COMPARATIVE EVALUATION OF FOREIGN AND LOCALLY ASSEMBLED HYBRID 3.5KVA INVERTER SYSTEM

BY

SEDE FAITH EMOSHOKE	**ENG2002325**
AISIEN JOHN ETINOSA	**ENG2002201**
OMOGUA SAHEED ENDURANCE	**ENG2002301**
OMIOJIEAHIOR GOD'STIME AMENAWON	**ENG2002300**
UYANWANNE EMMANUEL CHUKWUDARU	**ENG2002331**
VICTOR STEPHEN	**ENG2002333**

OF

BEING A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF B.ENG DEGREE IN FACULTY OF ENGINEERING, UNIVERSITY OF BENIN.

OCTOBER 2025

CERTIFICATION

This is to certify that this project work was carried out by SEDE FAITH EMOSHOKE, AISIEN JOHN ETINOSA, VICTOR STEPHEN, OMOGUA SAHEED ENDURANCE, UYANWANNE EMMANUEL CHUKWUDARU and OMIOJIEAHIOR GOD'STIME AMENAWON of the department of ELECTRICAL/ELECTRONICS Engineering, Faculty of Engineering, University of Benin, in partial fulfillment of the requirements of the award of the Bachelor of Engineering (B.Eng) Degree in ELECTRICAL/ELECTRONICS Engineering.

ENGR. DR. EDOSA OSA	ENGR. DR. S.O OMOROGIUWA
Project Supervisor	Head Of Department

DEDICATION

This report is offered to the God, the Wellspring of life and wisdom. We extend our heartfelt dedication to our parents, cherished ones, and supporters, whose unwavering presence have been a beacon of support, especially during challenging times.

ACKNOWLEDGEMENT

Our deepest gratitude goes to the Almighty who made our journey possible. We want to express our heartfelt thanks to Engineer Edosa Osa, our project supervisor, whose committed efforts made putting together this report much easier. His constant support and guidance meant a lot to us throughout the project.

We also want to thank the Department of Electrical/Electronic Engineering for creating an environment that supported the successful completion of this project, and to all the lecturers whose teachings have enriched our knowledge over the years. We must also acknowledge the head of the department, Engr. Dr. O.S Omorogiuwa, for his invaluable support and guidance.

Our most profound thanks go to our parents, Prof. and Mrs. M.A Sede, Prof. and Prof. (Mrs) Aisien, Mr. and Mrs. Omogua, Mr. and Mrs. Omiojieahior and Mr. and Mrs. Victor. Their unwavering financial and emotional support has been indispensable not only during this project but throughout our entire degree program and life journey.

ABSTRACT

The aim of this project is to carry out a comparative evaluation of foreign and homebased manufactured hybrid 3.5kva inverter system. Conventional non-hybrid inverter systems are characterized by their dependency on the grid, low efficiency in solar charging, limited energy management capabilities, and ineffective communication between components. Therefore, this endeavor is designed to integrate hybrid features to overcome these shortcomings.

The process entailed comparing a hybrid inverter system to address the limitations of non-hybrid inverters and to do this, we incorporated an alternative power source, i.e. solar energy, to charge the battery. This involved designing an MPPT (Maximum Power Point Tracking) charge controller and seamlessly integrating its circuitry with that of the inverter in the non-hybrid system. Additionally, we established effective communication between the DSPIC30F2010 microcontroller on the inverter and the DSPIC30F2010 microcontroller on the MPPT circuitry using serial communication, which we integrated into the inverter. All communication protocols were outlined in the source code. To ensure organization and tidiness, we housed all these components within a single enclosure.

The project successfully achieved its intended objectives by comparing the hybrid features of the homebased and foreign manufactured inverter systems. Through meticulous design and implementation, all identified limitations were effectively addressed, leading to significant improvements in system performance and functionality. Relevant tests such as output voltage and frequency test, load and no load test, as well as power efficiency tests were carried out to compare the performances of the foreign and home based manufactured hybrid inverter systems. The performance of the home based hybrid inverter was 219.8V for output voltage versus 230V for the foreign. Frequency for home based was 50.04Hz versus 50.0Hz for the foreign. Both inverters displayed a comparable sine wave output. Power efficiency for home based was 90.64 percent while for foreign, it was 94.5 percent, these results show that there was no remarkable difference between the output of the home based compared to the foreign inverter. Furthermore, the locally assembled inverter cost far less than the foreign counterpart. Hence, this study proves that cost efficient inverter systems can be manufactured locally.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

MPPT - MAXIMUM POWER POINT TRACKING

MOSFETS – METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR

DC – DIRECT CURRENT

AC – ALTERNATING CURRENT

PWM – PULSE WIDTH MODULATION

PV PANEL – PHOTOVOLTAIC PANELS

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND OF THE STUDY

Inverters are devices used to convert Direct Current (DC) into Alternating Current (AC) and this is an important feature that we will be exploiting in this project. The conversion of DC to AC has emerged with a vital role in standalone power supply systems (Dwivedi and Pahariya. 2021). Inverters are occasionally used in households as well as in industrial settings to act as an alternative source of electricity in the event that the network electrical supply is interrupted. Typical inverter systems consist of a low capacity battery and due to this, the inverter cannot be used to operate heavy load appliances. To work around limitations a hybrid inverter, which is essentially a battery-powered device with a solar battery charging system was introduced. This setup uses a charge controller to make the most of solar panel power and effectively charge the batteries. (Nasir. et al, 2023). Solar power is harnessed by using photovoltaic panels, and these panels generate Direct Current (DC) which is converted to Alternating current (AC) by the inverter. As a result, solar inverter systems are essential for transforming photovoltaic panel's solar energy into useful electrical power for a range of uses. By storing excess solar energy during sunny spells, battery storage can help balance the energy demand during times of low solar irradiance. Grid connectivity increases the system's resilience by enabling the option to take more power from the grid to charge the battery (Shinde. et al, 2023).

As opposed to typical inverter systems which have components like the DSPIC30F2010 micro controller, charge controller (MPPT), battery charger, and the inverter as separate components acting individually, hybrid inverter systems, however, integrate these various components into a single enclosure; not the components themselves but rather their functionalities. Hence the hybrid inverter can do what all these other components can do individually.

The comparison between hybrid foreign and homebased manufactured inverters is the main thrust of this work. It entails hybridizing a 3.5 Kva DSPIC30F2010 controlled inverter system such that it encompasses all the features of a hybrid inverter and then comparing with a hybrid foreign manufactured 3.5 Kva inverter (BREAD). The microcontroller, a DSPIC30F2010, plays a pivotal role in orchestrating the interactions within the home based inverter system. Through its advanced capabilities, it manages and regulates the charge controller, inverter, and other auxiliary components. The harmonious integration of these elements within the confines of a single box not only enhances the system's compactness but also streamlines communication protocols, thereby improving overall efficiency.

This all-encompassing approach to designing the inverter system not only makes the physical setup simpler but also helps it run more smoothly and efficiently. The teamwork between the charge controller and microcontroller allows for quick adjustments, making sure energy is converted and delivered optimally. As a result, this mixed inverter system does not just get the most out of solar panels through MPPT but also uses smart control methods to improve the overall system performance. Bringing all the parts together in one box highlights a dedication to proper functioning, reliability, and smooth operation for sustainable and effective energy use.

1.1 PROBLEM STATEMENT

The increasing demand for reliable power supply in Nigeria has led to a surge in the adoption of inverter systems. However, the market is flooded with both foreign and locally manufactured inverter systems making it challenging for consumers to choose the best option.

To ensure the smooth and enduring integration of solar energy systems into our energy infrastructure, several challenges stemming from their widespread adoption must be tackled. One major concern revolves around the efficiency and reliability of solar power systems. Despite being a clean and sustainable energy source, solar power's performance relies heavily on external factors such as sunlight intensity and duration. This unpredictability poses difficulties in maintaining a consistent and reliable power supply, especially during seasons with less sunlight.

A significant hurdle lies in the limitations of non-hybrid inverters utilized in solar energy systems, particularly concerning the management of fluctuations in solar power generation. This can lead to inefficient energy conversion and utilization. Additionally, the efficiency of solar charging in traditional inverters is crucial, as lower efficiency may constrain the system's ability to harness solar energy effectively. Non-hybrid inverters lack communication capabilities among various system components and solely rely on the grid for power. Moreover, these inverters lack the advanced energy management features present in hybrid systems, such as optimizing energy usage by storing excess energy for later use during peak demand periods or when electricity prices are higher.

The advancement of hybrid inverter systems, capable of effectively managing solar output variations, integrating with energy storage systems, and enhancing solar charging efficiency, holds promise in addressing these challenges. Furthermore, there is the need to grow a local inverter manufacturing industry so as to reduce overreliance on foreign coupled inverter systems. Thus, overtime, Nigeria could become an exporter of inverter systems.

1.2 AIM

This study aims to provide a comprehensive evaluation of foreign and locally manufactured 3.5KVA inverter systems. The findings will inform local consumers, manufacturers, and policymakers about the best options available in the market, ultimately contributing to the growth of the local inverter industry and promoting sustainable energy solutions.

1.3 OBJECTIVES

The specific objectives of this research work are as follows:

- Hybridize a locally assembled inverter system.
- Verify through extensive testing the hybrid characteristics introduced to the locally assembled system.
- Verify and test the performance of a foreign manufactured inverter system.
- Evaluate and compare the performances of foreign and locally manufactured inverter systems.

1.4 METHODOLOGY

- Investigating successful hybridization tactics and and a detailed design plan that outlines the integration of hybrid elements into the DSPIC30F2010 Controlled Inverter System. Executing the design plan by implementing necessary modifications to hardware components such as PCB design, etching of the board, soldering of components on a PCB board, coupling, and casing.

- Performance testing of the hybridized DSPIC30F2010 Controlled Inverter System in terms of output voltage and frequency, load and no load considerations, as well as output power efficiency.

- Performance testing of a foreign hybrid 3.5 KVA inverter (BREAD product) in terms of output voltage and frequency, load and no load considerations, as well as output power efficiency.

- Comparism of performances of foreign and home based manufactured 3.5KVA inverter systems based on output voltage and frequency, load and no load considerations, as well as output power efficiency.

1.5 SCOPE OF THE PROJECT

This project covers on one hand the design of a hybrid inverter system with a maximum solar charge current of 60 Amps and can take a Photo-voltaic (PV) input voltage up to 150V which will be used to power a 24 volt, 200Amperes Hour battery and inverter system. Secondly, it involves a performance comparism between the locally or home based assembled inverter system and a foreign (BREAD) 3.5KVA inverter system.

1.6 RELEVANCE OF WORK

Maximum Power Point Tracking (MPPT)-equipped charge controllers are essential because they maximize solar energy harvesting by dynamically altering the solar panels' operating point. This increases the system's overall efficiency and demonstrates a dedication to obtaining the maximum energy production from renewable sources.

The system architecture has undergone a paradigm shift with the integration of the microcontroller and charge controller into a single enclosure. Component communication is streamlined as a result of this consolidation, which enhances responsiveness and coordination. The DSPIC30F2010 microcontroller functions as a central coordinator, effectively operating the charge controller, inverter, and other supporting components.

Furthermore, the performance comparism between locally assembled inverter and a foreign inverter showcases the advancement in the Nigeria inverter production industry.

1.7 LAYOUT OF REPORT

This project comprises five (5) chapters. Chapter one provides an introduction to the project, chapter two delves into the literature review and theoretical background, chapter three focuses on system design and calculations, chapter four covers construction, testing, and packaging. Lastly, chapter five presents the conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 HISTORY OF THE HYBRIDIZATION OF INVERTER SYSTEM

A solar inverter is a device that converts the direct current (DC) output of a solar panel into alternating current (AC) that can be used by home appliances or fed into the grid. A solar inverter is an essential component of a solar power system, as it enables you to use the electricity generated by the sun.

The invention of solar inverters was motivated by the need to convert the direct current (DC) output of solar panels into alternating current (AC) that can be used by household appliances or fed into the grid. Solar inverters also enable the use of renewable energy sources, such as solar and wind, by synchronizing their variable and intermittent power with the stable and continuous power of the grid.

The history of solar inverters can be traced back to the late 19th century, when Nikola Tesla invented the first AC generator and transformer, which paved the way for the transmission and distribution of AC power. Tesla also had a dispute with Thomas Edison, who advocated for the use of DC power, which was more suitable for his inventions, such as the light bulb and the phonograph. Tesla’s AC power eventually prevailed over Edison’s DC power, as it was more efficient, reliable, and versatile (Yunisa et al., 2022).

The first solar inverter was developed in the 1950s, when the first solar cells were invented by Bell Labs. The solar inverter was a simple device that used a transformer and a switch to convert the DC power from the solar cell into AC power. The solar inverter was mainly used for space applications, such as satellites and rockets, as it was too expensive and inefficient for terrestrial use.

The history of hybrid inverters, marking a significant advancement in the evolution of inverter systems, has unfolded over the past few decades, with notable developments occurring in the late 20th and early 21st centuries. In the early years of solar energy system development, around the 1980s and 1990s, non-hybrid inverters were prevalent. These systems, consisting of separate components such as a microcontroller, charge controller, battery charger, and inverter, played a crucial role in converting solar-generated direct current (DC) into alternating current (AC) for various applications (Valunjkhar et al., 2014).

By the late 20th century, as solar power gained traction, researchers and engineers identified limitations in non-hybrid inverters, including inefficiencies in solar power utilization and challenges in adapting to dynamic energy demands. The need for more integrated and efficient solutions became evident, especially with the increasing demand for renewable energy alternatives.

The concept of hybridization started gaining traction in the early 2000s as a response to identified limitations. Engineers and researchers embarked on exploring ways to integrate the functionalities of individual components within a single enclosure. This led to the emergence of hybrid inverters, with advancements in technology, such as the introduction of Maximum Power Point Tracking (MPPT) and bidirectional energy flow management, aiming to improve overall efficiency (Tekade et al., 2017).

The integration of hybrid features became a focal point in the transition towards hybrid inverters, with notable developments in the mid-2000s. This involved incorporating MPPT technology to optimize solar panel power and efficiently charge batteries. Additionally, bidirectional energy flow management was introduced to enable smoother transitions between solar power, battery storage, and grid connectivity.

The hybridization of non-hybrid inverters resulted in a paradigm shift, particularly in the 2010s. The newly developed hybrid inverters showcased improved efficiency, reliability, and adaptability to varying energy conditions. Their streamlined design, integration of hybrid features, and the ability to handle both light and heavy loads contributed to their success in the renewable energy landscape.

