Development and Implementation of Smart Inverter System for Future Power Demand Through Renewable Source

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ABSTRACT

A sine wave is a smooth, continuous oscillation representing the ideal form of AC power, characterized by a single frequency (e.g., 50/60 Hz) and minimal harmonic distortion, ensuring compatibility with all electrical devices and the utility grid. The normal wave (commonly referring to a Modified Square Wave or Quasi-Sine Wave) is a stepped, non-sinusoidal waveform composed of a fundamental frequency and significant higher-order harmonics. The Pure Sine Wave inverter achieved an estimated efficiency of 85-90%, whereas the Square Wave inverter stayed around 35-39%.Charging of Sine Wave system reached 14.02V (3% higher than Square Wave).Discharge of Sine Wave system was 30% more resilient at the end of the test period (7.90V vs 6.06V). The OLED display confirmed a 50Hz stable frequency. This analysis confirms that the Pure Sine Wave Inverter is the most viable solution for future power demands through renewable sources due to its efficiency and compatibility with modern household appliances.

LIST OF ABBREVIATIONS

Abbreviation	**Full Form**
AC	Alternating Current
DC	Direct Current
PV	Photovoltaic
SPWM	Sinusoidal Pulse Width Modulation
OLED	Organic Light Emitting Diode
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
Hz	Hertz
V	Volt
A	Ampere
Ah	Ampere-hour

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CHAPTER 1

INTRODUCTION

1.1 General Background

The demand for electrical energy has increased rapidly due to population growth, industrial expansion, and the widespread use of electrical and electronic appliances. In developing countries like Bangladesh, uninterrupted and reliable electricity supply remains a major challenge, particularly in rural and semi-urban regions. Frequent power outages, voltage instability, and limited grid coverage have increased the dependence on alternative energy sources and backup power systems.

Renewable energy has gained significant importance as a sustainable solution to meet growing energy demands while reducing environmental impact. Among various renewable sources, solar energy is one of the most promising due to its abundance, cleanliness, and long-term availability. Solar photovoltaic (PV) systems convert sunlight directly into electrical energy and are widely used for domestic and small-scale applications.

However, solar energy systems require proper energy storage and power conditioning units to ensure a continuous and usable power supply. Batteries are used to store generated DC energy, and inverters are required to convert this DC power into AC power suitable for household appliances. The performance and reliability of a solar-based power system largely depend on the quality of the inverter output waveform.

1.2 Problem Statement

Conventional inverters commonly used in low-cost solar and backup power systems often generate square wave or modified sine wave outputs. Although these inverters are simple in design and relatively inexpensive, their output waveforms contain high harmonic distortion. Such distorted waveforms can cause excessive heating, audible noise, reduced efficiency, and potential damage to electrical appliances, especially those with inductive or electronic components.

Pure sine wave inverters, on the other hand, produce output waveforms that closely resemble standard grid electricity. These inverters offer better power quality, improved appliance compatibility, and higher system efficiency. However, pure sine wave inverters are more complex and comparatively expensive, which makes it important to understand their advantages over conventional square wave inverters.

Another challenge is the limited availability of affordable measurement tools for visualizing inverter output waveforms. Commercial oscilloscopes are costly and often unavailable in academic laboratories. This creates a need for low-cost and accessible waveform visualization methods suitable for educational and experimental purposes.

1.3 Motivation of the Project

The primary motivation of this project is to study and compare the output waveform characteristics of square wave and pure sine wave inverters used in a solar-powered system. Understanding waveform quality is essential for selecting suitable inverter technology for household and renewable energy applications.

This project is also motivated by the objective of integrating renewable energy systems, power conversion units, and basic measurement techniques into a single experimental setup. The use of a low-cost, Arduino-based oscilloscope enables practical waveform visualization without relying on expensive laboratory equipment.

From an academic perspective, the project provides mechanical engineering students with hands-on exposure to renewable energy systems, inverter technology, energy storage systems, and system-level integration of electrical and electronic components.

1.4 Objectives of the Project

The main objectives of this project are listed below:

- To design and develop a solar-powered inverter system with battery energy storage.
- To analyze and compare the output waveforms of square wave and pure sine wave inverters.
- To study the qualitative harmonic characteristics of different inverter outputs.

1.5 Scope of the Project

The scope of this project is limited to the design, implementation, and experimental observation of a small-scale solar-powered inverter system. The system is primarily intended for educational and demonstration purposes.

The project includes solar-based battery charging, DC-to-AC power conversion using two different inverter types, and waveform visualization using a DIY oscilloscope. The comparison focuses on qualitative waveform characteristics rather than advanced numerical analysis.

The project does not include real-load testing with household appliances, detailed harmonic analysis using FFT techniques, or large-scale commercial inverter development.

1.6 Significance of the Study

The development of a low-cost oscilloscope provides an effective educational tool for waveform observation and basic signal analysis. The study contributes to academic learning by offering a practical approach to understanding inverter behavior without requiring expensive measurement instruments.

1.7 Organization of the Thesis

This thesis is organized into nine chapters following the academic guidelines of the Department of Mechanical Engineering.

Chapter 1 presents the general background, problem statement, objectives, scope, and significance of the project.
Chapter 2 reviews existing literature related to solar energy systems, inverter technologies, and waveform analysis.
Chapter 3 describes the methodology and overall system operation.
Chapter 4 discusses the design analysis of individual system components.
Chapter 5 presents the prototype implementation and experimental observations.
Chapter 6 provides cost estimation for real-life implementation.
Chapter 7 discusses the advantages and limitations of the proposed system.
Chapter 8 outlines future scope and possible system improvements.
Chapter 9 concludes the thesis with final remarks and findings.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The growing demand for reliable, sustainable, and cost-effective electrical energy has increased research interest in renewable energy systems, particularly solar photovoltaic (PV) technology. Solar-based power systems are widely used in residential and small-scale applications where grid electricity is unreliable or unavailable. One of the most critical components of such systems is the inverter, which converts stored DC energy into usable AC power.

The quality of an inverter's output waveform significantly affects system efficiency, appliance performance, and operational safety. As a result, numerous studies have focused on inverter design, waveform characteristics, harmonic distortion, and compatibility with electrical loads. This chapter reviews relevant literature related to solar photovoltaic systems, battery energy storage, inverter technologies, waveform distortion, and low-cost measurement techniques.

The purpose of this review is to understand existing developments, identify the advantages and limitations of different inverter types, and establish the research gap addressed by this project.

2.2 Solar Photovoltaic Energy Systems

Solar photovoltaic systems convert sunlight directly into electrical energy using semiconductor materials **[5][6]**. A typical PV system consists of solar panels, a charge controller, battery storage, and an inverter. Solar energy is widely recognized as a clean, renewable, and environmentally friendly power source with minimal environmental impact.

Several studies emphasize the suitability of solar PV systems for off-grid and backup power applications, especially in developing regions where grid reliability is limited. Research shows that solar-based systems can reduce dependency on fossil fuels and provide a stable power supply when combined with efficient energy storage and power conditioning units.

Literature also highlights the importance of proper system sizing and component selection to ensure reliable operation. Without appropriate design, PV systems may suffer from energy losses, reduced efficiency, and shortened component lifespan.

2.3 Battery Energy Storage in Solar Systems

Battery storage is an essential part of solar power systems, as it allows excess energy generated during daylight hours to be stored for use during nighttime or cloudy conditions. Various battery technologies are used in solar systems, including lead-acid, lithium-ion, and gel batteries.

Many studies indicate that lead-acid batteries are commonly used in small-scale solar applications due to their low cost, availability, and proven reliability. Battery performance depends on factors such as charging method, depth of discharge, operating temperature, and maintenance practices.

Research emphasizes the importance of using a solar charge controller to regulate battery charging and discharging. Proper battery management prevents overcharging, deep discharge, and excessive heating, which significantly improves battery lifespan and system stability.

2.4 Inverter Technology Overview

An inverter is an electronic device that converts DC power into AC power suitable for electrical loads. Inverters are classified based on output waveform shape, power rating, and control technique. The most common inverter types include square wave, modified sine wave, and pure sine wave inverters.

Literature indicates that inverter selection plays a crucial role in determining power quality, system efficiency, and appliance compatibility. Poor inverter waveform quality can lead to power losses, noise, vibration, and reduced performance of connected devices.

Researchers have extensively studied inverter topologies and control methods to improve output waveform quality while maintaining cost-effectiveness and reliability [1].

2.5 Square Wave and Modified Sine Wave Inverters

Square wave inverters are the simplest type of inverter and are widely used in low-cost power backup systems. These inverters generate an output waveform that alternates directly between positive and negative voltage levels without gradual transitions.

Modified sine wave inverters attempt to improve waveform quality by introducing stepped voltage levels that approximate a sinusoidal shape. Despite this improvement, both square wave and modified sine wave inverters contain significant harmonic distortion.

Studies report that such inverters can cause excessive heating, audible noise, vibration, and reduced efficiency in inductive loads such as motors and transformers. Although these inverters are inexpensive and easy to implement, their limited power quality restricts their use with sensitive electrical appliances.

