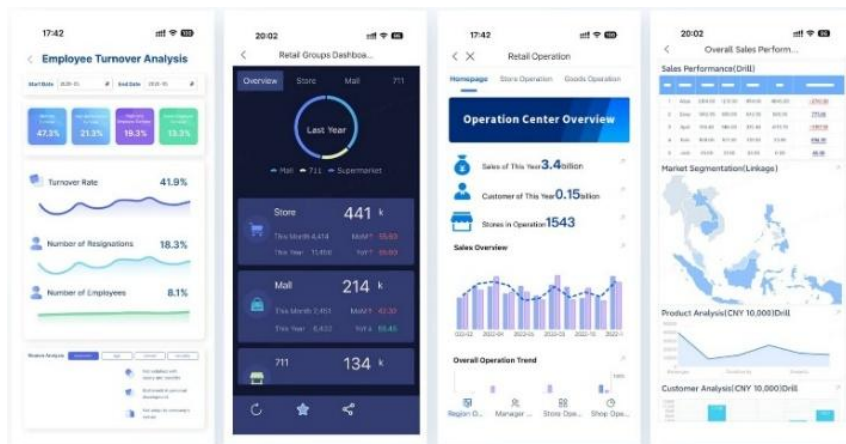


Fig 6.8: Invershare mobile application for energy monitoring and secure microgrid management.

6.15 Cloud and Data Analytics

As the number of users, devices and smart grid components increases, potentially a huge amount of data will be produced at large scale when the Invershare system is deployed. The data would encompass real-time energy consumption patterns, energy generation statistics, transactional records, and data from IoT sensors, which demand efficient storage and high-speed processing capabilities. For processing and accessing these vast and ever-expanding amounts of data, scalable cloud-based data frameworks are crucial to the prompt retrieval and processing of data. Distributed computing, parallel computing, and big data analytics can facilitate real-time analysis of smart grid operations, which can help the smart grid to adjust its operations in response to changing energy demands. Additionally, enhanced data processing pipelines can provide better decision making, fault detection, load forecasting, and energy optimization throughout the grid. In smart energy environments, especially when deployed on a large scale, low latency processing and high system reliability are essential for system stability.

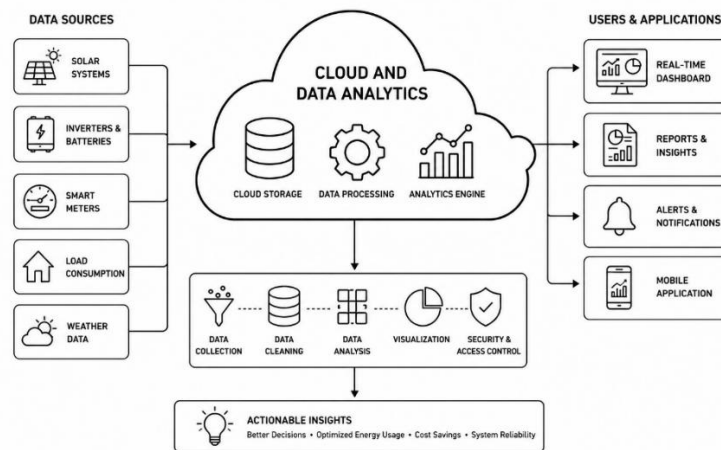


Fig 6.9: Cloud-Based Data Analytics Framework

6.16 Gamification and User Engagement Features

The use of gamification features in the Invershare system, like offering rewards or incentives to users who return surplus energy back to the grid, can have a substantial impact on user engagement and participation. The system can include gamification

features like points, badges, leader boards, and rewards for achievements, which can encourage users to actively engage in energy-sharing initiatives and promote energy-efficient actions in their daily lives. This strategy will be based on principles of behavioral psychology: positive reinforcement to help sustain user involvement and competition in a positive way. Furthermore, gamification can raise awareness of the consumer about energy conservation and encourage them to adopt energy-saving culture. These mechanisms can increase the system adoption rate, energy distribution efficiency and foster a more co-creative and community-based smart energy ecosystem over time.