As the benefits of hybrid inverters became evident, their global adoption increased significantly from the mid-2010s onwards. This widespread acceptance aligned with the growing emphasis on sustainability and green energy alternatives, contributing to the reduction of the environmental impact of energy production. (Nasir et al., 2023).

2.1 BENEFITS OF HYBRID HOME-BASED MANUFACTURED INVERTERS OVER HYBRID FOREIGN INVERTERS

i. **Cost Efficiency:** Locally made inverters often come at a lower price due to reduced import duties, shipping cost, and currency exchange fluctuations. This makes them more affordable for the average customer.

ii. **Tailored for local conditions:** Home-based manufacturers typically design their inverters to handle local grid instability, voltage fluctuation, and environmental conditions like heat and humidity. This enhances durability and performance in local settings.

iii. **Boost to local economy**: Purchasing locally manufactured inverters support domestic industries, create jobs, and reduce reliance on import, contributing to economic growth.

iv. **Customization and Flexibility:** Local manufacturers are often more responsive to customer feedback and can offer customized solution or quicker update based on user needs. (SRNE solar).

2.2 ADVANTAGES OF HYBRIDIZED DSPIC30F2010 CONTROLLED INVERTER SYSTEM

1. Enhanced Solar Charging Efficiency: The integration of bidirectional energy flow management and Maximum Power Point Tracking (MPPT) capabilities ensures optimal utilization of solar energy, addressing the inefficiencies seen in traditional inverters (Nwaogu et al., 2023).

2. Compact Design: Consolidating the microcontroller, charge controller, and inverter into a single enclosure improves system compactness. This not only saves space but also facilitates easier installation and maintenance.

3. Real-time Adjustments: The DSPIC30F2010 microcontroller serves as a central coordinator, allowing quick adjustments and efficient management of the entire system. This enhances responsiveness to variations in solar output, ensuring a steady power supply (Yunisa et al., 2023).

4. Streamlined Communication: Integration of components into a single enclosure enhances communication protocols, leading to improved coordination among the microcontroller, charge controller, and inverter. This streamlined communication contributes to overall system efficiency (Nwaogu et al., 2023).

5. Risk Mitigation: Bidirectional energy flow management helps overcome issues associated with backward charging in non-hybrid inverters. This mitigates risks such as battery overcharging, potential harm to appliances, safety hazards, and overall system inefficiencies (Milenov et al., 2023).

2.3 LIMITATIONS OF HYBRIDIZED DSPIC30F2010 CONTROLLED INVERTER SYSTEM

- **Complexity in Design:** Integrating multiple functionalities into a single enclosure may introduce complexity in the design, requiring careful consideration of factors such as heat dissipation, component compatibility, and overall system reliability (Milenov et al., 2023).

- **Cost:** The hybridized system may incur higher initial costs due to the integration of advanced components and technologies. However, the long-term benefits in efficiency and sustainability may outweigh these initial expenses.

- **Maintenance Challenges**: While the compact design is advantageous for installation, it could pose challenges for maintenance and repairs. Accessing individual components within the integrated enclosure may require specialized tools and expertise (Yunisa et al., 2022).

- **Technology Dependence:** The system's performance is dependent on the advanced capabilities of the DSPIC30F2010 microcontroller and other integrated technologies. Any malfunctions or advancements in technology may pose challenges for future upgrades or replacements (Valunjkhar et al., 2014).

- **Limited Scalability:** The design, focusing on a specific charge controller for a 24-volt solar inverter system, may have limitations when it comes to scalability for larger or different voltage systems (Milenov et al., 2023).

2.4 ADVANTAGES OF FOREIGN MANUFACTURED INVERTER SYSTEMS

1.High Efficiency: Foreign inverters often use advanced power conversion technologies that reduce energy loss and improve overall performance.

2. Pure Sinewave Output: They typically deliver clean, stable electricity that is safe for sensitive electronics like laptops, TVs and medical devices.

3. Durability and Build Qualities: These systems are usually built with high-grade components and tested to international standards, offering long-term reliability.

4. Thermal Protection: Enhances cooling systems help prevent overheating, especially in hot climates.

5. Smart Features: Many models include remote monitoring, mobile application control and intelligent load management (Kroemer,et al, 2001).

2.5 LIMITATIONS OF FOREIGN MANUFACTURED INVERTER SYSTEMS

1. Voltage Compatibility Issues: Foreign inverters may be designed for 110v systems, while Nigeria uses 220V. This mismatch can lead to inefficiencies or require additional transformers.

2. Frequency Mismatch: Some imported inverters operate at 60Hz, whereas Nigeria's grid standard is 50Hz. This can affect the performance of the connected appliances maintenance cost.

3. Battery Compatibility: Some foreign systems are optimized for specific battery types or voltages (i.e. 24V systems), which may hinder their wider application.

4. Spare part Availability: Replacement parts may be hard to source locally, leading to a longer downtime and higher not align with locally available batteries.

5. Import costs and Tariffs: Foreign systems often come with higher upfront cost due to import duties, shipping and currency exchange rates (techworms, 2025).

2.6 COMPARISON BEWEEN MAXIMUM POWER POINT TRACKING (MPPT) AND PULSE WIDTH MODULATION

Maximum Power Point Tracking (MPPT) and Pulse Width Modulation (PWM) are two commonly used techniques in charge controllers for optimizing the charging process of batteries or other energy storage systems in renewable energy systems like solar panels. Below is a delve into a comparison of these two methods:

2.6.1 Basic Principle

PWM Charge Controllers: PWM controllers regulate the charging current by rapidly switching the solar panel’s output between the battery and itself. It maintains the battery at a constant voltage by adjusting the width of the pulses sent to the battery.

MPPT Charge Controllers: MPPT controllers, on the other hand, continuously track the maximum power point (MPP) of the solar panel by dynamically adjusting the voltage and current to maximize the power output. They ensure that the solar panel operates at its peak efficiency, even under varying environmental conditions (Laguado. et al., 2019).

2.6.2 Efficiency

PWM Charge Controllers: These controllers are less efficient compared to MPPT controllers, especially when the solar panel's voltage is significantly higher than the battery voltage. PWM controllers may not fully utilize the available solar power as they operate at a fixed voltage, potentially leading to energy loss.

MPPT Charge Controllers: MPPT controllers are highly efficient in extracting maximum power from the solar panel. By dynamically adjusting the operating point to match the panel's

MPP, MPPT controllers can significantly improve energy conversion efficiency, especially in scenarios with fluctuating sunlight intensity or temperature changes (Putra. et al., 2023).

2.6.3 Flexibility

PWM Charge Controllers: These controllers are typically less flexible as they operate at fixed voltage levels. They are suitable for simpler systems where the solar panel's characteristics are well-matched with the battery voltage.

MPPT Charge Controllers: MPPT controllers offer greater flexibility as they can adapt to various solar panel configurations and environmental conditions. They can handle a wide range of panel voltages and battery voltages, making them suitable for diverse applications and system configurations (Robles et al., 2022).

2.6.4 Cost

PWM Charge Controllers: PWM controllers are generally less expensive compared to MPPT controllers. They are a cost-effective solution for small-scale applications or situations where maximizing energy output is not critical.

MPPT Charge Controllers: MPPT controllers tend to be more expensive due to their advanced electronics and capabilities. However, the higher initial investment is often justified by the increased energy harvest and long-term savings on electricity bills (Laguado et al., 2019).

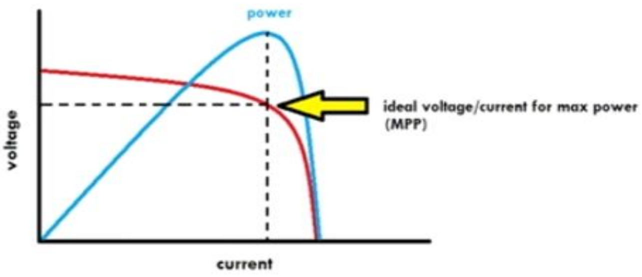

Figure 2.1: MPPT SOLAR I-V AND POWER CURVES

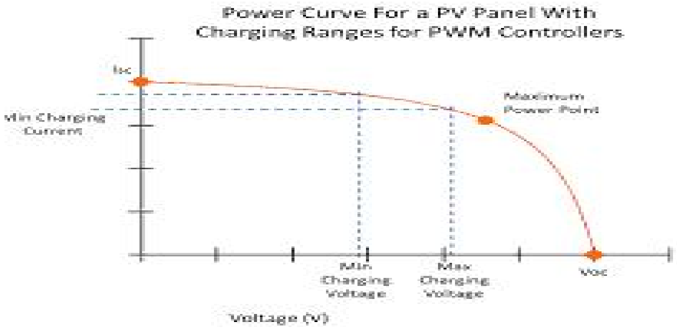

Figure 2.2: PWM SOLAR I-V AND POWER CURVES

2.7 REVIEW ON COMPONENTS USED IN THE HYBRIDIZATION OF A DSPIC30F2010 CONTROLLED INVERTER SYSTEM

Some of the components used in this project include:

2.7.1 DSPIC30F2010 Microcontroller:

This is a 16-bit microcontroller that belongs to the Digital Signal Peripheral Interface Controller (dsPIC) family of digital signal controllers. It has features such as 12-bit analog-to-digital converter, pulse-width modulation, quadrature encoder interface, and serial communication modules. It is suitable for applications that require high-performance digital signal processing and control functions (Microcontrollers Lab, 2013).

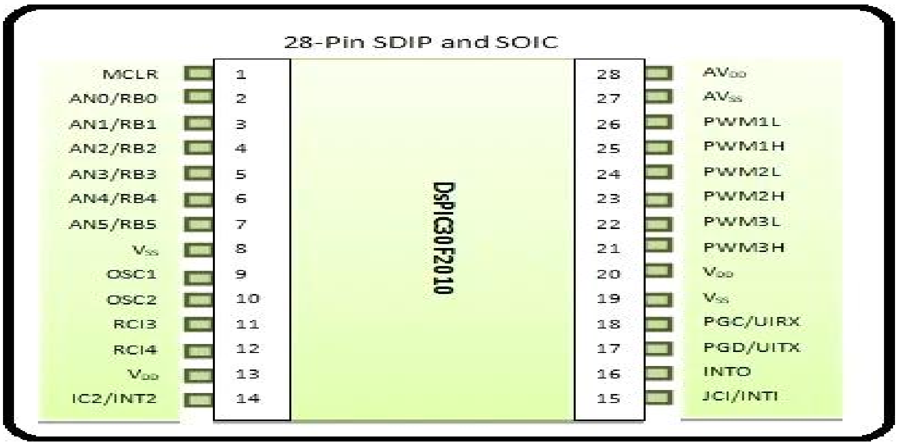

Figure 2.3: PIN LAYOUT OF DSPIC30F2010 MICROCONTROLLER

2.7.2 Inverter

This is a device that converts direct current (DC) to alternating current (AC). It is used to supply power to AC loads from DC sources such as batteries, solar panels, or fuel cells. There are several types of inverters, such as single-phase, three-phase, multilevel, or resonant inverters. The type of inverter used depends on the input and output voltage levels, frequency, power quality, and load characteristics (Evans, 2023).

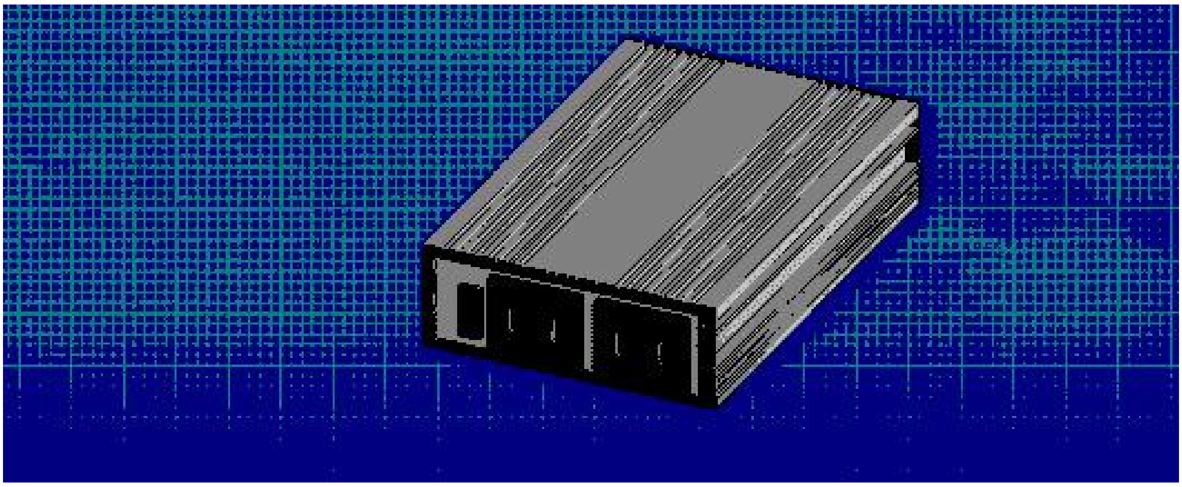

Figure 2.4: A TYPICAL INVERTER

2.7.3. Ferrite Core Inductor

A Ferrite Core Inductor is a two-terminal device passive electrical component which opposes changes of current flowing through it. It uses a ferrite material as its main core and has qualities such as high saturation, high impedance, fewer losses, stability within temperature and material properties (Electronics Project Focus, 2013).

Figure 2.5: IMAGE OF A FERRITE CORE INDUCTOR

2.7.4. 20x4 Liquid Crystal Display (LCD) Screen

This is a type of liquid crystal display that can show 20 characters per line and 4 lines of text. It is used to display the status and parameters of the hybrid inverter system, such as the input and output voltages, currents, frequencies, power, and modes (The Engineering Projects, 2019).

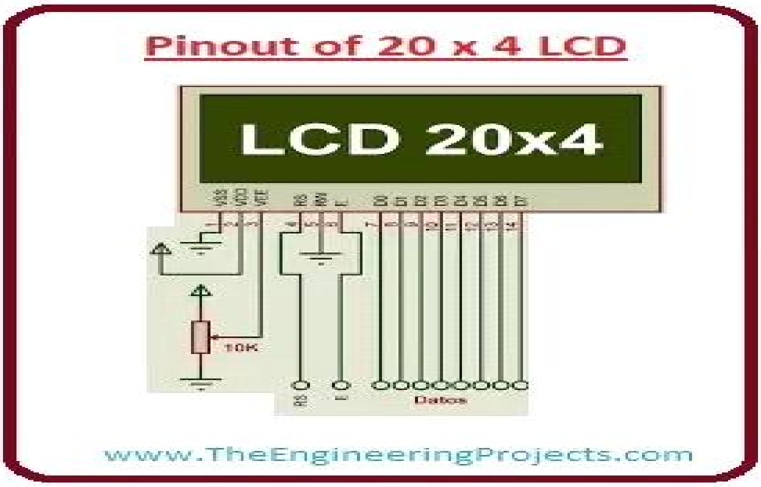

Figure 2.6: PIN LAYOUT OF 20X4 LCD SCREEN (The Engineering Projects, 2019)

2.7.5 Inter Integrated Circuit (I^2C) LCD Module

This is a type of interface module that allows the communication between the LCD screen and the microcontroller using the I^2C protocol. I^2C stands for inter-integrated circuit, and it is a serial bus that uses only two wires: one for data Serial Data Line (SDA) and one for clock Serial Clock Line (SCL). It reduces the number of pins and wires required to connect the LCD screen and allows multiple devices to share the same bus (Swagatam, 2019).

