MARCH 2025

AUTOMATED ENERGY MONITORING SYSTEM

PROJECT REPORT

Submitted by

VISHWANTH A (7376211EE205)
GEMINI R (7376211EE117)
SAIRAM P (7376211EE166)
SANJAY S (7376211EE171)

In partial fulfilment for the award of the degreeof

BACHELOR OF ENGINEERING

in

ELECTRICAL AND ELECTRONICS ENGINEERING

BANNARI AMMAN INSTITUTE OF TECHNOLOGY
(An Autonomous Institution Affiliated to Anna University, Chennai)
SATHYAMANGALAM-638401

ANNA UNIVERSITY: CHENNAI 600 025

MARCH 2025

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Certified that this project report **"AUTOMATED ENERGY MONITORING SYSTEM"** is the bonafide work of **"VISHWANATH A(7376211EE205) GEMINI R(7376211EE117) SAIRAM P(7376211EE166) SANJAY S(7376211EE171)"** who carried out the project work under my supervision.

SIGNATURE	**SIGNATURE**
Ms. MAHEWARI T K	OORAPPAN GM
HEAD OF THE DEPARTMENT,	**ASSISTANT PROFESSOR**
Professor & Head,	Assistant Professor Level III
Department of Electrical and Electronics Engineering,	Department Of Mechatronics Engineering,
Bannari Amman Institute of Technology,	Bannari Amman Institute Of Technologe, Erode – 638401.
Erode – 638401.	

Submitted for Project Viva Voce examination held on ………………

Internal Examiner I

Internal Examiner II

DECLARATION

We affirm that the project work titled **"AUTOMATED ENERGY MONITORING SYSTEM"** being submitted in partial fulfilment for the award of the degree of **Bachelor of Engineering** in **Electrical and Electronics Engineering** is the record of original work done by us under the guidance of **Mr. OORAPPAN**, Assistant Professor Level III**,** Department of Mechatronics. It has not formed a part of any other project work(s) submitted for the award of any degree or diploma, either in this or any other University.

(Signature of candidate)

VISHWANATH A
(7376211EE205)

(Signature of candidate)

GEMINI R
(7376211EE117)

(Signature of candidate)

SAIRAM P
(7376211EE166)

(Signature of candidate)

SANJAY S
(7376211EE171)

I certify that the declaration made above by the candidates is true.

(Signature of the Guide)

Mr. OORAPPAN G M

Assistant Professor Level **-** III

ACKNOWLEDGEMENT

We would like to enunciate heartfelt thanks to our esteemed Chairman **Dr. S.V. Balasubramaniam**, and the respected Principal **Dr. C. Palanisamy,** for providing excellent facilities and support during the course of study in this institute.

We are grateful to **Ms. MAHESWARI K T**, **Head of the Department, Department of Electrical and Electronics Engineering,** for her valuable suggestions to carry out the project work successfully.

We wish to express our sincere thanks to Faculty guide **Mr. OORAPPAN G M, Assistant Professor**, **Department of Mechatronics Engineering,** for his constructive ideas, inspirations, encouragement, excellent guidance, and much needed technical support extended to complete our project work.

We would like to thank our friends, faculty and non-teaching staff who have directly and indirectly contributed to the success of this project.

VISHWANATH A (7376211EE205)

GEMINI R (7376211EE117)

SAIRAM P (7376211EE166)

SANJAY S (7376211EE171)

ABSTRACT

This project presents the design and implementation of a smart energy meter utilizing an Arduino microcontroller, an ILCD display, and precise AC voltage and current sensors to continuously monitor and calculate power consumption in real-time. This intelligent system aims to empower users with detailed insights into their energy usage by providing real-time measurements of the grid's electrical parameters. The energy meter integrates an AC voltage sensor and an AC current sensor, ambient temperature which capture voltage and current values as analog signals. These signals are then processed by the Analog-to-Digital Converter (ADC) and converted into root mean square (RMS) values for voltage and current, allowing for accurate calculation of real power (in watts). By incorporating an estimated power factor, the device accurately determines true energy consumption, enhancing reliability. The measured values are displayed in real-time on an LCD screen, offering a convenient, continuous visual representation of power usage. With its low-cost design, this energy meter is intended to be accessible for a broad range of applications, including residential energy monitoring, industrial equipment management, and commercial building usage, facilitating better energy control and cost-saving measures. To further extend its utility, the ESP8266 provides Wi-Fi capabilities, allowing for potential future integration with remote monitoring solutions. With this feature, users could track and analyze their energy consumption data over time through a mobile app or a web interface, supporting informed decision-making for optimized energy management.

The project emphasizes rigorous calibration procedures to ensure measurement accuracy and establishes safety protocols to safeguard users when interfacing with AC mains electricity. Calibration involves fine-tuning the sensors to accurately detect real-world power conditions, while safety measures protect against risks associated with high-voltage handling. In addition to enhancing users' control over their energy usage, this project contributes to promoting energy efficiency and sustainability. By offering a clear view of real-time and historical energy patterns, it encourages users to identify high-energy devices and adopt practices that reduce overall energy consumption. levels.

Key words: Smart energy meter, Arduino microcontroller, ILCD display, AC voltage sensor, AC current sensor, Real-time monitoring, Power consumption

GLOSSARY

- **Smart Energy Meter** – A device that measures and monitors electricity consumption in real time, providing users with detailed insights into their energy usage.

- **Arduino Microcontroller** – A programmable electronic component that processes input signals from sensors and controls output devices, forming the core of the smart energy meter.

- **ILCD Display** – An Interactive Liquid Crystal Display used to show real-time energy consumption data for user convenience.

- **AC Voltage Sensor** – A sensor that detects and measures the alternating current (AC) voltage level in an electrical system.

- **AC Current Sensor** – A device that measures the current flowing through an AC circuit, helping in the calculation of power consumption.

- **Real-time Monitoring** – The continuous measurement and display of electrical parameters as they change over time.

- **Power Consumption** – The amount of electrical energy used by a device or system over a given period, measured in watts.

- **Analog-to-Digital Converter (ADC**) – A component that converts analog electrical signals (from voltage and current sensors) into digital signals for processing by the microcontroller.

- **Root Mean Square (RMS) Values** – A mathematical method used to determine the effective voltage and current levels in an AC circuit.

- **Real Power (Watts)** – The actual power consumed by electrical devices, calculated using voltage, current, and power factor.

- **Power Factor** – A measure of how effectively electrical power is being used, affecting the efficiency of power consumption.

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CHAPTER-1

INTRODUCTION

1.1 GENERAL

The need for energy efficiency has never been more pressing, given the increase in global energy demands, fluctuating energy prices, and environmental concerns. As individuals, businesses, and industries alike strive to manage their energy usage more effectively, a shift towards smart energy management tools has emerged. Traditional energy meters, which provide only periodic energy usage reports, often limit users' ability to track, understand, and optimize their consumption. This limited access to data means that consumers are frequently unaware of inefficient energy patterns or high-usage periods that could be adjusted to reduce costs. In contrast, smart energy meters empower users with continuous, real-time insights into their energy consumption, enabling proactive management and more informed decisions regarding energy use.

This project aims to develop a smart energy meter system based on an ESP32 microcontroller, paired with an I2C LCD display and AC voltage and current sensors. The ESP32 microcontroller enables real-time monitoring and accurate calculation of energy metrics by processing signals from the AC sensors, which measure key parameters like voltage and current from the grid. By calculating root mean square (RMS) values for both voltage and current, the system accurately determines the real power consumed, considering the impact of the power factor on energy consumption. This smart meter thus offers an efficient, accessible solution to monitor real-time power use and provides consumers with the data they need to make effective energy decisions.

1.2 Background and Need for Real-Time Energy Monitoring

In traditional setups, energy meters log cumulative energy use over time without providing information on when and how energy is consumed. This lack of granularity hinders users' ability to identify specific consumption patterns or the impact of individual appliances on total usage. For example, a household may experience spikes in energy usage during certain hours, driven by specific high-power devices or inefficient equipment. Without real-time insights, users cannot easily detect and address these energy patterns, potentially leading to wasted energy and higher electricity bills. By contrast, a smart energy meter provides instant feedback on energy consumption, breaking down the total into moment-by-moment data and specific electrical parameters, such as voltage, current, and power.

Real-time energy monitoring also plays a critical role in supporting sustainable energy usage by promoting more mindful consumption behaviors. Through constant feedback, users can immediately see the impact of turning off unused appliances, setting thermostats efficiently, or adjusting lighting, which can help reduce overall consumption. Furthermore, in industrial or commercial contexts, understanding the exact consumption patterns of machinery and lighting systems enables facility managers to optimize operational costs and energy efficiency, ultimately improving the bottom line.

Technical Overview of the Smart Energy Meter

The smart energy meter in this project is designed to provide a comprehensive view of energy consumption by capturing voltage and current values from the grid, processing them with an ESP32 microcontroller, and displaying real-time results on an I2C LCD screen. The ESP32 serves as the heart of the system, with its built-in Analog-to-Digital Converter (ADC) converting the analog signals from the AC voltage and current sensors into digital values. These sensors output proportional signals that reflect the real-time voltage and current passing through the meter, enabling the ESP32 to compute RMS values for each.

Calculating RMS values is essential for accurate power measurement, as it accounts for fluctuations in voltage and current that occur in typical AC systems. Using these RMS values, the ESP32 calculates the real power in watts, considering an estimated power factor to provide a closer representation of actual energy use. The processed data is then displayed on an I2C-connected LCD screen, giving users an easily readable display of current voltage, current, and power consumption in real-time.

The system design also enables future scalability for remote monitoring. With the Wi-Fi capability of the ESP32, the smart energy meter can potentially be connected to a local network, making it accessible via mobile or web-based applications. Through remote monitoring, users can track and analyze their energy usage patterns over time, potentially receiving alerts for high consumption or abnormal energy patterns, which can help mitigate issues and reduce energy costs.

Safety and Calibration Considerations

Given that the smart energy meter interacts with AC mains electricity, safety is a paramount concern in its design and implementation. AC mains involve high voltage levels, which, if mishandled, can lead to electric shock or system damage. To address this, the project includes comprehensive safety measures such as insulation, protective enclosures, and proper grounding. This ensures that the user is protected from potential risks while interacting with the energy meter. Additionally, sensors are carefully chosen and calibrated to ensure accurate readings, even under varying electrical conditions, which is crucial for a reliable measurement system.

Calibration is another key element in the design, as accurate energy measurement depends on the correct interpretation of sensor data. Variability in AC power systems, such as fluctuations in supply voltage, can impact sensor readings and thus the reliability of the meter. Through proper calibration techniques, the system adjusts to these variances, ensuring that the displayed values for voltage, current, and power remain precise. This attention to accuracy and reliability strengthens the smart energy meter’s role as a dependable tool for real-time energy monitoring.

Applications and Impact of the Smart Energy Meter

The smart energy meter offers a range of applications across different sectors, with residential, commercial, and industrial users benefiting from its insights. In households, for instance, real-time energy data allows users to identify high-energy devices and adjust usage patterns to minimize costs. This becomes especially valuable in settings where energy rates fluctuate based on peak hours, as users can shift usage to off-peak times to save on electricity bills. In commercial buildings and industrial facilities, the smart energy meter can aid in monitoring and managing equipment energy use, which is essential for both operational efficiency and budget control.

The project aligns with broader sustainability goals, as smart energy meters contribute to reducing the environmental impact of excessive energy use. By raising awareness about energy consumption patterns, smart meters encourage more efficient usage and reduction of waste, supporting global efforts to cut down on carbon emissions. As a low-cost and accessible tool, this smart energy meter has the potential to be adopted widely, making it feasible for individuals and organizations to take proactive steps toward energy conservation and efficiency.