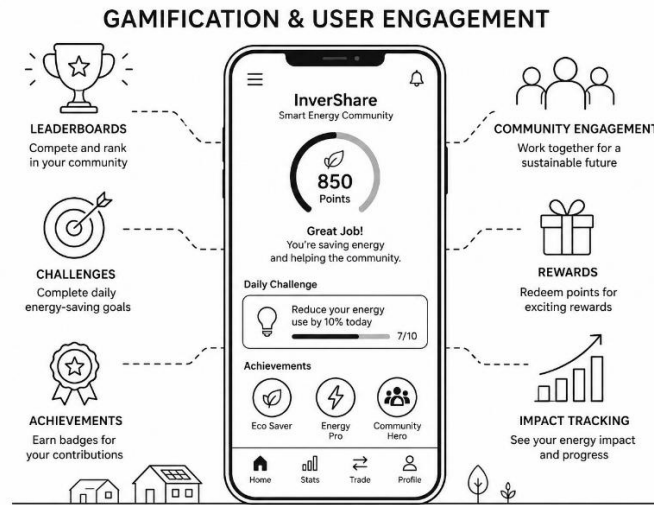


Fig6.10: Gamification and User Engagement Features

6.17 Wind and Hybrid System Integration

The project could be expanded to incorporate other renewable energy alternatives, like solar and wind energy, and make it a more sustainable and resilient power supply source. It is possible to use several renewable resources, so that the intermittency of renewables can be exploited and power generation can be continuous in various weather scenarios. The introduction of battery energy storage systems (BESS) and other advanced energy storage solutions could further improve the availability of energy, by storing excess energy generated at high points in the day, and providing energy use at low points in the day. Additionally, smart energy management algorithms may be deployed in the future to optimize the efficient distribution, storage and

generation of energy depending on the available environmental conditions and energy needs. The smart grid infrastructure can be used to enable bi-directional energy flow, demand response, and an efficient load balancing between consumers and prosumers. The system can also be used to facilitate predictive maintenance, remote monitoring, and AI-driven forecasting, which will boost operational efficiency and reduce maintenance costs. In addition, blockchain can be improved to facilitate faster, more secure, and scalable peer-to-peer energy transactions within larger distributed networks, while also incorporating electric vehicle (EV) infrastructure to allow EVs to act as both energy consumers and distributed energy storage devices via vehicle-to-grid (V2G) systems, which in turn could provide additional protection against potential cyber threats to energy trading processes, communication channels, and user data. The implementation of digital twin technology could also strengthen system planning, system simulation and real-time system performance optimization prior to operational changes, which will help develop a more sustainable, reliable and scalable renewable energy system for future applications in smart city and distributed energy networks and improve general energy security and dependency on traditional fossil fuel power generation [60].

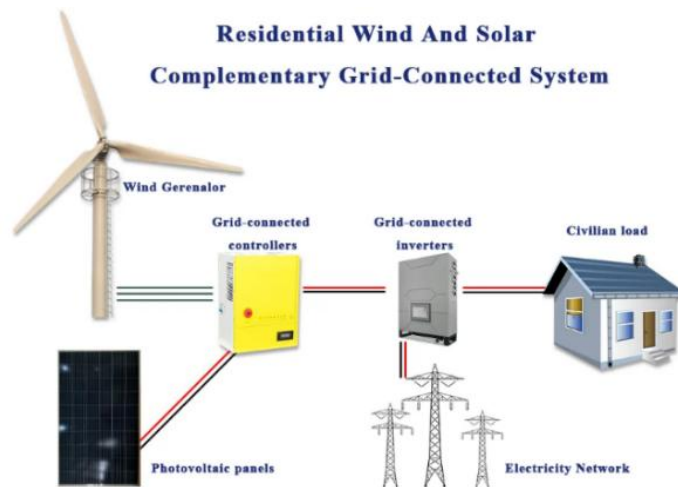


Fig 6.11: Energy storage wind solar hybrid systems. [60]

6.18 Security and Privacy Enhancements

While Invershare is being built on a distributed system architecture, it is vulnerable to a number of cyber-attacks. Therefore, it is important to use strong security measures to

ensure the system's safety [61]. Future versions will add end-to-end encryption to secure communication between nodes, protecting the confidentiality and integrity of data transmitted between nodes. The system will be protected against unauthorized access by implementing strong user authentication and role-based access control. Further, intrusion detection systems and ongoing security surveillance will be incorporated to detect and react to potential threats, in real-time. Frequent firmware updates, secure key management, and adherence to the latest cybersecurity protocols will further strengthen the platform's resilience and reliability.

6.19 Data Encryption and User Authentication Protocol

Implementation of end-to-end encryption protocols along with strong Multi-Factor Authentication (MFA) systems will play a key role in the security and integrity of the Invershare system. Data will be protected during transmission, with end-to-end encryption to ensure that the information is encrypted from the source to the destination, making it impossible for it to be accessed or altered by an unauthorized party or malicious entity. This is especially crucial in smart energy systems where critical user and operational information is frequently shared and transmitted between IoT devices, cloud-based servers, and energy grid resources. Further, Multi-Factor Authentication will provide an additional layer of security, with users and devices using multiple credentials to verify their identity, such as password, biometric verification or one-time authentication codes. This greatly improves the security of the access even if one authentication factor is compromised.

