

Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion

A project report is Submitted in Partial fulfillment of the requirement for the award of the Degree of Bachelor of Science in Electrical and Electronic Engineering.

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i

DECLARATION

I/We hereby declare that this project “Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion” represents my/our own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants. Signature of the candidates

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APPROVAL

The project entitled “**Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion**” submitted by Mahammad Kamruzzaman (ID: 213-33-1479), Shameem Ahmed (ID: 213-33-1483) & Md.Zubayer Alam (ID: 213-33-1476) has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in September, 2025.

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We must extend our deepest love and gratitude to our beloved family for their extraordinary strength as well as for their inspiration and support throughout our reflections in this institution.

ABSTRACT

This project focuses on the Design and Implementation of an Off-Grid SolarPhotovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion. The primary objective is to convert a 12V DC power source into AC output suitable for powering low-power AC loads. The system incorporates an H-bridge inverter circuit using four IRF540 MOSFETs, which are controlled by square wave signals generated by the Arduino. A 12V battery serves as the DC power source, and a step-up transformer is used to convert the low-voltage AC output of the H-bridge into high voltage AC.

To demonstrate the functionality of the system, a resistive load and a lamp are used as the output devices. The Arduino is programmed to generate square wave signals with a frequency of 50Hz, ensuring compatibility with standard AC appliances. Dead-time delay is incorporated into the switching logic to prevent short circuits in the H-bridge configuration. The project emphasizes cost-effectiveness, simplicity, and ease of implementation, making it suitable for small-scale applications such as emergency lighting systems, basic household appliances, or rural electrification.

The proposed inverter system is tested for efficiency, load handling, and output waveform characteristics. While the square wave output is less ideal than sine wave inverters due to higher harmonic distortion, it provides a practical solution for low-cost and low-power applications. This project serves as a foundation for further advancements in inverter design and demonstrates the potential of Arduino-based systems in power electronics.

CONTENTS

<u>DECLARATION</u>	<u>ii</u>
<u>APPROVAL</u>	<u>iii</u>
<u>ACKNOWLEDGEMENT</u>	<u>iv</u>
<u>ABSTRACT.....</u>	<u>v</u>
<u>CONTENTS.....</u>	<u>vi</u>
<u>FIGURES</u>	<u>ix</u>
<u>CHAPTER 1</u>	<u>1</u>
INTRODUCTION.....	1
INTRODUCTION	1
PROBLEM STATEMENT	3
OBJECTIVES	3
ORGANIZATION OF BOOK	4
<u>CHAPTER 2</u>	<u>5</u>
LITERATURE REVIEW.....	5
INTRODUCTION	5
RELATED RESEARCH.....	6
<u>CHAPTER 3</u>	<u>7</u>
RESEARCH METHODOLOGY	7

INTRODUCTION	7
HARDWARE SETUP	7
HARDWARE ELEMENTS.....	7
ARDUINO NANO.....	8
PIN CONFIGURATIONS	9
APPLICATIONS OF ARDUINO NANO.....	11
IRF 540.....	13
APPLICATIONS OF IRF540	14
DISADVANTAGES OF IRF540.....	14
TRANSFORMER.....	15
VOLTAGE REGULATOR.....	20
APPLICATIONS OF IC 7805.....	21
ADVANTAGES OF IC 7805.....	22
DISADVANTAGES OF IC 7805	22
RESISTOR.....	22
APPLICATIONS OF RESISTORS	24
BATTERY	25
LED.....	26
SOLAR PANEL.....	28
APPLICATIONS OF SOLAR PANELS	29
DIODE	31
LAMP	34
BLOCK DIAGRAM OF THIS PROJECT.....	36
CIRCUIT DIAGRAM.....	38
PROJECT HARDWARE IMAGE.....	40
WORKING PRINCIPLE	41
CHAPTER 4	43
RESULTS AND DISCUSSION.....	43
INTRODUCTION	43

OUTPUT WAVEFORM	44
.....	45
.....	45
DISCUSSION	46
<u>CHAPTER 5</u>	<u>47</u>
PROJECT COST	47
<u>CHAPTER 6</u>	<u>49</u>
IMPACT ON FUTURE WORKS.....	49
CONCLUSION	50
CONCULSIONS.....	50
<u>References.....</u>	<u>51</u>

FIGURES

Figure 1: The Arduino nano [11].	8
Figure 2: The pinout configuration of Arduino nano [12].	9
Figure 3: Pin diagram of IRF 540 MOSFET [13].	13
Figure 4: The single-phase transformer [14].	15
Figure 5: The Arduino IDE home page [15].	18
Figure 6: The pin diagram of 7805 IC [16].	20
Figure 7: The resistor [17].	23
Figure 8: Rechargeable battery.	25
Figure 9: The LED.	26
Figure 10: The Solar panel.	28
Figure 11: The Symbol of a Diode.	31
Figure 12: Internal Parts of an Incandescent Bulb.	34
Figure 13: The block diagram of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.	36
Figure 14: The circuit diagram of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion..	38
Figure 15: The circuit diagram of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.	39
Figure 16: The hardware image of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.	40
Figure 17: The oscilloscope waveform of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.	44
Figure 18: The Proteus waveform of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.	45

CHAPTER 1

INTRODUCTION

INTRODUCTION

The demand for efficient, reliable, and affordable power conversion systems has been steadily increasing worldwide. This demand is driven by the rising adoption of renewable energy technologies, such as solar photovoltaic (PV) panels, wind turbines, and energy storage systems. Most of these renewable energy sources generate direct current (DC), which cannot be directly used by the majority of household appliances and industrial equipment. Since modern society is heavily dependent on alternating current (AC) power distribution, an intermediate power conversion stage is required. This conversion is achieved using inverters, which play a crucial role in ensuring compatibility between renewable energy sources and the existing AC power infrastructure. Inverters are electronic devices that convert DC power into AC power. They can be classified into different types based on their output waveform, such as square wave, modified sine wave, and pure sine wave inverters. Among these, square wave inverters represent the most basic and cost-effective design. Although they produce a waveform with higher harmonic distortion and electrical noise compared to sine wave inverters, they remain a practical solution for many low-power applications. Their simple design, low cost, and ease of construction make them widely used in small appliances and experimental setups. This project focuses on the design and implementation of a single-phase square wave inverter controlled by an Arduino microcontroller. The inverter is designed using a full H-bridge topology consisting of four IRF540 N-channel MOSFETs. The H-bridge allows the DC supply to be alternately reversed, thereby generating an AC square wave output. The Arduino Nano is programmed to provide switching signals with a precise timing interval that ensures the output frequency is maintained at 50 Hz, which is compatible with the AC mains standard in most countries, including Bangladesh. The power source for the inverter is a 12V DC battery, chosen for its availability and suitability for small-scale applications. The inverter output from the H-bridge is first generated at a low voltage level, which is then stepped up to 220V AC using a transformer. This enables the inverter to power small household loads such as lamps, fans, and resistive elements. The inclusion of a transformer also provides galvanic isolation, improving the safety and reliability of the system. A major emphasis of this project is on simplicity and cost-effectiveness. The system uses readily available components such as MOSFETs, transformers, and an Arduino Nano, making it highly accessible for students, hobbyists, and individuals in resource-constrained environments. By using a microcontroller for switching control, the

design achieves higher accuracy and flexibility compared to traditional oscillators or analog circuits. The Arduino allows easy modification of the switching frequency and duty cycle, offering scope for future upgrades such as Pulse Width Modulation (PWM)-based control. In addition to cost-effectiveness, the project prioritizes reliability and safety. Short-circuit protection and proper gate driving are considered to ensure the MOSFETs operate efficiently without overheating or failure. Since MOSFETs are voltage-controlled devices, they are well-suited for microcontroller-based switching applications and provide high efficiency in low-voltage power electronic systems. The applications of this square wave inverter are numerous. It can serve as an emergency backup power supply in areas with frequent power outages. It can be used for rural electrification projects, where low-cost energy solutions are crucial. It also provides a practical means to power small appliances during camping, outdoor activities, or in remote locations where grid electricity is not available. The inverter can also be used as a learning platform for students and researchers interested in the fundamentals of power electronics. From an academic perspective, this project introduces learners to important concepts such as:

- The working principle of an H-bridge inverter.
- The use of microcontrollers for timing and control.
- Transformer-based voltage stepping and isolation.
- Square wave generation and its harmonic implications.

While the square wave inverter has limitations in terms of harmonic distortion and efficiency, it provides a strong foundation for future improvements. The design can be upgraded to include PWM-based modified sine wave control, which reduces harmonics and improves load compatibility. Further, the inverter can be integrated with feedback systems to regulate output voltage and protect against overloads. Advanced versions may also incorporate features such as battery charging, automatic transfer switching, and smart monitoring via IoT platforms. This project not only demonstrates a practical implementation of inverter technology but also encourages innovation. By starting with a simple square wave inverter, learners gain confidence in handling power electronic components, microcontroller programming, and real-world testing. This knowledge can later be applied to more advanced inverter designs, including those used in solar home systems, uninterruptible power supplies (UPS), and grid-tied renewable energy systems. In conclusion, the Arduino-controlled single-phase square wave inverter presented in this project is an effective blend of simplicity, affordability, and functionality. It addresses the increasing demand for accessible power conversion solutions, especially in developing regions. The project not only highlights

the practical utility of inverters but also serves as a stepping stone for further exploration in power electronics and renewable energy systems. By bridging theoretical knowledge with hands-on implementation, it contributes to both academic learning and real-world problem solving in the field of electrical engineering.

PROBLEM STATEMENT

The growing reliance on renewable energy sources, such as solar panels and batteries, has highlighted the importance of efficient and affordable power conversion technologies. In many parts of the world, especially in rural and remote areas, access to a stable AC power supply is either limited or unavailable. This creates a pressing need for low-cost and easy-to-implement inverter systems that can convert DC energy into usable AC power for basic appliances and lighting.

The motivation for this project stems from the desire to address this energy gap by designing a simple and cost-effective single-phase inverter. While advanced sine wave inverters are widely available, their complexity and cost make them less accessible for small-scale and low-income applications. Square wave inverters, though less efficient in terms of harmonic performance, offer a practical and economical solution for powering low-power loads, making them ideal for applications such as emergency power backup, rural electrification, and portable power systems.

Arduino microcontrollers provide a powerful yet affordable platform for implementing control systems, offering precision and flexibility in generating switching signals for inverter circuits. The integration of an Arduino-based control system with an H-bridge inverter topology ensures not only reliability but also ease of understanding for students and enthusiasts looking to learn about power electronics.

This project is driven by the need to develop a solution that combines simplicity, affordability, and functionality. By exploring the implementation of a square wave inverter, this work contributes to the broader goal of providing accessible energy solutions to underserved communities while fostering innovation in the field of power electronics.

OBJECTIVES

The specific objectives of the project are as follows:

1. Design a single-phase square wave inverter using Arduino and an H-bridge circuit.
2. Convert DC voltage from a battery to AC voltage using a step-up transformer.
3. Generate a stable 50Hz square wave output for powering low-power AC loads.
4. Test and evaluate the inverter's performance with resistive loads and lamps.

5. Develop a low-cost, easy-to-build inverter suitable for small-scale applications.

ORGANIZATION OF BOOK

Chapter 1: Introduction- This Chapter is all about background study, motivation, objectives, and project book organization.

Chapter 2: Literature Review-This section briefly reviews previous research papers, and provides a summary of this chapter.

Chapter 3: Methodology-This section briefly discusses the project methodology, the working principle, the system overview, and the required instruments.

Chapter 4: Result and Discussion- This section briefly discusses the project discussion, results analysis, advantages, applications, and system overview.