1.3 Future Prospects and Scalability

In addition to its current capabilities, this smart energy meter is designed with future enhancements in mind. The ESP32 microcontroller’s Wi-Fi functionality opens up the possibility for remote data access, allowing users to track and analyze energy data over time. With the integration of a mobile app or web interface, the system could provide data logging features, trend analysis, and even notifications for unusual consumption patterns. Such features could make energy management more comprehensive, offering users an extended view of their energy usage habits and helping them make more effective, long-term adjustments.

This project serves as a foundation for a scalable, user-friendly energy management system that meets modern needs for real-time data, cost-effectiveness, and sustainability. As energy costs continue to rise and the demand for electricity grows, the smart energy meter stands as a valuable solution for promoting efficient, informed energy use.

1.4 OBJECTIVE

The primary objective of this project is to design and implement a smart energy meter using an ESP32 microcontroller, AC sensors, and an I2C LCD display to deliver a low-cost, efficient solution for real-time monitoring and precise calculation of power consumption. Specific goals include:

- Real-Time Monitoring of Electrical Parameters: Develop a responsive system that continuously captures and displays voltage, current, and power consumption data, empowering users with immediate access to their energy usage and patterns.
- Accurate and Reliable Power Calculation: Implement advanced calculations to determine the root mean square (RMS) values of voltage and current, enabling accurate real power (in watts) readings that consider an estimated power factor for better precision in various electrical environments.
- Enhanced User Interface for Readable Energy Data: Utilize an I2C LCD display to show clear, real-time information on energy usage, making energy consumption data easily understandable and accessible to users in residential, commercial, or industrial settings.
- Energy Usage Tracking and Analysis: Provide a system that supports historical energy usage tracking, allowing users to analyze trends over time. This data will help identify high-energy appliances and peak usage periods, guiding cost-effective energy management decisions.
- Scalability for Remote and Mobile Access: Equip the ESP32 microcontroller with Wi-Fi capabilities, allowing for potential integration with mobile and web platforms to enable remote monitoring, data logging, and notifications on energy consumption, facilitating proactive energy management from anywhere.
- Implementation of Safety Protocols for AC Electricity Handling: Prioritize safety by incorporating insulation, protective enclosures, and grounding techniques, minimizing risks associated with handling AC mains power and ensuring user safety.
- Cost-Effective and Accessible Solution for Wide Adoption: Design the meter as an affordable, scalable solution suitable for broad use across households, businesses, and industries, making effective energy management tools accessible to a larger audience.

1.5 AIM OF THE PROJECT

The aim of this project is to develop a smart energy meter using an ESP32 microcontroller, I2C LCD display, and AC sensors, capable of accurately monitoring and calculating real-time power consumption. This device aims to provide users with instant insights into their energy usage, facilitating effective energy management and cost savings. Specifically, the project seeks to:

- Enable Real-Time Monitoring: Continuously measure and display voltage, current, and power consumption data, allowing users to monitor their energy use in real-time.
- Ensure Accuracy in Power Calculation: Utilize root mean square (RMS) calculations for precise measurement of real power (in watts) by accounting for variations in voltage, current, and estimated power factor.
- Enhance User Accessibility and Usability: Design an intuitive interface with an I2C LCD display for easy access to energy data, enabling users to track their consumption and identify high-usage periods.
- Promote Energy Efficiency: Encourage energy-saving habits by providing detailed usage data, helping users make informed decisions to reduce unnecessary energy consumption.
- Offer Scalability for Remote Monitoring: Leverage the ESP32's Wi-Fi capabilities to support future expansions into remote monitoring and data logging through mobile and web platforms.

CHAPTER-2

LITERATURE SURVEY

2.1 LITERATURE SURVEY

A. S. Alahmed and L. Tong, 2023 [1]

This paper explores the co-optimization of behind-the-meter resources under net metering, focusing on the efficient integration of distributed energy resources (DERs) such as solar panels, home batteries, and electric vehicles (EVs). The study aims to reduce energy costs for prosumers, who both produce and consume energy. By analyzing how solar energy production, EV charging, and battery storage can be strategically managed, the authors propose an optimization model that seeks to maximize energy self-consumption and minimize costs. The model includes the dynamics of energy production, consumption, and storage, while also accounting for varying tariff structures in net metering policies. The authors investigate how prosumers can make optimal decisions about energy usage and storage, considering factors such as electricity pricing and battery efficiency. Their findings suggest that proper energy management can significantly lower the costs of energy consumption and improve the economic efficiency of household energy systems.

Disadvantages: One limitation is the assumption of ideal market conditions and perfect forecasting, which may not hold in real-world scenarios. The optimization may not account for sudden price fluctuations or unexpected supply-demand mismatches, making the model less reliable in volatile markets.

S. Seal, B. Boulet, V. R. Dehkordi, F. Bouffard, G. Joos, 2023 [2]

This paper introduces a centralized Model Predictive Control (MPC) framework for home energy management systems, where electric vehicles (EVs) are used as mobile energy storage units. The paper focuses on optimizing the scheduling of household energy consumption and EV charging/discharging to minimize energy costs while ensuring that energy demands are met. Using real-time data on electricity prices and load forecasts, the MPC strategy adjusts the timing of appliance usage and EV charging to take advantage of low-cost energy periods and support grid stability. The model optimizes not only energy consumption but also leverages the flexibility of EVs as mobile storage to reduce demand during peak periods. By doing so, it enhances the overall efficiency of energy usage in homes, particularly in households equipped with solar energy systems. The results show a potential for significant energy cost savings and greater integration of renewable energy sources into residential energy management systems.

Disadvantages: The centralized MPC approach may not be scalable for larger communities or regions, and the reliance on a single point of control can create bottlenecks. Additionally, the model may fail to consider the varying charging patterns of EVs and their limited availability at times.

M. Jeon, L. Tong, Q. Zhao, 2023 [3]

In this work, the authors investigate the co-optimization of energy consumption and electric vehicle (EV) charging under net energy metering, aiming to reduce the overall energy costs for households. The paper explores how both the consumption behavior of prosumers and their EV charging schedules can be optimized to minimize the cost of electricity while maintaining a reliable energy supply. The model is designed to balance grid-supplied electricity and solar energy produced by residential solar panels, with an emphasis on maximizing self-consumption of renewable energy. By incorporating factors such as electricity tariffs, battery storage, and EV charging flexibility, the authors propose a strategy that allows prosumers to adjust their energy usage based on real-time pricing signals and energy availability. The results demonstrate how households can lower their energy bills through optimized scheduling of both consumption and EV charging, thus improving the overall efficiency of energy use in a net metering context.

Disadvantages: The optimization assumes that the EV charging can be controlled and that consumers follow the suggested schedule, which might not always be the case. This approach also overlooks practical constraints such as limited grid infrastructure and consumer reluctance to change behaviors.

B. Jeddi, Y. Mishra, G. Ledwich, 2020 [4]

This paper proposes a home energy management scheduler based on differential dynamic programming (DDP) to optimize energy consumption in residential settings. The goal is to minimize the household's energy costs while ensuring that comfort levels are maintained. The authors consider the complex dependencies between different appliances in the household and how their operational schedules impact overall energy demand. The DDP-based scheduler dynamically adjusts the operation of household appliances such as heating, cooling, and lighting, taking into account time-of-use tariffs, demand charges, and peak load periods. The model aims to reduce electricity costs by shifting appliance operation to off-peak hours, thus avoiding high-demand charges. Additionally, the scheduler attempts to maintain household comfort levels by considering constraints like temperature preferences and appliance usage patterns. The study shows that by using dynamic scheduling, households can significantly reduce their energy costs while maintaining a comfortable living environment.

Disadvantages: The approach can be computationally intensive, especially for large homes with many appliances. Additionally, it may struggle to handle real-time changes or emergencies like sudden appliance failures or power outages.

A. S. Alahmed and L. Tong, 2022 [5]

Summary: This paper investigates the integration of distributed energy resources (DERs) in residential energy systems and explores the optimal decisions for prosumers under various net metering tariffs. The authors analyze how prosumers, who both consume and produce energy, can optimize their energy use by considering factors like solar energy production, battery storage, and consumption patterns. The model examines different net metering schemes and how tariff structures affect prosumer decision-making. By integrating solar power, storage systems, and energy consumption scheduling, the authors propose strategies to maximize the economic benefits for prosumers, balancing the costs of grid-supplied electricity with the benefits of self-consumption. The study also addresses the potential impacts of varying tariff schemes on prosumer decisions, emphasizing the importance of pricing structures in promoting energy efficiency and the adoption of DERs. The results suggest that optimal integration of DERs can lead to significant cost savings for prosumers and promote sustainability.

Disadvantages: The study assumes that prosumers have full knowledge of energy production and consumption patterns, which may not always be the case due to the unpredictable nature of renewable resources like solar power. The study also does not consider regional regulatory differences, which can significantly affect outcomes.

K. Ashok, M.J. Reno, L. Blakely, D. Divan, 2019 [6]

This paper presents a systematic study of the data requirements and capabilities of Advanced Metering Infrastructure (AMI) for smart meter analytics, focusing on how accurate data can support home energy management. The authors investigate how smart meter data, including real-time consumption data and grid information, can be used to optimize energy use, improve grid operations, and reduce costs. The study evaluates the requirements for high-quality data, including frequency, accuracy, and timeliness, necessary for effective analytics. The paper discusses the role of AMI in enabling dynamic pricing models, load forecasting, and energy demand response programs, helping utilities better manage grid loads and optimize energy distribution. Additionally, the study examines the potential of integrating smart meters with other grid technologies, such as demand response systems and distributed energy resources. The authors highlight the importance of reliable and high-frequency data for driving smart grid innovations and improving energy efficiency at the residential level.

M.A. Devlin, B.P. Hayes, 2019

Summary: This paper focuses on non-intrusive load monitoring (NILM) techniques to classify the activities of daily living (ADLs) using residential smart meter data. NILM disaggregates the total energy consumption data from a smart meter into the energy usage of individual appliances, without the need for additional sensors. The authors apply this technology to classify activities such as cooking, heating, and lighting based on the energy signatures of appliances. By analyzing consumption patterns, the system can help households monitor their energy use more effectively, enabling more efficient energy management. The paper also discusses how NILM can be used to enhance demand-side management by identifying opportunities to reduce energy waste and shift consumption to off-peak periods. The approach provides valuable insights into how residents can optimize their energy usage and reduce their carbon footprint while maintaining comfort. It also highlights the potential of NILM to enable advanced energy monitoring and activity recognition in residential settings.

F. Luo, W. Kong, G. Ranzi, Z. Y. Dong, 2020

Summary: This paper proposes an optimal home energy management system that considers both demand charge tariffs and appliance operational dependencies to minimize overall energy costs. The authors focus on how appliances within a household can be scheduled in a way that maximizes energy efficiency while minimizing the impact of demand charges, which are based on peak energy usage. The system takes into account the operational dependencies between different appliances—such as the need for certain appliances to run simultaneously—and optimizes the timing of their operation. By adjusting the appliance schedules based on the time-of-use pricing and demand charges, the system reduces the household's total electricity costs. The model also addresses issues such as the limited flexibility of certain appliances and the varying power demands of different household devices. The results indicate that by using this optimal scheduling approach, households can significantly reduce their energy expenses while ensuring that comfort and convenience are not compromised.