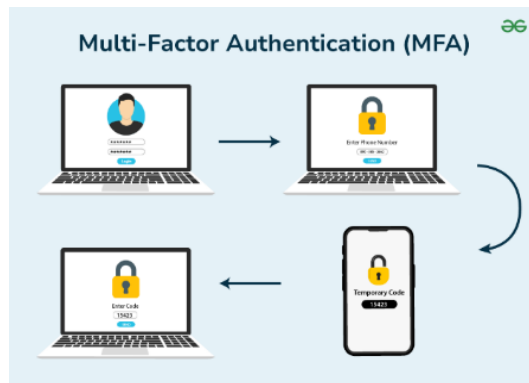


Fig 6.12: Multi-Factor Authentication

6.20 Real-World Deployment Challenges

Implementing the Invershare system on a large scale will require substantial amounts of capital, especially for purchasing and upgrading hardware, cloud computing resources, and Internet of Things (IoT) devices. These initial and operational costs can be significant and can be a major challenge, particularly in developing regions where funding and technical resources can be scarce. Hence, there is a need to research and adopt new ways of reducing costs and making the system more affordable and scalable. These can range from low-cost embedded hardware, to minimize cloud reliance with edge computing, open-source software frameworks, to optimized system architectures which minimize data transmission and storage requirements. Further, there are opportunities for reducing financial risk and for broader adoption through shared infrastructure models, government incentives, and public-private partnerships.

6.21 User Adoption Barriers and Mitigation Strategies

Some barriers to the introduction of DE systems may be lack of awareness and trust. Providing learning opportunities and/or rewards might help to drive users to engage with and adopt Invershare. Essentially, many users do not know how these decentralized systems work and thus have reservations about adopting them. Even system difficulty and user perception of difficulty can be exacerbated and this can discourage participation. Initial setup costs may also be a financial challenge that hinder users from adopting the system.

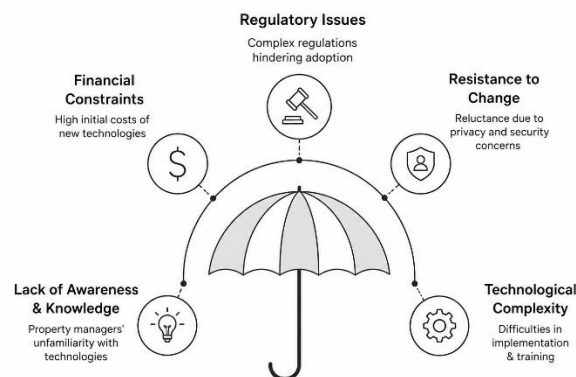


Fig. 6.13: Key challenges affecting technology adoption.

6.22 Conclusion

Improvements to the Invershare project in the future could also contribute to the creation of a more efficient and intelligent smart energy-sharing ecosystem using advancements in technology such as Artificial Intelligence (AI), the Blockchain, improved Internet of Things (IoT) technology, and cloud-based infrastructure solutions. By incorporating AI, predictive analytics for energy demand and supply forecasting can be achieved, optimizing energy distribution, and enhancing real-time decision-making. By implementing blockchain technology, energy transactions can be made secure, transparent and tamper-proof, fostering trust between participants in decentralized energy markets. In the meantime, smart IoT devices could enable real-time monitoring, data collection and communication between energy producers, consumers and the energy grid. Cloud computing could be an enabling technology to efficiently manage vast amounts of energy data and facilitate coordination across the system. All of these technological developments are in line with global goals that focus on the development of smart grids, more integration of renewable energy sources, and more decentralized energy trading systems. Overall, these enhancements would help to create a more sustainable, resilient, and intelligent energy system that can meet the future demands of smart city infrastructure and lessen reliance on traditional centralized energy grid.

REFERENCES

- [1] E. Fernandez, M. J. Hossain, K. Mahmud, M. S. H. Nizami, and M. Kashif, "A bi-level optimization-based community energy management system for optimal energy sharing and trading among peers," *Journal of Cleaner Production*, vol. 279, p. 123254, Jan. 2021, doi: 10.1016/j.jclepro.2020.123254.
- [2] C. K. Rao, S. K. Sahoo, and F. F. Yanine, "A literature review on an IoT-based intelligent smart energy management systems for PV power generation," *Hybrid Advances*, vol. 5, p. 100136, Dec. 2023, doi: 10.1016/j.hybadv.2023.100136.
- [3] W. Tushar et al., "Peer-to-peer energy systems for connected communities: A review of recent advances and emerging challenges," *Applied Energy*, vol. 282, Elsevier BV, p. 116131, Nov. 09, 2020, doi: 10.1016/j.apenergy.2020.116131.
- [4] A. Khalid, S. Aslam, K. Aurangzeb, S. I. Haider, M. Ashraf, and N. Javaid, "An efficient energy management approach using Fog-as-a-Service for sharing economy in a smart grid," *Energies*, vol. 11, no. 12, p. 3500, Dec. 2018, doi: 10.3390/en11123500.
- [5] C. K. Rao, S. K. Sahoo, and F. F. Yanine, "An IoT-based intelligent smart energy monitoring system for solar PV power generation," *Energy Harvesting and Systems*, vol. 11, no. 1, Nov. 2023, doi: 10.1515/ehs-2023-0015.
- [6] M. R. A. T et al., "Intelligent energy management across smart grids deploying 6G IoT, AI, and blockchain in sustainable smart cities," *IoT*, vol. 5, no. 3, p. 560, Aug. 2024, doi: 10.3390/iot5030025.
- [7] I. Hong, B. Kang, and S. Park, "Design and implementation of intelligent energy distribution management with photovoltaic system," *IEEE Transactions on Consumer Electronics*, vol. 58, no. 2, p. 340, May 2012, doi: 10.1109/TCE.2012.6227431.
- [8] International Energy Agency, "Global Energy Review 2021," 2021.
- [9] M. A. Hannan et al., "A review of Internet of Things for smart home: Challenges and solutions," *Journal of Network and Computer Applications*, vol. 103, pp. 1–17, 2018.