Chapter 5: Conclusion- This chapter covers our project's future recommendations and conclusion.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

A single-phase square wave inverter is a fundamental power electronic circuit used for DC-AC conversion. The inverter is commonly implemented using metal-oxide-semiconductor field-effect transistors (MOSFETs) or insulated-gate bipolar transistors (IGBTs), depending on power rating and efficiency requirements. In this project, IRF540 MOSFETs are used as switching devices controlled by an Arduino Nano microcontroller, ensuring the required pulse-width modulation (PWM) signals for operation.

The primary function of an inverter is to convert a low-voltage DC supply, such as a 12V battery, into an AC voltage suitable for running AC loads. The simplest inverter topology is the square wave inverter, which switches the output between positive and negative cycles at a fixed frequency. Although square wave inverters are less efficient than pure sine wave inverters due to harmonic distortion, they are cost-effective and suitable for applications that do not require a high-quality AC waveform.

MOSFETs play a crucial role in inverter circuits due to their fast switching capability and low conduction losses. The IRF540 is a commonly used N-channel MOSFET with a low on-resistance and high current-handling capacity, making it suitable for power electronics applications. The Arduino Nano serves as the controller, generating the necessary gate drive signals for the MOSFETs. A step-up transformer is used to boost the 12V AC square wave output to the desired voltage level, such as 220V AC, depending on the winding ratio.

The operation of the inverter involves a full-bridge configuration where four MOSFETs operate in a push-pull manner, ensuring that two transistors conduct at a time while the other two remain off. This alternates the polarity of the output waveform, resulting in a square wave AC signal.

Several studies have examined the design and performance of square wave inverters. For instance, in the paper "Design and Implementation of an Arduino-Based Single-Phase Inverter" (Reference 1), the authors highlight the role of microcontroller-based control in achieving reliable and efficient inverter operation. Another study, "MOSFET-Based Power Inverter for Low-Cost Energy Conversion" (Reference 2),

discusses the advantages of using IRF540 MOSFETs in inverter design. Additionally, the paper "Transformer-Based Voltage Step-Up in Low-Power Inverters" (Reference 3) provides insights into the design considerations for transformer selection and efficiency improvement.

While square wave inverters are simple and cost-effective, they produce higher harmonic distortion, which may affect sensitive electronic devices. To mitigate these issues, filtering techniques or modified sine wave approaches can be employed. However, for basic applications such as powering resistive loads or simple appliances, square wave inverters remain a viable solution.

The implementation of this project involves hardware integration, firmware development for the Arduino Nano, and testing to ensure proper functionality. Future improvements could include adding PWM control for a modified square wave output or integrating protection circuits to enhance system reliability.

RELATED RESEARCH

The Implementation of a Single-Phase Square Wave Inverter Controlled by Arduino presents the design, development, and testing of a low-cost inverter capable of converting 12V DC into 220V AC using an Arduino Nano for precise control. The inverter is based on four IRF540 MOSFETs, arranged in an H-bridge configuration, to switch the DC voltage and generate a square wave AC output. A step-up transformer (12V to 220V) is used to elevate the voltage to the required AC level. The Arduino Nano generates switching pulses that control the MOSFETs, ensuring stable and efficient operation. The square wave output is suitable for simple resistive loads but introduces harmonic distortion, which can affect sensitive electronic devices. The paper discusses circuit design, component selection, working principles, and performance analysis, along with efficiency considerations and thermal management strategies for improved reliability. Experimental results validate the inverter's functionality, demonstrating its capability to power AC loads effectively. The study highlights potential enhancements, such as PWM-based modified sine wave generation, to improve waveform quality and reduce harmonic distortion.

CHAPTER 3

RESEARCH METHODOLOGY

INTRODUCTION

The methodology for implementing a Single-Phase Square Wave Inverter Controlled by Arduino follows a structured approach, including design, simulation, hardware implementation, and testing. The system is built using four IRF540 MOSFETs in an H-bridge configuration, controlled by an Arduino Nano to generate 50Hz switching signals. A 12V to 220V step-up transformer is used to achieve the desired AC voltage output.

HARDWARE SETUP

The process begins with component selection and circuit design, followed by simulation using Proteus to verify switching behavior. The hardware is then implemented, and the Arduino is programmed to control MOSFET operation. The inverter is tested under different load conditions, and performance parameters such as output waveform, voltage levels, and efficiency are analyzed. Finally, possible improvements, such as PWM control for better waveform quality, are considered for future enhancements.

HARDWARE ELEMENTS

The project used many hardware and software components, which are described below:

- Arduino Nano
- IRF 540
- Battery
- On off switch
- Connection wire
- LED
- PCB board
- Vero-board
- Resistor
- IC-7805
- Bulb
- Resistor
- Bulb
- Transformer

ARDUINO NANO

Arduino Nano is one type of microcontroller board, and it is designed by Arduino.cc. It can be built with a microcontroller like Atmeg328. This microcontroller is also used in Arduino UNO. It is a small size board and also flexible with a wide variety of applications. Other Arduino boards mainly include Arduino Mega, Arduino Pro Mini, Arduino UNO, Arduino YUN, Arduino Lilypad, Arduino Leonardo, and Arduino Due. And other development boards are AVR Development Board, PIC Development Board, Raspberry Pi, Intel Edison, MSP430 Launchpad, and ESP32 board.

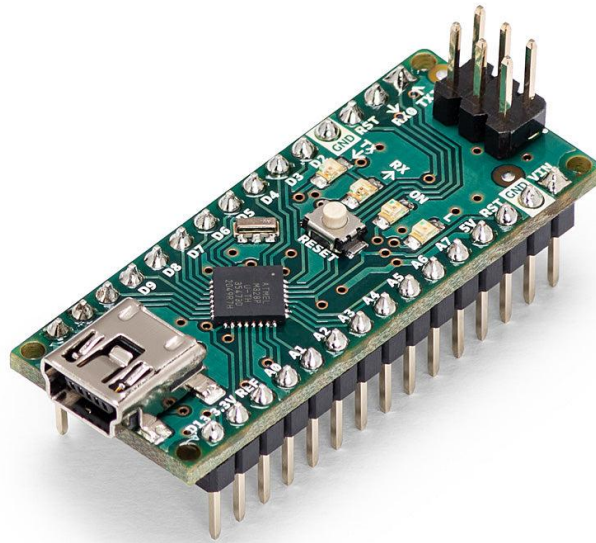


Figure 1: The Arduino nano [11].

This board has many functions and features like an Arduino Duemilanove board. However, this Nano board is different in packaging. It doesn't have any DC jack so that the power supply can be given using a small USB port otherwise straightly connected to the pins like VCC & GND. This board can be supplied with 6 to 20volts using a miniUSB port on the board.

PIN CONFIGURATIONS

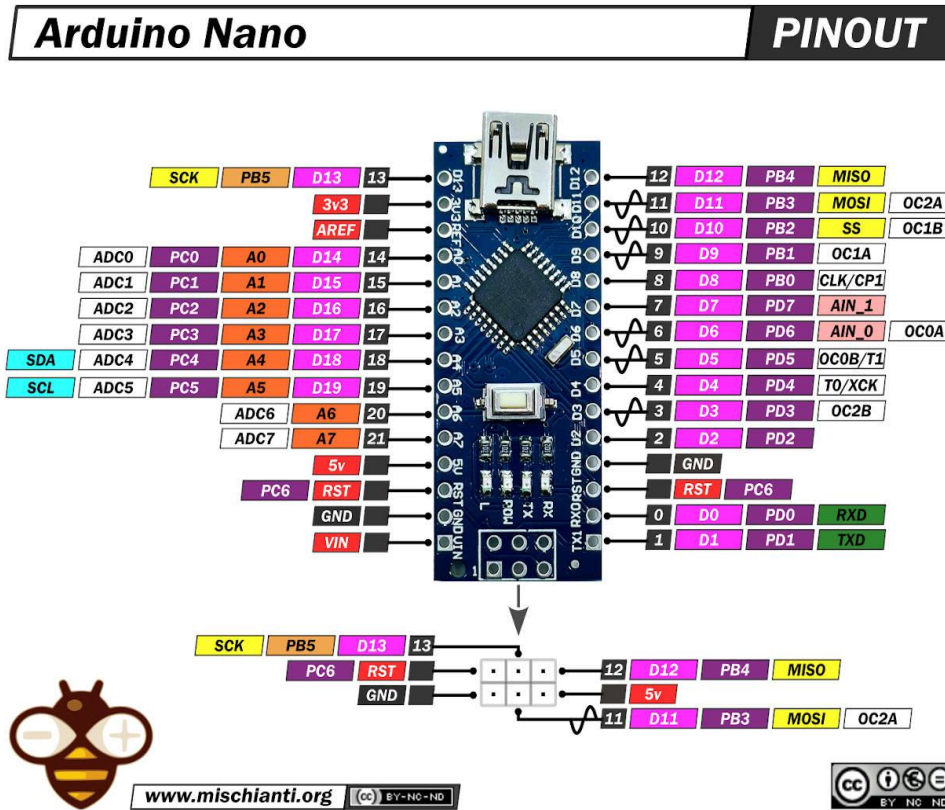


Figure 2: The pinout configuration of Arduino nano [12].

1. Microcontroller (ATmega328P)

The ATmega328P is the brain of the Arduino Nano. It processes input data, controls the output devices, and communicates with other components. The microcontroller executes the instructions written in the program (code), which is uploaded through the USB interface.

2. Input/Output Pins

The Arduino Nano has 14 digital I/O pins (0–13) and 8 analog input pins (A0–A7). These pins allow the board to interface with external components such as sensors, switches, and actuators.

- **Digital Pins:** These can be set as input or output and read or output HIGH (5V) or LOW (0V) states.
- **Analog Pins:** These can read analog signals (voltage levels) and convert them to digital values using the Analog-to-Digital Converter (ADC).

3. Power Supply

The Arduino Nano can be powered in several ways:

- **USB Power:** When connected to a computer via the USB cable, the Nano is powered through the USB connection (5V).
- **External Power Source:** A DC power supply can be connected to the Vin pin to supply the board with 7–12V, which is regulated down to 5V by an onboard voltage regulator.
- **Battery:** A battery can be used to power the Arduino Nano when not connected to a computer.

The board uses a voltage regulator to ensure that the voltage supplied to the microcontroller remains stable (5V), regardless of the input voltage.

4. The Bootloader

The Arduino Nano comes with a bootloader pre-installed. This small program allows you to upload your custom code to the board via the USB connection without needing an external programmer. When you connect the Nano to your computer, the bootloader listens for new code and, if available, writes it to the microcontroller's memory.

5. Pulse Width Modulation (PWM)

Some of the digital pins (3, 5, 6, 9, 10, and 11) on the Arduino Nano support PWM output. PWM allows you to simulate analog output by rapidly switching the output pin between HIGH and LOW states. This technique is used to control the speed of motors, brightness of LEDs, and more.

6. Communication

The Arduino Nano supports communication with other devices and microcontrollers using several protocols:

- **Serial Communication (UART):** The Nano communicates with a computer or another device through TX (transmit) and RX (receive) pins. This is used for debugging, sending data to a computer, or receiving commands from another device.
- **I2C and SPI:** The board also supports I2C (Inter-Integrated Circuit) and SPI (Serial Peripheral Interface) communication protocols, which are commonly used to connect sensors, displays, and other peripherals.

7. Programming and Execution

Arduino Nano is programmed using the Arduino IDE (Integrated Development Environment).

- Code (Sketch): The program is written in C/C++ and consists of two key functions: `setup()` initializes the necessary settings (runs once when the board is powered up or reset). `loop()` contains the main logic of the program and runs continuously after `setup()` completes.
- Execution: After the code is uploaded to the Nano, it starts executing automatically. The microcontroller reads input from sensors, processes it, and sends output signals to the connected devices like motors, LEDs, or displays.