B. S. England, A. T. Alouani, 2020

Summary: This paper explores real-time voltage stability prediction in smart grids using smart meter data and improved Thevenin estimates. The authors propose a method for monitoring voltage stability in smart grid areas by using real-time data from smart meters to estimate voltage conditions and predict potential stability issues. By combining smart meter data with improved Thevenin equivalents, the system can provide more accurate predictions of voltage instability in the grid. The model aims to enhance grid reliability by providing early warnings of voltage fluctuations, enabling more proactive grid management. The results show that this approach can significantly improve voltage regulation, reduce the likelihood of power outages, and support more efficient energy distribution. By relying on real-time data from smart meters, the system allows for more responsive and adaptive voltage control, helping utilities maintain grid stability even in the face of dynamic changes in demand and supply.

D. Cao, W. Hu, J. Zhao, Q. Huang, Z. Chen, F. Blaabjerg, 2020

Summary:This paper introduces a multi-agent deep reinforcement learning (DRL) approach for voltage regulation in smart grids using coordinated photovoltaic (PV) inverters. The authors propose a decentralized system in which multiple agents, representing individual PV inverters, coordinate with each other to regulate voltage in a smart grid. The agents use deep reinforcement learning to optimize the operation of inverters, adjusting their power output to maintain voltage stability across the grid. The system can dynamically respond to changes in grid conditions, such as fluctuations in renewable energy generation or sudden changes in demand. The approach enables a more flexible and adaptive grid operation, particularly in regions with high penetration of solar energy. The paper shows that this method can improve voltage regulation, enhance grid stability, and allow for better integration of renewable energy sources into the grid. The multi-agent system is capable of learning optimal strategies for voltage regulation, even in the presence of uncertainty and variability in the grid conditions.

CHAPTER-3

3.1 EXISTING SYSTEM:

Current energy monitoring systems vary in complexity and capability, ranging from simple analog meters to advanced smart meters. However, each of these systems comes with certain limitations in terms of real-time data access, ease of use, and user control over energy consumption patterns. Here’s an in-depth look at existing systems and their key features:

3.1.1 Analog and Digital Energy Meters:

Analog meters, still widely used in residential and industrial setups, measure cumulative energy consumption over time and display it on a mechanical dial. While these meters are cost-effective and reliable, they lack the ability to track real-time consumption or provide data on individual appliances. Digital meters are an upgrade, offering clearer readings and greater accuracy.

3.1.2 Utility-Provided Smart Meters:

Many utility companies now install smart meters for remote data collection and grid management. These meters allow two-way communication between the utility and the consumer, enabling features like remote meter readings, demand response, and dynamic pricing. While smart meters benefit utility providers by helping manage peak loads and improve billing accuracy, the information available to consumers is often limited.

3.1.3.Home Energy Monitoring Systems:

With the rise of smart homes, various devices such as energy monitoring plugs and smart sockets offer detailed monitoring of individual appliances. These plug-level monitors provide real-time data on device-specific consumption, helping users identify energy-hungry appliances. However, these systems only capture isolated parts of total household usage and often require multiple devices to achieve comprehensive monitoring. Additionally, the installation of numerous individual sensors can be costly and impractical for users who need an overview of entire property energy usage.

3.1.4 Building Management Systems (BMS):

In commercial and industrial settings, Building Management Systems (BMS) provide centralized monitoring of electrical systems, HVAC, lighting, and other facilities, often integrating with IoT technology for real-time analytics. However, BMS are complex, costly, and typically tailored to larger buildings or industrial plants. Smaller facilities or residential users often lack access to such advanced systems, as they are financially and logistically out of reach for individual consumers or smaller businesses.

3.1.5 Limitations of Existing Systems:

- Lack of Granular, Real-Time Data: Most conventional meters do not provide instant feedback, so users lack the immediate insights needed to adjust consumption patterns effectively.
- Limited User Interaction and Control: Utility smart meters are often managed by the service provider, which restricts the level of detail accessible to the end-user.
- Cost and Complexity for Comprehensive Solutions: BMS and plug-level systems can be costly and impractical, especially for residential or small business settings.

3.1.6 Need for a Comprehensive, User-Centric Solution

- Provide Real-Time Monitoring and Data Display: Allow users to see voltage, current, and power usage continuously to identify usage spikes or specific periods of high consumption.
- Be Accessible and Low-Cost: Make energy monitoring affordable for a wide audience, enabling individual households and small businesses to access reliable energy data without incurring high costs.

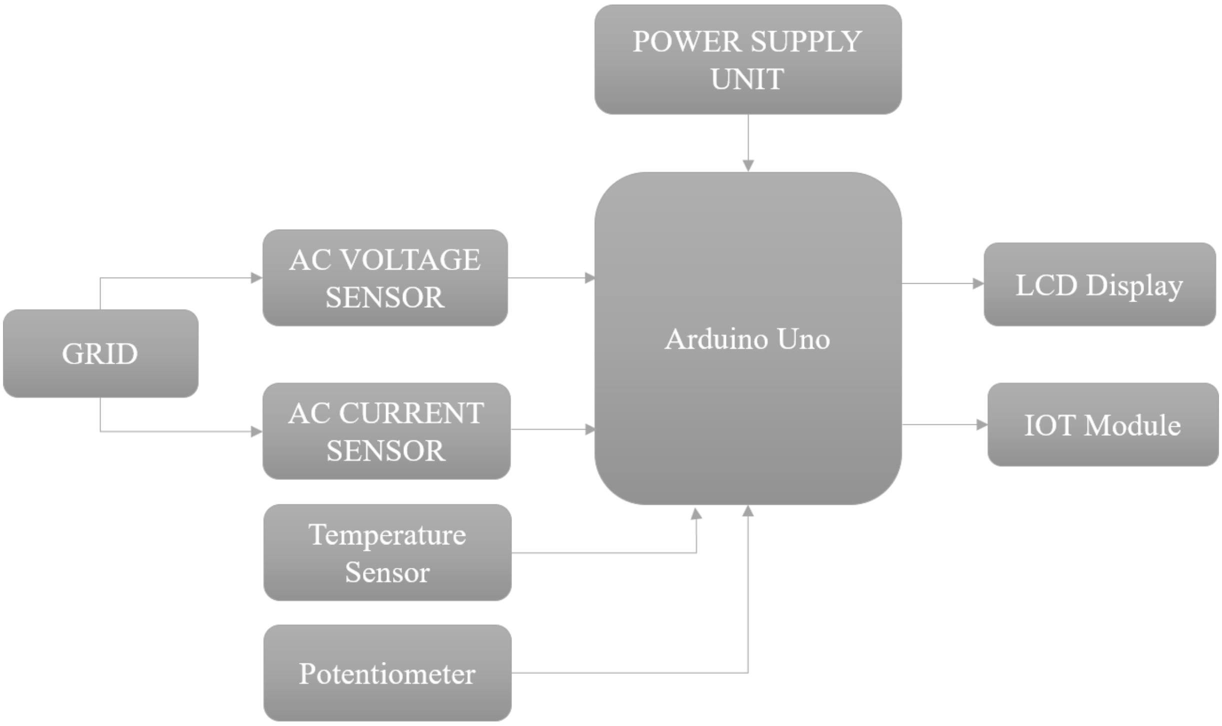
- Enable Remote Monitoring and Data Logging: Support future scalability with connectivity features like Wi-Fi, allowing users to track their usage remotely through mobile apps or web portals for more efficient energy management.
- Combine Simplicity with Flexibility: Offer an intuitive interface with clear energy data displays while maintaining flexibility to monitor total energy usage or specific patterns based on user needs.

3.2 PROPOSED SYSTEM

The proposed Automated Energy Monitoring System is designed to provide real-time monitoring, control, and analysis of key electrical parameters such as voltage, current, power consumption, and ambient temperature. By integrating Internet of Things (IoT) technology, this system enables remote access to real-time data, empowering users to make informed decisions and optimize energy consumption. The system leverages microcontrollers, sensors, and communication modules to measure, process, and transmit data to a cloud-based platform or mobile application, ensuring seamless monitoring and efficient management of energy usage. At the core of the system lies an Arduino Uno microcontroller, which acts as the central processing unit responsible for collecting data from various sensors and executing control commands. The voltage and current sensors continuously monitor the AC electrical parameters, capturing real-time values that are processed to calculate power consumption. A power calculation algorithm dynamically computes the power used by the connected load based on the measured voltage and current values. The system also includes a temperature sensor that monitors the ambient temperature of the environment where the electrical equipment operates. Monitoring the temperature is crucial to detect potential overheating and ensure the safety and longevity of electrical devices. To facilitate cost analysis and billing, the system incorporates a potentiometer that allows users to adjust the unit cost of electricity. By setting the appropriate unit cost, users can view the real-time cost of their electricity consumption, ensuring accurate billing. This feature is particularly useful in dynamic pricing scenarios where electricity tariffs fluctuate based on demand, time of day, or other factors. The real-time cost information is displayed on an LCD screen, allowing users to monitor energy usage and associated costs at a glance.