2.6 Pure Sine Wave Inverters

Pure sine wave inverters generate output waveforms that closely resemble standard utility grid electricity. These inverters use advanced switching techniques such as Sinusoidal Pulse Width Modulation (SPWM) to reduce harmonic distortion and produce smooth AC output [2][8].

Literature consistently shows that pure sine wave inverters provide superior performance compared to square wave inverters. They offer better compatibility with household appliances, improved efficiency, reduced noise, and lower thermal stress on components.

Although pure sine wave inverters are more complex and costly, research indicates that their long-term benefits in terms of appliance safety and system reliability outweigh the initial investment.

2.7 Harmonic Distortion in Inverter Output

Harmonic distortion refers to the presence of unwanted frequency components in an electrical waveform. High harmonic distortion can cause power losses, overheating, electromagnetic interference, and reduced lifespan of electrical equipment.

Several studies analyze the negative impact of harmonics generated by non-sinusoidal inverter outputs. Square wave inverters are found to produce high harmonic content, which affects transformer efficiency and motor operation [7].

In contrast, pure sine wave inverters significantly reduce harmonic distortion, resulting in smoother operation and improved power quality. This project focuses on qualitative harmonic observation through waveform visualization rather than advanced mathematical analysis [4][11].

2.8 Measurement and Visualization Techniques

Oscilloscopes are commonly used to observe voltage and current waveforms in electrical systems. However, professional oscilloscopes are expensive and may not be accessible in many educational laboratories.

Recent research highlights the development of low-cost waveform visualization systems using microcontrollers. These systems are particularly suitable for low-frequency signal observation, such as 50 Hz AC waveforms commonly found in power systems.

Such visualization techniques provide an effective learning platform for students and researchers to understand waveform behavior without relying on advanced instrumentation.

2.9 Arduino-Based Oscilloscope Systems

Arduino-based oscilloscopes utilize analog-to-digital converters and graphical displays to visualize voltage signals. Studies indicate that although these systems have limited sampling rates and accuracy, they are suitable for basic waveform observation and educational demonstrations.

Research shows that Arduino-based oscilloscopes are effective for comparing waveform shapes, identifying distortion, and understanding inverter behavior. Their low cost and simplicity make them ideal for academic projects and laboratory experiments.

Limitations include reduced resolution, narrow voltage range, and limited frequency response compared to professional equipment [9].

2.10 Review of Existing Inverter Studies

Numerous studies have investigated the performance of different inverter types used in solar and backup power systems. These studies typically focus on waveform quality, harmonic distortion, efficiency, and appliance compatibility [12].

Existing research consistently concludes that square wave and modified sine wave inverters generate distorted waveforms that negatively affect appliance performance. Pure sine wave inverters, in contrast, provide superior power quality and smoother operation.

Measurement methods used in previous studies include digital oscilloscopes, harmonic analyzers, and microcontroller-based visualization systems. Educational research increasingly supports the use of low-cost measurement tools for basic waveform analysis.

2.11 Research Gap Identification

From the reviewed literature, it is evident that while many studies analyze inverter waveforms using advanced equipment, limited research focuses on low-cost experimental visualization suitable for educational environments.

Additionally, few studies integrate solar charging, inverter comparison, and waveform visualization into a single experimental setup. This project addresses these gaps by combining renewable energy generation, inverter comparison, and low-cost waveform observation in one system.

2.12 Summary

This chapter reviewed existing literature related to solar photovoltaic systems, battery energy storage, inverter technologies, waveform distortion, and measurement techniques. The review highlights the importance of inverter waveform quality and establishes the foundation for the methodology and system design discussed in the following chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology adopted to design, implement, and evaluate the solar-powered inverter system developed in this project. The methodology focuses on the overall system architecture, power generation and storage process, inverter operation, power flow sequence, and waveform visualization using a low-cost Arduino-based oscilloscope.

The adopted approach ensures systematic integration of renewable energy generation, battery energy storage, power conversion, and waveform observation. Emphasis is placed on safe operation, simplicity, and educational suitability while maintaining relevance to real-life solar inverter systems.

3.2 Overall System Architecture

The overall system architecture consists of four major subsystems that operate together to achieve the project objectives:

- Solar power generation and charging unit
- Battery energy storage system
- Inverter system (square wave and pure sine wave)
- Waveform measurement and display unit (Arduino-based oscilloscope)

Each subsystem performs a specific function and is interconnected to ensure smooth energy flow and stable operation. The solar panel charges the battery bank, which supplies DC power to the inverter. The inverter converts DC power into AC power, and the output waveform is measured and visualized using the oscilloscope unit.

3.3 Solar Power Generation and Charging Method

A solar photovoltaic panel is used as the primary renewable energy source in the system. The solar panel converts sunlight into DC electrical energy, which is supplied to a solar charge controller. The charge controller regulates the charging process of the batteries by controlling voltage and current levels.

The regulated charging prevents overcharging and deep discharge of the batteries, ensuring safe operation and extended battery life. This controlled charging method provides a stable DC power source for the inverter system, which is essential for consistent waveform generation.

3.4 Battery Storage System

The battery storage system consists of two 12V lead-acid batteries used to store electrical energy generated by the solar panel. The batteries act as an energy buffer, supplying DC power to the inverter during periods of low or no solar generation.

The battery system is designed to provide sufficient voltage and current capacity for operating both inverter types during waveform observation. Proper wiring, insulation, and polarity protection are used to ensure safe and reliable operation.

3.5 Inverter System Methodology

Two different inverter systems are implemented in this project to compare output waveform quality under identical operating conditions. Both inverters are powered from the same battery system to ensure fair comparison.

3.5.1 Square Wave Inverter Operation

The square wave inverter operates by alternately switching the DC battery voltage between positive and negative states. This switching action produces a square-shaped AC waveform at the output.

The inverter uses a simple switching topology with minimal filtering components. Due to its simplicity, the square wave inverter is easy to construct and cost-effective. However, the output waveform contains abrupt voltage transitions and high harmonic content.

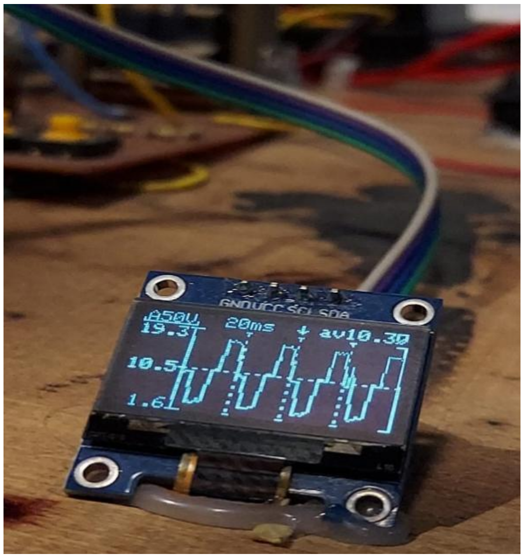

Figure 3.1: Output waveform of square wave inverter

3.5.2 Pure Sine Wave Inverter Operation

The pure sine wave inverter employs advanced switching techniques to generate a smooth AC output waveform. Sinusoidal Pulse Width Modulation (SPWM) is used to control the switching of MOSFETs arranged in an H-bridge configuration.

An inverter driver board is used to generate SPWM signals, which regulate output frequency and waveform shape. A step-up transformer and filtering components are applied to improve waveform smoothness and reduce harmonic distortion [10].

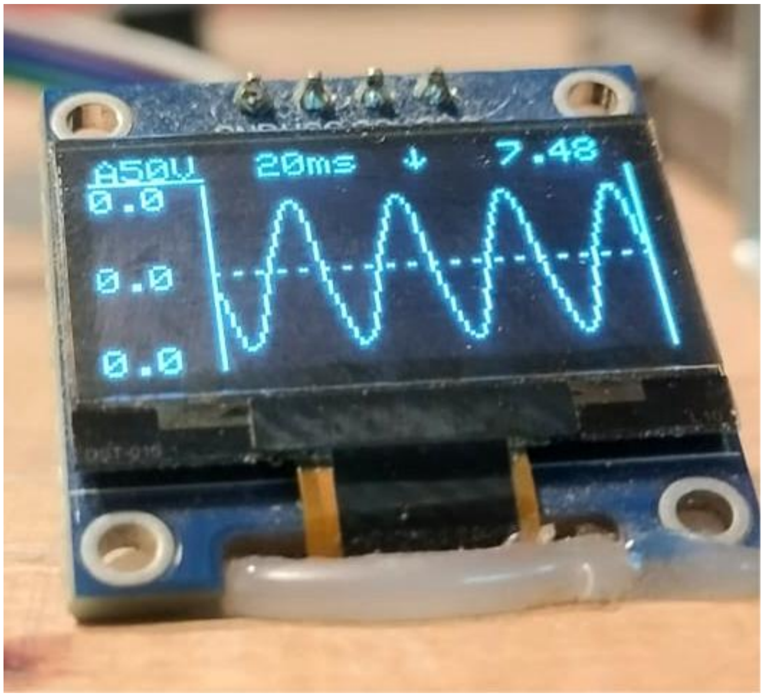

Figure 3.2: Output waveform of pure sine wave inverter

3.6 Power Flow Sequence

The operational sequence of the system follows a structured power flow:

- Solar panel generates DC electrical power.
- Solar charge controller regulates battery charging.
- Batteries supply DC power to the inverter system.
- Inverter converts DC power into AC power.
- Output AC voltage is reduced using a voltage divider circuit.
- Arduino samples the reduced voltage signal.
- OLED display visualizes the waveform in real time.