8. Onboard LED

The Arduino Nano has an onboard LED connected to pin 13. This LED can be used to indicate the status of the board or to test the functionality of the program (e.g., blink the LED).

By interacting with various components and sensors, the Arduino Nano serves as a powerful tool for building diverse applications, from basic sensors to complex systems like the gesture-controlled wheelchair project.

APPLICATIONS OF ARDUINO NANO

I. Power Electronics and Energy Systems

- DC–AC inverters (like your square wave inverter project)
- Solar charge controllers
- Battery monitoring and management systems (BMS)
- Power factor correction circuits
- Smart meters and power logging systems

II. Robotics and Automation

- Line follower and obstacle avoidance robots
- Robotic arms and pick-and-place systems
- Drone flight control (basic quadcopter controllers)
- Automated guided vehicles (AGVs)
- Industrial automation (motor drivers, relay controllers)

III. IoT (Internet of Things) Applications

- Smart home automation (controlling lights, fans, appliances via Wi-Fi/Bluetooth)
- Weather stations (temperature, humidity, pressure sensors)
- Remote data logging (using ESP8266/ESP32 as Wi-Fi modules)

- Smart agriculture (soil moisture, irrigation control)

IV. Sensor-Based Systems

- Real-time health monitoring (heartbeat, SPO2, ECG)
- Environmental monitoring (air quality, gas leakage detection)
- Motion detection (PIR sensors for security systems)
- Ultrasonic distance measurement
- Smart parking systems (IR/Ultrasonic sensors)

V. Embedded Control Systems

- Motor speed control (DC, stepper, BLDC motors)
- Servo control for automation and drones
- Relay-based switching circuits
- Home appliance controllers
- Small-scale PLC-like systems

VI. Communication Systems

- Serial communication (UART, I2C, SPI) with sensors/modules
- Wireless communication with NRF24L01, HC-05 Bluetooth, LoRa modules
- GSM-based projects (sending SMS alerts, remote monitoring)
- RFID-based attendance or access control systems

VII. Educational Projects

- Learning digital/analog electronics
- Demonstrating PWM, ADC, timers, and interrupts
- Signal generation (square wave, PWM, tone output)
- Basic oscilloscope/logic analyzer projects
- Simple games and displays (using OLED, LCD, 7-segment displays)

VIII. Prototyping and DIY Electronics

- Mini 3D printer controllers
- CNC machine control (basic G-code interpreter)
- Audio projects (tone generation, audio filters)
- LED displays and matrix animations
- Wearable electronics (due to its small size)

IRF 540

The IRF540 MOSFET is a widely used N-channel power MOSFET that operates as an electronic switch in power circuits. It is commonly used in DC-AC inverters, motor drivers, and power management systems due to its high current-handling capacity, fast switching speed, and low ON resistance. The working principle of the IRF540 is based on the Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) theory, where the gate voltage (V_{GS}) controls the conduction between the drain and source terminals.

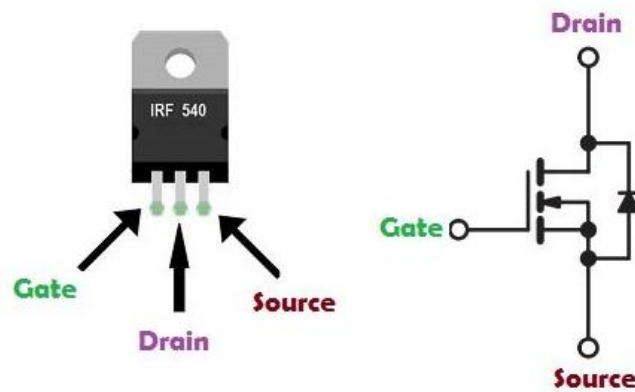


Figure 3: Pin diagram of IRF 540 MOSFET [13].

When the gate-to-source voltage (V_{GS}) is below the threshold voltage (V_{th}), the MOSFET remains OFF, and no current flows between the drain and source. When V_{GS} exceeds V_{th} (typically 2-4V), the MOSFET starts conducting, and when V_{GS} reaches around 10V-15V, the MOSFET is fully ON, allowing maximum current flow from drain to source. This makes it ideal for switching applications, as it can be turned ON and OFF rapidly.

In a single-phase square wave inverter, the IRF540 MOSFETs are configured in an H-bridge topology, where two pairs of MOSFETs switch alternately to reverse the polarity of the voltage applied to the transformer. The Arduino Nano generates the required PWM switching signals to control the MOSFETs, ensuring a square wave AC output. The MOSFETs efficiently handle the high current flow, and their low ON resistance ($R_{DS(on)}$) minimizes power loss.

The IRF540 is preferred for high-power switching applications due to its high efficiency, robustness, and ability to handle up to 33A of current. Proper gate drive voltage and heat dissipation techniques, such as heat sinks, are essential for reliable operation in inverter circuits.

APPLICATIONS OF IRF540

- DC-DC Converters (buck, boost, buck-boost regulators).
- DC-AC Inverters (H-bridge circuits for square wave or sine wave inverters).
- Motor Drivers (DC motor speed control, stepper motor control).
- Switching Power Supplies (SMPS) for efficiency improvement.
- Relay Replacement (solid-state switching in automation systems).
- Battery-Powered Circuits (solar charge controllers, UPS systems).
- LED Drivers and Dimming Circuits.
- Audio Amplifier Circuits (as output stage switches).
- Arduino / Microcontroller Projects (interfacing high-current loads with low-voltage logic).
- Induction Heating & Welding Circuits (low-frequency switching).

ADVANTAGES OF IRF540

- High Current Handling: Can drive loads up to ~33A.
- Low On-Resistance ($R_{ds(on)}$): Reduces conduction losses and heat dissipation.
- High Switching Speed: Suitable for high-frequency switching applications.
- Low Gate Drive Power: Since MOSFETs are voltage-driven (not current-driven like BJTs).
- Easily Controlled by Microcontrollers: Can be interfaced with Arduino, PIC, or ESP32 using gate driver circuits.
- Wide Availability & Low Cost: IRF540 is inexpensive and easily available.
- Durable & Rugged: Can handle voltage spikes better compared to BJTs.
- Better Efficiency than BJT Switches in most power electronics applications.

DISADVANTAGES OF IRF540

- Not Logic-Level: MOSFET Needs 10V gate drive for full conduction (microcontrollers like Arduino output only 5V, so performance is reduced unless a gate driver is used).
- Heat Dissipation: At high currents, it generates significant heat and requires a heatsink.
- Body Diode Limitation: The internal body diode is slow, making it less efficient in fast switching reverse current applications.

- Higher $R_{ds(on)}$ than Modern MOSFETs: Newer MOSFETs (like IRLZ44N, IRFZ44N, etc.) have much lower on-resistance.
- Limited for High-Frequency Applications: While decent for kHz switching, not ideal for MHz-level switching (like RF circuits).
- Parasitic Capacitance: High input capacitance (C_{iss}) requires stronger gate drivers for fast switching.
- Temperature Sensitivity: $R_{ds(on)}$ increases with temperature, reducing efficiency.

TRANSFORMER

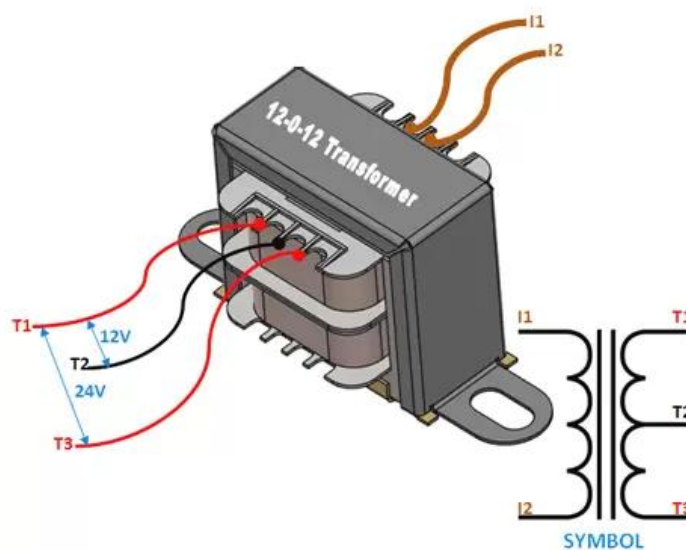


Figure 4: The single-phase transformer [14].

A transformer is an electrical device that is primarily used to change the voltage of an alternating current (AC) in a circuit. It operates based on the principle of electromagnetic induction. The transformer consists of two coils of wire, known as the primary and secondary coils, which are wound around a shared iron core. These coils are not electrically connected, but they interact magnetically through the core.

When an alternating current is passed through the primary coil, it creates a fluctuating magnetic field. The core of the transformer is designed to direct this magnetic field through the secondary coil. According to Faraday's Law of Induction, a changing magnetic field in the core induces an electromotive force (EMF) in the secondary coil, which results in an alternating current being generated in the secondary coil.

The voltage induced in the secondary coil is determined by the ratio of the number of turns in the primary coil to the number of turns in the secondary coil. This relationship is expressed as:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

Where V_1 and V_2 represent the voltages across the primary and secondary coils, and N_1 and N_2 represent the number of turns of wire in the primary and secondary coils, respectively. If the secondary coil has more turns than the primary, the transformer steps up the voltage; if the secondary has fewer turns, the voltage is stepped down.

In an ideal transformer, the power input to the primary coil is equal to the power output from the secondary coil, minus some losses. This means that when the voltage increases in the secondary coil, the current decreases, and vice versa. This relationship helps in efficiently transmitting electrical power across long distances, with minimal energy loss.

Thus, transformers are essential in power distribution systems, allowing electricity to be transported at high voltages and low currents to reduce energy loss, and then stepped down to usable voltages for homes and businesses.

APPLICATIONS OF TRANSFORMER IN AN INVERTER PROJECT

- i. Voltage Step-Up (Boosting AC Output)
 - The inverter H-bridge (using MOSFETs) usually produces a low-voltage AC (e.g., 12V AC from a 12V DC battery).

- A step-up transformer is used to convert this low AC voltage to the required 220V AC (in Bangladesh/Europe) or 110V AC (in USA) for powering appliances.
- ii. Electrical Isolation (Safety Purpose)
- The transformer provides galvanic isolation between the low-voltage DC side and the high-voltage AC output.
 - This prevents dangerous high voltage from feeding back into the battery or Arduino circuit, improving user safety.
- iii. Impedance Matching
- The transformer helps in matching the inverter's output impedance with the load impedance, improving power transfer efficiency.
- iv. Waveform Shaping
- Although mainly used for stepping voltage, the transformer also helps in filtering and smoothing the waveform when combined with capacitors/filters.
 - It reduces certain harmonic components of the square wave, giving a "cleaner" AC output.
- v. Current Transformation
- It not only changes voltage but also changes current levels accordingly.
 - For example, stepping up from 12V to 220V reduces current, which helps in transmitting power with less copper loss in wires.
- vi. Dual Purpose in Bidirectional Inverters
- In advanced inverter designs (UPS, solar inverters), transformers can also work in reverse to step down AC mains to DC for battery charging.