Figure 2.7: I^{2}C LCD MODULE

2.7.6 Power Diodes

These are semiconductor devices that allow current to flow in one direction only. They are used to rectify the AC output of the inverter into DC, and to prevent reverse current flow from the battery to the converter or the inverter. They also help to protect the circuit from overvoltage and short-circuit conditions (Electronics Coach, 2024).

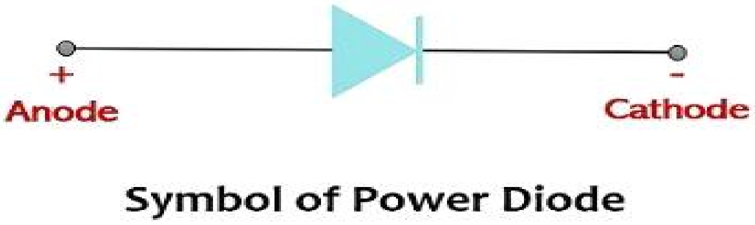

Figure 2.8: SYMBOL OF POWER DIODE

2.7.7 Printed Circuit Board (PCB)

This is a type of board that supports and connects the electronic components using conductive tracks, pads, and vias. It is used to design and implement the circuit of the hybrid inverter system, and to provide a compact and reliable layout (Das, 2024).

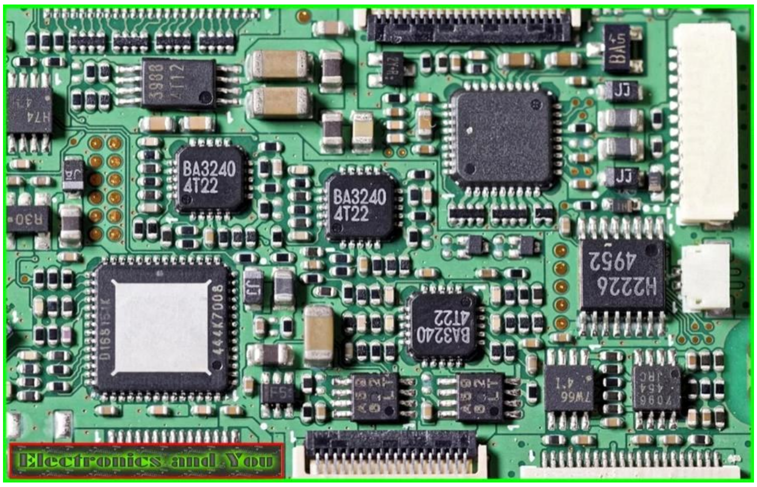

Figure 2.9: PRINTED CIRCUIT BOARD (PCB) BOARD

2.6.8 Terminal Blocks and Connectors

These are devices that allow the connection and disconnection of wires and cables without soldering. They are used to connect the input and output sources, loads, and components of the hybrid inverter system, and to provide a secure and convenient way of wiring (Cope, 2021).

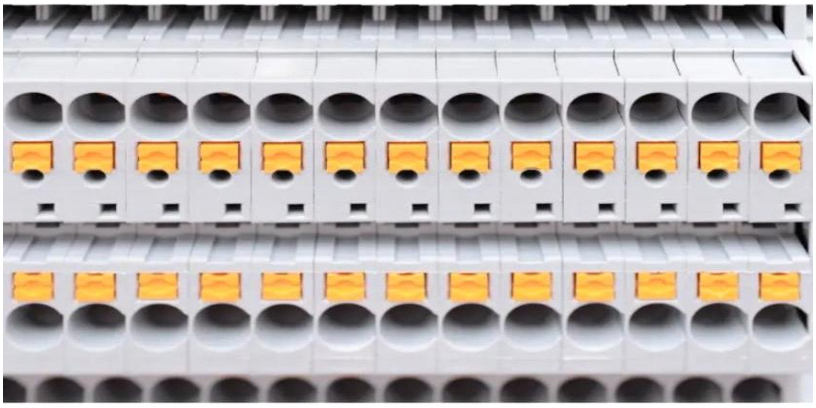

Figure 2.10: TERMINAL BLOCKS

2.7.9 Metallic Semiconductor Field Effect Transistors (MOSFETS)

These are types of transistors that use an electric field to control the current flow. They are used as switches in the converter and the inverter, and they can handle high voltages and currents with low losses. They also have a fast-switching speed and a low on-resistance (Micro DigiSoft, 2021).

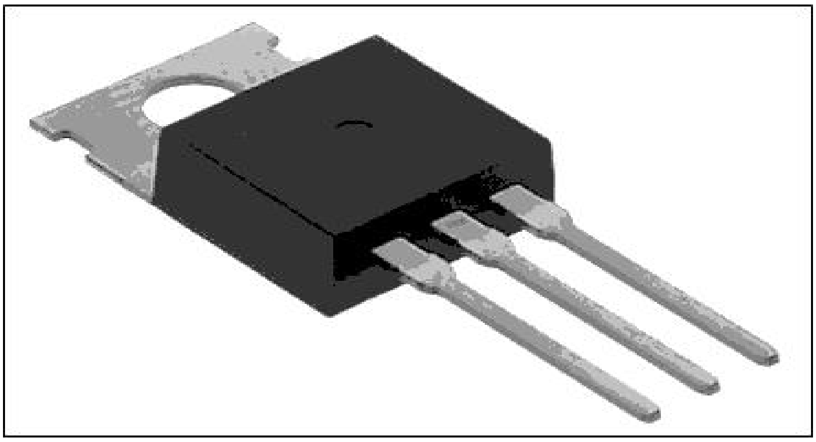

Figure 2.11: IMAGE OF A MOSFET

2.8 REVIEW ON COMPONENTS USED IN THE HYBRIDIZATION OF A FOREIGN MANUFACTURED INVERTER SYSTEM

2.8.1 Inverter Unit

The central unit that converts DC power from solar panel or batteries into AC power for your appliances.

2.8.2 Dual MPPT Controller

Built-in Maximum Power Point tracking controllers are crucial for maximizing the power harvested from solar panels, especially with two seperate inputs, ensuring high efficiency.

2.8.3 Battery Bank

A flexible system that works with both lithium and lead-acid batteries, storing energy for use when solar or grid power is unavailable.

2.8.4 H-bridge Topology

A common and efficient circuit configuration used in the inverter to convert DC to AC, significantly reducing harmonic distortion.

2.8.5 Inductors and Capacitors

These are the filtering components that smooth out the output to create a clean, pure sine wave, making it virtually identical to utility power (Noman p,R.R Desai).

2.8.6 Microcontroller

A control system (like the PIC18F4431) is used to manage the entire system, comparing signals to generate the correct PWM Outputs and manage power flow.

2.9 REVIEW OF RELATED WORKS

Nasir et al. (2023) in their research designed, implemented and fabricated a hybrid solar inverter to tackle the challenges facing the solar inverter system by incorporating maximum power point tracking (MPPT) to regulate output voltage and current to maximize efficiency. Their approach ensured that the solar panels operate at their maximum points regardless of variations in solar radiation and temperature and using an Arduino Mega as its microcontroller to examine the battery's voltage while comparing it to a predefined minimum value to determine if charging is required using solar energy or mains supply. When solar power supply is available, the load is supplied using the relay circuitry of the solar power supply. And when it is unavailable, the battery is charged by the main supply.

Nwaogu et al. (2023) designed a hybrid solar inverter using a Pulse Width Modulated (PWM) charge controller. They analyzed the load to be powered by the inverter system and used components which had suitable ratings to match the load requirements. The limitation to this work is the use of the Pulse Width Modulated (PWM) charge controller. This charge controller is associated with much losses when compared to the Maximum Power Point Tracker (MPPT) although the maximum power point tracking is more expensive.

Milenov et al. (2023) discussed the applications of hybrid inverters extensively. They also point out the features, principle of operation and advantages of hybrid inverters and how they may be used in domestic and commercial PV systems for self-consumption energy production. Their publication discusses hybrid inverter classifications, battery energy management in hybrid inverters, monitoring and data acquisition systems. They analyze results gotten from a case study comparing three different variants of a PV system.

Yunisa et al. (2022) designed a solar panel inverter system using solar panels, batteries, a charge controller, and an inverter matching specific requirements. The method used to achieve this included the location and manner of solar panel installation and the connection from the charge controller to the battery. The results gotten were analyzed and it was observed that 7.8% of total power was lost due to the components used. Their work can be improved if the type of charge controller used was stated and a microcontroller with fitting requirements were to be installed transforming the system into a hybrid solar inverter system.

Tiwari et al. (2022) designed a model of power inverters for solar panels in rural areas using a capacitor to connect a solar panel and a booster circuit. The inverter produces a sine wave AC output utilizing the pulse signal and a Pulse Width Modulator (PWM) as the charge controller. The limitation of this design is the use of a Pulse Width Modulator as the charge controller as it is associated with a lot of losses when compared to the Maximum Power Point Tracking (MPPT) which is more efficient.

Tekade et al. (2017) designed and developed a solar panel inverter with a Maximum Power Point Tracker (MPPT). The MPPT extracts maximum power from the panel most efficiently from the solar panels according to the intensity of sunlight. A microcontroller (PIC16F877A) was used to adjust the solar panels based on the given position of tilt times with respect to the natural position of the sun at separate times by processing the input voltage from the circuit and controlling the direction in which the motor must rotate to receive maximum intensity of light from the sun.

Thukral et al. (2016) designed and implemented a micro-controller based solar power inverter. Their publication investigates the application of this system operation during power disturbances and discusses how the inverter's controls are implemented with a digital approach using a microprocessor for the control system. The components used to achieve their design include; a microcontroller (AT8535), power amplifiers, voltage booster, transformer, lead acid battery, h-bridge, etc. They also make use of a Pulse Width Modulator as the charge controller for the system which is less efficient compared to the Maximum Power Point Tracking (MPPT).

Valunjkhar et al. (2014) in their publication discussed the implementation of maximum power point tracking charge controller to increase the efficiency of solar systems. The microcontroller used in their publication was the DSPIC30F2010 and the MPLAB Integrated Developer Environment (IDE) software was used to program it.

In summary, this project stands out from the related works reviewed due to its utilization of a DSPIC30F2010 microcontroller, known for its superior efficiency compared to controllers like the Arduino Mega, PIC16F877A, AT8535, etc. Additionally, while some works employ a less efficient Pulse Width Modulator (PWM) solar charge controller, this project utilizes the more effective Maximum Power Point Tracking (MPPT) solar charge controller.

When comparing locally manufactured inverters with foreign-made ones, difference in cost, performance, featutes and after-sale support are key. While foreign inverters from major global brands often offer higher efficiency and advanced technology, locally manufactured units can be more cost-effective and easier to service.

CHAPTER THREE

DESIGN METHODOLOGY

3.0 BLOCK DIAGRAM

The block diagram below (Figure 3.1) illustrates the design for the hybridized DSPIC30F2010 Controlled Inverter System. It is segmented into the following blocks: Microcontroller (DSPIC30F2010), Current Sensor, Voltage Sensor, Temperature Sensor, Battery Voltage Sensor, MOSFET, MOSFET Driver, LCD screen, Relay, Fan, Inductor, and Battery. The block diagram of the design is given below:

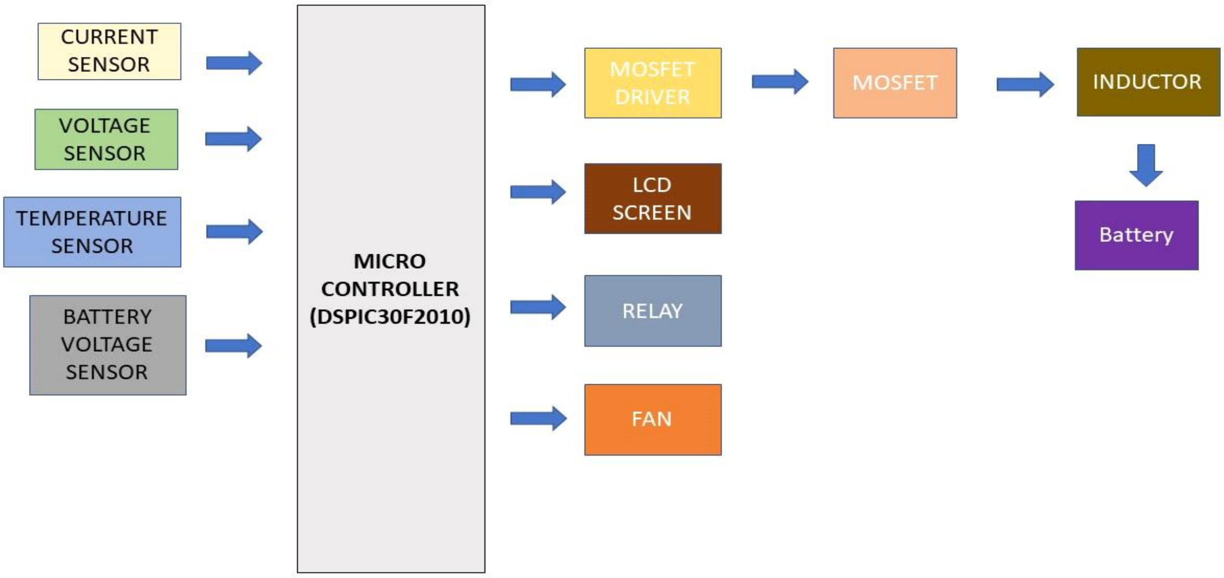

Figure 3.1: BLOCK DIAGRAM OF THE DESIGN

DESIGN CONSIDERATION

- **THE SENSORS UNIT**

This unit primarily comprises four sensors: voltage, battery voltage, current and temperature sensors.