- [10] W. Agustiarmi, Y. Huda, T. Sriwahyuni, et al., "Real-Time IoT-based Energy Power Consumption Monitoring System for Smart Homes," 2025. [Online]. Available: <https://www.researchgate.net/publication/376842543>.
- [11] C. A. Aldana B and E. F. Montenegro A, "A Low-Cost Wireless Sensor System for Power Quality Management in Single-Phase Domestic Networks," 2023.
- [12] Y. Cheddadi, H. Cheddadi, F. Cheddadi, et al., "Design and implementation of an intelligent low-cost IoT solution for energy monitoring of photovoltaic stations," 2020.
- [13] R. Dorak, C. M. Mahajan, M. Dorle, et al., "IoT Connected Smart Energy Meter," 2023.
- [14] C. Escarrega, W. L. Coggins, S. Hamed, et al., "Demand Charge Management: Prototype Design and Testing," 2025.
- [15] H. O. Garcés, J. Godoy, G. Rizzo, et al., "Development of an IoT-Enabled Smart Electricity Meter for Real-Time Energy Monitoring and Efficiency," 2025. [Online]. Available: <https://www.researchgate.net/publication/376842543>.
- [16] A. Hamdan, S. Sonko, A. Fabuyide, et al., "Real-time energy monitoring systems: Technological applications in Canada, USA, and Africa," 2024.
- [17] S. Lee, P. Shenoy, K. Ramamritham, et al., "AutoShare: Virtual community solar and storage for energy sharing," 2021.
- [18] M. Mahmoud and S. Ben Slama, "Driving Innovation: Prosumer Incentives in Peer-to-Peer Energy Trading," 2024.
- [19] A. Onay, G. Ertürk, C. K. İmamoğlu, et al., "A Smart Home Energy Monitoring System Based on Internet of Things and Inter Planetary File System for Secure Data Sharing," 2023.
- [20] Y. Wang, Q. Chen, T. Hong, and C. Kang, "Review of smart meter data analytics: Applications, methodologies, and challenges," *IEEE Transactions on Smart Grid*, vol. 10, no. 3, pp. 3125–3148, May 2019.

- [21] V. C. Gungor, D. Sahin, T. Kocak, et al., “Smart Grid Technologies: Communication Technologies and Standards,” *IEEE Transactions on Industrial Informatics*, vol. 7, no. 4, pp. 529–539, Nov. 2011.
- [22] A. H. Mohsenian-Rad, V. W. S. Wong, J. Jatskevich, et al., “Autonomous Demand-Side Management Based on Game-Theoretic Energy Consumption Scheduling for the Future Smart Grid,” *IEEE Transactions on Smart Grid*, vol. 1, no. 3, pp. 320–331, Dec. 2010.
- [23] X. Fang, S. Misra, G. Xue, et al., “Smart Grid—The New and Improved Power Grid: A Survey,” *IEEE Communications Surveys & Tutorials*, vol. 14, no. 4, pp. 944–980, 2012.
- [24] D. Alahakoon, X. Yu, “Smart Electricity Meter Data Intelligence for Future Energy Systems: A Survey,” *IEEE Transactions on Industrial Informatics*, vol. 12, no. 1, pp. 425–436, Feb. 2016.
- [25] S. Zahra, F. Rehman, N. Javaid, et al., “IoT based Energy Management and Monitoring System for Smart Home,” in *Proc. IEEE International Conference on Smart Energy Grid Engineering*, pp. 381–386, 2018.
- [26] R. Khan, P. Kumar, D. N. K. Jayakody, et al., “A Survey on Security and Privacy of 5G Technologies: Potential Solutions, Recent Advancements, and Future Directions,” *IEEE Communications Surveys & Tutorials*, vol. 22, no. 1, pp. 196–248, 2020.
- [27] D. Niyato, P. Wang, D. I. Kim, “Performance Analysis of Cloud-based Data Management for Internet of Energy Systems,” *IEEE Transactions on Industrial Informatics*, vol. 15, no. 3, pp. 1711–1720, Mar. 2019.
- [28] K. Shafique, B. A. Khan, S. Iqbal, et al., “Cloud-Based Residential Energy Management System for Smart Home,” *IEEE Access*, vol. 7, pp. 147089–147103, 2019.