ARDUINO IDE

The Arduino Integrated Development Environment (IDE) is a software platform that allows you to write, compile, and upload code to an Arduino board. It simplifies the process of programming microcontrollers for a wide range of projects. Here's how the Arduino IDE works:

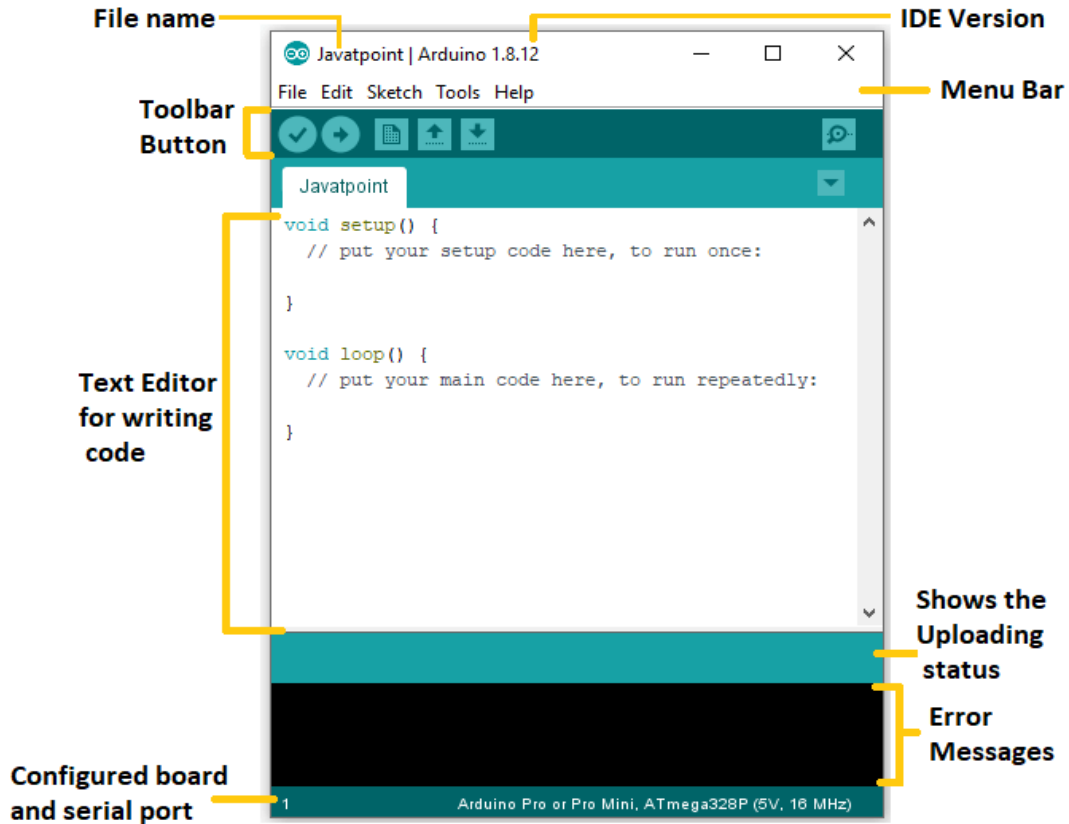


Figure 5: The Arduino IDE home page [15].

Working Principle of the Arduino IDE:

1. Writing the Code (Sketch):

- When you open the Arduino IDE, you start by writing a program (called a "sketch") in the text editor. The code is written using the Arduino programming language, which is based on C/C++ but has simplified functions and syntax for ease of use.
- The Arduino IDE provides two main functions that every sketch needs:
 - Setup(): This function runs once at the beginning and is used to initialize settings such as pin modes, serial communication, etc.

- `Loop()`: This function runs repeatedly, allowing the Arduino to continuously perform tasks.

2. Compiling the Code:

- After writing your sketch, you can click the Verify button (a checkmark icon) in the IDE. The Arduino IDE then compiles your code, which means it translates your human-readable code into machine-readable instructions (binary code). This step checks for any errors in the syntax and logic of your program.
- The IDE uses the GNU Compiler Collection (GCC) to compile the code, converting it into a format that can be understood by the microcontroller on the Arduino board.

3. Uploading the Code to the Arduino Board:

- Once the code is successfully compiled, you connect your Arduino board to your computer via USB. After ensuring the correct board type and port are selected in the IDE, you click the "Upload" button (an arrow icon).
- The IDE communicates with the Arduino board through a serial connection. The compiled code is then uploaded to the microcontroller's memory. The board is now ready to execute the code.

4. Execution of Code:

- The Arduino board begins running the uploaded sketch. The code inside the `setup()` function is executed first, and then the code in the `loop()` function is executed repeatedly, unless the program is interrupted or stopped.
- The Arduino IDE also allows you to communicate with the board in real-time via Serial Monitor. This feature allows you to send data between the Arduino and your computer, such as debugging information or sensor readings, by using simple serial commands like `Serial.Print()` in your code.

5. Libraries and Functions:

- The Arduino IDE supports the use of libraries—pre-written code that adds extra functionality to your project, such as controlling motors, reading sensors, or using communication protocols like I2C or SPI. These libraries can be easily included in your sketch to extend the capabilities of your Arduino board.

- The IDE provides a built-in library manager to easily install and manage libraries.

VOLTAGE REGULATOR

The 7805 voltage regulator IC is a popular linear voltage regulator used to provide a stable 5V output from a higher input voltage. Here's the working principle of the 7805 IC:

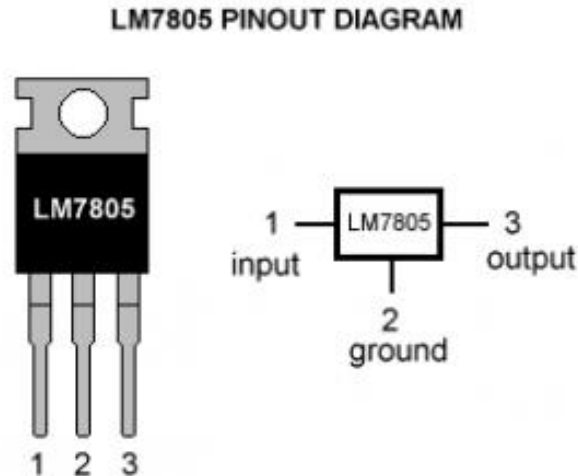


Figure 6: The pin diagram of 7805 IC [16].

Basic Operation:

1. **Input Voltage:** The 7805 requires a higher input voltage (typically between 7V to 35V) to regulate it down to a steady 5V output. This higher voltage is fed to the input pin (pin 1) of the IC.
2. **Internal Voltage Reference:** Inside the 7805 IC, there is an internal reference voltage of 5V, which is used as a comparison standard.
3. **Error Amplifier:** The 7805 has an error amplifier that compares the input voltage to the reference voltage. If the input voltage is higher than 5V, the regulator works to maintain the output at a constant 5V by adjusting its internal circuitry.
4. **Pass Transistor:** The 7805 uses an internal pass transistor (typically a NPN transistor) to maintain the voltage regulation. The error amplifier controls this pass transistor to adjust the current flow, ensuring the output remains stable at 5V.
5. **Output Voltage:** The regulated 5V output is available at pin 3 of the 7805. The output voltage is the difference between the input voltage and the small voltage drop across the pass transistor.

6. **Thermal Regulation:** The 7805 is a linear regulator, meaning it dissipates excess power as heat. For example, if the input voltage is 9V, the IC drops 4V ($9V - 5V = 4V$) and converts it into heat. The IC typically requires a heat sink or cooling to prevent overheating, especially with higher input voltages or larger currents.
7. **Capacitors:** For stable operation, capacitors are usually connected to the input and output pins. Typically, a $0.33\mu F$ capacitor is placed at the input and a $0.1\mu F$ capacitor at the output to filter noise and provide better stability.

The 7805 Voltage Regulator IC has three pins, and here are the pin details:

1. **Pin 1: Input (V_{in})**
 - **Function:** This is the input pin where the unregulated input voltage is supplied. The input voltage should typically be between 7V and 35V for proper regulation.
 - **Typical Voltage Range:** 7V to 35V.
2. **Pin 2: Ground (GND)**
 - **Function:** This is the ground or common pin. It is connected to the negative terminal of the power supply.
 - **Typical Voltage:** 0V.
3. **Pin 3: Output (V_{out})**
 - **Function:** This is the regulated 5V output. The 7805 will maintain a stable 5V on this pin, as long as the input voltage is higher than 5V and within the specified range.
 - **Typical Voltage:** 5V.

APPLICATIONS OF IC 7805

1. **Microcontroller Power Supply**
 - Provides stable +5V supply for Arduino, PIC, AVR, ESP8266 (with level shifting), and other digital ICs.
2. **Sensor Circuits**
 - Many sensors (IR sensors, ultrasonic, temperature sensors, etc.) require a regulated 5V supply.
3. **Communication Modules**
 - Used to power GSM, GPS, RFID, and Bluetooth modules that run on 5V.
4. **Embedded Systems & Robotics**

- Provides regulated 5V supply for logic circuits, LCD displays, and servo motors.
5. Power Conversion
 - Converts higher DC voltages (12V, 9V, etc.) to a stable 5V DC. Example: In your inverter project, a 12V battery can be stepped down to 5V to power the Arduino Nano using 7805.
 6. Consumer Electronics
 - Found in TV circuits, DVD players, set-top boxes, etc., as a 5V regulator.
 7. Portable Devices & Chargers
 - Used in small regulated 5V USB power supplies.

ADVANTAGES OF IC 7805

1. Fixed 5V Output: Provides a stable and precise +5V DC irrespective of input fluctuations (within limits).
2. Built-in Protection: Has short-circuit protection, overheat (thermal) shutdown, and safe-area protection.
3. Low Cost & Readily Available: Very cheap and available worldwide.
4. Easy to Use: Just connect input, ground, and output pins (with capacitors) to get 5V.
5. Reliable: Widely used in hobby, academic, and industrial circuits.
6. Low Ripple and Noise: Provides a clean DC output suitable for sensitive ICs.
7. Can Deliver High Current: Up to 1A (more with heatsink).

DISADVANTAGES OF IC 7805

1. Linear Regulator = Power Loss – Wastes excess voltage as heat. Example: $12V \rightarrow 5V$ at $1A = (12-5) \times 1 = 7W$ heat loss.
2. Requires Heatsink: At high current, it overheats and needs proper cooling.
3. Inefficient at High Currents: Not suitable for battery-powered applications where efficiency is critical.
4. Input Voltage Limitation: Needs at least 7V input; cannot regulate if input is very close to 5V.
5. Fixed Output Only: Provides only 5V, unlike adjustable regulators (LM317).

RESISTOR

A resistor (also known as an electrical resistor) is defined as a two-terminal passive electrical element that provides electrical resistance to current flow. Resistance is a measure of the opposition to the flow of

current in a resistor. The larger a resistor's resistance, the greater the barrier against the flow of current. There are many different types of resistors, such as a thermistor.

In an electrical and electronic circuit, the primary function of a resistor is to "resist" the flow of electrons, i.e., electric current. That is why it is called a "resistor".

Resistors are passive electrical elements, meaning they can't provide energy to a circuit. Instead, they absorb energy and release it as heat when current flows through them.

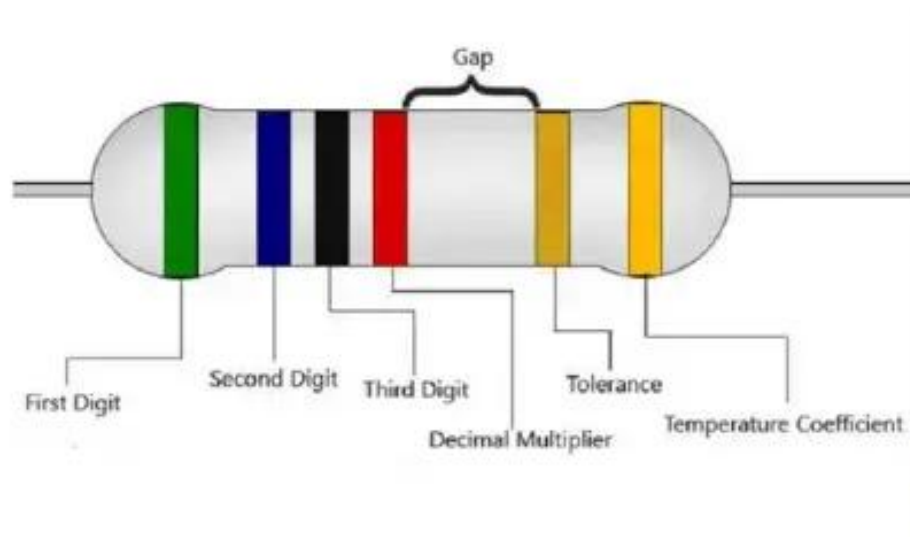


Figure 7: The resistor [17].