3.1.1.1 VOLTAGE SENSOR BLOCK

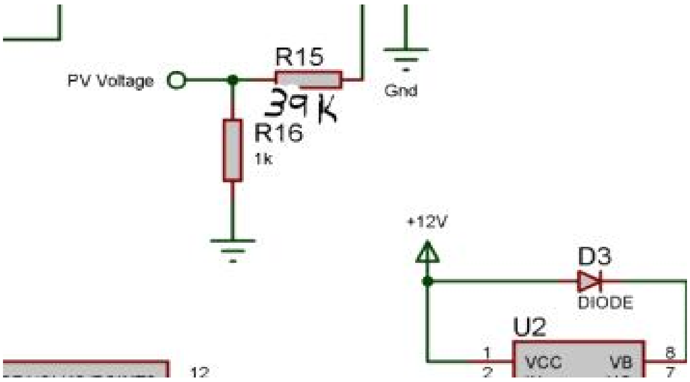

Figure 3.2: VOLTAGE SENSOR CIRCUIT DIAGRAM

In this project, a voltage sensor employing a voltage divider arrangement with a pair of resistors in series is utilized. Due to the limitation of the DSPIC30F2010 microcontroller's internal Analog to Digital Converter (ADC) to read voltages exceeding 5 volts directly, a voltage divider circuit becomes essential. The voltage received by the microcontroller's analog input pin can be calculated using the voltage divider equation.

The equation that determines the voltage drop across one resistor (R16) in a voltage divider setup consisting of resistors R15 and R16, is given as:

Voltage drops across R_{16} = V x ....(3.1)

Likewise, the voltage drop across the resistor R15 is given as;

Voltage drop across R_{15} = V x ....(3.2)

In this project, the voltage divider circuit is employed to reduce the voltage from the PV panel, which typically does not exceed 200V, to a level not surpassing 5V. Consequently, a scaling factor of 40:1 (i.e., 200:5) is implemented to achieve this voltage reduction.

Utilizing the voltage divider equation in this particular project, we have:

Given that;

V_{out} = Voltage Output from Voltage Divider

V_{in} = Input Voltage from the PV panels.

R_{15} = First Resistor

R_{16} = Second Resistor

Therefore, Voltage output from voltage divider becomes;

$$V_{out} = V_{in} \text{ x } \ldots\ldots\ldots(3.3)$$

From the above equation input voltage becomes;

$$V_{in} = V_{out} \text{ x } \ldots\ldots\ldots(3.4)$$

The circuit is configured to regulate the output from the voltage divider circuit to 5V, even if the input voltage from the PV panels reaches 200V. Despite the PV panels having a maximum output voltage rating of 200V, it’s crucial to incorporate a margin of safety to prevent the voltage divider circuit output from exceeding 5V. Any voltage surpassing this threshold could potentially damage the controller. This precaution is visually represented on the scale below.

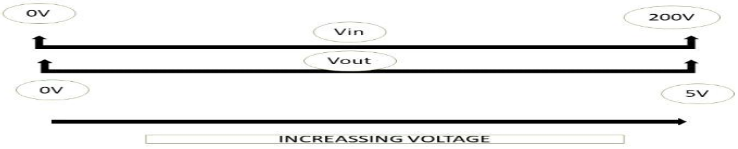

Figure 3.3: SCALE OF VOLTAGE DIVIDER OUTPUT

The output voltage from the voltage divider circuit is determined as follows:

Given:

$R_{16} = 1000\Omega$,

$R_{15} = 39{,}000\Omega$,

$V_{in} = 200V$

$V_{out} = 200$ x

$V_{out} = 5V$

The Resistors, R_{16} and R_{15} are chosen as 1 KΩ and 39 KΩ, respectively, to maintain a ratio of 40 to 1. Different values for R_{16} and R_{15} can be utilized, provided they adhere to the scaling factor of 40:1.

The DSPIC30F2010 module retrieves the output voltage from the voltage divider, then, through its programmed code, it restores the voltage to its original value through multiplying it by 40. Subsequently, the PV voltage is exhibited on the LCD screen.

3.1.1.1.1 VOLTAGE SENSORS CALIBRATION

The DSPIC30F2010 utilizes its analog to digital converter module to read the output voltage from the voltage divider circuit, storing the readings on a 10-bit register. This register has a capacity ranging from 0 to 1024 bits (2^{10} bits), accommodating values corresponding to voltages between 0 and 5V. Each voltage within this range is assigned a specific value within the scale. The A/D conversion process is delineated by the following equations;

$V_{out} = ADC_{RESULT} X$ ……..(3.5)

Illustrating through a case study where the ADC stores 512 bits (ADC_{RESULT}) in its internal register, the calculation for the input voltage supplied to the controller's analog pin can be elucidated as follows:

ADC_{RESULT} = 512 bits (represented in binary as 1000000000).

$V_{out} = ADC_{RESULT} X$

$V_{out} = 512 x = 2.5V$

3.1.1.2 BATTERY VOLTAGE SENSOR BLOCK

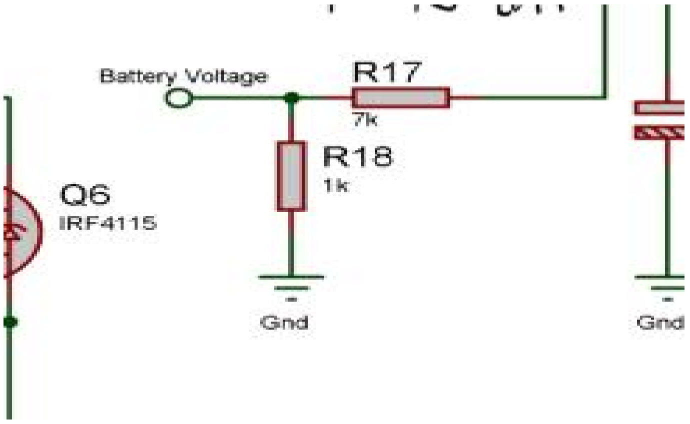

Figure 3.4: BATTERY VOLTAGE SENSOR CIRCUITRY

Similar to the voltage sensor, the battery voltage sensor also employs a voltage divider arrangement comprising a pair of resistors in series. As discussed in the previous section on the voltage sensor, the DSPIC30F2010 microcontroller's internal Analog to Digital Converter (ADC) is limited in its ability to directly measure voltages exceeding 5 volts. Therefore, the utilization of a voltage divider circuit becomes necessary.

The circuit is designed to constrain the output of the voltage divider circuit to 5V, even if the battery input voltage rises to 30V. Exceeding this threshold could potentially harm the Controller.

The output voltage from the voltage divider circuit is determined as follows:

Given:

From equation (3.3)

$R_{16} = R_{18} = 1000\Omega$,

$R_{15} = R_{17} = 7{,}000\Omega$,

$V_{in} = 30V$

$V_{out} = 30$ x

$V_{out} = 3.75V$

Resistors R_{18} and R_{17} are selected as 1 KΩ and 7 KΩ, respectively, ensuring a ratio of 8 to 1. Alternative values for R18 and R17 may be employed as long as they maintain the 8:1 scaling factor.

The DSPIC30F2010 module captures the output voltage from the voltage divider and, using its programmed code, restores the voltage to its original magnitude by multiplying it by

8. The resulting PV voltage is then displayed on the LCD screen. Its Voltage sensor calibration is the same as that of the voltage sensor.

3.1.1.3 CURRENT SENSOR BLOCK

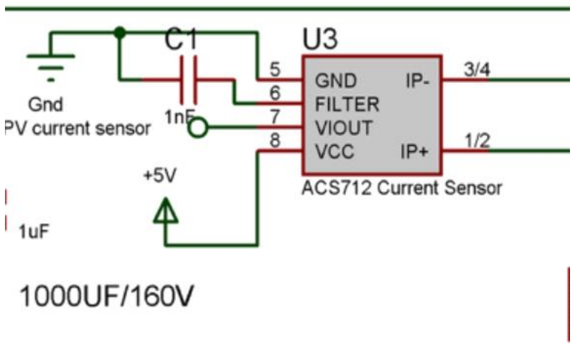

Figure 3.5: CIRCUIT DIAGRAM OF THE CURRENT SENSOR

The project utilizes a Hall Effect current sensor, specifically the ACS712, renowned for its affordability, effectiveness, and versatile features. This sensor, chosen for its bidirectional current sensing capabilities and user-friendly design, integrates hall effect-based technology with $2.1kV_{RMS}$ voltage isolation and a low-resistance current conductor.

Functionally, the ACS712 operates as a current sensor, utilizing its conductor to accurately measure current flow. Its specifications include an 80kHz bandwidth, 66 to 185 mV/A output sensitivity, and a low-noise analog signal path. With a device bandwidth set via the FILTER pin and internal conductor resistance of 1.2mΩ, the ACS712 boasts a total output error of 1.5% at TA = 25°C and stable output offset voltage, minimizing magnetic hysteresis.

The sensor employs indirect sensing, leveraging the Hall Effect to detect incoming current through magnetic field generation. A 30Amps ACS712A variant is employed in this project, offering direct proportional voltage output relative to the current flow from PV panels to the load. Remarkably, it discerns current direction, providing a voltage range of 0V to 2.5V for negative current flow and 2.5V to 5V for positive flow.

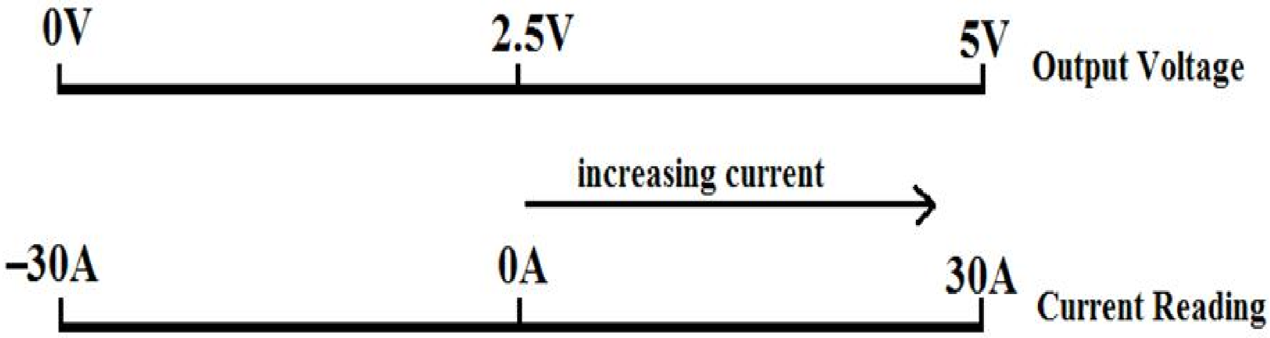

Figure 3.6: NUMBER LINE OF THE ACS712 CURRENT SENSOR

To interface with the sensor, a DSPIC30F2010 micro controller reads its voltage output via its Analog to Digital Converter (ADC), scaling the readings with a ratio of 12:1 (i.e., 30 Amps: 2.5Volts). This seamless integration enables precise calculation of load power and energy consumption, showcasing the ACS712's pivotal role in the project's success.

$I_{in} = (V_{out} - 2.5V) \times 12$……………(3.6)

Where,

I_{in} = Current flowing from panels to Load.

V_{out} = output Voltage from the current sensor.

Considering a case where, $V_{out} = 4V$, Therefore the DSPIC30F2010 microcontroller calculates the corresponding I_{in} as;

$I_{in} = (4V-2.5V) \times 12$

$I_{in} = 18Amps$

3.1.1.4 TEMPERATURE SENSOR

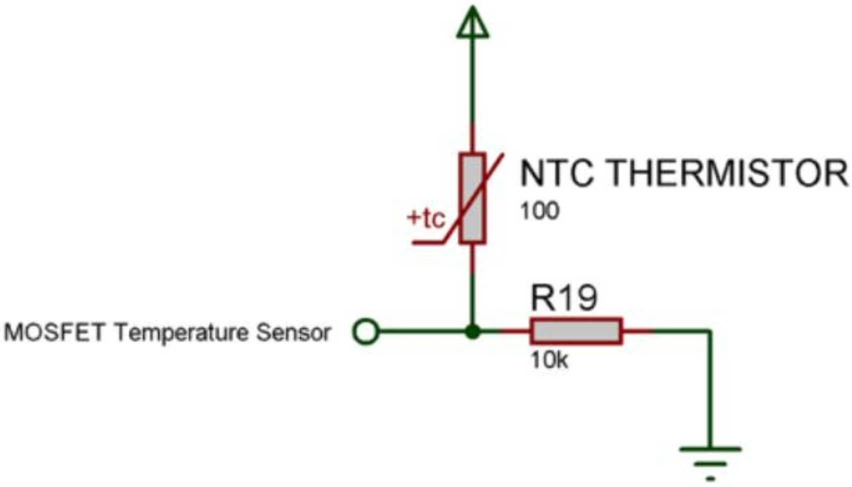

Figure 3.7: CIRCUIT DIAGRAM OF TEMPERATURE SENSOR

This sensor comprises an NTC (Negative Temperature Coefficient) thermistor connected in series with a 10-kilo ohm resistor. In this setup, the resistance of the NTC thermistor decreases as the temperature rises, while the 10-kilo ohm resistor maintains a constant resistance.

As the temperature fluctuates, the combined resistance of the NTC thermistor and the resistor changes, leading to variations in the voltage across the circuit. At a temperature of 500°C, a voltage drop of 5V occurs. Conversely, at 0°C, there is no voltage drop observed. This voltage shift is then detected by the microcontroller's analog-to-digital converter, enabling accurate temperature measurements.

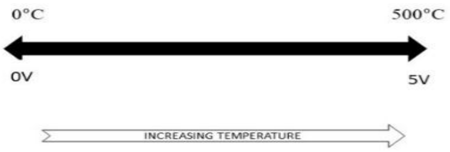

Figure 3.8: NUMBER LINE OF THE TEMPERATURE SENSOR

3.1.2 Liquid Crystal Display Block

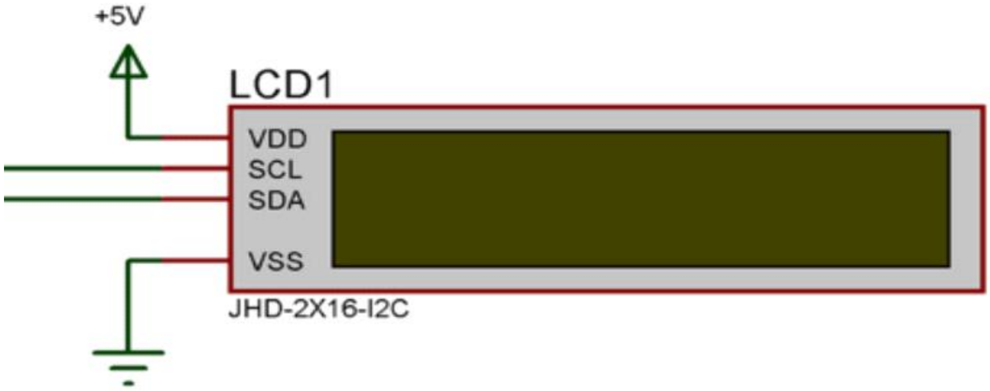

Figure 3.9: CIRCUIT DIAGRAM OF THE LCD BLOCK

This section dedicated to the liquid crystal display (LCD) outlines the LCD screen itself along with its associated circuitry. Serving as an interface for the system operator, the LCD screen exhibits crucial data regarding the system's temperature and other relevant information. Specifically, a 20 x 4 LCD screen is employed for this purpose. It showcases essential values such as Temperature, Voltage, Current, and facilitating easy local observation. Above is the circuit diagram illustrating the configuration of the liquid crystal display block.