A key component of the proposed system is the integration of an ESP8266 Wi-Fi module, which enables seamless connectivity to the internet. The ESP8266 module establishes a wireless connection between the monitoring system and a cloud platform, enabling users to remotely monitor and control their energy consumption through a web-based interface or mobile application. The IoT-enabled remote access allows users to stay informed about their energy usage even when they are away from the premises, providing greater flexibility and control. Through the web interface, users can access historical data, analyze trends, and receive alerts about abnormal energy consumption patterns. The system is designed to promote energy efficiency by identifying trends and inefficiencies in energy usage. By analyzing the collected data over time, the system can generate insights that enable users to take corrective actions and reduce energy wastage. For instance, the system can identify peak load times, excessive power usage, or potential equipment malfunctions, allowing users to implement measures to optimize energy consumption and lower their electricity bills. The data analytics capability of the system ensures that users gain a comprehensive understanding of their energy usage patterns, facilitating better decision-making for energy management. The system's real-time data collection and analysis capabilities make it highly suitable for various applications, including residential, commercial, and industrial environments. In residential settings, users can monitor household energy consumption and take steps to reduce unnecessary usage. Commercial establishments can leverage the system to optimize energy usage across multiple devices and reduce operational costs. In industrial settings, the system can be used to monitor critical equipment and ensure that energy usage remains within optimal limits, preventing downtime and enhancing operational efficiency. To ensure the reliability and accuracy of the system, calibration and testing are conducted during the initial setup phase. The voltage and current sensors are calibrated to provide precise measurements, while the temperature sensor is tested for accuracy in diverse environmental conditions. The system undergoes rigorous testing to validate its performance under varying load conditions, ensuring that it delivers consistent and reliable data. The calibration and testing process ensures that the system maintains high levels of accuracy in energy monitoring and cost analysis. The proposed system is also designed with scalability and flexibility in mind, allowing it to be easily adapted for different use cases and expanded to accommodate additional sensors or devices. The modular architecture of the system enables seamless integration of new features or components without requiring significant modifications to the existing infrastructure. This scalability makes the system future-proof, allowing it to evolve in line with technological advancements and changing user requirements. One of the standout features of the proposed system is its ability to provide actionable insights through advanced data analytics. The collected data is processed and analyzed using machine learning algorithms to identify anomalies, predict potential faults, and optimize energy usage. The system can generate detailed reports that highlight trends, anomalies, and recommendations for improving energy efficiency. By leveraging predictive analytics, the system can anticipate potential failures or inefficiencies and notify users before they escalate, enabling proactive maintenance and minimizing downtime. The user interface of the system is designed to be intuitive and user-friendly, ensuring that users of all technical backgrounds can easily navigate and interpret the data. The LCD screen provides real-time updates on voltage, current, power, and temperature, while the web interface or mobile application offers a more detailed view of historical data, trends, and alerts. Users can configure personalized alerts to receive notifications when energy consumption exceeds predefined thresholds or when abnormal conditions are detected. This level of customization ensures that the system meets the specific needs and preferences of individual users. Security is a critical aspect of the proposed system, given the sensitive nature of energy consumption data. The system employs robust encryption protocols to protect data transmitted between the monitoring system and the cloud platform. Authentication mechanisms are implemented to ensure that only authorized users have access to the system, preventing unauthorized access and data breaches. Regular security audits and firmware updates are conducted to safeguard the system against emerging threats and vulnerabilities. The proposed system also includes a fault detection and alert mechanism that enhances the safety and reliability of the monitored equipment. If the system detects any anomalies, such as abnormal voltage or temperature levels, it triggers an immediate alert to notify the user and relevant authorities. The alert can be delivered via SMS, email, or push notifications, ensuring prompt intervention to prevent equipment damage or hazardous situations. This proactive fault detection capability minimizes the risk of costly equipment failures and ensures the continued safety of electrical systems. In addition to real-time monitoring and control, the system supports data logging and storage for future reference. Historical data is stored on the cloud platform, allowing users to access and analyze past energy usage patterns. This historical data is invaluable for conducting energy audits, identifying areas for improvement, and implementing energy-saving measures. The data storage capability ensures that users have a comprehensive record of their energy consumption, facilitating long-term energy management and optimization. To further enhance the system's functionality, integration with smart home or building automation systems is also possible. By interfacing with smart appliances and control systems, the energy monitoring system can automate energy-saving actions, such as turning off unnecessary devices during peak load times or adjusting temperature settings to optimize energy usage. This level of automation maximizes energy efficiency and reduces operational costs without requiring constant manual intervention. The system is designed to be cost-effective and easy to install, making it accessible to a wide range of users. The use of readily available components such as Arduino Uno, ESP8266, voltage and current sensors, and LCD screens ensures that the system remains affordable without compromising on performance or reliability. The installation process is straightforward, with clear instructions provided to guide users through the setup and configuration steps. Once installed, the system requires minimal maintenance, making it a hassle-free solution for long-term energy monitoring. The proposed system is also aligned with the principles of sustainability and environmental responsibility. By enabling users to monitor and optimize their energy consumption, the system contributes to reducing carbon emissions and minimizing the environmental impact of energy usage. Promoting energy efficiency through data-driven insights empowers users to adopt sustainable energy practices and reduce their overall carbon footprint. The proposed Automated Energy Monitoring System offers a comprehensive solution for real-time energy monitoring, cost analysis, and remote access through IoT technology. The system empowers users to take control of their energy usage, optimize consumption patterns, and reduce operational costs. Its advanced features, including real-time data visualization, remote monitoring, predictive analytics, fault detection, and smart automation, make it an invaluable tool for residential, commercial, and industrial applications. The system's scalability, security, and user-friendly interface ensure that it meets the diverse needs of modern energy management while promoting sustainability and energy efficiency.

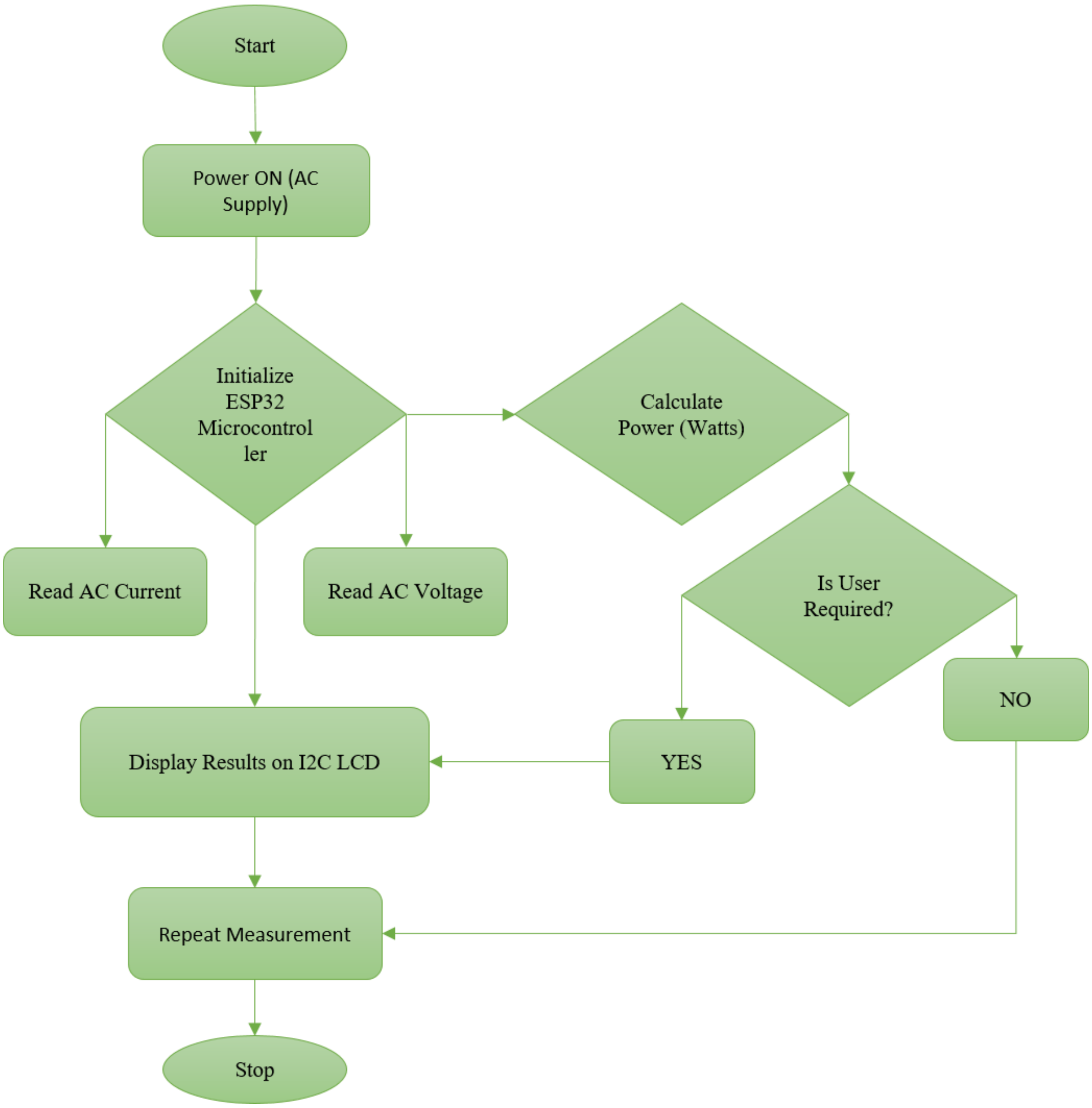
3.2.1 BLOCK DIAGRAM



3.2.2 BLOCK DIAGRAM EXPLANATION

The proposed smart energy meter system features a comprehensive block diagram that illustrates the interconnections between its key components. At the center of the system is the ESP32 microcontroller, which acts as the processing unit, performing essential calculations and data management. It receives data from two crucial sensors: the AC voltage sensor and the AC current sensor. The AC voltage sensor is connected in parallel to the AC load, where it accurately measures the voltage across the load and outputs a scaled-down DC signal proportional to this voltage. This allows the ESP32 to monitor the grid's voltage levels effectively. Similarly, the AC current sensor is integrated in series with the load to measure the current flowing through the circuit, producing an analog voltage output that corresponds to the instantaneous current flow. These sensor outputs are directed to the analog input pins of the ESP32, enabling it to calculate the real power consumption in watts using the formula P = V × I × Power Factor, thereby accounting for any reactive components in the load. The processed data is then displayed on an I2C LCD screen, which connects to the ESP32 via the I2C communication protocol. This connection allows for efficient communication with just two wires, facilitating a user-friendly interface for viewing real-time energy consumption, voltage, and current values.

3.2.3 FLOW CHAT



3.2.4 ADVANTAGES

- Real-Time Insight and Cost Savings: The system empowers users to manage their energy consumption more effectively by providing real-time data, helping them identify high-usage appliances and peak times to make timely adjustments, potentially leading to cost savings.
- Scalable and Accessible Monitoring Solution: With Wi-Fi connectivity, users can remotely monitor their energy consumption, enabling long-term tracking and analysis. This feature makes the system scalable, allowing it to be integrated into larger smart home or industrial monitoring solutions.
- User-Centric and Sustainable Design: By offering an intuitive, affordable energy monitoring tool, the proposed system encourages sustainable energy use practices, promoting energy conservation and helping users make informed choices toward a greener lifestyle.

3.2.5 APPLICATIONS

- Household Energy Management: Homeowners can use the system to track their daily energy use, reduce high-consumption periods, and cut down on unnecessary energy waste, which can help lower utility bills.
- Commercial and Industrial Energy Monitoring: Businesses can leverage the system to monitor specific equipment or track overall consumption, helping them improve operational efficiency and reduce overhead costs.
- Educational and Research Applications: The smart energy meter can serve as an educational tool for students and researchers studying energy management, providing hands-on experience with real-time data and energy measurement techniques.

CHAPTER-4

SOFTWARE REQUIREMENT

4.1 ARDUINO IDE

The Arduino integrated development environment (IDE) is a cross-platform application (for Windows, macOS, Linux) that is written in the programming language Java. It is used to write and upload programs to Arduino board. The source code for the IDE is released under the GNU General Public License, version 2. The Arduino IDE supports the languages C and C++ using special rules of code structuring.[4] The Arduino IDE supplies a software library from the Wiring project, which provides many common input and output procedures. User-written code only requires two basic functions, for starting the sketch and the main program loop, that are compiled and linked with a program stub main() into an executable cyclic executive program with the GNU tool chain, also included with the IDE distribution.[5] The Arduino IDE employs the program avrdude to convert the executable code into a text file in hexadecimal encoding that is loaded into the Arduino board by a loader program in the board's firmware.

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board

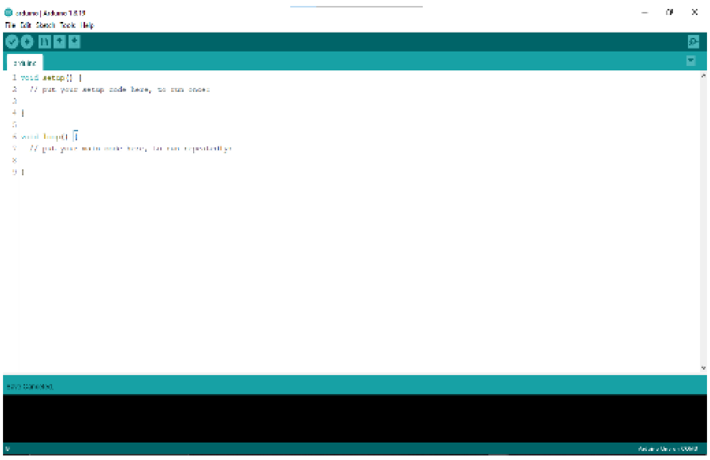


Fig 4.1: Arduino IDE

The Arduino IDE

The Arduino IDE is incredibly minimalistic, yet it provides a near-complete environment for most Arduino-based projects. The top menu bar has the standard options, including “File” (new, load save, etc.), “Edit” (font, copy, paste, etc.), “Sketch” (for compiling and programming), “Tools” (useful options for testing projects), and “Help”. The middle section of the IDE is a simple text editor that where you can enter the program code. The bottom section of the IDE is dedicated to an output window that is used to see the status of the compilation, how much memory has been used, any errors that were found in the program, and various other useful messages.