Resistors in electrical and electronic circuits limit current flow and create voltage drops. They come in various resistance values, ranging from fractions of an Ohm (Ω) to millions of Ohms. According to ohm's law, the voltage (V) across a resistor is directly proportional to the current (I) flowing through it. Where the resistance R is the constant of proportionality.

In an electrical and electronic circuit, resistors are used to limit and regulate current flow, divide voltages, adjust signal levels, bias active elements, etc. For example, many resistors are connected in series used to limit the current flowing through the light-emitting diode (LED). Other examples are discussed below.

Color Coding of Resistors:

Resistor values are typically indicated by color bands on their body. The color code system is a way of representing the resistance value, tolerance, and sometimes the temperature coefficient. Here's how it works. 4-Band Color Code (Common for Standard Resistors):

- Band 1 (First Band): Represents the first digit of the resistance value.
- Band 2 (Second Band): Represents the second digit of the resistance value.
- Band 3 (Multiplier Band): Represents the multiplier (i.e., how many zeros to add).
- Band 4 (Tolerance Band): Represents the tolerance (the accuracy of the resistor's value).

APPLICATIONS OF RESISTORS

1. Current Limiting: Used to control and limit the flow of current in a circuit (e.g., protecting LEDs).
2. Voltage Division: Used in voltage divider circuits to provide a required voltage.
3. Biasing of Transistors: Provides stable bias current/voltage in amplifier circuits.
4. Pull-up and Pull-down: Ensures logic circuits default to HIGH or LOW state.
5. Heat Generation: Used in heaters, toasters, and irons where electrical energy is converted into heat.
6. Load Resistor: Used to test power supplies and amplifiers by providing a load.
7. Signal Conditioning: Shapes or controls signals in filters and audio circuits.
8. Feedback Networks: Used in op-amp circuits for gain control and feedback.
9. Impedance Matching: Helps match source and load impedance in communication circuits.
10. Timing Circuits: Works with capacitors (RC circuits) to produce delays or oscillations.
11. Measuring Instruments: Precision resistors are used in multimeters and bridges for measurement.
12. Snubber Circuits: Protects switching devices from voltage spikes.
13. Lighting Control: Used in dimmers and brightness control circuits.
14. Energy Dissipation: Used to absorb excess energy in crowbar or protection circuits.
15. Electronic Filters: Works with capacitors/inductors in low-pass, high-pass, and band-pass filters.

BATTERY

The battery serves as the primary power source for the entire system, ensuring that all the electronic components and motors function smoothly. Here's how the battery works in this project:



Figure 8: Rechargeable battery.

1. Power Supply for the Components

The battery provides the necessary electrical power to operate the following components:

- **Motors:** High-power DC motors require significant current to drive the wheels of the wheelchair.
- **Microcontrollers (Arduino Nano):** These require a steady low-voltage DC supply (5V).
- **Bluetooth Modules:** Powered at 3.3V to 5V for wireless communication between microcontrollers.
- **Gesture Sensor:** Needs a stable 3.3V or 5V supply for proper functioning.
- **Ultrasonic Sensor:** Operates at 5V to detect obstacles.
- **Motor Driver (L298N):** Requires a higher voltage (often 7V–12V) to drive the motors effectively.

2. Charging and Maintenance

- Rechargeable batteries must be connected to a charger circuit compatible with the battery type.
- Proper charging is essential to maintain battery health and prevent overcharging, which could damage the battery or reduce its lifespan.

In this project, the battery acts as the heart of the system, supplying power to motors, sensors, and microcontrollers. It ensures the wheelchair operates seamlessly, providing mobility and functionality for the user. Proper selection, integration, and maintenance of the battery are crucial for the optimal performance and reliability of the gesture-controlled wheelchair.

LED

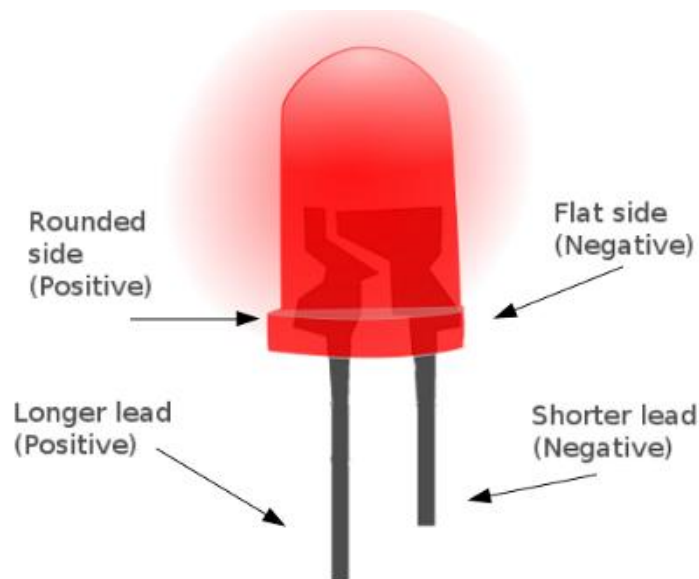


Figure 9: The LED.

Working Principle of LED (Light Emitting Diode)

A Light Emitting Diode (LED) is a special type of semiconductor diode that emits light when a suitable voltage is applied across it. The operation of an LED is based on the principle of electroluminescence, which is the phenomenon in which a material emits light when an electric current passes through it.

1. Structure of an LED

- An LED is a PN junction diode, but unlike regular diodes, it is made from direct bandgap semiconductor materials such as Gallium Arsenide (GaAs), Gallium Phosphide (GaP), or Gallium Nitride (GaN).

- The P-region of the LED contains a high concentration of holes (positive charge carriers), while the N-region contains a high concentration of electrons (negative charge carriers).
- The junction area is where the recombination of electrons and holes occurs, producing light.
- LEDs also have a transparent case or lens to allow light to escape efficiently.

2. Forward Bias Operation

- For an LED to emit light, it must be forward biased: the positive terminal of the power supply is connected to the P-region, and the negative terminal is connected to the N-region.
- When forward biased, electrons from the N-region move toward the P-region, and holes from the P-region move toward the N-region. At the junction, electrons and holes recombine.

3. Recombination and Light Emission

- When an electron recombines with a hole, it moves from a higher energy level to a lower energy level.
- This transition releases energy in the form of photons, which is observed as visible light.
- The wavelength (color) of the emitted light depends on the energy band gap of the semiconductor material.
- This makes LEDs capable of emitting light of different colors depending on the material used.

4. Reverse Bias Condition

- If the LED is connected in reverse bias (positive terminal to N-region, negative to P-region), the LED does not emit light.
- Only a very tiny leakage current flows, which is not enough to produce light.
- Applying too high a reverse voltage can damage the LED permanently.

5. Efficiency and Advantages

- LEDs are highly energy-efficient because they convert most of the electrical energy into light rather than heat.
- They have a long lifespan, compact size, and are environmentally friendly compared to incandescent or fluorescent bulbs.

- LEDs are widely used in displays, indicators, traffic lights, and lighting systems due to their low power consumption and bright light output.

SOLAR PANEL



Figure 10: The Solar panel.

A 12V solar panel is a simple but smart way to charge small batteries using sunlight. Here's how it works:

The panel is made of special materials called photovoltaic (PV) cells. When sunlight hits these cells, it excites tiny particles called electrons, causing them to move — and this movement creates electricity. The type of electricity it produces is DC (Direct Current), which is the same kind most small batteries use.

Since the panel is made to output 5 volts, it's perfect for charging 5V batteries or powering small devices like USB gadgets. But there's one thing to keep in mind: the panel needs to charge the battery safely. That's why we often use a charging controller or a small circuit (like the TP4056 module for lithium batteries). This helps control how much voltage and current goes into the battery so it doesn't get overcharged or damaged.

Also, at night or when it's cloudy, electricity might try to flow back from the battery to the panel. To stop this, a tiny part called a blocking diode is sometimes used. It acts like a one-way gate for electricity.

In short, a 12V solar panel takes sunlight, turns it into clean DC power, and with the right setup safely charges your battery without needing any plug or wall outlet. It's a simple and eco-friendly way to power small electronics anywhere, anytime.

APPLICATIONS OF SOLAR PANELS

1. Residential Power Supply

- Solar panels can provide electricity to homes, reducing dependency on the grid.
- Used for lighting, fans, TVs, refrigerators, and small appliances.
- Can be combined with battery storage for nighttime use.

2. Commercial and Industrial Power

- Offices, factories, and commercial buildings use solar panels to reduce electricity bills.
- Large solar farms can supply power to the national grid.

3. Street Lighting

- Solar panels are used in solar street lights to illuminate roads and public areas without grid connection.

4. Water Pumping and Irrigation

- Solar-powered water pumps are widely used in agriculture for irrigation.
- Reduces reliance on diesel pumps, saving fuel and reducing pollution.

5. Remote Area Electrification

- Provides electricity to villages or areas not connected to the grid.
- Used in schools, hospitals, and homes in remote locations.

6. Solar-Powered Vehicles

- Solar panels are used in solar cars, boats, and drones to provide clean energy.
- Reduces fuel consumption and promotes eco-friendly transportation.

7. Space Applications

- Solar panels power satellites, space stations, and spacecraft, where conventional electricity is unavailable.

8. Solar Heating

- Solar panels can heat water for homes, swimming pools, or industrial processes.

9. Off-Grid Applications

- Charging batteries, mobile phones, laptops, and small devices in areas without electricity.

- Useful for camping, trekking, and emergency situations.

10. Grid-Tied Solar Systems

- Excess electricity generated can be fed back to the grid, reducing electricity bills and providing renewable energy.

11. Solar-Powered Gadgets

- Small devices like solar calculators, lights, fans, and lanterns are powered by solar panels.

12. Desalination Plants

- Solar energy is used in solar desalination systems to convert seawater into drinking water.

13. Traffic Signals and Signboards

- Solar panels power traffic lights and information boards, ensuring uninterrupted operation during power cuts.

14. Industrial Process Heating

- Used in industries for drying, baking, and other heating processes using solar thermal energy.

15. Emergency Power Supply

- Solar panels provide backup power during natural disasters, blackouts, or remote operations.

Solar panels are versatile, eco-friendly, and reduce reliance on fossil fuels, making them a key technology for sustainable energy.

DIODE

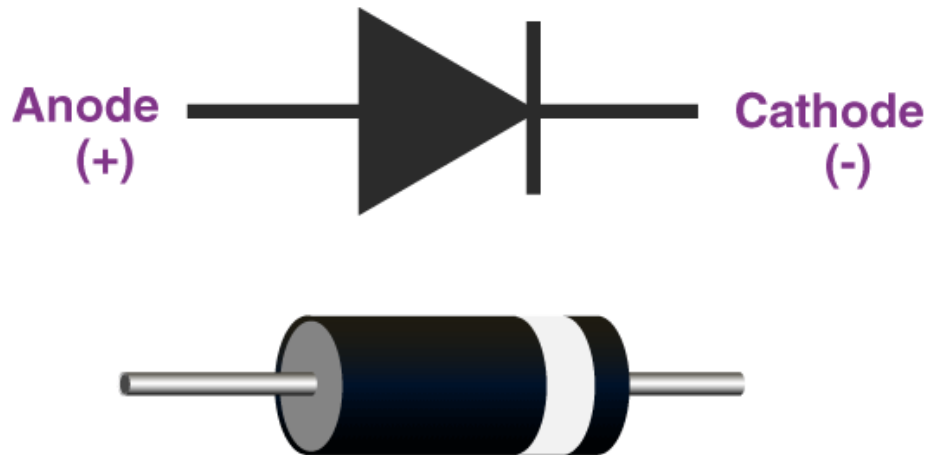


Figure 11: The Symbol of a Diode.