3.1.3 MOSFET DRIVERS BLOCK

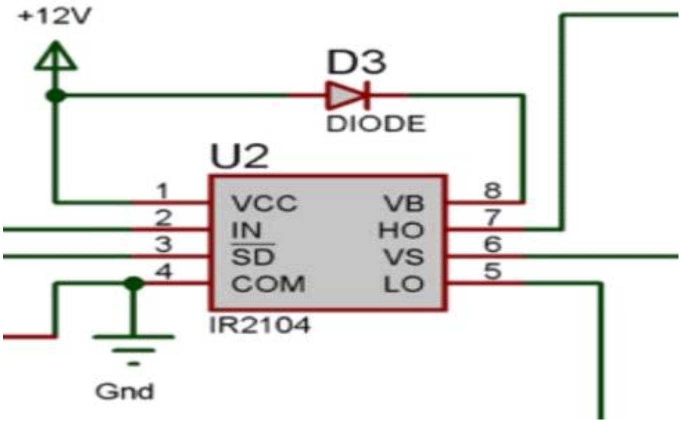

Figure 3.10: CIRCUIT DIAGRAM OF THE MOSFET DRIVER

The MOSFET driver selected for optimized performance in our system is the IR2104. Its choice was made after careful consideration of specifications tailored to our specific requirements. The IR2104 offers essential features necessary for effectively driving MOSFETs, such as robust handling of high current and voltage, rendering it ideal for powering switching applications.

Within this project, MOSFET drivers play a pivotal role in coordinating the behavior of MOSFETs. Serving as crucial intermediaries between the control circuitry especially the DSPIC30F2010 microcontroller and the MOSFETs, these drivers facilitate efficient and reliable switching operations.

The MOSFET driver receives pulses at a defined frequency known as the switching frequency "F_{sw}," with a value of 78.12KHz originating from the DSPIC30F2010 microcontroller. It then interprets the pulse information and emits a switching signal with values of either 0 or 1, corresponding to 0V and 5V, respectively.

The MOFET driver has its supply pin "V_{cc}" connected to the 12V side of the voltage regulator circuitry a shown below:

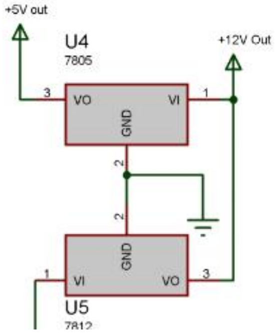

Figure 3.11: CIRCUIT DIAGRAM OF THE VOLTAGE REGULATOR

The MOSFET driver will use this 12V, with the switching frequency from the microcontroller and with higher current from the voltage regulator to switch the MOSFETS.

As observed in Figure 23, the MOSFET driver features two pins labeled High Output (HO) and Low Output (LO). When the switching signal is high, current flows through the circuitry connected to the "HO" pin at a voltage of 5V. Similarly, when the switching signal is low, current flows through the circuitry connected to the "LO" pin, also at a voltage of 5V.

3.1.4 MOSFET BLOCK

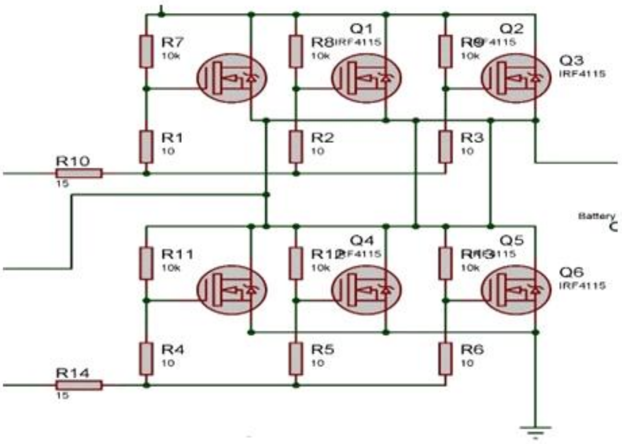

Figure 3.12: CIRCUIT DIAGRAM SHOWING TRANSISTOR ARRANGEMENT

The MOSFETs utilized in this project are the IRFB4115 MOSFETs, boasting a maximum drain-source voltage of 150V and a maximum drain current of 104A. Within our circuit, three of these transistors are arranged in parallel, forming part of the "BUCK CONVERTER" circuit, which will be elaborated on in subsequent sections of this chapter.

Examining the arrangement above, it is evident that the top half (comprising Q1, Q2, and Q3) mirrors the bottom half (comprising Q4, Q5, and Q6). Let's delve into the functionality of the top arrangement. When the MOSFET driver enters a switching state of "1," the top arrangement becomes energized (which is connected to pin “HO” of the MOSFET driver), allowing current to flow through it from the MOSFET driver.

Within the top portion, each transistor (Q1, Q2, Q3) is accompanied by a current-limiting resistor (R1, R2, R3), each valued at 10KΩ. These resistors play a crucial role in limiting the current from the driver by a factor of 1/3, ensuring that the current through Q1, Q2, Q3 is a third of the total current "I," effectively switching the transistors on.

Additionally, the diagram above reveals the presence of discharge resistors (R7, R8, R9), each with a value of 10KΩ. These resistors serve to discharge the voltage and current after the MOSFET driver has transitioned to a switching state of “0” (which is connected to pin “LO” of the MOSFET driver), thereby energizing the bottom circuit while the top circuit is deactivated. During this period, the transistors in the top circuit should ideally be off; however, residual capacitive voltage between the gate and the drain may prevent this, posing a potential issue in the circuit. The discharge resistors mitigate this problem by lowering the voltage and facilitating the discharge of current, ensuring proper functionality of the circuit.

3.1.5 RELAY BLOCK

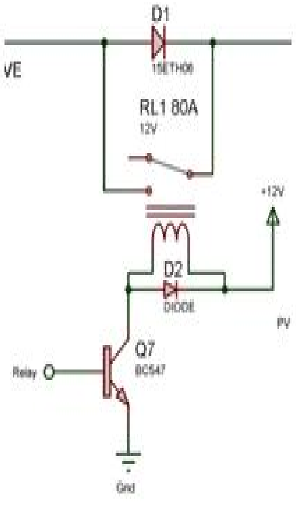

Figure 3.13: RELAY SCHEMATIC DIAGRAM

This section covers the critical role of the relay as an essential component in controlling the flow of electricity between vital elements like solar panels and batteries. The relay utilized in this project boasts an impressive current rating of 80A and a voltage rating of 12V.

To address the potential issue of PV backflow current, where the solar panel voltage drops below that of the battery, particularly during low-light conditions such as nighttime, a diode (D1) is employed. Positioned strategically between the solar panel and the battery, this diode prevents reverse current flow, ensuring efficient energy transfer from the solar panel to the battery and mitigating the risk of inefficiencies and system damage.

During daylight hours, when the solar panel voltage exceeds that of the battery, all components except the microcontroller remain inactive as there is no load connected, hence no current flow. However, the microcontroller actively monitors the voltage on the line via the voltage sensor circuit and compares it against the battery voltage sensor. Upon detecting a higher voltage at the panel than the battery, the microcontroller signals the relay to close the circuit, as depicted in the diagram. Due to the internal resistance of the diode, current flows through the path of least resistance, bypassing the diode effectively.

3.1.6 FAN BLOCK

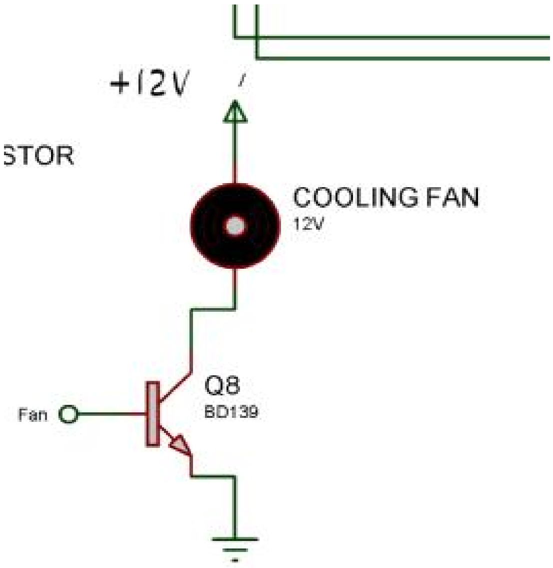

Figure 3.14: CIRCUIT DIAGRAM OF FAN

While designing our DSPIC30F2010 controlled hybrid inverter system, it was deemed necessary to ensure efficient thermal management to maintain optimal operating conditions. Hence, we installed Fans having a rating of 12V within the systems to help dissipate heat generated during operation, ensuring the longevity and reliability of critical components. Positioned strategically, these fans facilitate airflow to regulate temperature levels within the system, preventing overheating and component degradation.

Central to this thermal management process is the microcontroller, which serves as the system's control unit. Tasked with temperature monitoring and control, the microcontroller receives input from temperature sensors strategically placed throughout the system. These sensors continuously monitor temperature levels, allowing the microcontroller to take proactive measures when necessary. When the temperature exceeds a predefined threshold, typically set around 25 degrees Celsius, the microcontroller initiates action to mitigate overheating. It compares the measured temperature to the reference threshold and, upon detection of a temperature rise, sends an output pulse to activate the fans.

This prompts the fans to draw in ambient air and expel heated air from the system, facilitating cooling and temperature regulation. Conversely, when the temperature drops below the reference threshold, the microcontroller signals the fans to deactivate, conserving energy and reducing wear and tear on fan components. This dynamic control of fan operation based on real-time temperature feedback optimizes system performance and efficiency. By ensuring that critical components operate within their specified temperature ranges, the DSPIC30F2010 controlled hybrid inverter system enhances reliability, prolongs component lifespan, and maintains overall system integrity.

3.1.7 INDUCTOR BLOCK

The Inductor Block accommodates the "BUCK CONVERTER," with the inductor being a key component. Specifically, the inductor employed in this project is a "TOROID INDUCTOR" having a “FERRITE CORE”. Functionally, an inductor stores electric current and releases it when saturated. It is this property that the buck converter leverages to enhance system efficiency.

3.1.7.1 BUCK CONVERTER UNIT

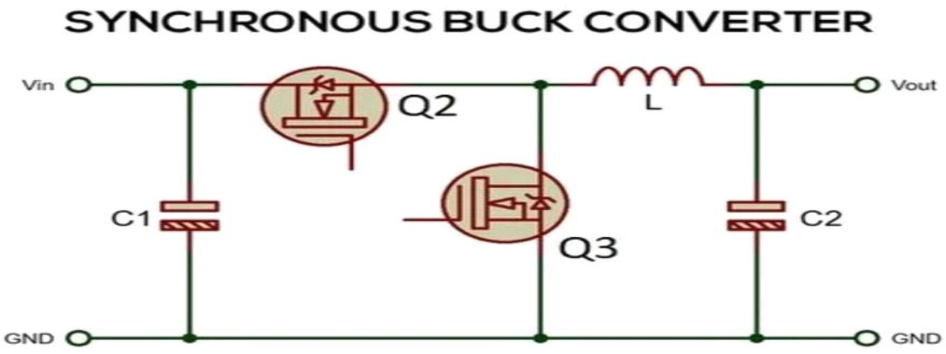

Figure 3.15: A BASIC BUCK CONVERTER CIRCUITRY

Buck converters serve as regulators that transform a higher voltage input into a lower voltage output. Unlike linear regulators such as the well-known 7805 IC, buck regulators do not dissipate excess voltage and current as heat for regulation. Whether operating as a Buck, Boost, or Buck-Boost, these regulators prioritize power conservation. Furthermore, a buck regulator exhibits a current amplification effect: as voltage decreases at the output, the current it can provide surpasses that of the input.

Operating as a form of switching regulator, a buck converter employs a PWM signal, transistors, capacitors, an inductor, and feedback to regulate voltage and current. In this project, a synchronous buck converter is utilized. It is achieved by replacing the diode of an Asynchronous Buck converter with a MOSFET, which significantly reduces voltage drop.

Additionally, as shown in figure above MOSFETs Q2 and Q3 cannot be simultaneously open or closed; their switching must be controlled by the microcontroller. When current flows through the circuit, transistor Q2 closes while Q3 opens. During this phase, the inductor stores some current while allowing a portion to flow to the battery. As the inductor becomes saturated, the microcontroller signals Q2 to open and Q3 to close. Consequently, the inductor discharges the stored current, allowing more current to flow to the battery.

3.1.7.1 CONTINUOUS MODE

As previously discussed, the inductor allows for continuous flow of current. Upon turning on the MOSFET Q2, the input voltage provides current to the inductor. Over time, as the supply increases, the inductor's current rises, resulting in the appearance of Vs at the output. At this juncture, MOSFET Q3 is switched off, indicating the operation of the buck converter in continuous mode.

$V_L - V_{in} - V_o = 0$ ....(3.7)

$V_L = V_{in} - V_o$ ....(3.8)

Also recall,

Inductor Voltage, $V_L = L$..........(3.9)

Substituting (iii) in (ii)

$V_{in} - V_o = L$..........(3.10)

=

=)dt

=dt

$I = t + C$……(3.11)

Substituting Initial condition, $I = 0$ and $t = 0$ in (xi)

$C = 0$

Hence;

$I = t$ …….(3.12)

DISCONTINUOUS MODE

As explained earlier, the inductor Discharges. Upon turning off the MOSFET Q2, and MOSFET Q3 is switched on, indicating the operation of the buck converter in discontinuous mode.

In this scenario, the inductor discharges, causing its polarity to reverse from that of the continuous mode.