This sequence ensures controlled energy conversion and safe waveform observation.

3.7 Arduino-Based Oscilloscope Methodology

An Arduino Uno microcontroller is used to develop a low-cost oscilloscope for waveform visualization. The inverter output voltage is scaled down using a voltage divider circuit to a level suitable for the Arduino's analog input.

The Arduino samples the voltage signal and processes the data to display the waveform on a 0.96-inch OLED screen. The oscilloscope is designed for low-frequency AC signals, making it suitable for observing standard 50 Hz inverter output waveforms.

3.8 Signal Conditioning and Protection

To protect the Arduino and display module, proper signal conditioning techniques are applied. Voltage scaling ensures that high AC voltage does not exceed safe limits. Capacitors and protective components are used to minimize noise and voltage spikes.

These measures ensure safe operation and reliable waveform visualization during experimentation.

3.9 Control and Operational Logic

The control logic of the system is simple and sequential. Once the inverter is powered ON, the oscilloscope continuously samples the output voltage. The Arduino processes the incoming analog data and updates the waveform display in real time.

No complex control algorithms are required, as the primary objective is waveform observation rather than automated power control.

3.10 Safety Considerations

Safety is a critical aspect of the methodology. Proper insulation, secure wiring, and protective components are used to minimize electrical hazards. Experiments are conducted under no-load conditions to reduce risk during testing.

Cooling mechanisms are provided to prevent overheating of inverter components during operation.

3.11 Summary

This chapter described the methodology used to develop and evaluate the solar-powered inverter system and waveform observation setup. The chapter explained the system architecture, power flow, inverter operation, and oscilloscope methodology.

The next chapter presents the component-wise design analysis of the system.

CHAPTER 4

DESIGN ANALYSIS (COMPONENT-WISE)

4.1 Introduction

This chapter presents a detailed design and functional analysis of each major component used in the solar-powered inverter and waveform comparison system. The purpose of this analysis is to explain the working principle, design considerations, and justification for selecting individual components in the overall system.

The design analysis focuses on solar power generation, battery storage, inverter circuits, filtering components, thermal management, and the Arduino-based oscilloscope. Emphasis is placed on inverter design and waveform quality, as these are the primary objectives of the project.Advanced inverter topologies and switching loss considerations are described in modern inverter design studies [3].

4.2 Solar Panel Design Analysis

A photovoltaic solar panel is used as the primary renewable energy source in the system. The solar panel converts sunlight directly into DC electrical energy.

4.2.1 Working Principle

When sunlight strikes the photovoltaic cells, photons transfer energy to electrons within the semiconductor material, generating a DC voltage across the panel terminals. The output power depends on solar irradiance, temperature, and panel orientation.

4.2.2 Design Justification

A low-power solar panel is selected to meet the energy requirements of the prototype system. Although the panel capacity is limited, it is sufficient for charging the batteries and demonstrating solar-based inverter operation in an educational environment.

Figure 4.1: Solar panel used in the system

4.3 Solar Charge Controller Analysis

A solar charge controller is used to regulate the charging process of the batteries.

4.3.1 Function

The charge controller performs the following functions:

- Prevents battery overcharging
- Prevents deep discharge
- Regulates charging voltage and current

4.3.2 Importance in System Design

Without proper charge regulation, batteries may experience reduced lifespan and unsafe operating conditions. The charge controller ensures stable DC supply to the inverter, which is critical for consistent waveform generation.

Figure 4.2: Solar charge controller

4.4 Battery Storage System Design

The battery storage system consists of two 12V lead-acid batteries.

4.4.1 Battery Configuration

The batteries are configured to provide adequate voltage and current capacity for inverter operation. Lead-acid batteries are selected due to their affordability, availability, and reliability in small-scale energy systems.

4.4.2 Design Considerations

Key factors considered in battery selection include:

- Charging current capacity
- Depth of discharge
- Safety and ventilation

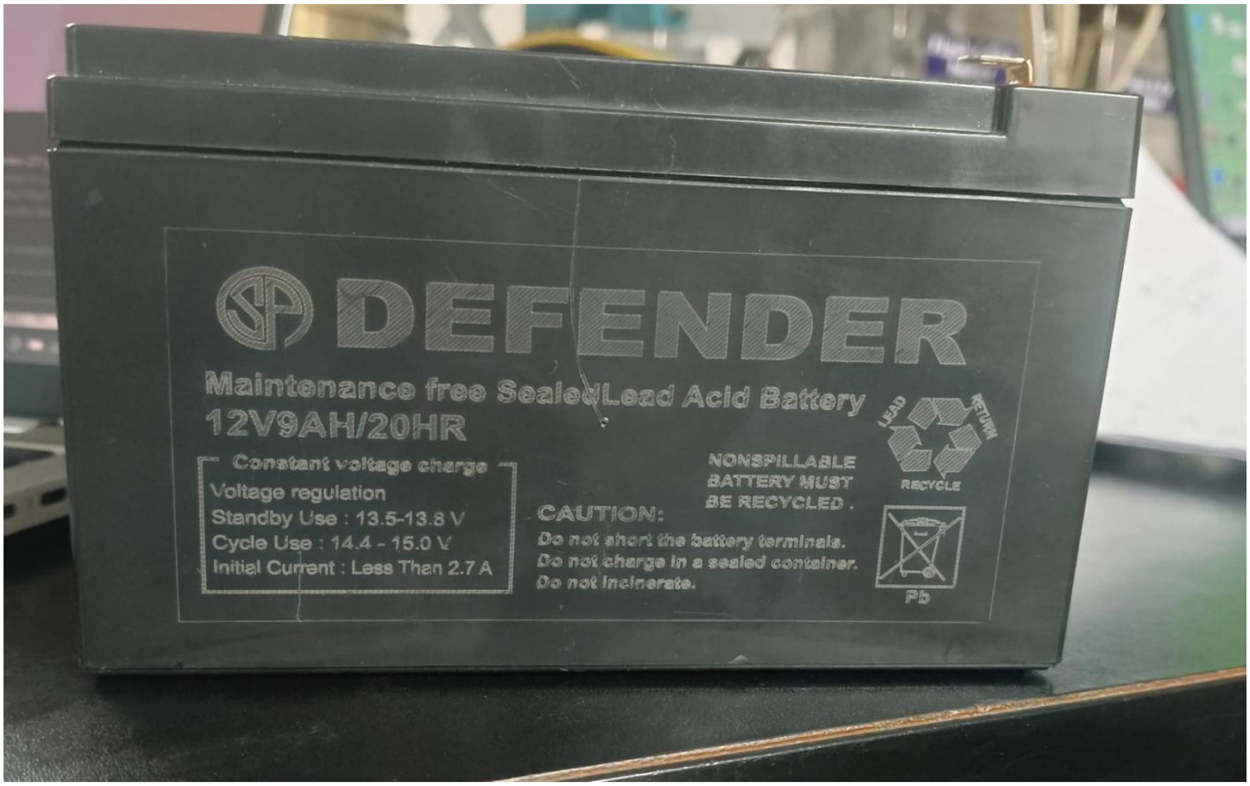

Figure 4.3: Battery storage system

4.5 Square Wave Inverter Design Analysis

4.5.1 Operating Principle

The square wave inverter operates by alternately switching the DC input voltage between positive and negative states. This switching produces a square-shaped AC output waveform.

4.5.2 Circuit Characteristics

- Simple switching topology
- Minimal filtering components
- High harmonic content

4.5.3 Advantages and Limitations

Advantages:

- Simple design
- Low cost
- Easy construction

Limitations:

- Poor waveform quality
- High harmonic distortion
- Unsuitable for sensitive loads

4.6 Pure Sine Wave Inverter Design Analysis

The pure sine wave inverter is the most critical component of the system.

4.6.1 SPWM Driver Board

An inverter driver board is used to generate Sinusoidal Pulse Width Modulation (SPWM) signals.