A diode is a two-terminal semiconductor device that allows electric current to flow in one direction only while blocking it in the opposite direction. The operation of a diode is based on the properties of the PN junction, which is formed when P-type and N-type semiconductors are joined together. Diodes are fundamental components in electronic circuits and are used for rectification, voltage regulation, switching, and signal processing.

1. Structure of a Diode

- A typical diode consists of a P-type semiconductor and an N-type semiconductor.
- The P-type region has an excess of holes (positive charge carriers), while the N-type region has an excess of electrons (negative charge carriers).
- The junction between these two regions is called the PN junction, which is the key functional area of the diode.
- The diode has two (terminals: i) Anode (P-side) and ii) Cathode (N-side)
- Often, the diode is encased in a small package with a marking on the cathode side to indicate polarity.

2. Formation of the PN Junction

When the P-type and N-type materials are joined:

- Diffusion of Charge Carriers:
 - Electrons from the N-region diffuse into the P-region.

- Holes from the P-region diffuse into the N-region.
- Depletion Region Formation:
 - In the region around the junction, electrons and holes recombine, leaving behind fixed positive ions in the N-region and fixed negative ions in the P-region.
 - This forms the depletion region, which is devoid of free charge carriers and acts as an insulating barrier.
- Built-in Potential:
 - The recombination creates an internal electric field across the junction that opposes further movement of charge carriers.
 - For silicon diodes, this built-in potential is approximately 0.7V, and for germanium diodes, it is approximately 0.3V.

3. Forward Bias Operation

- Forward bias occurs when the positive terminal of a voltage source is connected to the anode (P-side) and the negative terminal to the cathode (N-side).
- This applied voltage reduces the potential barrier at the junction, allowing charge carriers to move across the depletion region.
- Process:
 - Electrons in the N-region are pushed toward the junction.
 - Holes in the P-region move toward the junction.
 - At the junction, electrons and holes recombine, allowing current to flow through the diode.
- Threshold Voltage:
 - The diode starts conducting significantly only after the applied voltage exceeds the threshold ($\approx 0.7V$ for silicon).
 - Below this voltage, only a tiny current called leakage current flows.

4. Reverse Bias Operation

- Reverse bias occurs when the positive terminal of the voltage source is connected to the cathode (N-side) and the negative terminal to the anode (P-side).
- The applied voltage increases the potential barrier of the PN junction.
- Process:
 - Electrons in the N-region are pulled away from the junction.

- Holes in the P-region are pulled away from the junction.
- The depletion region widens, preventing current flow.

5. Breakdown in Reverse Bias

- If the reverse voltage exceeds a certain limit called the breakdown voltage, the diode begins to conduct heavily in reverse.
- This can damage a regular diode if not controlled.
- Special diodes like Zener diodes are designed to operate safely in reverse breakdown for voltage regulation.
- Types of break-down:
 - Zener Breakdown: Occurs at low reverse voltage due to quantum tunneling.
 - Avalanche Breakdown: Occurs at high reverse voltage when charge carriers gain enough energy to create more carriers via collisions.

6. Energy Band Concept

- In forward bias, electrons in the conduction band of the N-region move toward the P-region and fall into holes in the valence band, releasing energy.
- In some diodes (like LEDs), this energy is emitted as light; in regular diodes, it is emitted as heat.

7. Applications of Diodes (Related to Working Principle)

- Rectifiers: Convert AC to DC.
- Voltage Regulation: Zener diodes maintain constant voltage.
- Signal Demodulation: Extract audio from radio signals.
- Overvoltage Protection: Diodes protect circuits from voltage spikes.

LAMP

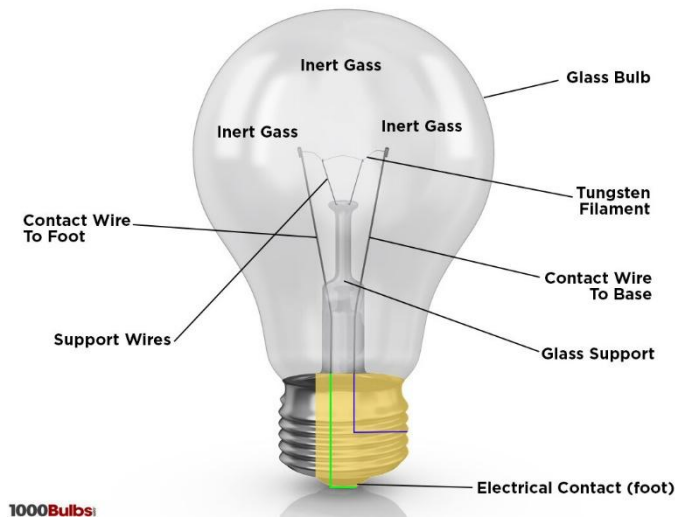


Figure 12: Internal Parts of an Incandescent Bulb

An incandescent lamp is one of the most common types of electric lamps, and it works by producing light from a heated filament. It is also called a filament lamp. The principle behind its operation is incandescence, which is the emission of light by a substance when it is heated to a high temperature. Essentially, an incandescent lamp converts electrical energy into both light and heat. Although it is less efficient compared to modern lighting systems like LEDs or fluorescent lamps, it is still widely used because of its simplicity, low cost, and ability to provide continuous and warm light.

1. Structure of an Incandescent Lamp

- **Filament:**The filament is usually made of tungsten due to its high melting point (around 3422°C) and ability to emit bright light when heated. It is extremely thin to offer sufficient resistance and produce high heat when current passes through it.
- **Glass Bulb:**The filament is enclosed in a glass bulb. The bulb can be either evacuated (vacuum) or filled with an inert gas such as argon or nitrogen. The purpose of the bulb is to protect the filament from oxidation and extend its life.
- **Base:**The metallic base provides an electrical connection to the supply and mechanical support to hold the filament in place. Standard bases allow easy installation in lamps or fixtures.

2. The operation of an incandescent lamp is based on Joule heating:

- When the lamp is connected to an electric supply, a current flows through the filament, which has resistance.

- The electrical energy is converted into heat energy, causing the filament to become extremely hot.
- As the filament temperature rises to about 2000–3000°C, it starts to emit visible light.
- This emission of light due to high temperature is called incandescence.
- The filament emits not only visible light but also infrared radiation, which is why incandescent lamps produce a significant amount of heat. Only 5–10% of the electrical energy is converted into visible light, while the rest is wasted as heat.

3. Role of the Glass Bulb

- The glass bulb surrounding the filament has a critical role
- It prevents contact with air, thereby protecting the filament from oxidation.
- The bulb may be filled with inert gases (like argon or nitrogen) to reduce filament evaporation and improve the lamp's efficiency and lifespan.
- Without the bulb or gas, the filament would burn out almost immediately when exposed to air.

4. Color and Brightness of Light

- The color of light depends on the temperature of the filament.
- At lower temperatures, most of the radiation is in the infrared range, producing more heat than visible light.
- As the filament gets hotter, it emits more visible light, appearing bright white or yellowish depending on the temperature. This is why incandescent lamps give a warm light that is pleasing to the human eye.

5. Energy Conversion

- The energy conversion in an incandescent lamp can be summarized as
- Electrical Energy → Heat Energy → Light Energy
- Since a significant portion of energy is converted to heat, incandescent lamps are less efficient than modern alternatives such as LEDs or compact fluorescent lamps (CFLs). However, their simplicity and instant illumination make them still useful in many situations.

6. Applications

- **Household Lighting:** Provides bright and continuous light in homes.

- Decorative Lighting: Used in lamps, chandeliers, and decorative fixtures for warm illumination.
- Indicator Lamps: Used in appliances and panels as small indicator lights.
- Photography and Film: High-intensity incandescent lamps are used as studio lights.

7. Advantages

- Simple and inexpensive to manufacture.
- Provides warm and continuous light.
- Instant illumination without delay.

8. Disadvantages

- Low efficiency (most energy wasted as heat).
- Short lifespan compared to LEDs and CFLs.
- Produces excessive heat, which can increase cooling costs.

BLOCK DIAGRAM OF THIS PROJECT

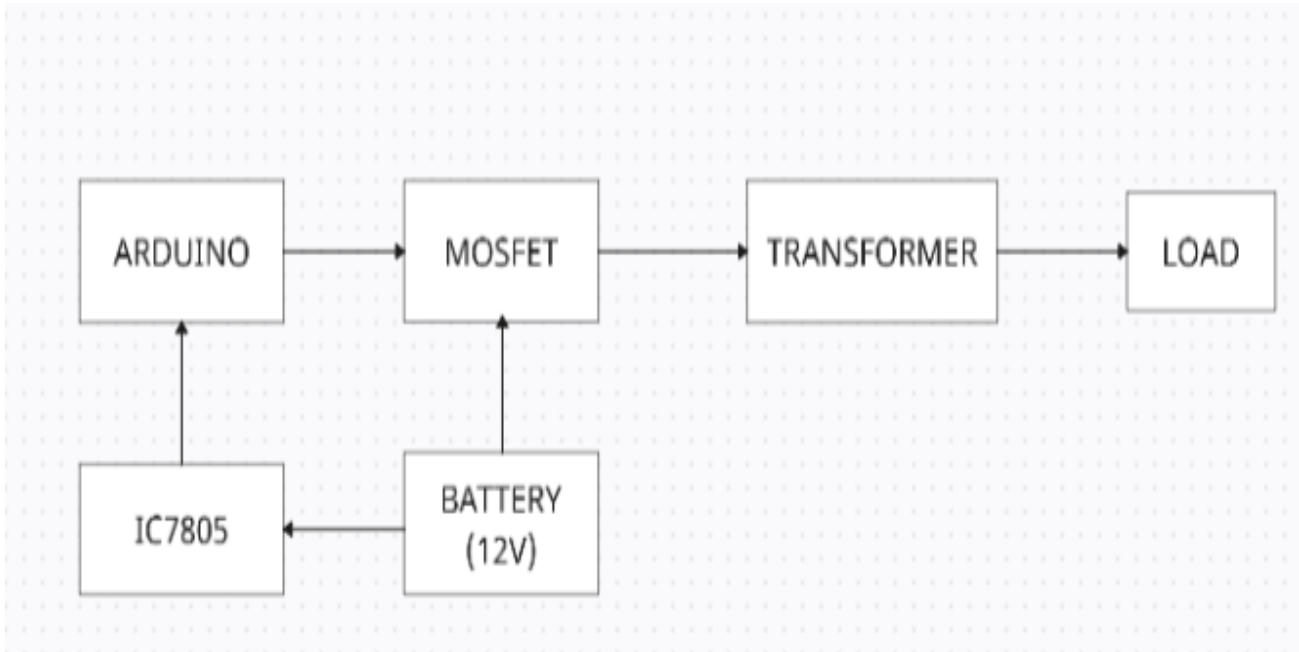


Figure 13: The block diagram of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.

The image describes an inverter system.

1. Arduino: This microcontroller acts as the brain of the system. It processes the sensor data and sends it to the Bluetooth module.
2. MOSFET: It is converting the dc voltage to ac voltage.
3. Transformer: It is increasing the voltage level.
4. Load: It is use as an indicator.
5. Battery: This provides the necessary power for all the components in the system.
6. IC7805: It is supplying 5 Volt for Arduino.