Projects made using the Arduino are called sketches, and such sketches are usually written in a cut-down version of C++ (a number of C++ features are not included). Because programming a microcontroller is somewhat different from programming a computer, there are a number of device-specific libraries (e.g., changing pin modes, output data on pins, reading analog values, and timers). This sometimes confuses users who think Arduino is programmed in an “Arduino language.” However, the Arduino is, in fact, programmed in C++. It just uses unique libraries for the device.

The Arduino Integrated Development Environment - or Arduino Software (IDE) - contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino and Genuino hardware to upload programs and communicate with them.

Programs written using Arduino Software (IDE) are called **sketches**. These sketches are written in the text editor and are saved with the file extension .ino. The editor has features for cutting/pasting and for searching/replacing text. The message area gives feedback while saving and exporting and also displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information. The bottom righthand corner of the window displays the configured board and serial port. The toolbar buttons allow you to verify and upload programs, create, open, and save sketches, and open the serial monitor.

LIBRARIES

Libraries provide extra functionality for use in sketches, e.g. working with hardware or manipulating data. To use a library in a sketch, select it from the **Sketch > Import Library** menu. This will insert one or more **#include** statements at the top of the sketch and compile the library with your sketch. Because libraries are uploaded to the board with your sketch, they increase the amount of space it takes up. If a sketch no longer needs a library, simply delete its **#include** statements from the top of your code.

There is a list of libraries in the reference. Some libraries are included with the Arduino software. Others can be downloaded from a variety of sources or through the Library Manager. Starting with version 1.0.5 of the IDE, you do can import a library from a zip file and use it in an open sketch.

CONNECTING THE ARDUINO

Connecting an Arduino board to your PC is quite simple. On Windows:

1. Plug in the USB cable - one end to the PC, and one end to the Arduino board.

2. When prompted, select "Browse my computer for driver" and then select the folder to which you extracted your original Arduino IDE download.

3. You may receive an error that the board is not a Microsoft certified device - select “Install anyway.”

4. Your board should now be ready for programming.

When programming your Arduino board it is important to know what COM port the Arduino is using on your PC. On Windows, navigate to Start->Devices and Printers, and look for the Arduino. The COM port will be displayed underneath.

Alternatively, the message telling you that the Arduino has been connected successfully in the lower-left hand corner of your screen usually specifies the COM port is it using.

PREPARING THE BOARD

Before loading any code to your Arduino board, you must first open the IDE. Double click the Arduino .exe file that you downloaded earlier. A blank program, or "sketch," should open.

The Blink example is the easiest way to test any Arduino board. Within the Arduino window, it can be found under File->Examples->Basics->Blink.

Before the code can be uploaded to your board, two important steps are required.

1. Select your Arduino from the list under Tools->Board. The standard board used in RBE 1001, 2001, and 2002 is the Arduino Mega 2560, so select the "Arduino Mega 2560 or Mega ADK" option in the dropdown.

2. Select the communication port, or COM port, by going to Tools->Serial Port.

If you noted the COM port your Arduino board is using, it should be listed in the dropdown menu. If not, your board has not finished installing or needs to be reconnected.

LOADING CODE

The upper left of the Arduino window has two buttons: A checkmark to Verify your code, and a right-facing arrow to Upload it. Press the right arrow button to compile and upload the Blink example to your Arduino board.

The black bar at the bottom of the Arduino window is reserved for messages indicating the success or failure of code uploading. A "Completed Successfully" message should appear once the code is done uploading to your board. If an error message appears instead, check that you selected the correct board and COM port in the Tools menu, and check your physical connections.

If uploaded successfully, the LED on your board should blink on/off once every second. Most Arduino boards have an LED prewired to pin 13.

It is very important that you do not use pins 0 or 1 while loading code. It is recommended that you do not use those pins ever. Arduino code is loaded over a serial port to the controller. Older models use an FTDI chip which deals with all the USB specifics. Newer models have either a small AVR that mimics the FTDI chip or a built-in USB-to-serial port on the AVR micro-controller itself.

4.2 HARDWARE REQUIREMENT

ESP32 MICROCONTROLLER

The ESP32 is an exceptionally versatile and powerful microcontroller designed for a wide range of Internet of Things (IoT) applications. Developed by Espressif Systems, it integrates advanced features, including built-in Wi-Fi and Bluetooth capabilities, which facilitate seamless connectivity to the internet and other devices. At its core, the ESP32 is powered by a dual-core Tensilica LX6 processor, capable of running at speeds up to 240 MHz, enabling it to handle multiple tasks simultaneously. This makes it suitable for complex applications that require significant processing power, such as real-time data analytics and control systems.

With 520 KB of SRAM and the ability to support external SPI flash memory of up to 16 MB, the ESP32 can accommodate extensive programming and data logging requirements. Its rich set of peripherals includes up to 34 programmable GPIO pins, ADC (Analog-to-Digital Converters) with 12-bit resolution, and DAC (Digital-to-Analog Converters) for generating audio signals or other analog outputs. The presence of various communication protocols, such as SPI, I2C, and UART, allows for easy integration with a multitude of sensors and devices, enhancing its applicability across various projects.

Power management is another strength of the ESP32, featuring several power-saving modes that are particularly beneficial for battery-operated devices. These modes allow the microcontroller to enter deep sleep states, significantly reducing power consumption when the device is idle. Furthermore, robust security features, including hardware encryption (AES, SHA-2), secure boot, and flash encryption, ensure secure communication and data integrity, which are essential for many IoT applications where data security is paramount.

The ESP32 is widely supported by various development environments, including the Arduino IDE and Espressif's own IoT Development Framework (ESP-IDF), which provide extensive libraries and examples to accelerate the development process. Its applications span diverse fields, from smart home devices that automate lighting and security systems to wearable technology for fitness tracking and health monitoring. The microcontroller is also used in environmental monitoring systems that measure temperature, humidity, and air quality, as well as in industrial automation for monitoring equipment performance and controlling automated processes. In the realm of robotics, the ESP32 serves as a central control unit, facilitating wireless communication and sensor integration for complex robotic systems.

In conclusion, the ESP32 stands out as a highly capable and adaptable microcontroller, combining performance, versatility, and extensive connectivity features in a compact package. Its dual-core architecture and comprehensive set of peripherals make it an excellent choice for a wide variety of applications in the ever-expanding field of IoT. Whether for simple hobbyist projects or sophisticated industrial solutions, the ESP32 continues to gain popularity among developers and engineers for its performance, ease of use, and robust feature set, ultimately paving the way for innovative technological advancements in numerous domains.

Fig4.2 : **ESP32 PIN**

ESP32 PIN FUNCTIONS

- GPIO Pins: Up to 34 configurable General Purpose Input/Output pins for versatile applications. These pins can be programmed for digital input or output, making them suitable for interfacing with a variety of sensors and actuators.
- ADC: Up to 18 channels with 12-bit resolution for accurate analog signal measurement. This feature allows the ESP32 to read varying voltage levels from sensors, providing precise data for applications like environmental monitoring.
- DAC: 2 channels with 8-bit resolution for generating analog outputs. The DAC can be used for audio applications or to control devices that require variable voltage levels.
- Power Pins: V5 for 5V input, V3 for 3.3V output, and multiple GND pins. These power pins facilitate connections to external devices and ensure that the ESP32 operates within its required voltage range.
- I2C Interface: SDA and SCL pins for connecting I2C devices. The I2C protocol allows multiple devices to share the same bus, simplifying the wiring and connections needed for complex projects.

- SPI Interface: Standard pins for MISO, MOSI, SCK, and CS for SPI communication. SPI is a high-speed interface ideal for connecting fast peripherals, such as sensors and memory cards.
- UART Interface: TX and RX pins for serial communication. These pins enable the ESP32 to communicate with other devices over a serial interface, useful for debugging and data transmission.
- Touch Sensor Pins: Configurable pins for touch-sensitive input. This feature allows for the development of user interfaces that can detect touch input, enhancing interactivity in applications.
- RTC Functions: Pins for real-time clock operations and wake-up triggers. These functions are essential for applications requiring time-based operations, even during low power modes.
- Programming/Debugging: EN pin for chip enable and IO0 for boot mode selection during programming. These pins are crucial for loading new firmware and debugging the ESP32 during development.

ESP32 Specifications

- Microprocessor: Dual-core Tensilica LX6 processor with up to 240 MHz clock speed. This architecture allows for efficient handling of multiple tasks simultaneously, making it suitable for demanding applications.
- Memory: 520 KB of SRAM and support for up to 16 MB of external SPI flash memory. The ample memory capacity enables the execution of complex algorithms and the storage of extensive data.
- Wireless Connectivity: Integrated Wi-Fi (IEEE 802.11 b/g/n) and Bluetooth (Classic and BLE). This dual connectivity enhances the flexibility of the ESP32 in IoT applications, allowing seamless communication with various devices.
- GPIO Pins: Up to 34 General Purpose Input/Output pins for various applications. These pins can serve multiple functions, such as analog input, PWM output, or digital signaling, making the ESP32 adaptable to different project needs.

- Analog Features: 12-bit ADC with up to 18 channels and 2 channels of 8-bit DAC. The high-resolution analog features are ideal for applications requiring precise signal measurement and generation.
- Power Supply: Operates within a voltage range of 3.0V to 3.6V. This range allows the ESP32 to be powered by various sources, including batteries and regulated power supplies, enhancing its usability in portable applications.
- Power Management: Multiple power-saving modes, including deep sleep. These modes significantly reduce power consumption, making the ESP32 suitable for battery-operated devices and energy-efficient applications.
- Operating Temperature: Functional range from -40°C to 85°C. This wide temperature range ensures reliable performance in diverse environmental conditions, from industrial applications to outdoor deployments.
- Security Features: Hardware encryption (AES, SHA-2), secure boot, and flash encryption. These security measures help protect sensitive data and ensure the integrity of the device, which is critical in IoT applications.
- Development Support: Compatible with Arduino IDE, Espressif ESP-IDF, and other frameworks. The extensive development support, along with a rich set of libraries and resources, simplifies the programming process and accelerates project development.

POWER SUPPLY

The 7812 and 7805 voltage regulators are commonly used components to provide stable DC voltage outputs of +12V and +5V, respectively, from a higher input voltage source.

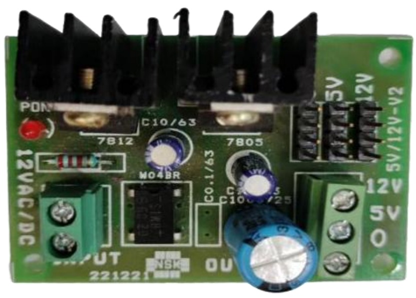


Fig 4.3: 7812 Voltage Regulator

7812 Voltage Regulator

Input Voltage: Typically requires an input voltage slightly higher than 12V (usually around 14-16V) to regulate effectively.

Output Voltage: Provides a stable +12V DC output.

Capacitors:

C1000/25: This likely refers to a capacitor with a capacitance of 1000µF and a voltage rating of 25V. This capacitor is typically placed on the input side (between input and ground) to stabilize the input voltage, reducing noise and providing a reservoir of charge to handle transient spikes.

C10/63: This could refer to a capacitor with a capacitance of 10µF and a voltage rating of 63V. This capacitor is usually placed on the output side (between output and ground) to stabilize the output voltage, filtering out any remaining noise and improving regulation.

Resistor: A resistor isn't typically used directly with the 7812 regulator in the same way as capacitors are, but it can be part of the circuit design for specific applications, such as in voltage dividers or as part of a feedback loop for stability.