Functions:

Generates sinusoidal PWM pulses

Controls MOSFET switching

Maintains output frequency

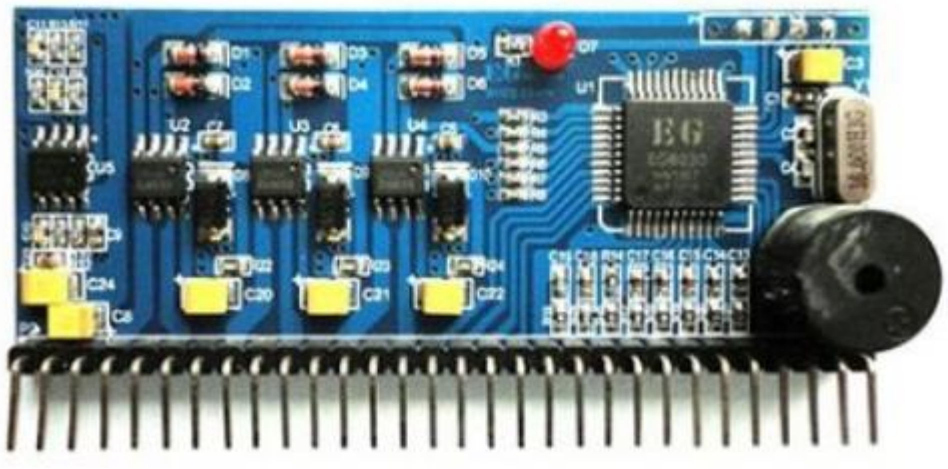

Figure 4.4: Inverter driver board

4.6.2 MOSFET Selection and H-Bridge Design

Power MOSFETs are selected due to their high current-handling capability and fast switching performance. Four MOSFETs are arranged in an H-bridge configuration to convert DC input into alternating AC voltage.

4.6.3 Transformer Design Analysis

A step-up transformer is used to increase the inverter output voltage to standard AC levels.

Design considerations include:

- Power rating
- Core material
- Insulation and cooling

The transformer also provides electrical isolation between the DC and AC sides.

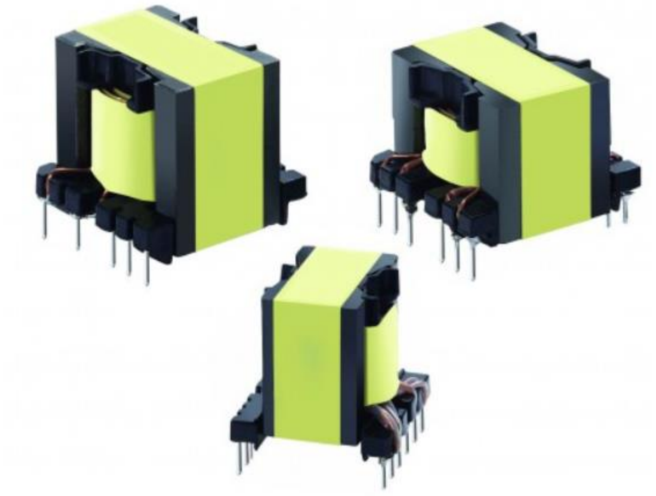

Figure 4.5: Step-up transformer used in inverter

4.7 Filtering and Output Smoothing Components

Filtering components are used to reduce high-frequency switching effects and improve output waveform smoothness.

4.7.1 Output Filter Capacitor

A high-voltage capacitor is used to smooth the output waveform and reduce ripple.

4.7.2 Diodes and Protection

Fast-recovery diodes are used to protect the circuit and manage reverse current flow.

4.8 Thermal Management and Protection

4.8.1 Cooling Fan and Control

A DC cooling fan is used to dissipate heat generated by power components. The fan is controlled using a transistor-based switching circuit.

4.8.2 Temperature Sensing

A temperature sensor is used to monitor operating conditions and prevent overheating.

4.9 Arduino-Based Oscilloscope Design Analysis

4.9.1 Arduino Microcontroller

The Arduino microcontroller serves as the processing unit for waveform sampling and display.

4.9.2 Voltage Divider Circuit

A voltage divider circuit reduces the inverter output voltage to a safe level suitable for analog input.

4.9.3 OLED Display

A compact OLED display is used to visualize voltage waveforms clearly and in real time.

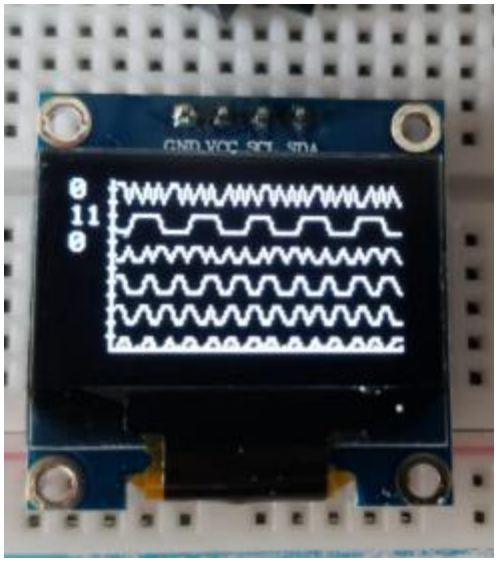

Figure 4.9: OLED waveform display

4.10 Component Integration and System Reliability

Proper integration of all components ensures stable system operation, accurate waveform visualization, and electrical safety. Secure wiring, insulation, and mounting techniques are applied to enhance reliability and minimize losses.

4.11 Summary

This chapter presented a detailed component-wise design analysis of the solar-powered inverter system. Each component was selected based on functionality, cost, and suitability for waveform comparison. The next chapter describes the prototype setup and implementation of the system.

CHAPTER 5

PROTOTYPE VIEW AND IMPLEMENTATION

5.1 Introduction

This chapter presents the physical realization and practical implementation of the proposed solar-powered inverter and waveform observation system. The prototype is developed to demonstrate the integration of solar charging, battery storage, inverter operation, and waveform visualization in a single experimental setup.

The implementation focuses on translating the theoretical design into a functional hardware model suitable for educational and experimental purposes. The prototype allows observation and comparison of inverter output waveforms under controlled conditions.

5.2 Prototype Setup Description

The complete prototype is composed of several interconnected subsystems arranged to ensure safe operation and ease of observation. The major sections of the prototype include:

- Solar panel and charging unit
- Battery storage system
- Square wave inverter
- Pure sine wave inverter
- Arduino-based oscilloscope
- Cooling and protection components

Each section is positioned to maintain proper electrical isolation and ventilation. Secure wiring and insulation are applied throughout the setup to minimize electrical hazards.

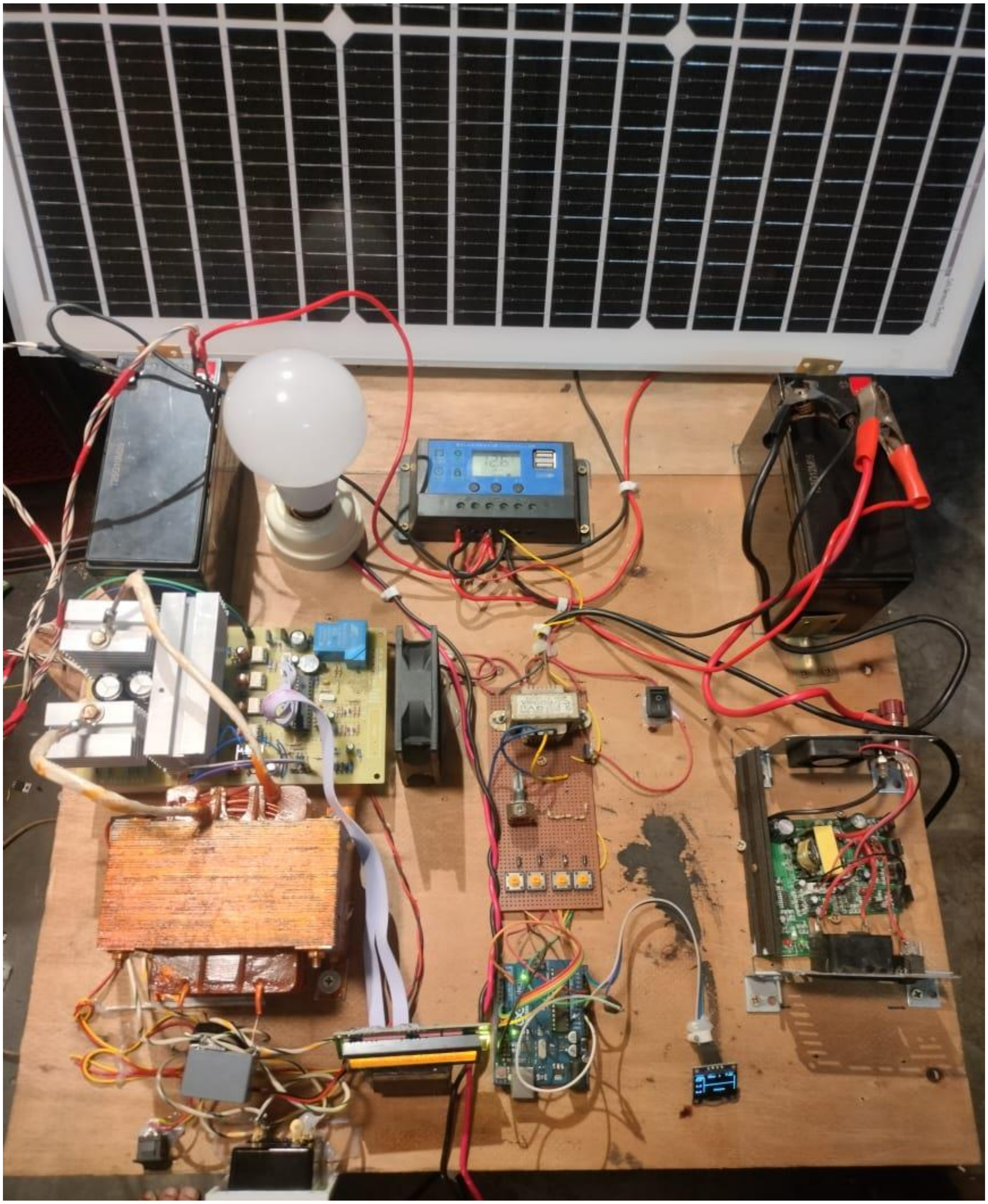

Figure 5.1: Complete prototype setup of the solar-powered inverter system

5.3 Solar Charging and Battery Implementation

The solar panel is placed in an open area to receive adequate sunlight. The DC output of the solar panel is connected to the solar charge controller, which regulates the charging process of the batteries.