CIRCUIT DIAGRAM

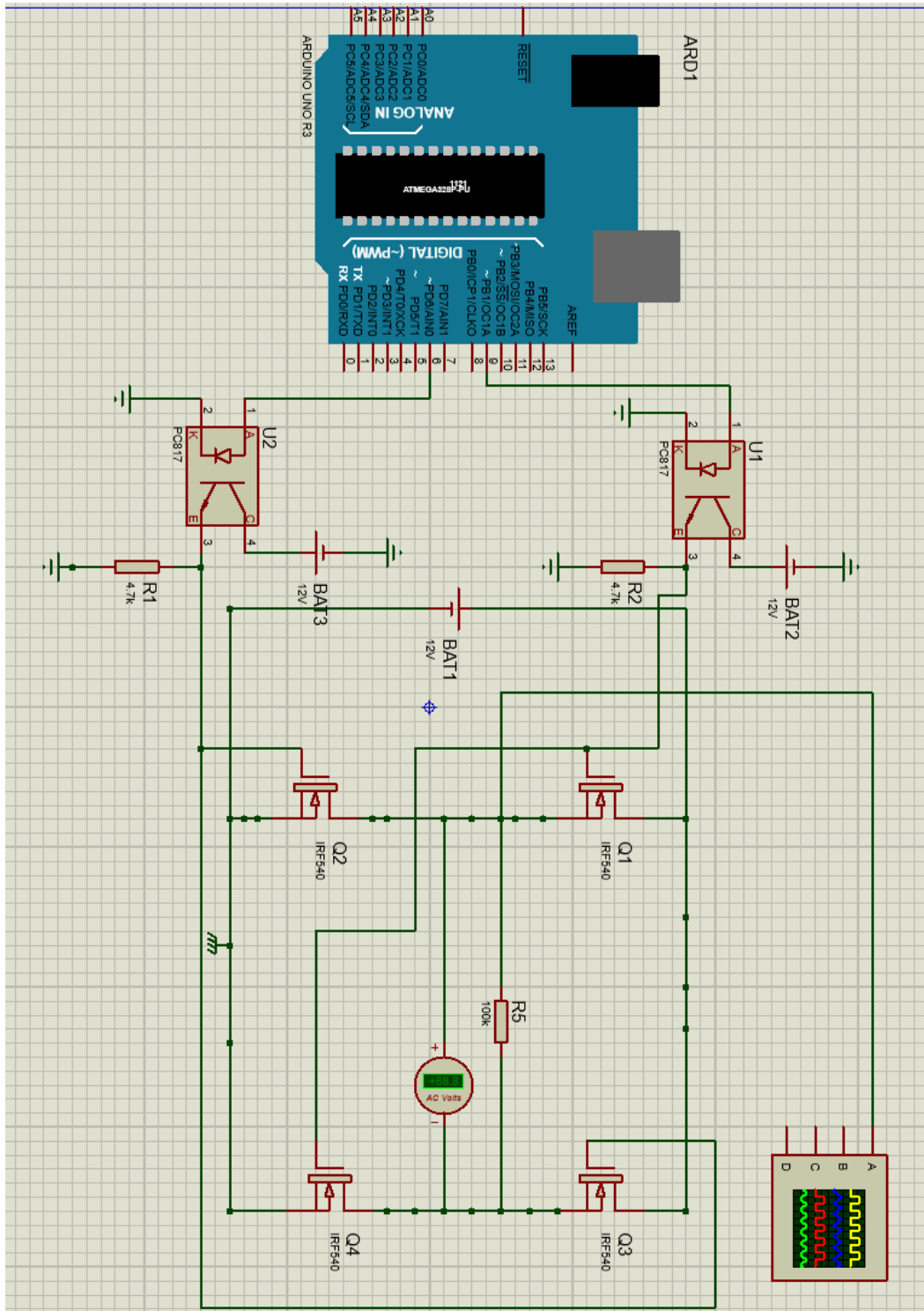


Figure 14: The circuit diagram of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion

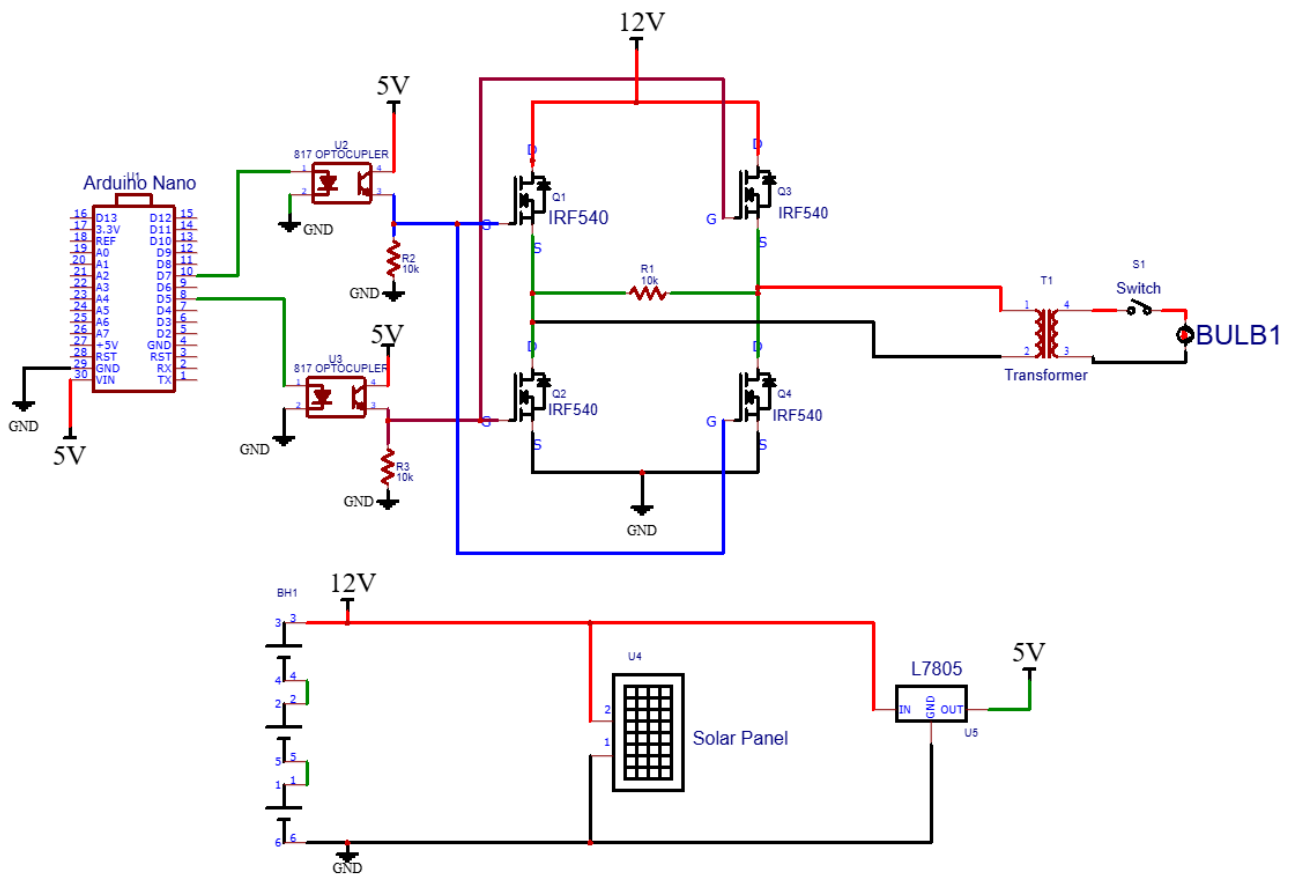


Figure 15: The circuit diagram of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.

PROJECT HARDWARE IMAGE



Figure16: The hardware image of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.

An H-Bridge inverter is a type of power conversion circuit that transforms DC (Direct Current) into AC (Alternating Current) using four switching devices, typically MOSFETs or IGBTs, arranged in an H-shaped configuration. This circuit is widely used in power electronics applications such as inverters, motor control, and renewable energy systems. The working principle of the H-Bridge inverter is based on the controlled switching of these four transistors to alternate the direction of current flow through the load, effectively generating an AC output from a DC source.

The H-Bridge consists of four MOSFETs (Q1, Q2, Q3, and Q4), a DC power supply (such as a battery or solar panel), and a load (such as a transformer or an AC appliance). The switching sequence determines the polarity of the voltage applied to the load, allowing it to produce an alternating waveform. In the first state, Q1 and Q4 are turned ON, while Q2 and Q3 remain OFF. This allows current to flow in one direction through the load, creating a positive voltage. In the next state, Q2 and Q3 are turned ON, while Q1 and Q4 are turned OFF, reversing the current flow and generating a negative voltage across the load. By continuously alternating between these two states, a square wave AC output is produced.

WORKING PRINCIPLE

An inverter is an electronic device that converts direct current (DC) power into alternating current (AC) power. This project utilizes an Arduino Nano, MOSFETs in an H-Bridge configuration, a step-up transformer, and a 12V battery to generate 220V AC output, which can be used to power an AC load such as a lamp. The inverter circuit operates by switching the DC voltage in a controlled manner to create an alternating signal, which is then stepped up to a usable voltage level.

The power supply for this inverter is a 12V battery, which serves as the primary energy source. The battery provides the necessary DC voltage to the circuit, which is then processed by other components to convert it into AC. To ensure the Arduino Nano operates efficiently, a voltage regulator IC 7805 is used to step down the 12V DC to a stable 5V DC supply, which is required for the microcontroller's operation.

The Arduino Nano plays a crucial role in this project as it generates the pulse-width modulation (PWM) signals that control the MOSFETs. These MOSFETs, arranged in an H-bridge configuration, act as high-speed electronic switches. The alternating switching of these MOSFETs creates a waveform that mimics

an AC signal. The frequency and duty cycle of the PWM signal are carefully controlled to produce a stable AC output.

Once the MOSFETs generate a low-voltage AC signal, it is fed into a step-up transformer. The function of the transformer is to increase the voltage from 12V AC to 220V AC, making it suitable for standard electrical appliances. Additionally, the transformer provides isolation between the low-voltage and high-voltage sections of the circuit, ensuring safety.

The output of the inverter can be connected to a lamp or any AC-powered device. When the inverter is switched on, the lamp lights up, indicating the successful conversion of DC power into AC. The use of MOSFETs ensures that power conversion is efficient, reducing energy loss. The Arduino-based design allows for flexibility, making it possible to modify the waveform or adjust the output frequency according to specific needs.

This inverter project offers several advantages, including efficient power conversion, low standby power consumption, and ease of control through the microcontroller. It is particularly useful for power backup applications, providing electricity during outages. It can also be integrated into renewable energy systems, such as solar or wind energy setups, where DC power needs to be converted into AC for household or industrial use. Additionally, it serves as a portable power supply for outdoor activities and can be used to run small AC appliances.

Overall, this inverter project demonstrates an effective method of converting low-voltage DC power into high-voltage AC power using a microcontroller and MOSFET-based switching. The step-up transformer ensures compatibility with standard AC appliances, making it a practical solution for emergency power and off-grid applications. The microcontroller-based control further enhances efficiency, providing precise control over the output waveform.

CHAPTER 4

RESULTS AND DISCUSSION

INTRODUCTION

A single-phase square wave inverter controlled by an Arduino is designed to convert 12V DC power into 220V AC using an H-bridge MOSFET switching circuit and a step-up transformer. The Arduino generates pulse-width modulation (PWM) signals to control the switching of four MOSFETs, which alternate the DC polarity to produce a square wave AC output. The transformer steps up the voltage to a usable level for powering AC loads. This system is simple, cost-effective, and suitable for basic power backup and low-power AC applications.