- [29] S. Al-Fuqaha, M. Guizani, M. Mohammadi, et al., "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.
- [30] N. Liu, X. Yu, C. Wang, et al., "Energy-Sharing Model with Price-Based Demand Response for Microgrids of Peer-to-Peer Prosumer Networks," *IEEE Transactions on Power Systems*, vol. 32, no. 5, pp. 3569–3583, Sept. 2017.
- [31] Y. Zhang, Y. Wang, J. Zhao, et al., "Design and Implementation of a Solar Energy Sharing System Based on Inverter Communication," *Energy Reports*, vol. 8, pp. 1066–1075, 2022.
- [32] W. Tushar, C. Yuen, T. Morstyn, et al., "Peer-to-Peer Energy Systems for Connected Communities: A Review of Recent Advances and Emerging Challenges," *Applied Energy*, vol. 282, p. 116131, 2021.
- [33] OpenADR Alliance, "OpenADR 2.0b Profile Specification," 2015. [Online]. Available: <https://www.openadr.org/>
- [34] A. Sanguinetti, D. Kar, W. Y. Lee, "A Multi-Inverter Control System for Coordinated Voltage Regulation in Distribution Networks," *IEEE Transactions on Industry Applications*, vol. 51, no. 4, pp. 3405–3413, July-Aug. 2015.
- [35] A. Mahmood, N. Javaid, S. Razzaq, "A Review of Wireless Communications for Smart Grid," *Renewable and Sustainable Energy Reviews*, vol. 41, pp. 248–260, 2015.
- [36] B. N. Alhasnawi et al., "A Novel Internet of Energy Based Optimal Multi-Agent Control Scheme for Microgrid including Renewable Energy Resources," *IEEE Transactions on Smart Grid*, 2021.
- [37] H. Tu et al., "An IoT-Based Framework for Distributed Generic Microgrid Controllers," *IEEE Internet of Things Journal*, 2024.
- [38] Labcenter Electronics, Proteus Design Suite Version 8, User Manual. Labcenter Electronics Ltd., 2021.

- [39] R. W. Erickson and D. Maksimovic, Fundamentals of Power Electronics, 3rd ed. New York, NY, USA: Springer, 2020.
- [40] P. Horowitz and W. Hill, The Art of Electronics, 3rd ed. Cambridge, UK: Cambridge University Press, 2015.
- [41] Allegro MicroSystems, ACS712 Fully Integrated, Hall Effect-Based Linear Current Sensor IC Datasheet, Rev. 12. Manchester, NH, USA: Allegro MicroSystems, 2020.
- [42] Espressif Systems, ESP32 Technical Reference Manual, Version 5.0. Shanghai, China: Espressif Systems Co., Ltd., 2023.
- [43] IPC, IPC-2221B: Generic Standard on Printed Board Design. Bannockburn, IL, USA: IPC – Association Connecting Electronics Industries, 2012.
- [44] K. Kok, C. Warmer, and I. Kamphuis, "PowerMatcher: Multiagent control in the electricity infrastructure," in Proc. 4th Int. Joint Conf. on Autonomous Agents and Multi-Agent Systems (AAMAS), Utrecht, Netherlands, Jul. 2005, pp.
- [45] IEEE Standards Association, IEEE Std 802.11-2020: IEEE Standard for Information Technology – Telecommunications and Information Exchange Between Systems – Local and Metropolitan Area Networks – Specific Requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. New York, NY, USA: IEEE, 2020.
- [46] A. Botta, W. de Donato, V. Persico, and A. Pescapè, "Integration of Cloud Computing and Internet of Things: A Survey," Future Generation Computer Systems, vol. 56, pp. 684–700, 2016.
- [47] N. S. Mohammed and N. H. Selman, "Real-time monitoring of the prototype design of an electric system using the Ubidots platform," International Journal of Power Electronics and Drive Systems / International Journal of Electrical and Computer Engineering, vol. 11, no. 5, pp. 5568–5574, 2021.

- [48] C. A. A. B. and E. F. M. A., “A Low-Cost Wireless Sensor System for Power Quality Management in Single-Phase Domestic Networks,” *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 8, Jan. 2023.
- [49] I. M. Moreno-García, A. Moreno-Muñoz, V. Pallares-López, M. González-Redondo, E. J. García, and C. Moreno, “Development and application of a smart grid test bench,” *Journal of Cleaner Production*, vol. 162, pp. 45–52, 2017.
- [50] I. W. D. Pancane, I. N. G. Adrama, and I. W. Sutama, “Development of Smart Energy Monitoring Internet of Things System Based on App Inventor for Electric Energy Efficiency,” *Advance Sustainable Science, Engineering and Technology*, vol. 3, no. 1, 2021.
- [51] C. Escarrega, W. L. Coggins, S. Hamed, M. Iranpour, and M. R. Narimani, “Demand Charge Management: Prototype Design and Testing,” *arXiv (Cornell University)*, Sep. 2025.
- [52] E. A. Prasty, M. Junus, and E. Rohadi, “Design and Development of a Micro Inverter Power Monitoring System to Enhance Photovoltaic System Performance by Integrating LoRaWAN and IoT,” *E3S Web of Conferences*, vol. 473, p. 1011, Jan. 2024.
- [53] N. V. Guillem, “Design and development of an advanced software and hardware architecture for intelligent energy management in residential environments,” 2025. [Online]. Available: (Accessed: Feb. 2026).
- [54] W. Tushar et al., “Peer-to-Peer Energy Systems for Connected Communities: A Review of Recent Advancements and Emerging Challenges,” *Applied Energy*, vol. 282, Elsevier B.V., pp. 116131–116131, Nov. 2020, doi: 10.1016/j.apenergy.2020.116131.
- [55] N. Malsa, V. Gupta, R. Jain, S. S. Rawat, and K. Sharma, “Hybrid Peer-to-Peer Energy Trading Approach Using Ethereum, IoT, and AWS,” pp. 1–6, Aug. 2025, doi: 10.1109/ic366947.2025.11290173.