Two 12V lead-acid batteries are connected to the charge controller to store the generated electrical energy. The charge controller monitors battery voltage and charging status, ensuring safe operation and preventing overcharging or deep discharge.

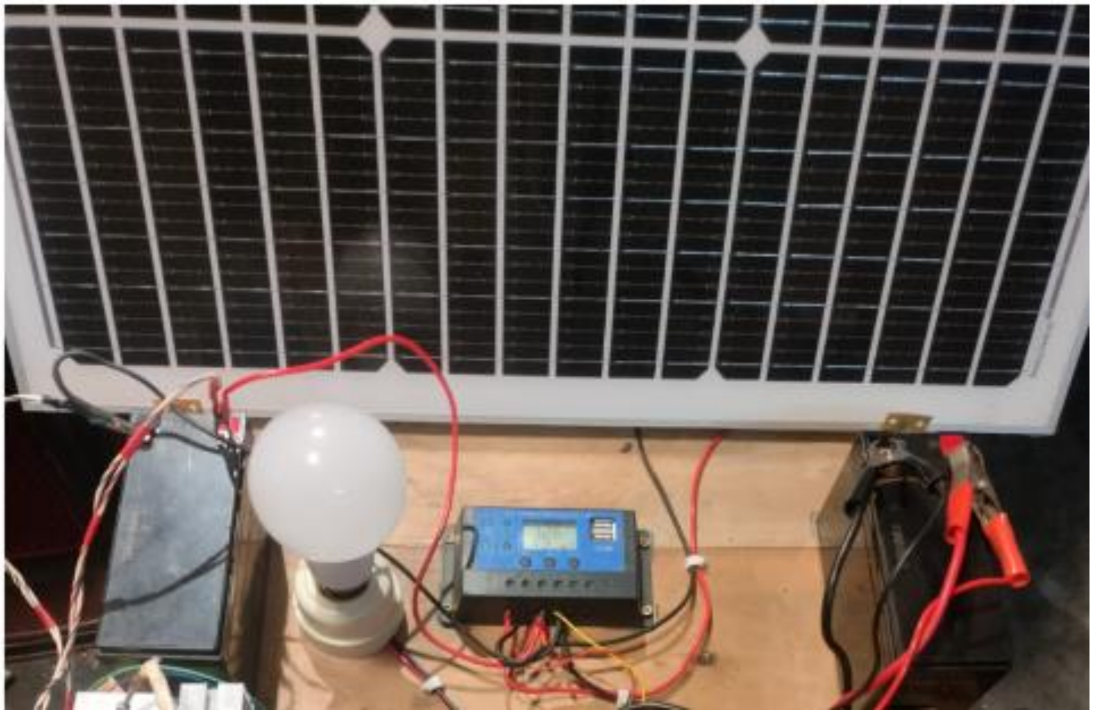

Figure 5.2: Solar panel and battery charging setup

5.4 Inverter Implementation

Two different inverter types are implemented to allow waveform comparison under identical power conditions.

5.4.1 Square Wave Inverter Setup

The square wave inverter is connected to the battery system through a main power switch. Proper insulation and secure wiring are used to prevent short circuits and accidental contact.

When powered ON, the inverter produces a non-sinusoidal AC output waveform. This waveform serves as the first test case for waveform observation using the Arduino-based oscilloscope.

5.4.2 Pure Sine Wave Inverter Setup

The pure sine wave inverter is implemented using an SPWM-based inverter driver board, MOSFET H-bridge configuration, step-up transformer, and output filtering components. A cooling fan is installed to manage heat generated during operation.

The inverter is powered from the same battery system used for the square wave inverter to ensure a fair comparison. Upon activation, the inverter generates a smooth AC output waveform with reduced harmonic distortion.

5.5 Arduino-Based Oscilloscope Implementation

The Arduino microcontroller is programmed to sample the inverter output voltage through a voltage divider circuit. The voltage divider reduces the high AC voltage to a safe level suitable for the Arduino's analog input pins.

The sampled signal is processed and displayed on a compact OLED screen. The oscilloscope is designed specifically for low-frequency AC waveform observation and operates effectively at standard inverter output frequency.

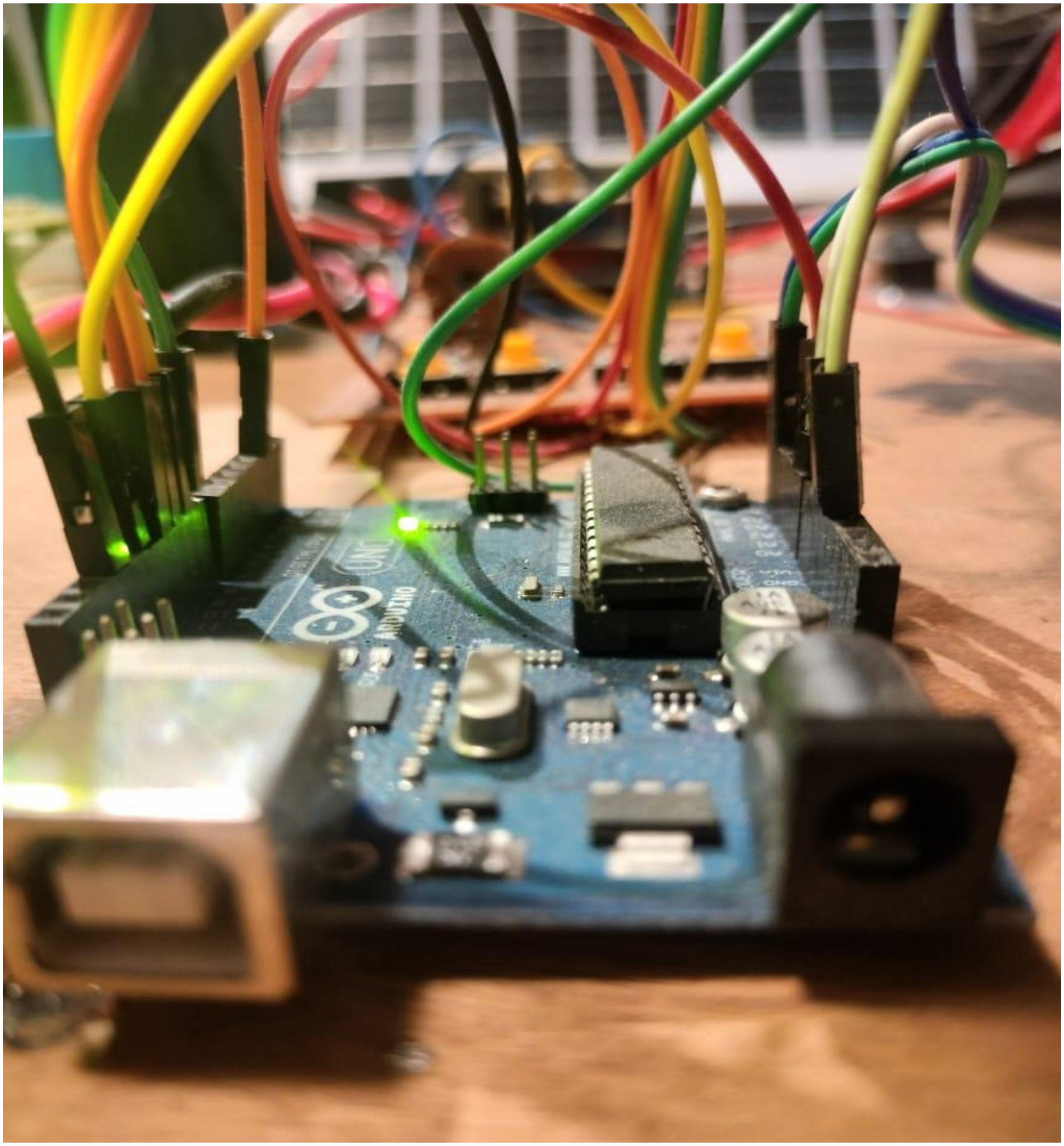

Figure 5.3: Arduino-based oscilloscope hardware setup

5.6 Experimental Procedure

The following procedure is followed during experimental observation:

- The solar panel charges the batteries through the charge controller.
- The inverter is connected to the battery supply.
- No external electrical load is connected to the inverter output.
- The Arduino-based oscilloscope is connected using a voltage divider circuit.
- The inverter is powered ON.
- The output waveform is observed on the OLED display.
- The procedure is repeated for both inverter types.