OUTPUT WAVEFORM

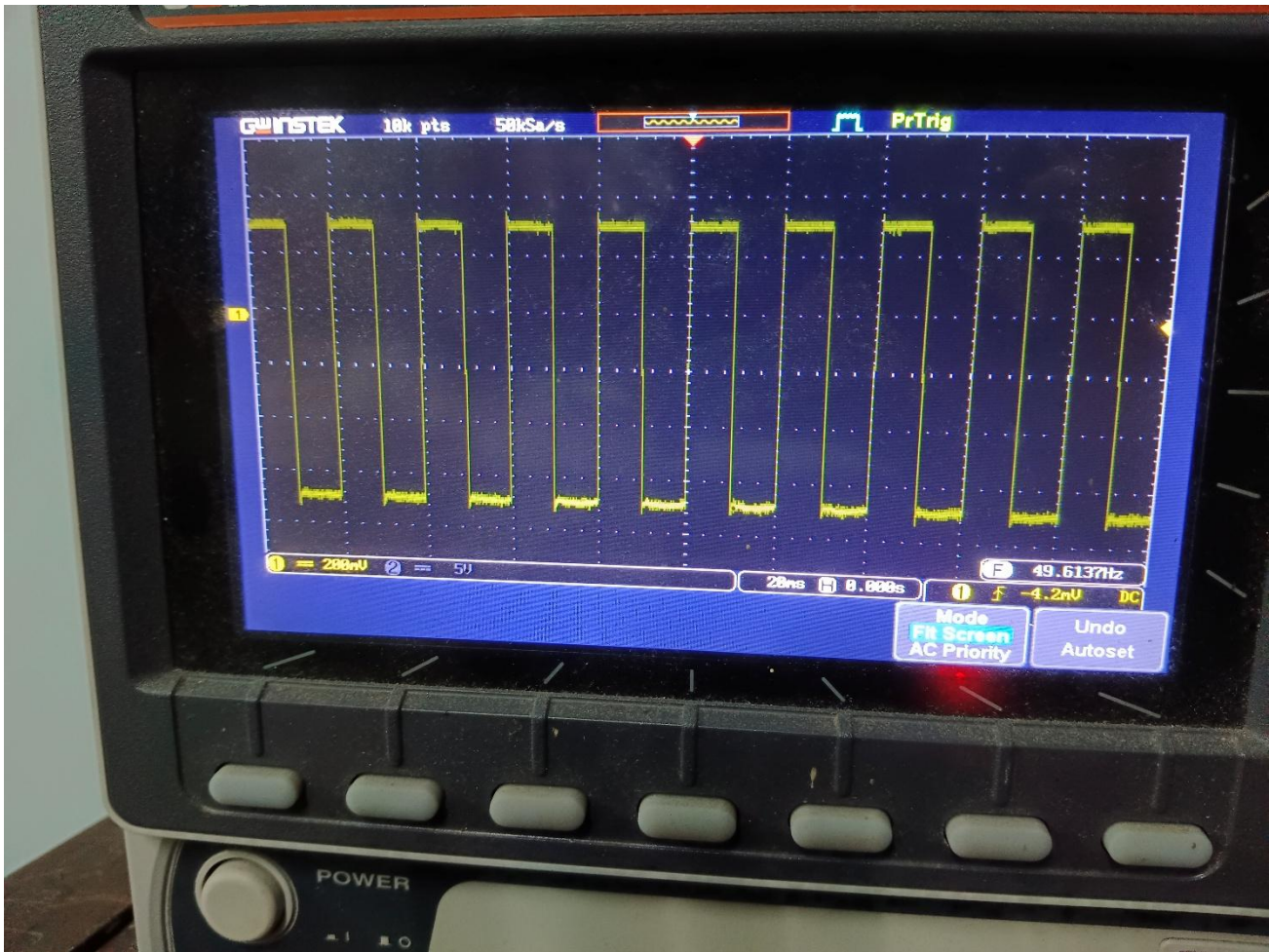


Figure17: The oscilloscope waveform of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.

DSO Output

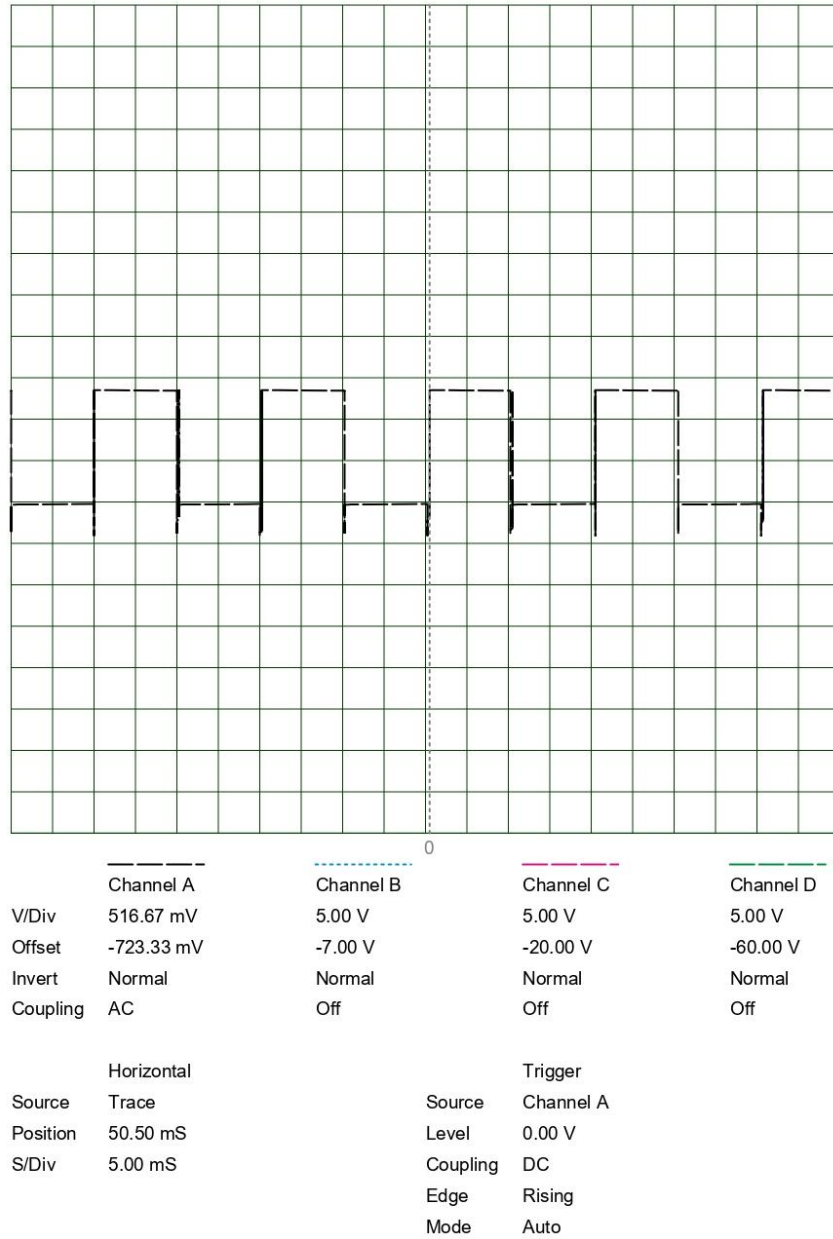


Figure18: The Proteus waveform of Design and Implementation of an Off-Grid Solar Photovoltaic System Integrated with an Inverter for Efficient DC to AC Conversion.

DISCUSSION

A single-phase square wave inverter controlled by an Arduino is designed to efficiently convert 12V DC power from a battery into 220V AC using an H-bridge switching circuit and a step-up transformer. This inverter consists of four MOSFETs arranged in an H-bridge configuration, an Arduino as the control unit, a transformer to step up the voltage, and a load to demonstrate the output. The primary function of this system is to generate a stable AC voltage suitable for powering basic electrical appliances.

The Arduino is responsible for generating precise pulse-width modulation (PWM) signals, which control the switching sequence of the MOSFETs. By alternately switching the MOSFETs on and off, the circuit creates an alternating polarity, producing a square wave AC output. This square wave signal is then fed into a step-up transformer, which increases the voltage from 12V AC to 220V AC, making it compatible with standard household appliances.

Upon testing the inverter, the results show that it effectively converts the low-voltage DC supply into a high-voltage AC output. A connected load, such as a lamp, operates efficiently, confirming the proper functioning of the circuit. The MOSFET-based switching ensures efficient power conversion, while the Arduino provides precise timing control for stable operation. However, since the inverter produces a square wave output, it is most suitable for resistive loads like incandescent bulbs and heating elements. Some sensitive electronic devices may experience performance issues due to harmonic distortion caused by the square wave signal.

Overall, this inverter offers a cost-effective and straightforward solution for converting DC power into AC, making it ideal for basic power backup applications, small household loads, and off-grid energy systems. The use of an Arduino for control enhances flexibility, allowing easy modifications to improve efficiency or adjust the output waveform as needed.

CHAPTER 5

PROJECT COST

Sl. No.	Components	Quantity	Unit Price	Total Cost
1	Arduino Nano	1	600	600
2	IRF 540	4	180	720
3	Battery	3	150	450
4	Transformer	1	800	800
5	Bulb	1	40	40
6	Diode	8	10	80
7	IC-7805	1	60	60
8	Resistor	20	80	80
9	Transistor	4	10	40
10	LED	5	5	15
11	Switch	5	10	50
12	PC817	4	150	600
13	Holder	1	50	50
14	Socket	1	30	30
15	Solar Panel	1	855	855
16	PCB Board	1	1700	1700
17	Vero-board	5	40	200
18	Male-Female Rail	10	50	500
19	Connection Wire	15	10	150

20	Soldering Lead	1	480	480
21	Glue stick	10	30	300
Total Cost				7800

CHAPTER 6

IMPACT ON FUTURE WORKS

1. Improving Waveform Quality

- Upgrade from a square wave to a pure sine wave or modified sine wave output to reduce harmonic distortion.
- Implement advanced PWM techniques and filtering circuits to smooth the waveform for better compatibility with electronic devices.

2. Voltage Regulation and Feedback System

- Integrate voltage and current sensing to maintain a stable AC output under varying loads.
- Enable the Arduino to dynamically adjust the PWM signals for improved efficiency and performance.

3. Increasing Power Capacity

- Use higher-rated MOSFETs and a more robust transformer to support higher loads.
- Improve heat dissipation and cooling mechanisms to ensure system stability under continuous operation.

4. Battery Charging and Monitoring

- Implement a built-in battery charging circuit to allow the inverter to function as a UPS (Uninterruptible Power Supply).
- Add battery health monitoring to track voltage, charge status, and temperature for enhanced reliability.

5. Wireless Monitoring and IoT Integration

- Incorporate Wi-Fi or Bluetooth modules for remote monitoring and control.
- Develop a mobile app or web interface to display real-time inverter performance, battery status, and power usage.

By implementing these improvements, the inverter can become more efficient, reliable, and versatile, making it suitable for a wide range of applications, including emergency backup, off-grid power systems, and renewable energy integration.

CONCLUSION

CONCLUSIONS

The implementation of a single-phase square wave inverter controlled by an Arduino successfully demonstrates the conversion of 12V DC into 220V AC using an H-bridge MOSFET switching circuit and a step-up transformer. The Arduino efficiently manages the switching process, ensuring a stable square wave output. The inverter effectively powers resistive loads like incandescent bulbs, making it suitable for basic power backup applications. However, due to harmonic distortion, it may not be ideal for sensitive electronic devices. Overall, this project provides a simple, cost-effective, and easily customizable solution for small-scale AC power generation, with potential improvements through waveform modification for better compatibility with various loads.

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