7805 Voltage Regulator:

Input Voltage: Requires an input voltage typically around 7-25V (ideal 7-20V) to regulate effectively.

Output Voltage: Provides a stable +5V DC output.

Capacitors:

C1000/25: As with the 7812, this capacitor stabilizes the input voltage to the regulator.

C10/63: This capacitor stabilizes the output voltage of the regulator.

Resistor: Similar to the 7812, resistors are not directly part of the typical configuration but can be used in specific applications.

Circuit Considerations:

Decoupling Capacitors: These capacitors (like C1000/25 and C10/63) are crucial for filtering out noise and stabilizing the voltage levels, ensuring reliable operation of your circuit.

Heat Dissipation: Both regulators can generate heat, especially when dropping significant voltage. Adequate heat sinking may be necessary depending on the current drawn and the input-output voltage differential.

Current Requirements: Ensure that the regulators can supply enough current for your application. If higher currents are required, additional heat sinking and possibly parallel regulators may be needed.

In summary, the 7812 and 7805 voltage regulators, along with capacitors like C1000/25 and C10/63, form a basic yet effective setup for providing stable +12V and +5V outputs in electronic circuits, suitable for a wide range of applications from powering microcontrollers to analog circuits.

CURRENT SENSOR:

A current sensor is a device used to detect and measure the amount of current flowing through a conductor. These sensors are crucial in various applications, such as power monitoring, battery management, motor control, and energy metering.

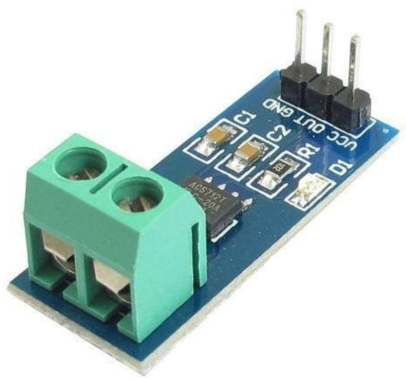


Fig 4.4 :CURRENT SENSOR

Types of Current Sensors

- **Shunt Resistor Sensors:** Use a precision resistor to measure voltage drop, which is proportional to the current flow.

- **Hall Effect Sensors:** Utilize the Hall effect principle to measure the magnetic field generated by current flow.
- **Current Transformer (CT) Sensors:** Inductive devices used to measure alternating current (AC) by transforming high currents to a lower, more manageable level.
- **Rogowski Coil Sensors:** Flexible coils used to measure AC currents without physical contact with the conductor.
- **Magnetoresistive Sensors:** Measure changes in resistance due to the magnetic field generated by current flow.

Working Principle

Current sensors work by detecting the magnetic field generated by the current or by measuring the voltage drop across a known resistor. The output is typically an analog signal proportional to the current, which can be processed by a microcontroller or other monitoring device.

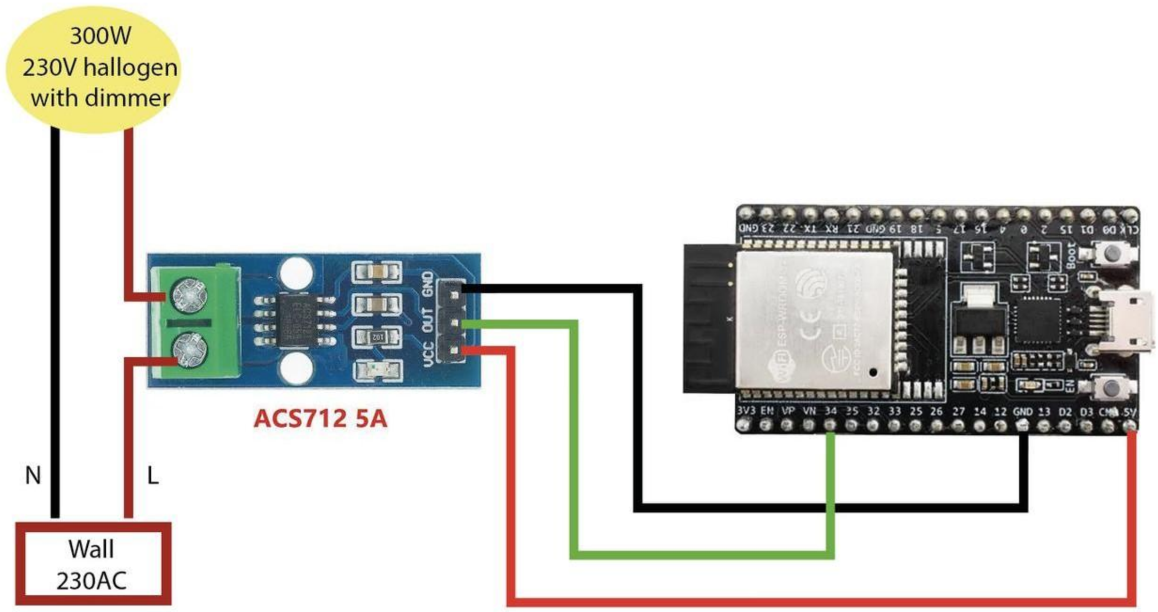


Fig 4.5 : Working Principle

Applications

- **Power Monitoring:** To measure current consumption in power systems and ensure efficient energy usage.
- **Battery Management:** To monitor charging and discharging currents in battery-powered devices.
- **Motor Control:** To measure and control the current supplied to motors in industrial and automotive applications.
- **Energy Metering:** To measure current consumption in residential, commercial, and industrial settings.
- **Renewable Energy Systems:** To monitor current flows in solar panels and wind turbines.

AC VOLTAGE SENSOR:

An AC voltage sensor is a device designed to measure alternating current (AC) voltage levels, commonly used in power monitoring systems to detect the voltage supplied by the grid. It outputs an analog or digital signal proportional to the measured AC voltage, which is then processed by a microcontroller for further calculations or display.

Fig 4.6:AC VOLTAGE SENSOR

WORKING PRINCIPLE

The AC voltage sensor operates by first taking the high AC voltage from the main power line and safely converting it to a lower, manageable voltage level. This conversion is typically done using a step-down transformer, which reduces the voltage without altering the AC waveform, allowing the sensor to read high voltage levels without direct exposure. The stepped-down voltage is then passed through a rectifier circuit, converting the AC signal into a DC signal if needed by the monitoring system. Capacitors are used for filtering this signal, smoothing out fluctuations to produce a stable output voltage. The resulting DC output is directly proportional to the input AC voltage, and this analog voltage signal is fed into an Analog-to-Digital Converter (ADC) of a microcontroller, like an ESP32. Here, the microcontroller processes the signal to determine the AC voltage's Root Mean Square (RMS) value, a measure commonly used to represent AC power. The voltage data can then be used for power calculations, allowing the system to display real-time values or alert users if the voltage deviates from safe levels. This method ensures that high voltages are accurately measured and safely isolated, making AC voltage sensors essential for any system that involves monitoring or managing AC power.

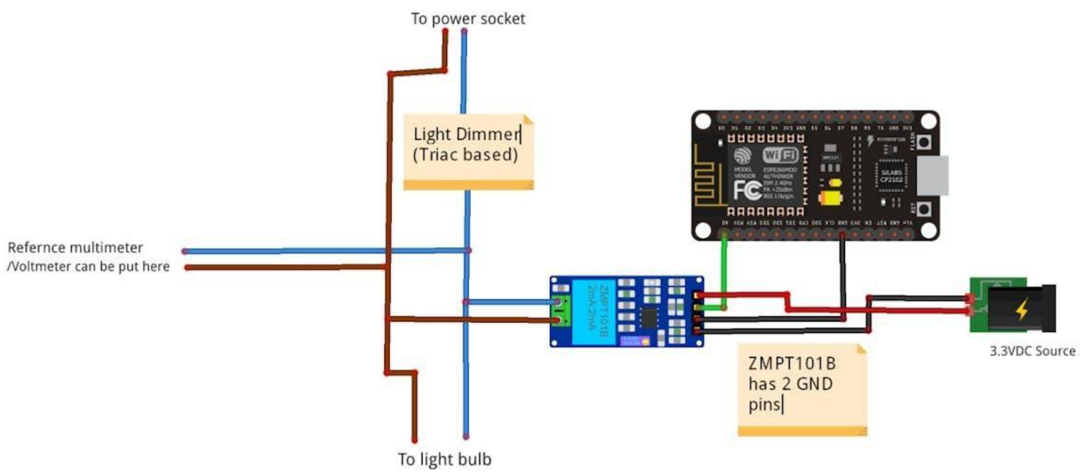


Fig 4.7: Configuration of AC voltage Sensor

KEY SPECIFICATIONS

- Voltage Range: Specifies the input voltage range the sensor can safely measure, e.g., 100V-250V AC for household applications, or higher for industrial sensors.
- Accuracy: Indicates the sensor's precision, which is important for reliable measurements, typically around ±1% to ±2%.
- Output Type: Defines the type of signal output:
  1. Analog Output: Provides a proportional DC signal corresponding to the AC voltage.
  2. Digital Output: Some advanced sensors offer digital communication protocols (I2C, SPI) for direct interfacing with microcontrollers.
- Operating Frequency: The frequency range in which the sensor can operate accurately, often 50-60Hz for standard power grids.
- Isolation Voltage: Ensures electrical isolation between the input high voltage and output, usually in the range of several kilovolts (e.g., 4kV) for safety.

APPLICATIONS:

- Smart Energy Meters: Monitors real-time grid voltage to accurately calculate energy consumption, often paired with current sensors for full power measurement.
- Home & Industrial Automation: Continuously tracks voltage levels in automated systems to prevent over-voltage and ensure safe operation of appliances and machinery.
- Power Quality Monitoring: Analyzes voltage stability to detect sags, swells, and harmonics, crucial for data centers, medical facilities, and manufacturing.
- Renewable Energy Systems: Monitors voltage in solar, wind, and hybrid systems, maintaining stable outputs to protect batteries and inverters.
- Grid Management Systems: Part of smart grids, providing data for efficient voltage distribution and monitoring of fluctuations across the grid.

POTENTIOMETER:

A potentiometer, often referred to simply as a "pot," is a three-terminal variable resistor that allows for adjustable electrical resistance. It's commonly used in electronics to control various parameters such as volume, brightness, speed, and other analog settings.

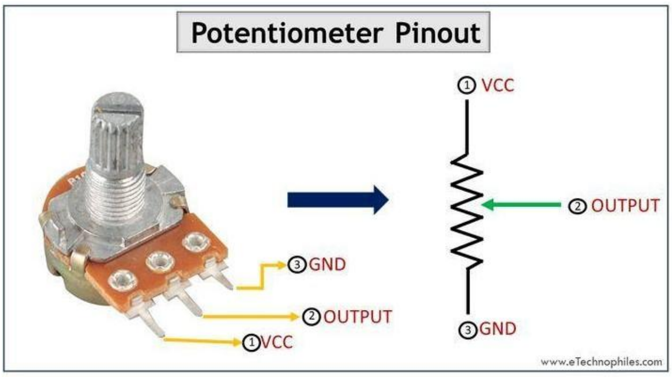


Fig 4.8: POTENTIOMETER

Structure and Operation

Three Terminals:

- Potentiometers typically have three terminals: two outer terminals and one wiper terminal (the movable contact).
- The resistance between the two outer terminals is fixed and determines the total resistance of the potentiometer.
- The wiper terminal is adjustable and moves along a resistive track between the two outer terminals.

Variable Resistance:

- By rotating the shaft or knob of the potentiometer, the position of the wiper changes along the resistive track.
- This movement changes the resistance between the wiper terminal and either of the outer terminals, creating a variable resistance.