This systematic approach ensures consistent conditions for waveform comparison.

5.7 Observed Output Waveforms

5.7.1 Square Wave Inverter Output

The waveform observed from the square wave inverter shows abrupt transitions between voltage levels. The waveform shape is significantly different from a standard sinusoidal waveform, indicating the presence of high harmonic content.

5.7.2 Pure Sine Wave Inverter Output

The waveform observed from the pure sine wave inverter closely resembles a sinusoidal waveform. Smooth transitions between voltage levels indicate reduced harmonic distortion and improved waveform quality.

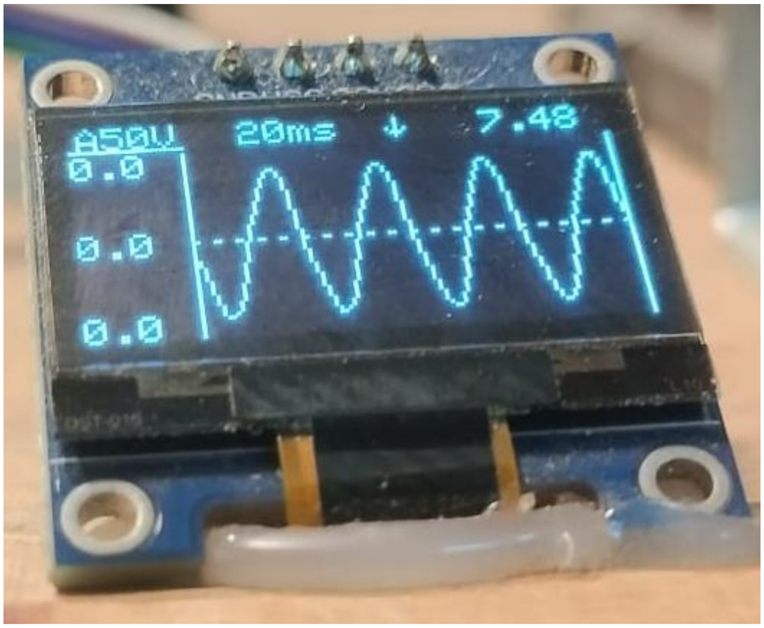

Figure 5.4: Pure sine wave inverter output observed on OLED display

5.8 Safety Measures During Implementation

Several safety measures are adopted during prototype implementation and experimentation:

- Proper insulation of high-voltage connections
- Secure mounting of components
- Operation under no-load conditions
- Continuous monitoring of temperature and cooling fan operation

These measures reduce the risk of electrical hazards during testing.

5.9 Limitations of the Prototype Implementation

The prototype is designed primarily for educational and demonstration purposes. Limitations include:

- Absence of real-load testing
- Limited resolution of the Arduino-based oscilloscope
- Restricted frequency and voltage measurement range

Despite these limitations, the prototype effectively demonstrates waveform differences between inverter types.

5.10 Summary

This chapter described the physical prototype setup, inverter implementation, experimental procedure, and waveform observation process. The observed results provide practical insight into inverter waveform characteristics. The next chapter presents the cost estimation for real-life implementation of the proposed system.

CHAPTER 6

RESULT & DISCUSSION

6.1: Data Collection & Calculation:

Date	Temperature	Solar Time	Pure Sine wave
18-01-2026	26C	11:00 Am	12.20 V
18-01-2026	27C	12:00 Pm	13.17 V
18-01-2026	28C	01:00 Pm	14.02 V

Table 6.1: Pure Sine wave Charging Data

Here,

1 hour =1.16V charging time

Total battery full charge time =10 hours (Approximate)

Date	Temperature	Solar Time	Square wave
18-01-2026	26C	11:00 Am	12.01 V
18-01-2026	27C	12:00 Pm	12.90 V
18-01-2026	28C	01:00 Pm	13.70 V

Table 6.2: Square wave Charging Data

Here,

1 hour =0.89V charging time

Total battery full charge time =13 hours (Approximate)

Date	Temperature	Solar Time	Pure Sine wave
18-01-2026	25C	05:00 Pm	12.08 V
18-01-2026	23C	06:00 Pm	10.10 V
18-01-2026	21C	07:00 Pm	7.90 V

Table 6.3: Pure Sine wave Discharge Data

Here,

Loss per hour=1.98 W/hr

Given Data,

Battery - 12v, 9A.h

Power of battery=12 x 9=108 W.hr

Load= 20 W

We know,

E(out)= Power x Time

= 20x2

= 40 W.h

E(battery) = 198×0.80 =86 W.h

Suppose, Battery energy used= 80%.

Efficiency =((useful output Energy)/(Battery Energy used))*100%

=(40/86)×100%= 46%

Note: pure sine inventen efficiency = 85-90%. But we have used a battery under 10 W.hr as a result of efficiency drop.

For Load Calculation,

Given

Bulb rating: 20 W, 230 V

Bulb type: Resistive (filament bulb)

We know

$$P=\frac{V_{rms}^2}{R}$$

Bulb resistance

$$R= \frac{V^2}{P} = \frac{230^2}{20} = 2645\ \Omega$$

Pure Sine Wave Output

$$P=\frac{230^2}{2645} =20W$$

Date	**Temeprature**	**Solar Time**	**Square wave**
18-01-2026	25C	05:00 Pm	12.15 V
18-01-2026	23C	06:00 Pm	9.90 V
18-01-2026	21C	07:00 Pm	06.06 V

Table 6.4: Square wave Discharge Data

Here,

Loss per hour=2.25 W/hr

Given Data,

Battery - 12v, 9Ah

Power of battery =12 x 9=108 W/hr

Load= 20 W

We know,

E(Out)= Power x Time

= 20x2 = 40 W.hr

E(battery) = 108×0.95 =103 Wh

Suppose, Battery energy used = 95%

Efficiency = ((Useful output Energy)/(Battery Energy used))* 100%

=(40/103)×100% = 39%

For Load Calculation,

Given

Bulb rating: 20 W, 230 V

Bulb type: Resistive (filament bulb)

We know

$$P=\frac{V_{rms}^2}{R}$$

Bulb resistance

$$R=\frac{V^2}{P}=\frac{230^2}{20}=2645\ \Omega$$

Squre Wave

$$P=\frac{230^2}{2645}=20W$$

6.2: Result Analysis:

The experimental results clearly indicate that the pure sine wave inverter performs better than the square wave inverter in both charging and discharging conditions. From the charging data presented in Tables 6.1 and 6.2, the pure sine wave inverter shows an average charging rate of 1.16 V per hour, whereas the square wave inverter charges at a lower rate of 0.89 V per hour. As a result, the estimated total charging time for the battery using the pure sine wave inverter is approximately 10 hours, compared to 13 hours for the square wave inverter. This demonstrates that the pure sine wave inverter provides faster and more efficient battery charging.

During the discharge test, the pure sine wave inverter exhibited a lower voltage drop over time compared to the square wave inverter. The calculated energy loss for the pure sine wave inverter was 1.98 W/hr, while the square wave inverter showed a higher loss of 2.25 W/hr. This indicates that the square wave inverter dissipates more energy during operation due to higher harmonic distortion and inefficient power conversion.

Efficiency calculations further support this observation. For the pure sine wave inverter, the useful output energy was 40 W.hr**,** and the effective battery energy used was 86 W.hr, resulting in an efficiency of approximately 46%**.** In contrast, the square wave inverter delivered the same output energy of 40 W.hr, but consumed 103 W.hr of battery energy, producing a lower efficiency of approximately 39%**.** The higher efficiency of the pure sine wave inverter confirms its superior energy utilization.

Although the practical efficiency of a pure sine wave inverter is typically within 85–90%**,** the observed efficiency reduction in this experiment is attributed to the use of a low-capacity battery and small-scale experimental conditions. Despite this limitation, the comparative results consistently demonstrate that the pure sine wave inverter offers better charging performance, lower energy loss, and higher efficiency than the square wave inverter. Therefore, based on the experimental data, the pure sine wave inverter is identified as the best and most suitable option for household and renewable energy applications**.**

CHAPTER 7

COST ESTIMATION FOR REAL-LIFE IMPLEMENTATION

7.1 Introduction

Cost estimation is an essential part of engineering system development, particularly for systems intended for real-life application. This chapter presents a detailed cost estimation of the proposed solar-powered inverter system. The analysis provides an understanding of the financial requirements and economic feasibility of implementing the system for household use.