- [56] A. Ipakchi and F. Albuyeh, “Grid of the future,” *IEEE Power and Energy Magazine*, vol. 7, no. 2, pp. 52–62, Mar.–Apr. 2009.
- [57] U.S. Department of Energy, “Smart grid system report,” Office of Electricity Delivery and Energy Reliability, 2022.
- [58] P. Palensky and D. Dietrich, “Demand side management: Demand response, intelligent energy systems, and smart loads,” *IEEE Transactions on Industrial Informatics*, vol. 7, no. 3, pp. 381–388, Aug. 2011.
- [59] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, 4th ed. Pearson, 2020.
- [60] Y. Wang, Q. Chen, C. Kang, and M. Zhang, “Load profiling and its application in residential electricity demand forecasting,” *IEEE Transactions on Smart Grid*, vol. 6, no. 2, pp. 752–761, Mar. 2015.
- [61] I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning*. MIT Press, 2016.

ABBREVIATIONS

AC — Alternating Current

API — Application Programming Interface

DC — Direct Current

ESP32 — Espressif Systems 32 Microcontroller

ESS — Energy Storage System

GPIO — General-Purpose Input/Output

GUI — Graphical User Interface

IoT — Internet of Things

LCD — Liquid Crystal Display

MAPE — Mean Absolute Percentage Error

MCU — Microcontroller Unit

MOSFET — Metal-Oxide-Semiconductor Field-Effect Transistor

PCB — Printed Circuit Board

PV — Photovoltaic (Solar Power)

PWM — Pulse Width Modulation

RMS — Root Mean Square

SAR — Successive-Approximation Register

SDG — Sustainable Development Goal

UI / UX — User Interface / User Experience

Wi-Fi — Wireless Fidelity

ANNEXURE

Annexure A – Hardware Specifications

The Invershare prototype is developed using the ESP32 microcontroller as the primary processing unit due to its integrated Wi-Fi and Bluetooth capabilities, making it suitable for IoT-based smart energy management applications.

Hardware Used

- ESP32 Development Board
- Voltage Sensor
- Current Sensor
- Relay Module
- Power Supply Unit

ESP32 Specifications

- Dual-core Xtensa® LX6 Processor
- Operating Voltage: 3.3 V
- Clock Speed: Up to 240 MHz
- Wi-Fi: IEEE 802.11 b/g/n
- Bluetooth: BLE 4.2
- Flash Memory: 4 MB
- GPIO Pins: 34
- ADC Channels: 18
- PWM Support
- SPI, UART, and I²C Communication Interfaces

Annexure B – Circuit Simulation

The electronic circuitry of the Invershare system was designed and verified using Proteus 8 Professional.

Circuit simulation was performed before hardware implementation to validate electrical connections, verify component functionality, and minimize design errors. The complete schematic and PCB layout are included in this annexure.

Annexure C – Software Implementation

The software architecture consists of both frontend and backend components to enable real-time monitoring and control of energy sharing.

Frontend Technologies

- HTML5
- CSS3
- JavaScript

Backend Technologies

- Node.js
- Firebase Authentication
- Firebase Realtime Database
- Firebase Cloud Services

The frontend provides an interactive dashboard for users to monitor energy generation, energy consumption, and shared energy. The backend manages user authentication, data synchronization, and communication between the ESP32 device and the cloud database.

Annexure D – Testing and Validation

Testing was conducted to verify the functionality, reliability, and performance of both the hardware and software components.

Hardware Testing

- Voltage measurement using a digital voltmeter.
- Sensor calibration and integration testing.
- ESP32 communication testing.
- Relay switching verification.
- Power supply stability testing.

Software Testing

- Firebase database connectivity testing.
- Node.js server communication.
- User authentication testing.
- Real-time data synchronization.

- Dashboard functionality testing.

System Validation

- Real-time sensor data transmission.
- Accurate voltage monitoring.
- Successful Firebase data storage and retrieval.
- Stable communication between ESP32 and the cloud server.
- End-to-end system operation under different load conditions.