The pin configuration of a typical potentiometer depends on its type and design, but here's a general outline of the standard pin connections for a potentiometer:

Outer Terminals:

There are two outer terminals, often labeled as "1" and "3".

Terminal 1 (often marked as "CCW" or "CW") is typically connected to the outer end of the resistive track.

Terminal 3 (often marked as "CW" or "CCW") is connected to the other end of the resistive track.

Wiper Terminal:

The middle terminal, labeled as "2" or sometimes with an arrow symbol, is the wiper terminal.

The wiper moves along the resistive track when the potentiometer knob or shaft is rotated.

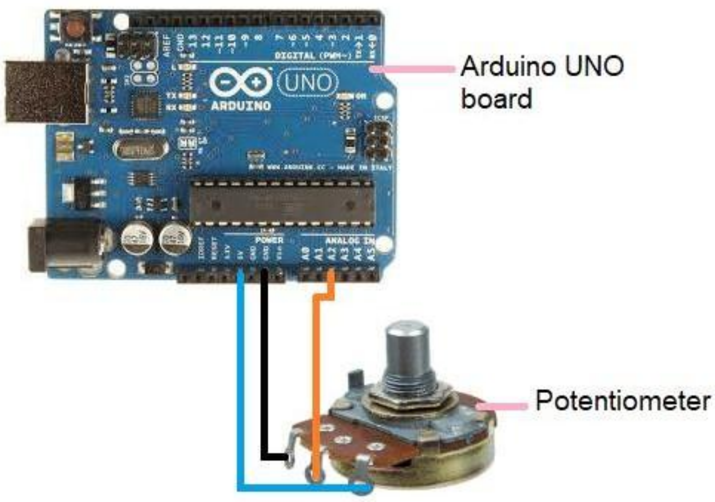


Fig 4.9: Wiper Terminal

Applications:

- Voltage Divider: Used in voltage divider circuits to generate a variable output voltage based on the position of the wiper.
- Control Input: Provides an adjustable input signal to control parameters in electronic circuits (e.g., volume control in audio amplifiers).

- Sensor Adjustment: Adjusts sensor readings or analog signals in instrumentation and control systems.

DHT11 Sensor:

The DHT11 is a basic, low-cost digital sensor used for measuring temperature and humidity. It is commonly used in various applications due to its simplicity, ease of use, and affordability.

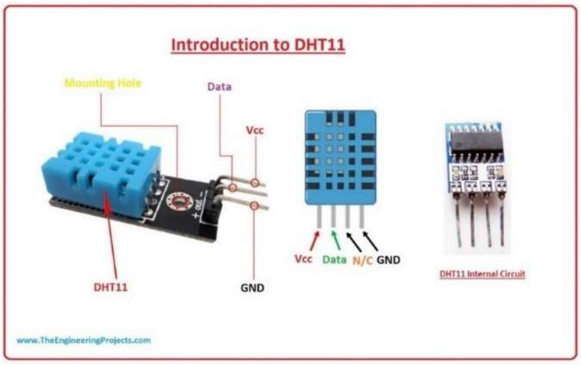


Fig 4.10: **DHT11 Sensor**

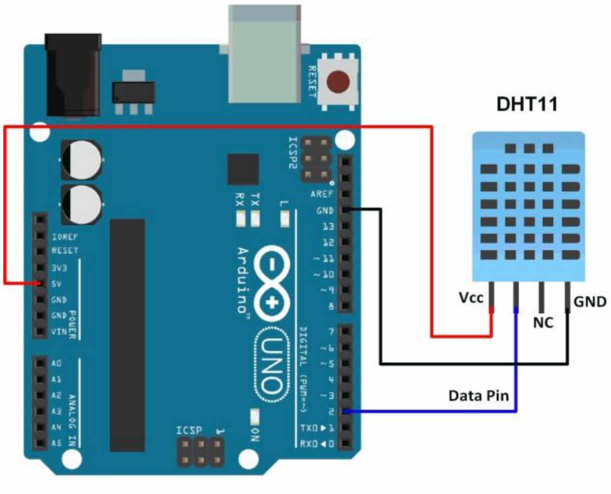
Features

- **Output:** Provides a calibrated digital output that is easy to interface with microcontrollers and other digital systems.
- **Cost and Availability:** Affordable and widely available, making it a popular choice for hobbyists and educational projects.
- **Interface:** Communicates using a single-wire serial interface, simplifying connections and wiring.

Pin Configuration

VCC	+3.3V to +5V
GND	Ground of the power supply
DATA	Send temperature and humidity data to a microcontroller
Range(T):	0 to 50°C

Accuracy	±2°C
Range(H):	20% to 90% RH
Accuracy:	±5% RH



Applications

- The DHT11 sensor is suitable for various applications, including:
- Weather Stations**:** Monitoring environmental temperature and humidity.
- HVAC Systems: Climate control in heating, ventilation, and air conditioning systems.
- **Greenhouses:** Maintaining optimal environmental conditions for plant growth.
- Home Automation: Smart home systems for monitoring and controlling indoor climate.
- Industrial Monitoring**:** Ensuring appropriate environmental conditions in industrial settings.

LIQUID CRYSTAL DISPLAY

A liquid crystal display (LCD) is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images which can be displayed or hidden, such as preset words, digits, and 7-segment displays as in a digital clock. They use the same basic technology, except that arbitrary images are made up of a large number of small pixels, while other displays have larger elements. An LCD is a small low cost display. It is easy to interface with a micro-controller because of an embedded controller (the black blob on the back of the board). This controller is standard across many displays (HD 44780) which means many micro-controllers (including the Arduino) have libraries that make displaying messages as easy as a single line of code.

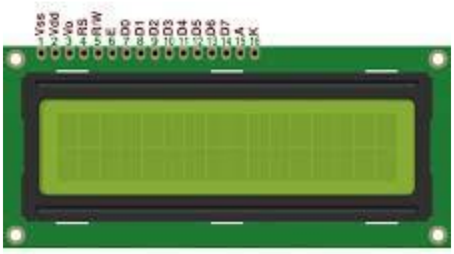


Fig 4.11: LCD display unit

LCDs are used in a wide range of applications including computer monitors, televisions, instrument panels, aircraft cockpit displays, and signage. They are common in consumer devices such as video players, gaming devices, clocks, watches, calculators, and telephones, and have replaced cathode ray tube (CRT) displays in most applications. They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they do not suffer image burn-in. LCDs are, however, susceptible to image persistence.

16X2 LCD SPECIFICATIONS

- Display Format: 16 characters per line, 2 lines total.
- Character Size: 5x8 pixels for standard characters.
- Dimensions: Approximately 80mm x 36mm x 13mm.
- Interface: Parallel (4-bit or 8-bit mode).
- Supply Voltage: Typically 5V DC.
- Current Consumption: Around 1.5 mA at 5V.
- Backlight: LED backlight (3.3V to 5V).
- Temperature Range: 0°C to 70°C operating, -20°C to 80°C storage.
- Response Time: Under 10 ms.
- Mounting: PCB or breadboard compatible.

- Character Set: Standard ASCII with custom character support.

I2C (Inter-Integrated Circuit)

The I2C connection for an LCD display enables efficient and simplified interfacing with microcontrollers, like the ESP32, by requiring only two data lines: SDA (data) and SCL (clock). This setup significantly reduces the number of pins needed, compared to traditional parallel connections, allowing other I/O pins on the microcontroller to remain free for additional sensors or peripherals. The I2C interface is controlled by a small I2C module on the back of the LCD, typically using a chip like the PCF8574, which converts the I2C signals into parallel signals the LCD can interpret.

Each device on the I2C bus has a unique address (e.g., 0x27 for many LCD modules), letting the microcontroller communicate with specific devices even if there are multiple I2C components on the same bus. The power (VCC) and ground (GND) lines complete the connections, and the data transfer is synchronous, meaning the microcontroller (master) sends commands in sync with the LCD (slave). Commands like positioning the cursor, clearing the display, or updating text are all handled through simple I2C libraries that streamline programming. This makes I2C ideal for projects that require organized wiring and efficient communication, especially in setups where pin limitations and space are considerations.

CHAPTER-5

5.1 RESULT

The result of this project is a sophisticated smart energy monitoring system that accurately tracks and displays real-time power consumption using an ESP32 microcontroller, I2C LCD, and AC voltage and current sensors. The system effectively measures the AC voltage and current drawn from the grid, allowing for precise calculations of power consumption in watts through the RMS values of the voltage and current, adjusted by an estimated power factor. Users benefit from a continuous visual representation of their energy usage on the I2C LCD screen, which enhances awareness of consumption patterns and facilitates informed decision-making regarding energy management.

The successful integration of analog sensor data with digital processing capabilities on the ESP32 highlights the system's versatility and reliability in various applications, ranging from household energy monitoring to small industrial environments. With careful calibration, the system achieves high accuracy in its readings, providing confidence in its performance. The use of the I2C interface not only simplifies the wiring but also allows for easy expansion of the system. This is particularly beneficial in multi-sensor setups, where additional sensors can be connected without the need for extensive reconfiguration of the microcontroller's pin assignments.

The project culminates in a cost-effective and user-friendly solution that empowers users to monitor their energy consumption actively. By enabling the tracking of power usage trends, the system encourages energy-saving practices and helps users identify peak consumption periods. Furthermore, the architecture of the system supports potential future enhancements, such as data logging capabilities for historical analysis, and the addition of wireless communication for remote monitoring via smartphone apps or web interfaces.

Ultimately, this smart energy meter not only aims to lower utility costs for its users but also fosters a broader culture of energy efficiency and sustainability. By making energy consumption data accessible and understandable, the project contributes to promoting more responsible energy usage behaviors, which are essential in today's context of rising energy costs and environmental concerns.

CHAPTER-6

6.1 CONCLUSION

In conclusion, the smart energy meter system designed using the ESP32 microcontroller, AC voltage and current sensors, and an I2C LCD display represents a significant advancement in energy management technology. This system effectively enables real-time monitoring of electrical consumption, which is crucial for both residential and commercial users seeking to optimize their energy usage. By accurately measuring voltage and current, the smart energy meter calculates real power consumption in watts, allowing users to understand their energy usage patterns and identify opportunities for efficiency improvements.

The integration of the ESP32 microcontroller not only facilitates seamless data processing and communication but also allows for future enhancements, such as wireless connectivity and data logging capabilities. With Wi-Fi or Bluetooth functionality, users can potentially access their energy consumption data remotely, enhancing convenience and usability. Furthermore, the user-friendly I2C LCD display ensures that information is readily available at a glance, empowering users to make informed decisions about their energy consumption habits.

This project highlights the importance of energy awareness in today's context of rising energy costs and environmental concerns. By providing real-time data, the smart energy meter encourages users to adopt more sustainable practices, such as reducing peak load consumption and shifting to energy-efficient appliances. This proactive approach not only helps in managing electricity bills but also contributes to broader goals of energy conservation and reduction of carbon footprints.

The emphasis on safety and proper calibration in the design of the energy meter underscores the necessity of adhering to electrical standards and practices when dealing with AC mains electricity. This focus on safety ensures that users can confidently implement the technology without the risk of electrical hazards.

The smart energy meter stands as a practical, cost-effective solution for energy monitoring that fosters a culture of energy efficiency and conservation. As the demand for smart home technologies continues to rise, projects like this one play a pivotal role in advancing energy management solutions that are both innovative and user-centric. Looking ahead, further developments could include integration with smart grid technologies and home automation systems, paving the way for a more connected and efficient future in energy consumption.