The cost estimation is divided into two parts: the cost of the developed prototype system and the estimated cost of implementing a real-life household-scale solar inverter system. Market prices of components may vary depending on location, brand, and availability.

7.2 Prototype Cost Estimation

The prototype developed in this project is primarily intended for educational and experimental purposes. Low-power components are selected to reduce cost while maintaining the functionality required for waveform comparison and system demonstration.

Sl. No.	Component Description	Quantity	Unit Price (BDT)	Total Price (BDT)
1	Solar Panel (40 W)	1	2200	2200
2	Solar Charge Controller	1	555	555
3	12V Battery	2	2400	2400
4	Square Wave Inverter	1	1000	1000

Sl. No.	**Component Description**	**Quantity**	**Unit Price (BDT)**	**Total Price (BDT)**
5	Pure Sine Wave Inverter Components	1 set	9000	9000
6	Step-Up Transformer	1	3000	3000
7	Arduino Uno	1	1400	1400
8	OLED Display	1	350	350
9	MOSFETs, PCB, Wiring, Fan	19	1200	1200
Total Estimated Prototype Cost				21,105

Table 7.1: Prototype Cost Estimation

7.3 Cost Factors Affecting Prototype Development

Several factors influence the overall cost of the prototype system, including:

- Use of low-power components suitable for educational demonstration
- Manual assembly and wiring
- Absence of industrial-grade enclosure
- No real-load operation

These factors help reduce cost while fulfilling academic objectives.

7.4 Real-Life Implementation Cost Estimation

For real-life household application, the system must be scaled to handle higher power ratings, typically between 500 W and 1 kW. This requires higher capacity solar panels, batteries, and inverter hardware.The following sections present cost estimation for real-life system components.

7.5 Solar Power Generation Cost (Real-Life System)

A real-life system requires solar panels with sufficient capacity to meet household energy demand. Multiple panels may be connected in series or parallel depending on system design.

Component	Specification	Quantity	Estimated Cost (BDT)
Solar Panel	500 W Total Capacity	1 Pcs	12,000
Solar Panel	1 kW Total Capacity	1 Pcs	50,000

Table 7.2: Solar Panel Cost Estimation

7.6 Bttery Storage Cost

Battery storage is essential to ensure power availability during non-sunlight hours and power outages.

Component	Specification	Quantity	Estimated Cost (BDT)
Battery Bank	12V, 100Ah or Higher	14,000	14,000

Table 7.3: Battery Storage Cost Estimation

7.7 Inverter and Control System Cost

Pure sine wave inverters are preferred for real-life household applications due to their improved power quality.

Component	Specification	Estimated Cost (BDT)
Pure Sine Wave Inverter	500 W	20,000
Pure Sine Wave Inverter	1 kW	40,000
Control and Protection Circuits	800W	10,000

Table 7.4: Inverter and Control System Cost Estimation

7.8 Additional Components and Installation Cost

Additional components and installation services are required to ensure safe and reliable system operation.

Component	Estimated Cost (BDT)
Mounting Structure	3000
Wiring and Protection Devices	2000
Enclosure and Accessories	1200
Installation Labor	2000
Total Additional Cost	**8200**

Table 7.5: Additional Components and Installation Cost

7.9 Total Estimated Cost of Real-Life System

System Type	Estimated Cost (BDT)
Prototype System	1200
Real-Life System (500 W)	2900
Real-Life System (1 kW)	5800

Table 7.6: Total Estimated Cost Summary

7.10 Economic Feasibility Discussion

Although the initial investment of a solar inverter system can be high, the long-term benefits include reduced electricity costs, renewable energy utilization, and increased energy independence. Over time, the system can recover its cost through energy savings.

The feasibility of the system depends on component cost, system size, and energy consumption patterns.

7.11 Summary

This chapter presented a detailed cost estimation framework for both the prototype and real-life implementation of the solar-powered inverter system. The cost analysis highlights the financial considerations involved while allowing flexibility for market-based price variation. The next chapter discusses the advantages and limitations of the proposed system.

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CHAPTER 8

ADVANTAGES AND LIMITATIONS

8.1 Introduction

Every engineering system has its strengths and constraints. This chapter discusses the advantages and limitations of the proposed solar-powered inverter system and waveform comparison setup. The evaluation is based on system design, implementation, performance observation, and practical feasibility.

The discussion highlights both the technical benefits of the system and the challenges encountered during development and experimentation.

8.2 Advantages of the Proposed System

8.2.1 Utilization of Renewable Energy

One of the major advantages of the proposed system is the use of solar energy as the primary power source. Solar energy is clean, renewable, and environmentally friendly. The system demonstrates how solar power can be effectively converted and utilized for AC applications.

8.2.2 Comparative Study of Inverter Technologies

The system enables a direct comparison between square wave and pure sine wave inverters under identical operating conditions. This comparative approach provides clear insight into waveform quality, harmonic content, and practical usability.

8.2.3 Educational and Experimental Value

The project offers significant educational value, especially for students of mechanical and electrical engineering. It provides hands-on experience in:

- Power electronics
- Renewable energy systems
- Signal observation and instrumentation

8.2.4 Low-Cost Oscilloscope Implementation

The Arduino-based oscilloscope provides an economical alternative to commercial oscilloscopes for low-frequency waveform observation. It allows visualization of inverter output waveforms without requiring expensive laboratory equipment.

8.2.5 Modular System Design

The modular architecture of the system allows individual subsystems to be modified or upgraded independently. This flexibility enhances maintainability and scalability.

8.2.6 Safe Demonstration Platform

The prototype is designed primarily for no-load testing and waveform observation, making it safer for academic demonstrations and laboratory use.

8.3 Limitations of the Proposed System

8.3.1 Limited Load Testing Capability

The system was tested without connecting any real electrical load. As a result, performance under actual load conditions such as voltage drop, efficiency variation, and thermal behavior could not be evaluated.

8.3.2 Low Oscilloscope Resolution

The Arduino-based oscilloscope has limited sampling rate and resolution compared to professional oscilloscopes. This restricts its ability to capture high-frequency harmonics or transient events.

8.3.3 Manual Data Observation

The waveform observation process relies on visual interpretation rather than automated data logging or numerical analysis. This limits the depth of quantitative evaluation.

8.3.4 Prototype-Scale Power Handling

The prototype operates at relatively low power levels suitable for demonstration. Scaling the system for real-life household applications would require significant hardware upgrades.

8.3.5 Thermal and Protection Constraints

Although basic cooling and protection measures are implemented, the prototype lacks advanced protection features such as overcurrent protection, short-circuit protection, and fault diagnostics.

8.3.6 Environmental Dependency

Solar power generation depends on sunlight availability. The system's performance may vary under cloudy conditions or during nighttime.

8.4 Comparative Summary

A brief comparative summary of inverter types is presented in Table 7.1.

Parameter	**Square Wave Inverter**	**Pure Sine Wave Inverter**
Waveform Shape	Non-sinusoidal	Smooth sinusoidal
Harmonics	High	Low
Appliance Compatibility	Limited	High
Efficiency	Lower	Higher
Cost	Low	Higher

Table 8.1 Inverter Comparison Summary

8.5 Summary

This chapter discussed the advantages and limitations of the proposed solar-powered inverter system. While the system offers significant educational value and demonstrates clear waveform differences, it also highlights limitations related to load testing, measurement accuracy, and scalability. These limitations provide opportunities for future improvements, which are discussed in the next chapter.

CHAPTER 9

FUTURE SCOPES

9.1 Introduction

Although the proposed solar-powered inverter and waveform comparison system successfully demonstrates the differences between square wave and pure sine wave inverters, there remains significant scope for further improvement and expansion. This chapter discusses potential future enhancements that can improve system performance, functionality, accuracy, and real-life applicability.

The future scope focuses on technical upgrades, advanced analysis techniques, system scalability, and broader applications in renewable energy systems.

9.2 Load-Based Performance Evaluation

One major extension of this project would be testing inverter performance under actual electrical loads. Future work may include connecting different types of loads such as:

- ✓ Resistive loads (bulbs, heaters)
- ✓ Inductive loads (fans, motors)
- ✓ Electronic loads (chargers, televisions)

This would allow evaluation of voltage regulation, efficiency, waveform distortion, and thermal behavior under real operating conditions.

9.3 Harmonic Analysis Using Advanced Tools

In this project, harmonic analysis was performed qualitatively through waveform observation. Future studies may include:

- ➢ Fast Fourier Transform (FFT) analysis
- ➢ Total Harmonic Distortion (THD) measurement
- ➢ Power quality analysis using digital signal processing techniques

These additions would provide quantitative insights into inverter waveform quality.

9.4 Improved Oscilloscope Design

The Arduino-based oscilloscope can be further enhanced by:

- ✓ Increasing sampling rate
- ✓ Improving resolution
- ✓ Adding data logging and PC interfacing
- ✓ Incorporating current waveform measurement

Using more powerful microcontrollers or dedicated ADC modules would significantly improve measurement accuracy.