$V_L + V_o = 0$……….(3.13)

$V_L = -V_o$…………….(3.14)

From (iii)

Inductor Voltage, $V_L = L$

Substituting (iii) in (viii)

$-V_o = L$…….(3.15)

$=$

$=$)dt

$=$dt

$I = t + C$ …….(3.16)

Initial condition, I = 0 and t = 0:

C = 0

Hence;

I = t …….(3.17)

3.1.7.2 SELECTION OF INDUCTOR VALUE

In selecting the inductor, the following were taken into account;

Solar panel voltage = 150V/1800W

Battery Voltage = 30V

Input voltage (V_{in}) = 150 V

Output Voltage (V_{out}) = 30 V

Output Current (I_{out}) = =60A

Switching Frequency (F_{sw}) = 78,120Hz

dI = Ripple current

L = ...(3.18)

For a well-designed system, the typical range for ripple current is between 30% to 40% of the load current.

Let

dI =35% of I_{out}

dI = 0.35 x 60 =21A

L = 14.96μH

3.1.7.3 CALCULATION FOR NUMBER OF TURNS OF THE INDUCTOR

The number of turns of the inductor can be calculated by using

........(3.19)

N = Number of turns =?

L = inductance = 14.96μH

Also, from the data sheet, with core use CS508125, the following values were gotten;

A = Area = 1.25

= Permeability = 125

l = Mean length = 12.73*cm*

N = 312 turns

3.1.7.4 SELECTION OF CAPACITOR VALUE

...............(3.20)

dV = ripple voltage

Let voltage ripple (dV) = 7.15Mv

3.1.8 MICROCONTROLLER BLOCK

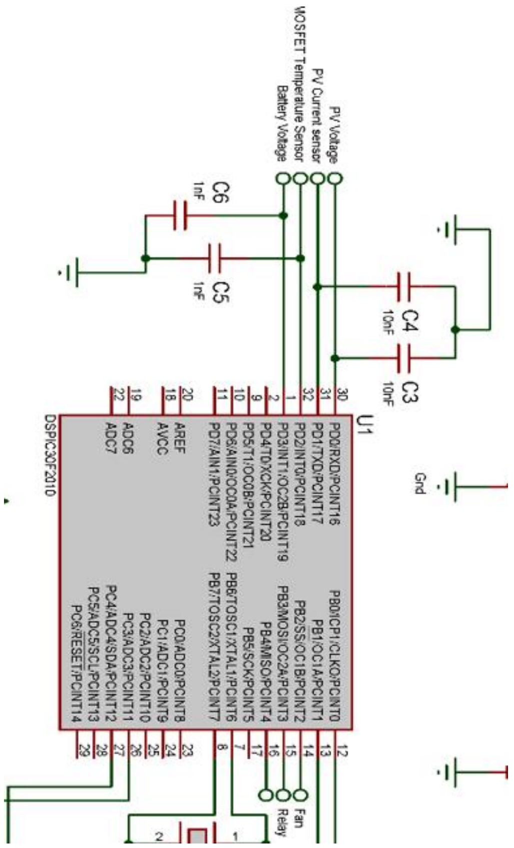

Figure 3.16: CIRCUIT DIAGRAM OF THE DSPIC30F2010

For our project, we selected the dsPIC30F2010 microcontroller from Microchip Technology's dsPIC30F series. This decision stems from its unique blend of capabilities, combining the functionalities of a digital signal processor (DSP) with those of a conventional microcontroller, specifically engineered for demanding digital signal processing and control tasks. Operating at clock speeds of up to 30 MIPS, this microcontroller features a robust architecture, boasting Flash Program Memory of up to 24 KB, RAM of up to 1.5 KB, and EEPROM Data Memory of up to 256 bytes. These attributes facilitate efficient program storage, data manipulation, and non-volatile data retention.

Furthermore, the dsPIC30F2010 encompasses an extensive suite of integrated peripherals, including analog-to-digital converters (ADCs), pulse-width modulation (PWM) modules, timers, UART, SPI, I2C, and comparators. This comprehensive set of peripherals enables seamless interfacing with external sensors, communication modules, and actuators, thereby enhancing the microcontroller's versatility.

Functioning as the central processing unit of our circuitry, the dsPIC30F2010 facilitates proper communication between the inverter circuitry and the charger controller circuitry. It receives inputs from various sensors, as outlined in section 3.1.1 of our project, executes specified operations based on its programmed code, and dispatches outputs to the MOSFET driver, fan, relay, and LCD display. These actions collectively ensure the optimal functioning of the system.

In the specific context of our project, focusing on the charge controller circuitry incorporating Maximum Power Point Tracking (MPPT), the dsPIC30F2010 proves highly effective. Leveraging its integrated ADCs for sampling voltage and current from solar panels, along with PWM outputs for regulating charging voltage and current, the microcontroller serves as the cornerstone of the charge controller algorithms. This ensures optimal power output, even amidst fluctuating environmental conditions. Additionally, its robust design and wide operating temperature range ensure reliability, particularly in the challenging environments commonly encountered in renewable energy applications.

3.1.8.1 FLOW CHART OF MICROCONTROLLER

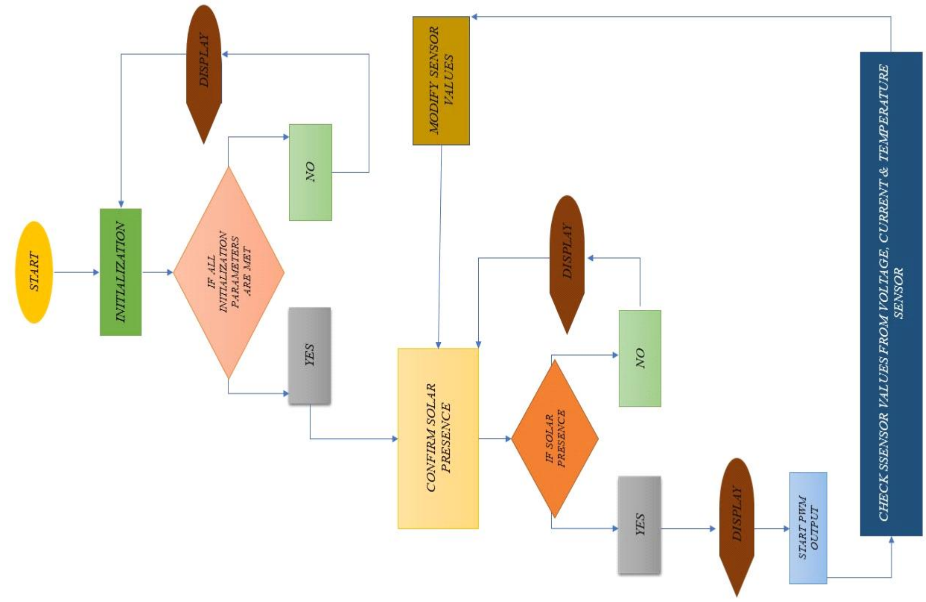

Figure 3.17: FLOW CHART OF MICROCONTROLLER OPERATION

- **OVERALL CIRCUIT DIAGRAM**

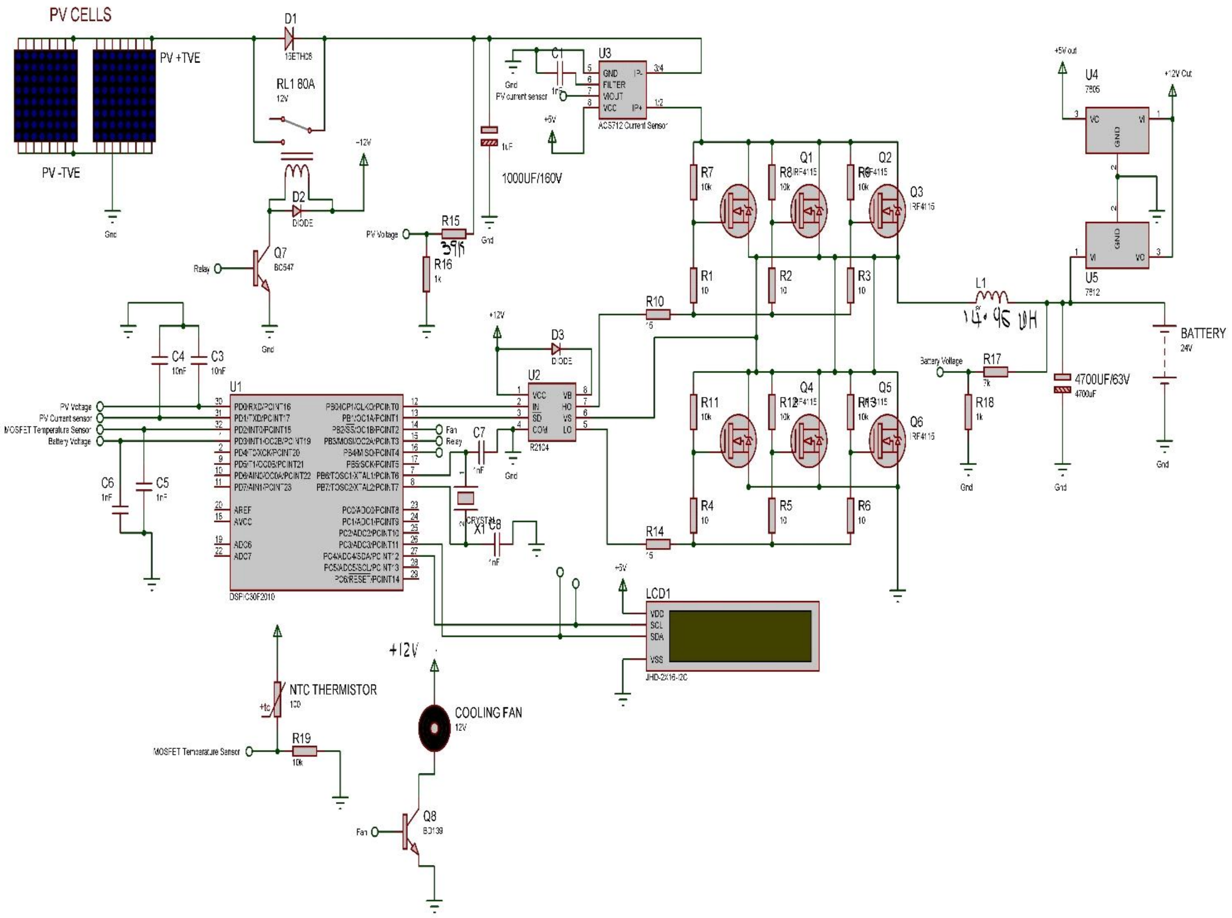

Figure 3.18: OVERALL CIRCUIT DIAGRAM

- **PRINCIPLE OF OPERATION**

The operational principle of the depicted circuit diagram unfolds as follows: the microcontroller employs the voltage sensor to detect the voltage along the PV line, subsequently comparing it with the voltage sensed by the battery voltage sensor to determine its course of action.

Now, let's examine two scenarios:

CASE 1: Sunlight Present

In the presence of sunlight, voltage exists in the line without current. The voltage sensor along the PV line transmits a voltage value to the microcontroller. Given sunlight, the voltage from the sensor surpasses that of the battery sensor. The microcontroller, confirming the presence of sunlight, signals the relay to close the switch. It also emits pulses at a switching frequency of 78.12KHz to the MOSFET driver, powered by the 12V side of the voltage regulator. The MOSFET driver amplifies these pulses and directs them to the 3 transistors in parallel (Q1, Q2, Q3). Connected to the gate of each transistor are current limiting resistors (R1, R2, R3) rated at 10KΩ each, which regulate the current flow. Notably, the microcontroller sends voltage pulses corresponding to 5V for High and 0V for Low. A High input activates the circuit connected to the "HO" (High Output) pin while deactivating the circuit linked to the "LO" (Low Output) pin, ensuring the transistors do not close simultaneously. Once closed, current flows from the PV side to the inductor, charging the battery by storing the bulk of the current. Discharge resistors (R7, R8, R9) between the drain and gate of the transistors discharge any capacitive voltage post-operation to prevent circuit damage.

CASE 2: No Sunlight

Similarly, the microcontroller compares voltage values from the voltage sensor and the battery voltage sensor. If the voltage is lower than that of the battery, the microcontroller remains inert, and the circuit refrains from charging the battery.

CHAPTER FOUR

DESIGN IMPLEMENTATION, TESTING AND RESULTS

The execution of this design offers a glimpse into the external aesthetics of the device, the stages involved in its physical design, and the materials employed for both internal and external components during implementation.

4.1 OUTWARD APPEARANCE AND DIMENSIONS OF LOCAL DESIGN PACKAGE

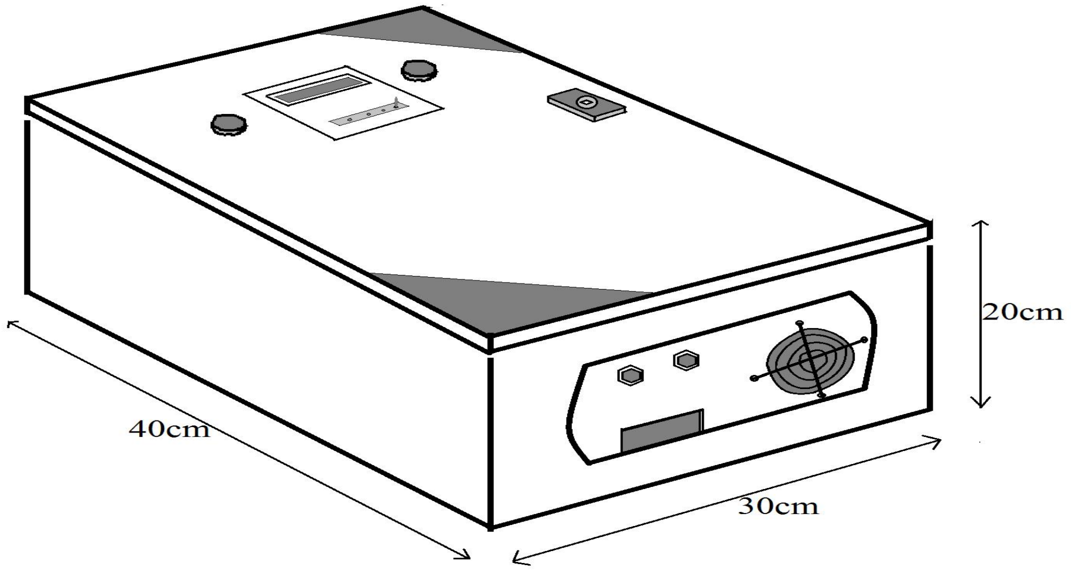

Figure 4.1: OUTWARD APPEARANCE OF LOCALLY ASSEMBLED INVERTER SYSTEM

The illustrated design and package dimensions of the locally assembled Hybridized inverter system are depicted in Figure 4.1 above.