6.2 FUTURE ENHANCEMENTS

- Remote Monitoring: Add cloud connectivity for real-time monitoring and remote control via smartphone.
- Data Analytics: Include consumption pattern analysis and cost prediction to help optimize energy use.
- Real-Time Billing: Display real-time billing based on current rates, helping users manage costs.
- Renewable Energy Tracking: Integrate with solar or wind sources to monitor total energy usage.
- Smart Load Management: Automate load control to reduce peak demand and improve efficiency.
- Safety Alarms: Add overload and anomaly alerts to prevent electrical hazards.
- Battery Backup: Ensure continuous data logging during power outages.
- Smart Home Compatibility: Integrate with Google Home, Alexa, etc., for seamless smart home control.
- Enhanced Display: Upgrade to a color touchscreen for easy navigation of usage stats.
- Multi-Phase Support: Enable support for three-phase systems for industrial applications.

REFERENCE

- A. S. Alahmed and L. Tong, "Co-optimizing behind-the-meter resources under net metering", Proc. IEEE Texas Power Energy Conf., pp. 1-6, 2023.
- S. Seal, B. Boulet, V. R. Dehkordi, F. Bouffard and G. Joos, "Centralized MPC for home energy management with EV as mobile energy storage unit", IEEE Trans. Sustain. Energy, vol. 14, no. 3, pp. 1425-1435, Jul. 2023.
- M. Jeon, L. Tong and Q. Zhao, "Co-optimizing consumption and EV charging under net energy metering", Proc. IEEE Power Energy Soc. Gen. Meeting, pp. 1-5, 2023.
- B. Jeddi, Y. Mishra and G. Ledwich, "Differential dynamic programming based home energy management scheduler", IEEE Trans. Sustain. Energy, vol. 11, no. 3, pp. 1427-1437, Jul. 2020.
- A. S. Alahmed and L. Tong, "Integrating distributed energy resources: Optimal prosumer decisions and impacts of net metering tariffs", SIGENERGY Energy Inform. Rev., vol. 2, no. 2, pp. 13-31, Aug. 2022.
- K. Ashok, M.J. Reno, L. Blakely and D. Divan, "Systematic study of data requirements and AMI capabilities for smart meter analytics", Proc. 7th Int. Conf. Smart Energy Grid Eng., pp. 53-58, 2019.
- M.A. Devlin and B.P. Hayes, "Non-Intrusive load monitoring and classification of activities of daily living using residential smart meter data", IEEE Trans. Consum. Electron., vol. 65, no. 3, pp. 339-348, Aug. 2019.
- F. Luo, W. Kong, G. Ranzi and Z. Y. Dong, "Optimal home energy management system with demand charge tariff and appliance operational dependencies", IEEE Trans. Smart Grid, vol. 11, no. 1, pp. 4-14, Jan. 2020.
- B. S. England and A. T. Alouani, "Real time voltage stability prediction of smart grid areas using smart meters data and improved Thevenin estimates", Int. J. Elect. Power Energy Syst., vol. 122, pp. 1-8, Nov. 2020.

- D. Cao, W. Hu, J. Zhao, Q. Huang, Z. Chen and F. Blaabjerg, "A multi-agent deep reinforcement learning based voltage regulation using coordinated PV inverters", IEEE Trans. Power Syst., vol. 35, no. 5, pp. 4120-4123, Sep. 2020.

ANNEXURE - I

INDIVIDUAL WORK CONTRIBUTION

AUTOMATED ENERGY MONITORING SYSTEM

A.VISHWANATH 7376211EE205

an IoT-based energy monitoring and management system was successfully developed to enable remote tracking and control of energy usage in real time. A cloud-based solution, leveraging platforms such as AWS, Google Cloud, or ThingSpeak, was integrated to collect and analyze energy consumption data. The microcontroller interfaced with energy meters and sensors, transmitting real-time data to the cloud via MQTT or HTTP protocols, ensuring efficient and secure communication between devices.

To facilitate user interaction, a web or mobile application was designed, providing a real-time dashboard displaying energy consumption statistics and trends. This interface enabled users to monitor energy usage, detect anomalies, and receive insights into power consumption patterns. Various sensors, including voltage sensors (ZMPT101B), current sensors (ACS712), and power meters, were integrated into the system to ensure comprehensive data collection.

The collected energy data was processed and analyzed to identify usage patterns, optimize power consumption, and improve system efficiency. By leveraging predictive analytics, the system could forecast energy demand and recommend optimal usage strategies. Additionally, alert mechanisms were incorporated to notify users in case of abnormal power consumption, aiding in fault detection and preventive maintenance.

The system's IoT capabilities extended beyond monitoring to include automated energy control. Smart devices were programmed to optimize energy consumption based on predefined conditions. For example, lighting and HVAC systems could be adjusted based on occupancy and time schedules, reducing unnecessary power usage. Moreover, demand-side management strategies were implemented, allowing for intelligent load distribution based on energy availability and cost efficiency.

Security and scalability were key considerations throughout development. Encryption protocols were used to secure communication between IoT devices and cloud services, preventing unauthorized access. Additionally, user authentication mechanisms were implemented to ensure that only authorized personnel could access and modify energy data. The scalable architecture allowed for the seamless integration of additional sensors and control devices, expanding the system’s capabilities for broader applications such as smart energy grids and industrial automation.

By implementing this IoT-based energy monitoring and management system, users can optimize energy usage, reduce operational costs, and improve energy efficiency. The project lays the groundwork for future advancements in smart energy grids, renewable energy integration, and sustainable energy solutions, contributing to a more energy-efficient and environmentally friendly future.

[A.VISHWANATH]

AUTOMATED ENERGY MONITORING SYSTEM

R.GEMINI 7376211EE117

During the first week of our project, an Arduino-based energy monitoring system was successfully developed and configured to interface with key sensors, including energy meters, voltage sensors (ZMPT101B), and current sensors (ACS712). The microcontroller was programmed to read real-time data from these sensors, process the information, and prepare it for transmission to a cloud platform for remote monitoring. The primary objective was to analyze energy consumption trends and provide real-time insights into power usage. Additionally, the system allowed for local data visualization through an LCD screen or the Serial Monitor for immediate observation.

A significant aspect of this phase involved configuring the microcontroller to continuously measure voltage and current, converting analog sensor values into digital readings. The ZMPT101B voltage sensor was used to detect AC voltage levels, while the ACS712 current sensor measured the current flow. The system computed real power consumption by multiplying measured voltage and current values and then integrated the power over time to determine energy usage in kWh. These calculations formed the foundation for efficient energy monitoring and anomaly detection in power consumption.

To enable real-time data access, initial configurations were made to transmit the collected sensor readings to cloud platforms such as AWS, Google Cloud, or ThingSpeak using MQTT or HTTP protocols. This setup ensured secure data transmission and storage, allowing users to visualize energy consumption patterns through interactive dashboards. The potential for integrating alert mechanisms to detect unusual power usage was also explored, paving the way for future implementations in fault detection and energy optimization.

Additionally, a local display interface was implemented using an LCD screen or OLED module, providing instant feedback on energy consumption. The Serial Monitor was also leveraged for debugging and real-time analysis of sensor data. Libraries such as ACS712.h and ZMPT101B.h were used for seamless sensor integration, while PubSubClient.h was considered for MQTT-based communication.

In parallel, security and scalability were analyzed to enhance system performance. Encryption protocols and authentication mechanisms were planned to secure data transmission and cloud access. The system was also designed to be scalable, allowing for the integration of additional sensors in future phases, expanding its applications to industrial energy monitoring and smart home automation.

By the end of the first week, the foundation for the IoT-based energy monitoring system was successfully established. This phase set the stage for advanced data processing, real-time cloud visualization, and automated energy optimization

[R.GEMINI]

AUTOMATED ENERGY MONITORING SYSTEM

P SAIRAM 7376211EE166

I designed and developed an energy monitoring system using Proteus to simulate and validate its performance before proceeding with hardware implementation. The primary objective was to create a reliable system capable of analyzing real-time energy data while ensuring precise measurement of voltage, current, and power consumption.

The development process began with designing the circuit schematic in Proteus, where I carefully integrated key components such as the Arduino microcontroller, voltage sensors (ZMPT101B), current sensors (ACS712), and Wi-Fi modules for remote communication. Extensive simulation tests were conducted to evaluate the system's functionality, ensuring that the power measurement calculations were accurate and consistent.

A critical aspect of this work was establishing seamless communication between the microcontroller and external devices. I implemented a data acquisition process where sensor inputs were processed, analog signals were converted into digital readings, and real-time power consumption was computed. These calculations were systematically validated through simulation to ensure precise energy monitoring.

The simulation phase also played a crucial role in verifying the accuracy of power calculations. By continuously monitoring voltage and current values, the system computed real power consumption and integrated the data over time to determine total energy usage (in kWh). The Proteus simulations allowed me to fine-tune the circuit design, optimize sensor interfacing, and ensure the reliability of the monitoring system before transitioning to hardware implementation.

Through this process, I successfully established a solid foundation for the hardware phase, enabling seamless integration with cloud-based platforms for real-time monitoring, data visualization, and energy optimization. The completion of this simulation phase ensured that the system was not only functional but also scalable and efficient for real-world energy management applications.

[P.SAIRAM]

AUTOMATED ENERGY MONITORING SYSTEM

S.SANJAY 7376211EE171

In this project, I was responsible for the design, development, and implementation of an IoT-based energy monitoring system that integrates multiple hardware and software components. The core objective was to create an efficient, real-time monitoring solution capable of accurately measuring power consumption while ensuring seamless data transmission and remote accessibility.

The initial phase involved extensive research on sensor selection to ensure accurate measurement of electrical parameters. I incorporated ACS712 current sensors and ZMPT101B voltage sensors, which were carefully calibrated to improve precision and eliminate external interference. Signal conditioning techniques, including noise filtering and amplification, were applied to ensure the reliability of the acquired data before feeding it into the microcontroller. The Arduino or STM32 microcontroller was programmed to process sensor inputs, calculate power consumption, and store data for analysis.

To enable real-time monitoring and remote accessibility, I integrated Wi-Fi modules such as ESP8266 and ESP32, allowing seamless data transmission to cloud platforms like Firebase and ThingSpeak. For areas with limited internet connectivity, I implemented GSM modules, enabling SMS-based alerts and data retrieval through mobile networks. The system was designed to provide users with real-time notifications regarding abnormal power usage, helping in energy conservation and efficiency improvements.

A critical aspect of the system was power management and safety. I designed and implemented a robust power supply circuit that ensures stable voltage regulation, preventing fluctuations that could damage sensitive components. Special emphasis was placed on ensuring electrical isolation and protection mechanisms, such as fuse-based safeguards and transient voltage suppressors, to prevent risks associated with interfacing with AC mains.

Beyond hardware integration, I also worked on data visualization by developing an intuitive dashboard using web technologies. The dashboard provides users with graphical representations of energy usage trends, peak consumption times, and predictive insights based on historical data. Advanced features like customizable alerts, automated reports, and interactive charts were incorporated to enhance user experience.

To validate the system's performance, I conducted extensive simulations using Proteus, ensuring that all components functioned optimally before proceeding to physical implementation. The simulations helped identify and rectify potential design flaws, ultimately leading to a more efficient and reliable system. The final prototype was tested in a real-world environment, demonstrating its capability to monitor and analyze energy consumption effectively.

Through this work, I successfully developed a scalable, cost-effective, and user-friendly energy monitoring system. The project not only enhances energy efficiency but also contributes to sustainable energy management practices by providing actionable insights into power consumption patterns.

[S.SANJAY]