9.5 Integration of Smart Control Systems

Future systems can integrate microcontroller-based control algorithms to enable:

- ➢ Automatic inverter switching
- ➢ Load prioritization
- ➢ Fault detection and protection
- ➢ Real-time monitoring via IoT platforms

This would enhance system intelligence and operational safety.

9.6 Scalability for Real-Life Applications

The prototype system can be scaled for practical household or commercial use by:

- ✓ Increasing solar panel capacity
- ✓ Using higher-rated batteries
- ✓ Implementing industrial-grade inverters
- ✓ Adding proper enclosures and safety mechanisms

Such scaling would transform the system from a demonstration model into a functional renewable energy solution.

9.7 Integration with Grid-Tied Systems

Another future direction is integrating the inverter system with grid-tied solar systems. This would allow:

- ➢ Net metering
- ➢ Improved energy utilization
- ➢ Hybrid operation with grid and solar sources

This approach is increasingly relevant in modern power systems.

9.8 Energy Management and Monitoring

Advanced energy management systems can be implemented to monitor:

- Battery state of charge
- Power consumption patterns
- Solar generation efficiency

These features would improve energy efficiency and user awareness.

9.9 Educational and Research Applications

The developed system can serve as a laboratory platform for:

- Undergraduate teaching
- Research in power electronics
- Renewable energy experimentation

Further modifications could allow the system to support multiple academic experiments.

9.10 Summary

This chapter discussed the future scope and potential enhancements of the proposed system. By incorporating advanced analysis techniques, smart control features, and scalability improvements, the system can evolve into a comprehensive renewable energy solution. The final chapter presents the conclusion of the thesis.

CHAPTER 10

CONCLUSION

10.1 Introduction

This chapter presents the overall conclusion of the thesis entitled **“Design and Analysis of a Solar-Powered Inverter System with Waveform Quality Comparison.”** The conclusion summarizes the objectives, methodology, implementation, and key findings of the project while highlighting its academic and practical significance.

10.2 Summary of the Work

In this project, a solar-powered inverter system was designed and implemented to study and compare the output waveform characteristics of square wave and pure sine wave inverters. A solar photovoltaic panel was used to charge two 12V batteries through a solar charge controller, ensuring a stable DC power source for inverter operation.

Two different inverter types were connected to the same battery system to maintain consistent testing conditions. A square wave inverter was used to represent low-cost conventional inverter designs, while a pure sine wave inverter was implemented using an SPWM-based driver circuit. To visualize and analyze the output waveforms, a low-cost Arduino-based oscilloscope with an OLED display was developed.

The system was tested under no-load conditions, and the output waveforms were observed and recorded. The square wave inverter produced a non-sinusoidal waveform with abrupt transitions, while the pure sine wave inverter generated a smooth waveform closely resembling standard AC grid supply.

10.3 Achievement of Project Objectives

All major objectives of the project were successfully achieved. The solar charging system functioned effectively, providing regulated DC power to the inverter system. The inverter circuits operated as expected, and waveform visualization was successfully implemented using the Arduino-based oscilloscope.

The project clearly demonstrated the differences between square wave and pure sine wave inverter outputs in terms of waveform shape, harmonic content, and expected appliance compatibility. The oscilloscope design proved effective for low-frequency AC waveform observation, fulfilling its intended educational purpose.

10.4 Key Observations and Findings

The key findings of the project can be summarized as follows:

- ✓ Square wave inverters produce waveforms with high harmonic distortion, making them unsuitable for sensitive electrical appliances.
- ✓ Pure sine wave inverters provide smoother output waveforms with reduced harmonics, resulting in better power quality.
- ✓ The quality of inverter output waveform plays a crucial role in appliance performance and system efficiency.
- ✓ Low-cost Arduino-based oscilloscopes are effective tools for basic waveform visualization in educational environments.

10.5 Practical and Academic Significance

From a practical perspective, the project highlights the importance of selecting appropriate inverter technology for solar power systems, especially for household applications. The comparative study helps users understand why pure sine wave inverters are preferred despite higher cost.

Academically, the project provides hands-on experience in renewable energy systems, power electronics, and measurement techniques. It serves as a valuable learning platform for engineering students and can be extended for further research and experimentation.

10.6 Limitations of the Study

Although the project achieved its objectives, certain limitations were identified. The system was tested without connecting real electrical loads, and waveform analysis was limited to qualitative observation. The oscilloscope had limited resolution and sampling capability compared to professional instruments.

These limitations do not undermine the educational value of the project but indicate areas for future improvement.

10.7 Concluding Remarks

In conclusion, this thesis successfully demonstrates the design, implementation, and analysis of a solar-powered inverter system with waveform quality comparison. The project confirms that pure sine wave inverters offer superior performance and compatibility compared to square wave inverters. The integration of renewable energy, power electronics, and low-cost instrumentation makes this project both technically relevant and educationally valuable.

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APPENDIX

```
#include <Wire.h>
#include <EEPROM.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>

#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define REC_LENGTH 200

#define OLED_RESET -1
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET);

const char voltageRangeName[10][5] PROGMEM = {"A50V","A 5V"," 50V"," 20V"," 10V"," 5V","  2V","  1V","0.5V","0.2V"};
const char * const vstring_table[] PROGMEM = {
  voltageRangeName[0],voltageRangeName[1],voltageRangeName[2],voltageRangeName[3],
  voltageRangeName[4],voltageRangeName[5],voltageRangeName[6],voltageRangeName[7],
  voltageRangeName[8],voltageRangeName[9]
};

const char hRangeName[8][6] PROGMEM = {" 50ms"," 20ms"," 10ms","  5ms","  2ms"," 1ms","500us","200us"};
```

```
const char * const hstring_table[] PROGMEM = {

  hRangeName[0],hRangeName[1],hRangeName[2],hRangeName[3],

  hRangeName[4],hRangeName[5],hRangeName[6],hRangeName[7]

};


int waveBuff[REC_LENGTH];

char chrBuff[10];

String hScale="xxxAs";

String vScale="xxxx";


float lsb5V=0.005371;

float lsb50V=0.05371;


volatile int vRange;

volatile int hRange;

volatile int trigD;

volatile int scopeP;

volatile boolean hold=false;

volatile boolean paraChanged=false;

volatile int saveTimer;

int timeExec;


int dataMin,dataMax,dataAve;
```

```
int rangeMax,rangeMin;

int rangeMaxDisp,rangeMinDisp;

int trigP;

boolean trigSync;

int att10x;


void setup(){

  Serial.begin(9600);

  pinMode(2,INPUT_PULLUP);

  pinMode(8,INPUT_PULLUP);

  pinMode(9,INPUT_PULLUP);

  pinMode(10,INPUT_PULLUP);

  pinMode(11,INPUT_PULLUP);

  pinMode(12,INPUT);

  pinMode(13,OUTPUT);


  if(!display.begin(SSD1306_SWITCHCAPVCC,0x3C)){for(;;);}

  loadEEPROM();

  analogReference(INTERNAL);

  attachInterrupt(digitalPinToInterrupt(2),pin2IRQ,FALLING);

  startScreen();

}
```

```
void loop(){
  digitalWrite(13,HIGH);
  setConditions();
  readWave();
  digitalWrite(13,LOW);
  dataAnalize();
  writeCommonImage();
  plotData();
  dispInf();
  display display();
  saveEEPROM();
  while(hold){
    dispHold();
    delay(10);
  }
}

void setConditions(){
  strcpy_P(chrBuff,(char*)pgm_read_word(&(hstring_table[hRange])));
  hScale=chrBuff;
  strcpy_P(chrBuff,(char*)pgm_read_word(&(vstring_table[vRange])));
  vScale=chrBuff;
```

```
  switch(vRange){

    case 0: att10x=1; break;

    case 1: att10x=0; break;

    case 2:
rangeMax=50/lsb50V;rangeMaxDisp=5000;rangeMin=0;rangeMinDisp=0;att10x=1;break;

    case 3:
rangeMax=20/lsb50V;rangeMaxDisp=2000;rangeMin=0;rangeMinDisp=0;att10x=1;break;

    case 4:
rangeMax=10/lsb50V;rangeMaxDisp=1000;rangeMin=0;rangeMinDisp=0;att10x=1;break;

    case 5:
rangeMax=5/lsb5V;rangeMaxDisp=500;rangeMin=0;rangeMinDisp=0;att10x=0;break;

    case 6:
rangeMax=2/lsb5V;rangeMaxDisp=200;rangeMin=0;rangeMinDisp=0;att10x=0;break;

    case 7:
rangeMax=1/lsb5V;rangeMaxDisp=100;rangeMin=0;rangeMinDisp=0;att10x=0;break;

    case 8:
rangeMax=0.5/lsb5V;rangeMaxDisp=50;rangeMin=0;rangeMinDisp=0;att10x=0;break;

    case 9:
rangeMax=0.2/lsb5V;rangeMaxDisp=20;rangeMin=0;rangeMinDisp=0;att10x=0;break;

  }

}
```