Syed Khawar shah

InvershareFypThesis



Document Details

Submission ID

trn:oid::3618:144534035

Submission Date

Jun 29, 2026, 5:35 PM GMT+0

Download Date

Jun 30, 2026, 5:02 AM GMT+0

File Name

InvershareFypThesis.pdf

File Size

3.0 MB

81 Pages**19,282 Words****121,128 Characters**

9% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Match Groups

-  **162 Not Cited or Quoted 8%**
Matches with neither in-text citation nor quotation marks
-  **2 Missing Quotations 0%**
Matches that are still very similar to source material
-  **0 Missing Citation 0%**
Matches that have quotation marks, but no in-text citation
-  **0 Cited and Quoted 0%**
Matches with in-text citation present, but no quotation marks

Top Sources

- 4%  Internet sources
- 4%  Publications
- 6%  Submitted works (Student Papers)

Integrity Flags

0 Integrity Flags for Review

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

Match Groups

- 162 Not Cited or Quoted 8%**
Matches with neither in-text citation nor quotation marks
- 2 Missing Quotations 0%**
Matches that are still very similar to source material
- 0 Missing Citation 0%**
Matches that have quotation marks, but no in-text citation
- 0 Cited and Quoted 0%**
Matches with in-text citation present, but no quotation marks

Top Sources

- 4% Internet sources
- 4% Publications
- 6% Submitted works (Student Papers)

Top Sources

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

- 1** Student papers
Higher Education Commission Pakistan on 2026-05-05 <1%
- 2** Publication
Pramod R. Gunjal, Satish R. Jondhale, Jaime Lloret, Karishma Agrawal. "Internet o... <1%
- 3** Internet
www.coursehero.com <1%
- 4** Publication
Amit Kumar Tyagi, Shrikant Tiwari. "AI and Blockchain in Smart Grids - Fundamen... <1%
- 5** Student papers
Universiti Kuala Lumpur on 2026-06-09 <1%
- 6** Publication
Pawan Kumar, Srete Nikolovski, Z Y Dong. "Internet of Energy Handbook", CRC Pr... <1%
- 7** Internet
www.mdpi.com <1%
- 8** Publication
Vijay Pandiarajan. "Integrated Business Innovation - Case Studies and Framewor... <1%
- 9** Student papers
University of Hong Kong on 2025-04-30 <1%
- 10** Student papers
Jabatan Pendidikan Politeknik Dan Kolej Komuniti on 2025-11-11 <1%

11	Publication	Poonam Nandal, Tapas Kumar, Meeta Singh, Mamta Dahiya. "Progressive Compu...	<1%
12	Student papers	The British College on 2026-05-11	<1%
13	Internet	lib.buet.ac.bd:8080	<1%
14	Internet	umpir.ump.edu.my	<1%
15	Student papers	University of Greenwich on 2025-12-12	<1%
16	Student papers	Bahrain Polytechnic on 2026-05-21	<1%
17	Internet	ucf.digital.flvc.org	<1%
18	Internet	hvlopen.brage.unit.no	<1%
19	Student papers	Universiti Teknikal Malaysia Melaka - Library on 2026-06-17	<1%
20	Student papers	The Northcap University on 2026-06-29	<1%
21	Student papers	Universiti Kuala Lumpur on 2026-06-09	<1%
22	Student papers	Universiti Kuala Lumpur on 2026-06-14	<1%
23	Internet	bdears.busitema.ac.ug	<1%
24	Student papers	Politeknik Sultan Haji Ahmad Shah (POLISAS) on 2026-04-26	<1%

25	Student papers	University of Glamorgan on 2021-09-30	<1%
26	Student papers	Middle East College on 2025-12-27	<1%
27	Student papers	Nottingham Trent University on 2010-04-30	<1%
28	Publication	Sushil Kumar Singh, Himanshu Gupta, Rajendrasinh Jadeja, Ashish Khanna, Bal Vi...	<1%
29	Internet	projectshelve.com	<1%
30	Internet	www.analog.com	<1%
31	Publication	Abhishek Kumar, Hemant Kumar Saini, Ashutosh Kumar Dubey, Vicente García-Dí...	<1%
32	Student papers	Info Myanmar College on 2022-03-16	<1%
33	Student papers	University of Sunderland on 2026-05-22	<1%
34	Publication	Shichang Cui, Yan-Wu Wang, Yang Shi, Jiang-Wen Xiao. "A New and Fair Peer-to-P...	<1%
35	Student papers	Universiti Kuala Lumpur on 2026-06-12	<1%
36	Student papers	University of Wolverhampton on 2021-05-14	<1%
37	Internet	jupa-nordwalde.de	<1%
38	Publication	Muhammad Asif. "Handbook of Energy Transitions", CRC Press, 2022	<1%