4.2 MATERIALS USED IN LOCAL INVERTER ASSEMBLY

The system is enclosed in a metal box crafted from iron, providing sturdy protection. To prevent interference, medium density fiber (MDF) plywood serves as a base, separating the internal circuits from the metal casing. Also, materials such as polyvinyl chloride (PVC) plastics and aluminum are used in this package's assembly, contributing to its durability and functionality.

4.3 CONSTRUCTION OF LOCAL INVERTER

The development process for this pure sine wave inverter system involved the following steps:

1. Acquisition of Materials and Components: Procuring all necessary materials and electronic components required for the project.

2. Organizing Tools: Sorting and organizing tools needed for the assembly and construction process.

3. PCB Etching and Masking: Etching and masking the printed circuit board (PCB) to create the necessary circuitry layout for the inverter system.

4. Soldering and Connection: Soldering and connecting electronic components and modules together as per the designed system configuration.

5. Packaging: Packaging the assembled components and modules into a final enclosure or housing, ensuring proper protection and presentation of the inverter system.

4.3.1 ACQUISITION OF COMPONENTS FOR LOCAL INVERETER

We obtained various components for the project from different sources. Some were purchased from AliExpress, an online international marketplace. Others were sourced from Hub360 electronics shop via their website (www.hub360.com.ng), and a few were acquired from the New Benin Market located in Benin City, Edo State, Nigeria.

Some of the materials include:

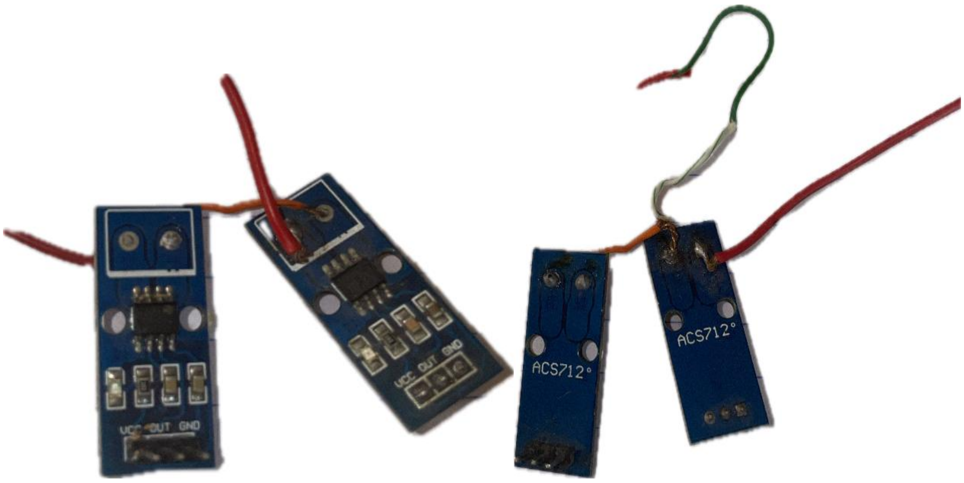

Figure 4.2: CURRENT SENSOR

Figure 4.3: PICTURE OF RELAY

4.3.2 SORTING OF TOOLS

When the appropriate tools are not at hand, completing certain tasks becomes challenging or even impossible, as tools play a crucial role in facilitating efficiency and speed. In the implementation and testing phases of the Hybridized DSPIC30F2010 pure sine wave inverter project, a variety of tools were utilized to ensure smooth progress and accurate assessment. The tools employed include:

1. Pliers

2. Screwdriver

3. Cutter

4. Soldering iron

5. Digital Multimeter

6. Cutting knife

7. Hammers

8. Digital Oscilloscope

9. Adjustable Spanner

10. Measuring Tapes

11. Electric Tapes

Each tool served a specific purpose, ranging from soldering components together to measuring electrical parameters and ensuring precise assembly. Through the effective use of these tools, the implementation and testing phases were conducted efficiently, contributing to the successful development and evaluation of the locally assembled Hybridized DSPIC30F2010 pure sine wave inverter.

Figure 4.4: TOOLS UTILIZED DURING IMPLEMENTATION

4.3.3 Printed Circuit Board Etching and Masking

The PCB design is created using ARES (Advanced Routing and Editing Software), which is part of the Proteus Design Suite. ARES offers a comprehensive set of tools for net-list based PCB design, including high-performance design automation features. Some key features of ARES Professional include:

- A 32-bit high-precision database providing linear resolution of 10nm, angular resolution of 0.1°, and support for a maximum board size of +/- 10m. ARES supports up to 16 copper layers, two silk screens, four mechanical layers, and solder resist and paste mask layers.
- Hardware-accelerated display utilizing Direct 2D or OpenGL, leveraging the power of your graphics hardware to enhance speed and provide true layer transparency.
- State-of-the-art ergonomic user interfaces featuring modeless selection, selection and activity indicators, and localized functionality accessible via context menus.

- Live netlist and shared database binding with the ISIS schematic capture module, facilitating seamless integration of schematic and PCB design, including the ability to specify routing information directly on the schematic.

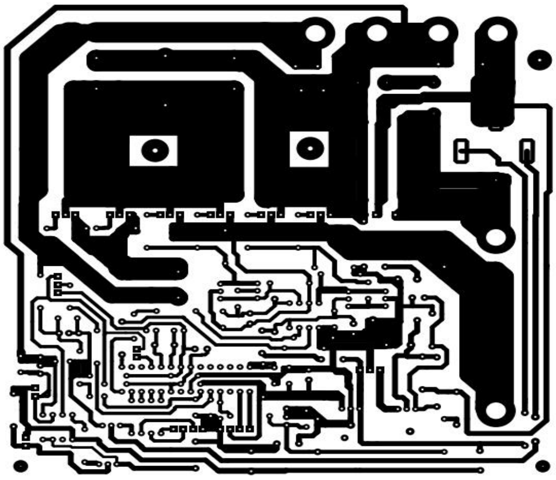

Figure 4.5: PCB OF THE MPPT BOTTOM VIEW

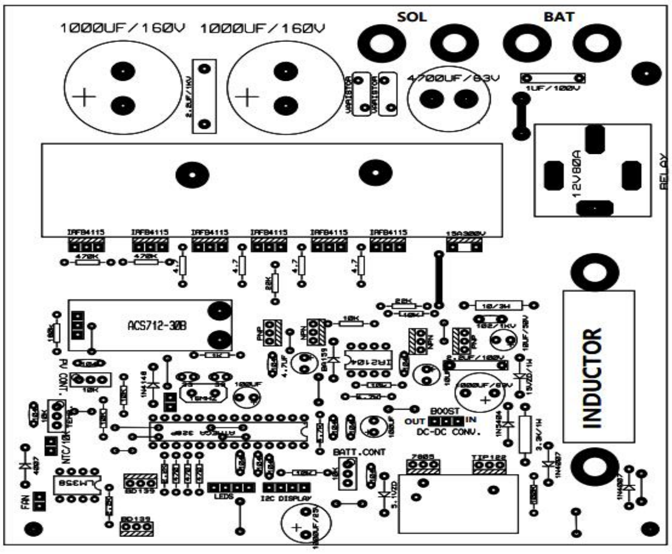

Figure 4.6: PCB OF THE MPPT TOP VIEW

4.3.4 SOLDERING AND BUILD UP

Soldering serves as the method for creating enduring connections between electronic components. Utilizing a Vero circuit board, the electronic components are soldered in accordance with the circuit schematics.

Figure 4.7: CHARGE CONTROLLER BOARD (MPPT)

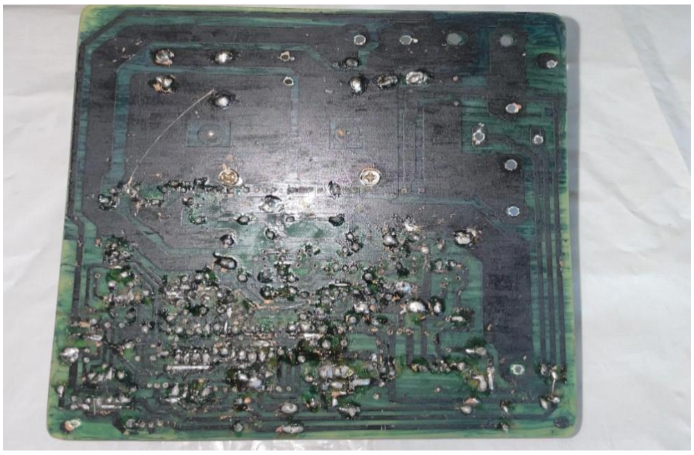

Figure 4.8: SOLDER WORK DONE ON THE CHARGE CONTROLLER BOARD

4.3.5 PACKAGING

All the packaging of this device is shown below:

Figure 4.9: PACKAGING AND ASSEMBLY OF COMPONENTS

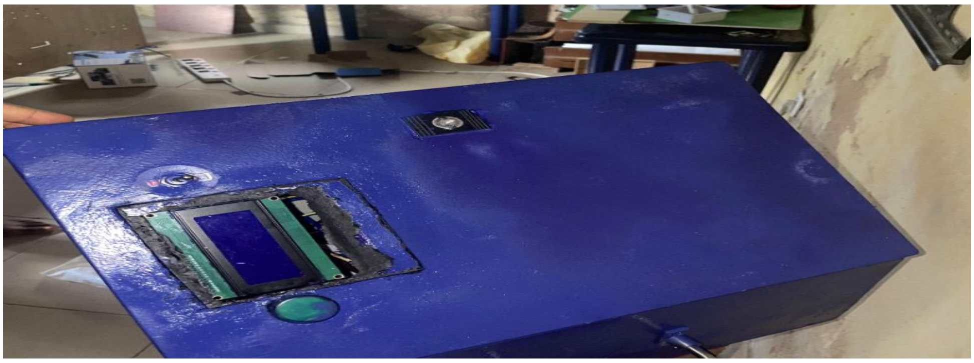

Figure 4.10: PACKAGING SHOWING SIDE VIEW

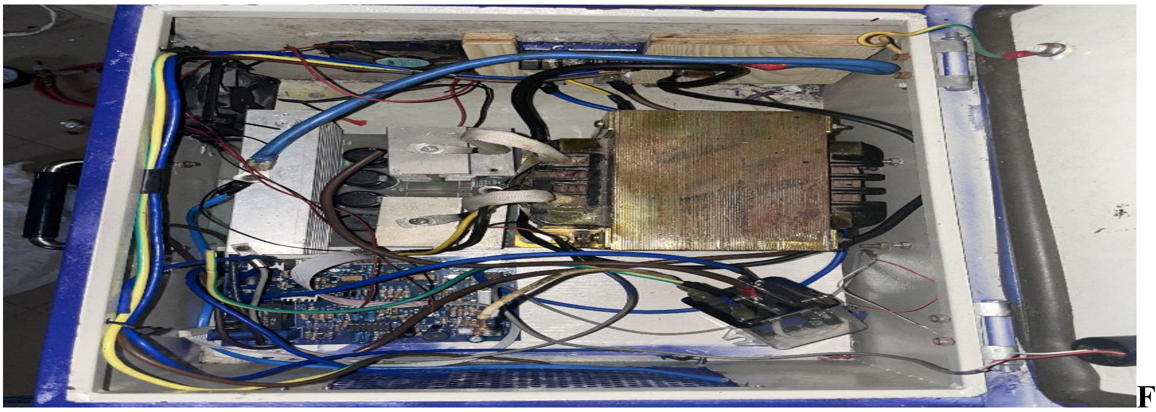

Figure 4.11: PACKAGING SHOWING INTERNAL COMPONENTS

4.4 OUTWARD APPEARANCE OF A FOREIGN (BREAD) HYBRID INVERTER

Figure 4.12: OUTWARD APPEARANCE OF FOREIGN INVERTER SYSTEM

4.5 TEST AND RESULT ANALYSIS

The following tests will be carried out on both the locally assembled and foreign inverter systems.

- Output Voltage and Frequency test
- Load and Overload test
- Sinusoidal Output test
- Power Efficiency test

4.5.1. OUTPUT VOLTAGE AND FREQUENCY TEST

This examination is carried out using a digital multimeter in a straightforward manner. To measure voltage, switch the multimeter to the AC voltmeter setting and place the meter's probes on the inverter's output connectors. The multimeter's display will then show the AC voltage reading. For the locally assembled inverter, the test results consistently showed an AC voltage of 219.8V. While for the foreign inverter, the test results consistently showed an output voltage of 230V AC.

Figure 4.13: OUTPUT VOLTAGE TEST FOR LOCAL INVERTER

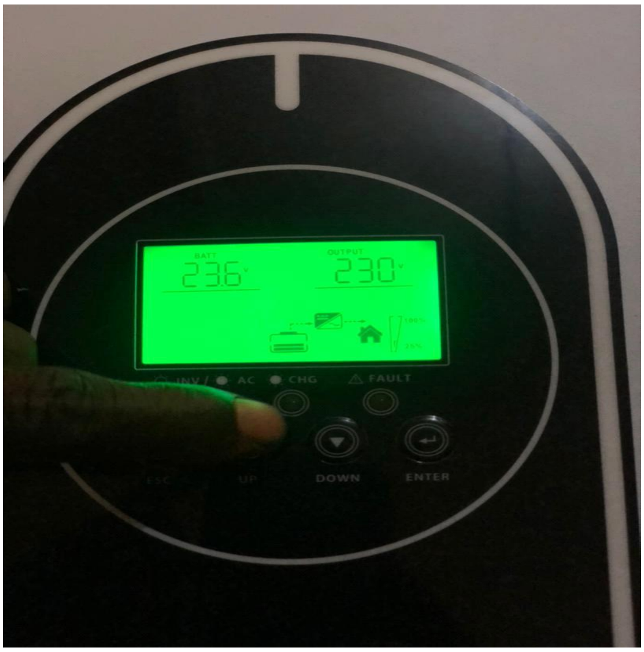

Figure 4.14: OUTPUT VOLTAGE TEST FOR FOREIGN INVERTER

For frequency measurement, switch the multimeter to the frequency measurement setting and once again position the probes on the inverter's output connectors. The display will indicate the frequency of the AC voltage. In this test, a steady frequency reading of 50.04Hz was observed for the locally assembled inverter. For the foreign inverter, a frequency reading of 50.0Hz was observed.