39	Student papers	The Robert Gordon University on 2026-04-17	<1%
40	Student papers	Zambia Centre for Accountancy Studies on 2025-05-31	<1%
41	Internet	docplayer.net	<1%
42	Student papers	Glasgow Caledonian University on 2019-04-25	<1%
43	Student papers	Higher Education Commission Pakistan on 2025-05-14	<1%
44	Student papers	University of East London on 2026-05-08	<1%
45	Student papers	University of Hertfordshire on 2026-06-09	<1%
46	Internet	eprints.usm.my	<1%
47	Student papers	Higher Education Commission Pakistan on 2026-06-29	<1%
48	Student papers	Kingston University on 2013-01-28	<1%
49	Student papers	University of Nottingham on 2025-09-01	<1%
50	Internet	researchspace.ukzn.ac.za	<1%
51	Internet	www.autocarpro.in	<1%
52	Student papers	Glyndwr University on 2019-05-07	<1%

53	Student papers	University of Sheffield on 2025-05-12	<1%
54	Internet	manualzilla.com	<1%
55	Internet	www.techgropse.com	<1%
56	Internet	www.theibfr.com	<1%
57	Student papers	Higher Education Commission Pakistan on 2026-06-28	<1%
58	Student papers	Librarian NITT on 2026-04-21	<1%
59	Student papers	Malta College of Arts,Science and Technology on 2026-05-19	<1%
60	Student papers	University of Hertfordshire on 2026-06-09	<1%
61	Student papers	University of Sydney on 2024-03-04	<1%
62	Internet	managementjournal.usamv.ro	<1%
63	Internet	mptf.undp.org	<1%
64	Internet	www.ewubd.edu	<1%
65	Internet	www.newegg.com	<1%
66	Internet	www.theseus.fi	<1%

67	Publication	Abdennabi Morchid, Bouali Et-taibi, Zahra Oughannou, Rachid El Alami et al. "IoT-...	<1%
68	Student papers	Army Institute of Technology on 2026-06-14	<1%
69	Publication	Bhabani Prasanna Pattanaik, Dharendra Kumar Shukla, Sambit Satpathy, Kamala...	<1%
70	Student papers	Jabatan Pendidikan Politeknik Dan Kolej Komuniti on 2025-11-12	<1%
71	Publication	Manzoor Ansari, Syed Arshad Ali, Mansaf Alam. "Next-Generation Artificial Intelli...	<1%
72	Student papers	Monash University on 2018-05-26	<1%
73	Student papers	PSB Academy on 2026-06-23	<1%
74	Publication	Sai Vasudeva Bhagavatula, Venkata Rupesh Bharadwaj Yellamraju, Karthik Chan...	<1%
75	Publication	Sangita S. Chaudhari, Gautam Borkar, Dhanajay Dakhane, Sachin Jain, Abhi Desh...	<1%
76	Publication	Shalli Rani, Ayush Dogra. "Emerging Trends in Smart Computing and Sustainable ...	<1%
77	Student papers	Universiti Kuala Lumpur on 2026-06-09	<1%
78	Student papers	University of Central Lancashire on 2026-04-10	<1%
79	Student papers	University of Cyberjaya on 2026-06-08	<1%
80	Student papers	University of South Africa on 2026-05-18	<1%

81	Student papers	University of Warwick on 2024-12-23	<1%
82	Internet	documents.mx	<1%
83	Internet	ebin.pub	<1%
84	Internet	eprints.utm.my	<1%
85	Internet	leobit.com	<1%
86	Student papers	universalaiuniversity on 2025-07-08	<1%
87	Internet	www.majju.pk	<1%
88	Internet	www.ti.com	<1%
89	Student papers	Universiti Kuala Lumpur on 2026-06-09	<1%
90	Student papers	Griffth University on 2025-10-17	<1%
91	Student papers	Politeknik Sultan Salahuddin Abdul Aziz Shah (PSA) on 2025-11-25	<1%
92	Student papers	SSBAS on 2026-04-12	<1%
93	Publication	Sai Kiran Oruganti, Manoj V. Bhalerao, Vishal Gangadhar Naranje, Dalia A. Magdi,...	<1%
94	Student papers	Universiti Kuala Lumpur on 2026-06-10	<1%

Syed Khawar shah

InvershareFypThesis



Document Details

Submission ID

trn:oid::3618:144534035

Submission Date

Jun 29, 2026, 5:35 PM GMT+0

Download Date

Jun 30, 2026, 5:02 AM GMT+0

File Name

InvershareFypThesis.pdf

File Size

3.0 MB

81 Pages

19,282 Words

121,128 Characters

*% detected as AI

AI detection includes the possibility of false positives. Although some text in this submission is likely AI generated, scores below the 20% threshold are not surfaced because they have a higher likelihood of false positives.

Caution: Review required.

It is essential to understand the limitations of AI detection before making decisions about a student's work. We encourage you to learn more about Turnitin's AI detection capabilities before using the tool.

Disclaimer

Our AI writing assessment is designed to help educators identify text that might be prepared by a generative AI tool. Our AI writing assessment may not always be accurate (it may misidentify writing that is likely AI generated as AI generated and AI paraphrased or likely AI generated and AI paraphrased writing as only AI generated) so it should not be used as the sole basis for adverse actions against a student. It takes further scrutiny and human judgment in conjunction with an organization's application of its specific academic policies to determine whether any academic misconduct has occurred.