Figure 4.15: FREQUENCY OF OUTPUT VOLTAGE FOR LOCAL INVERTER

Figure 4.16: FREQUENCY OF OUTPUT VOLTAGE FOR LOCAL INVERTER

4.5.2 LOAD AND OVERLOAD TEST.

This assessment aims to determine the capability of the Hybridized inverter systems to meet the power requirements of the household without triggering its overload safety feature. The procedure entails gradually increasing the load on the Hybridized inverter from zero to its maximum capacity while monitoring for any indications of overload. The findings of this evaluation are summarized in the table below.

Table 4.1 Load and Overload Test

S/N	Description of Load	Overload Indication
1	No Load	No
2	Lights Only	No
3	Lights, TV, Laptop, Fans and Phones	No
4	Lights, TV, Laptop, Fans, Phones and Refrigerator	No

4.5.3 SINUSOIDAL OUTPUT TEST

As seen in the digital Oscilloscope outputs below the hybridized inverters supplied similar sinusoidal output voltage and current.

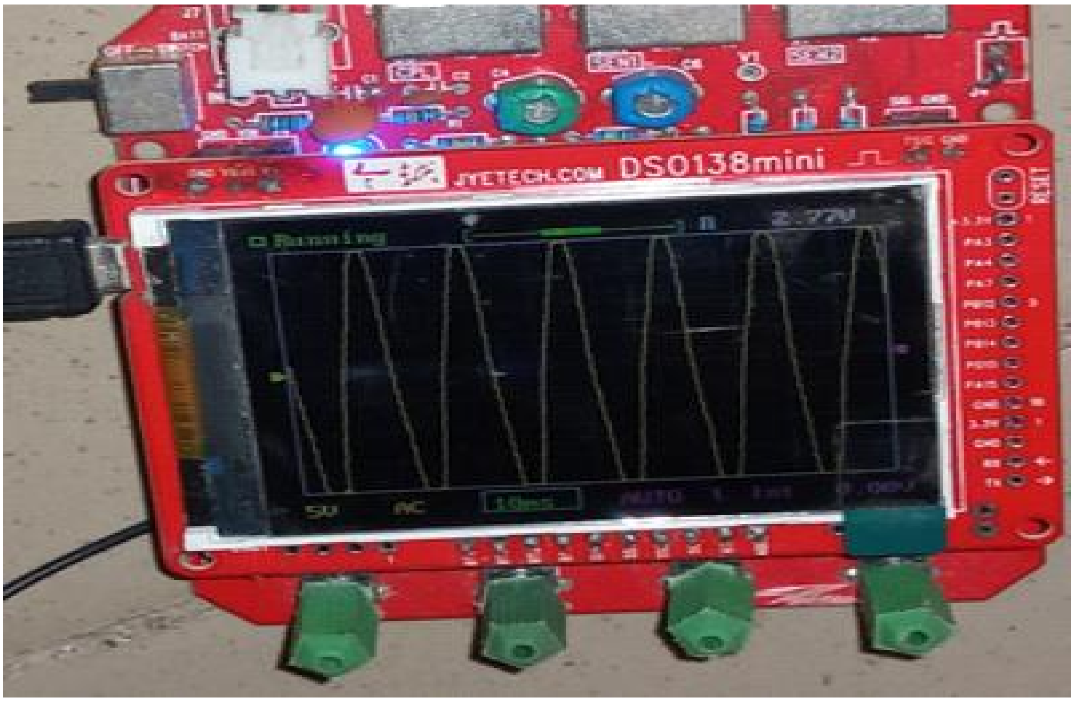

Figure 4.17: SINUSOIDAL OUTPUT TEST LOCAL INVERTER

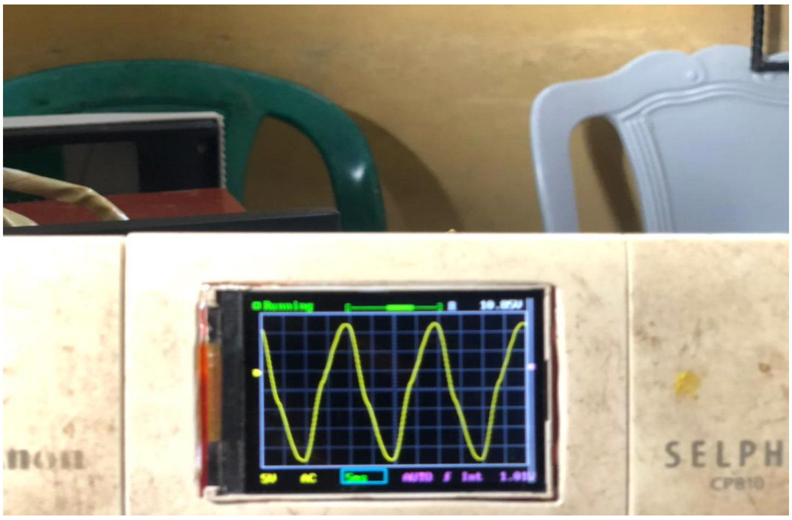

Figure 4.18: SINUSOIDAL OUTPUT TEST FOREIGN INVERTER

4.5.4 POWER EFFICIENCY TEST

This assessment's objective is to evaluate the energy efficiency of the Hybridized inverter system. This is achieved by utilizing a clamp meter to monitor both the input current drawn from the battery and the output current supplied to the household when the Hybridized inverter is operating at its maximum capacity. Furthermore, measurements of the battery voltage and the AC output voltage are taken into account. The efficiency percentage of the inverter is then calculated using a specific formula based on these measurements. As shown below:

Power Efficiency = Output Power/ Input Power ....(4.1)

Output Power in VA = Output Voltage x Output Current..........(4.2)

Assuming a Power factor of 0.8,

Output Power = Output Voltage x Outout Current..........(4.3)

Input Power = Input Voltage x input Current...........(4.4)

The table below show the voltage and current readings entering and leaving the local and foreign inverter systems respectively. While operating on full load, a clamp meter is used to extract these readings.

Table 4.2 Power Ratings for locally Assembled Inverter

	Voltage (V)	Current(A)	Power (W)
Input	24.5	81.63	1989.9
Output	220V	8.63	1803.7

Table 4.3 Power Ratings for Foreign Inverter

	Voltage (V)	Current(A)	Power (W)
Input	23.6	2.331	55
Output	230	0.226	52

4.4 BILL OF ENGINEERING (BOM)

Item	**Amount**	**Unit**	**Price-per unit(N)**	**Total Cost(N)**
Inductor Coil	1	Piece	10000	10000
Ferrite Core	1	Piece	4000	4000
ATmega328P Microcontroller	1	Piece	8000	8000
Darlington Pair Transistor IC	2	Pieces	800	1600
IC Sockets	5	Pieces	500	2500
20 x 4 LCD Screen	1	Pieces	5000	5000
I2C LCD module	1	Piece	2500	2500
Power Diodes	4	Pieces	350	1400
PCB Board	1	Piece	2000	2000
Terminal Blocks and Connectors	10	Pieces	300	3000
MOSFETS	10	Piece	500	5000
Buzzer	1	Piece	500	500
Transistors	20	Pieces	50	1000

Push Buttons	10	Pieces	20	200
LEDs	5	Bulbs	20	100
Cables, wires and jumpers	10	Yards, pieces	200	2000
Diodes	8	Pieces	100	800
Capacitors.	10	Pieces	10	100
Soldering lead	10	Yards	150	1500
Resistors	20	Pieces	20	400
Potentiometer	2	Pieces	50	100
Bolt and Screws	5	Pieces	50	250
Total Cost of Materials	-	-	-	**51,950**
Shipping fee for materials	-	-	-	10000
Total Cost of Local Design	-	-	-	**87,450**
Cost of Foreign Inverter	1			**290, 000**

CHAPTER FIVE

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

5.1 CONCLUSION

This project aimed carry out a comparative evaluation between foreign and locally assembled hybrid 3.5KVA inverter systems. To achieve the aim of this project, first a detailed design of a Hybridized DSPIC30F2010 Controlled Inverter System was carried out. Secondly, the performance of this local inverter was evaluated based on output voltage and frequency, load and no load test, sinusoidal output test and power efficiency. Thirdly, a foreign 3.5KVA inverter was subjected to the same performance testing as the locally assembled inverter. Finally, a comparative evaluation of the performances of both inverter systems was carried out. Results showed that the performance of the local inverter was comparable with that of the foreign inverter. Furthermore, the locally assembled inverter cost far less than the foreign inverter.

Throughout the project, our team learned a lot about electrical and electronics engineering, especially about power electronic devices. We used both basic and advanced engineering principles and equations to solve problems we encountered. Despite some initial challenges, our hard work paid off with successful design and testing, showing that our system meets its goals and works well in real-life situations.

5.2 LIMITATIONS

The locally assembled Hybrid DSPIC30F2010 Controlled Inverter System had several limitations such as:

1. Lack of Remote Monitoring Support: One significant limitation is the absence of user convenience due to the lack of support for remote monitoring. Without remote monitoring capabilities, users are unable to access real-time information about the system's performance, which could hinder their ability to troubleshoot issues or optimize system operation remotely.

2. Absence of Fault Detection Techniques: Another limitation is the lack of fault detection techniques within the system. Without robust fault detection mechanisms, the system may struggle to identify and address potential faults or malfunctions promptly, increasing the risk of system downtime or damage to components.

3. Limited Energy Storage Capacity: The battery storage capacity of the hybrid inverter system may be limited by factors such as cost constraints or physical space limitations. This restricts the system's ability to store excess solar energy during periods of high solar irradiance, potentially impacting its ability to provide consistent power output during periods of low solar input.

5.3 RECOMMENDATIONS

To address the identified limitations mentioned above, the following recommendations are proposed:

1. Implement Remote Monitoring System: Integrate a remote monitoring system into the design to enable users to access real-time data and monitor the system's performance remotely. This can be achieved by incorporating wireless communication modules, such as Wi-Fi or GSM/GPRS, and developing a user-friendly interface for remote access.

2. Incorporate Fault Detection Techniques: Develop and implement fault detection techniques within the system, such as sensor-based monitoring and diagnostic algorithms. This can help identify and diagnose potential faults or malfunctions proactively, allowing for timely intervention and system maintenance.

3. Expand Energy Storage Capacity: Explore options to increase the energy storage capacity of the system, such as utilizing higher-capacity batteries or incorporating modular battery banks. Consider optimizing battery management algorithms to maximize energy storage efficiency and extend battery lifespan.

By implementing these recommendations, the limitations of the project can be effectively addressed, resulting in a more robust, reliable, and user-friendly hybrid inverter system that meets the needs of diverse applications and environments.

REFERENCES

“Introduction to dsPIC30F2010 microcontroller.” Available at: HYPERLINK "about:blank"" HYPERLINK "about:blank"https://microcontrollerslab.com/dspic30f2010-microcontroller/ HYPERLINK "about:blank"" HYPERLINK "about:blank" dsPIC30F2010 MICROCONTROLLER

Dwivedi, A. and Pahariya, Y. (2021). “Design and analysis of hybrid multilevel inverter for asymmetrical input voltages.” Journal of Electrical Engineering and Technology, Volume 16.

Electronics Project Focus. “Ferrite Core Inductor: Working, Types, Calculations, Losses and its Application.”

Evans, P. (2023) “What is an Inverter?” Available at: www.theEngineeringMindset.com/What is an Inverter? - [Accessed 14 April 2024]

Laguado, M. A., Paipa, E. A., Sepulveda, S. and Marquez, L.F. (2019) “Performance comparison between PWM and MPPT charge controllers.” Technical University of Pereira. Volume 24, ISSN: 2344-7214.

Meshram, P. and Mujumdar, U. B. (2013). “Design and Development of MPPT based converter for efficient Solar Power Conversion.” International Journal of Applied Information Systems (IJAIS). ISSN: 2249-0868.

Milenov, V. and Zahari, Z. (2023). “Application of Hybrid Inverters in Photovoltaic systems.” 2023 18th Conference on Electrical Machines, Drives and Power Systems (ELMA).

Nasir, A., Gul, N., Ahmad, R. and Raza, S. S. (2023). "Implementation and Fabrication of Hybrid solar inverter." Journal of Artificial Intelligence and Computing (JAIC). Volume 1, ISSN: 3005-3358. Available at: Implementation and Fabrication of Hybrid Solar Inverter (researchgate.net)

Nwaogu, C. C. and Inyama, K. (2023). "Hybrid Inverter using Pulse Width Modulation." Engineering Research Journal. Volume 03, ISSN: 2782-8212. Available at: www.ijaar.org

Power Stage design details of a 3kva pure wave inverter. World Journal of Innovation and modern Technology, E-issn 2756-5491. Vol 9. no. 6

Putra, A. S., Afianti, H. and Watiasih, R. (2022) "Comparative Analysis of Solar Charge Controller Performance Between MPPT and PWM on Solar Panels." Journal of Electrical Engineering and Computer Sciences. Volume 07, P-ISSN: 2528-0260; E-ISSN: 2579-5392.

Rafay, A. (2018). "Smart Hybrid Inverter." HITEC University Taxila Cantt, Pakistan.

Robles, C., Olivero-Ortiz, C. and Leal, D. A. (2022) "Techno-Economic Analysis of MPPT and PWM Controllers performance in Off-Grid PV Systems. International Journal of Energy Economics and Policy. ISSN: 2146-4553.

Shinde, P., Surjuse, G., Girhe, M., Yende, S., Pothi, P. and Polke, A (2023). "Solar based hybrid Solar Inverter." International Research Journal of Modernization in Engineering Technology and Science. Volume 05, ISSN: 2582-5208. Available at: fin_irjmets1673673619.pdf

Tekade, V. T., Kude, M. R., Deore, B. D. and Ahire, P. V. (2017). “Design and Development of Solar panel inverter using MPPT.” International Research Journal of Engineering and Technology. Volume 04, ISSN: 2395-0056.

Thukral, R. and Kumar, G. (2016) “Microcontroller based Solar Power Inverter.” International Journal of Electrical Engineering Technology. Volume 07, ISSN Print: 0976-6545, ISSN Online: 0976-6553.

Tiwari, O., Goyal, H., Sharma, S., Banerjee, S. and Kashyap, A. (2022). “Power inverters for solar panels.” Journal of Information and Optimization Sciences. Volume 43, ISSN: 0252-2667.

Valunjkar, S. S., Joshi, S. D. and Kulkarni, N. R. (2014) “Implementation of Maximum Power Point Tracking Charge Controller for Renewable Energy.” 2014 International Conference of Advanced Communication, Control and Computing Technologies.

Yunisa, Y., Zhimwang, J. T., Aminu, I., Shaka, O.S. and Frank, L. M. (2022). “Design and Construction of 5KVA Solar Power Inverter System.” International Journal of Advances in Engineering and Management (IJAEM). Volume 04, ISSN: 2395-5252. Available at: www.ijaem.net.