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IoT Energi Sense: Adaptive Smart Home Energy Management System with IoT and Consumption Optimization

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KEYWORDS

Internet of Things (IoT), Energy Monitoring System, Smart Energy Management, ESP32 Microcontroller, Voltage and Current Sensing, Power Consumption Analysis, Cloud-Based Monitoring, ThingSpeak, Home Automation, Energy Efficiency.

ABSTRACT

The rapid increase in energy consumption and the growing need for efficient energy management have led to the development of smart monitoring systems using Internet of Things (IoT) technology. This project presents an IoT-based Smart Home Energy Management System, named IoT Energi Sense, which is designed to monitor, analyze, and control electrical energy consumption in real time.

The system utilizes sensors such as the ACS712 current sensor and ZMPT101B voltage sensor to measure electrical parameters like current and voltage. These values are processed by the ESP32 microcontroller, which calculates power consumption using embedded algorithms. The processed data is displayed locally on an LCD display and simultaneously transmitted to the Thing Speak cloud platform using Wi-Fi communication.

The cloud platform stores the data and provides graphical visualization, enabling users to monitor energy usage remotely. The system also incorporates a relay module for controlling electrical appliances, allowing automatic or manual switching based on energy consumption levels. This helps in reducing energy wastage and improving efficiency.

The proposed system is cost-effective, user-friendly, and scalable, making it suitable for smart home applications. It provides real-time monitoring, remote access, and automated control, contributing to energy conservation and sustainable usage. The implementation demonstrates reliable performance and effective integration of IoT technologies for smart energy management.

1. INTRODUCTION

1.1 INTRODUCTION TO SMART ENERGY MONITORING SYSTEM

In the present era, energy has become one of the most essential resources for human life. It powers homes, industries, transportation systems, and modern technologies that support daily activities. With the rapid growth in population and technological advancements, the demand for electricity has increased significantly. The increased usage of electrical appliances such as air conditioners, refrigerators, lighting systems, and electronic devices has led to higher energy consumption. However, most traditional energy systems are not efficient in monitoring and controlling energy usage, which results in excessive energy wastage and increased electricity costs.

Traditional electrical systems mainly focus on supplying power without providing real-time insights into energy consumption. Users are often unaware of how much energy each appliance consumes, which makes it difficult to control unnecessary usage. In addition, these systems do not offer automation or intelligent control, leading to inefficient utilization of resources. As a result, there is a growing need for smart systems that can monitor, analyze, and control energy usage effectively.

The advancement of the Internet of Things (IoT) has introduced new possibilities in energy management. IoT enables devices to communicate with each other and share data through the internet, allowing for real-time monitoring and control. By integrating sensors, microcontrollers, and communication technologies, IoT-based systems provide a smart solution for managing energy efficiently.

The proposed system, IoT Energi Sense: Adaptive Smart Home Energy Management System with IoT and Consumption Optimization, is designed to address the limitations of traditional energy systems. This system uses sensors such as ACS712 for current measurement and ZMPT101B for voltage measurement to collect real-time data. The ESP32 microcontroller processes this data and calculates power consumption. The system displays the measured values on an LCD screen, allowing users to monitor their energy usage continuously. Additionally, a relay module is used to control electrical appliances, enabling users to switch devices ON or OFF based on their requirements.

One of the key features of this system is its ability to provide real-time monitoring and control. Users can observe voltage, current, and power values instantly, which helps them understand their energy consumption patterns. This awareness plays an important role in reducing unnecessary energy usage and improving efficiency. The system also supports automation, which reduces manual intervention and enhances convenience.

The IoT Energi Sense system is designed to be cost-effective, user-friendly, and efficient. It can be easily implemented in homes and small-scale environments without requiring complex infrastructure. The system demonstrates how IoT technology can be used to develop smart energy solutions that contribute to energy conservation and sustainable development. Overall, this project provides a practical and reliable approach to improving energy management in modern households.

1.2 NEED FOR THE PROJECT

Energy consumption is increasing rapidly due to the growing use of electrical and electronic devices in everyday life. Most households rely heavily on electricity for various activities such as lighting, cooking, cooling, and entertainment. However, the lack of proper monitoring systems makes it difficult for users to track their energy usage. Traditional electricity meters only provide total consumption readings and do not give detailed information about individual appliance usage.

One of the major problems with existing systems is the absence of real-time monitoring. Users are unable to identify which appliances consume more energy, leading to inefficient usage and increased electricity bills. In addition, there is no mechanism to control appliances automatically based on energy consumption. This results in unnecessary power wastage, especially when devices are left ON without being used.

Another important issue is the lack of awareness among users regarding energy conservation. Without proper data and monitoring, users cannot make informed decisions about their energy usage. This not only affects individual households but also contributes to overall energy shortages and environmental issues.

The proposed IoT Energi Sense system addresses these challenges by providing a smart solution for energy monitoring and control. It enables users to monitor their energy consumption in real time and control appliances efficiently. The system helps in reducing energy wastage, lowering electricity costs, and promoting energy conservation.

Furthermore, the system reduces dependency on manual monitoring and provides automated control, making it more efficient and convenient. It also improves safety by monitoring electrical parameters such as voltage and current, which can help in detecting abnormal conditions.

Fig 1.2: Need for Smart Energy Management System

Overall, the need for this project arises from the increasing demand for efficient energy management systems that can provide real-time monitoring, automation, and better control of electrical appliances.

1.3 OBJECTIVES OF THE PROJECT

The main objective of the IoT Energi Sense system is to design and develop a smart energy management system that can monitor and control energy usage effectively. The system aims to provide real-time information about energy consumption, helping users make better decisions regarding their electricity usage.
One of the primary objectives is to measure electrical parameters such as voltage and current using sensors. These measurements are used to calculate power consumption, which is displayed to the user. This helps users understand how much energy they are consuming at any given time.
Another important objective is to provide real-time monitoring of energy usage. The system continuously updates the data and displays it on an LCD screen, allowing users to track their consumption easily. This real-time capability is essential for identifying high energy usage and taking corrective actions.
The system also aims to control electrical appliances using a relay module. This allows users to switch devices ON or OFF based on their requirements, reducing unnecessary energy consumption. Automation features can also be added to improve efficiency.
In addition, the project focuses on creating a cost-effective and user-friendly system that can be easily implemented in homes. The use of simple components and straightforward design makes the system accessible to a wide range of users.

Another objective is to promote energy conservation by increasing user awareness. By providing detailed information about energy usage, the system encourages users to adopt energy-saving practices.

1.4 OVERVIEW OF IoT IN ENERGY MANAGEMENT

The Internet of Things (IoT) has revolutionized the way devices interact and communicate with each other. In energy management systems, IoT plays a crucial role by enabling real-time data collection, analysis, and control. IoT systems consist of sensors, microcontrollers, communication modules, and cloud platforms that work together to provide intelligent solutions.
In the IoT Energi Sense system, sensors collect data related to voltage and current, which is processed by the ESP32 microcontroller. The processed data is used to calculate power consumption and is displayed to the user. The system can also be extended to transmit data to cloud platforms for remote monitoring and analysis.
IoT-based energy management systems provide several advantages over traditional systems. They offer real-time monitoring, automation, and remote access, making them more efficient and user-friendly. These systems also support scalability, allowing additional features and devices to be integrated easily.
Another important benefit of IoT is its ability to support smart home development. IoT enables the creation of interconnected systems where devices can communicate and operate automatically. This improves convenience, reduces manual effort, and enhances energy efficiency.

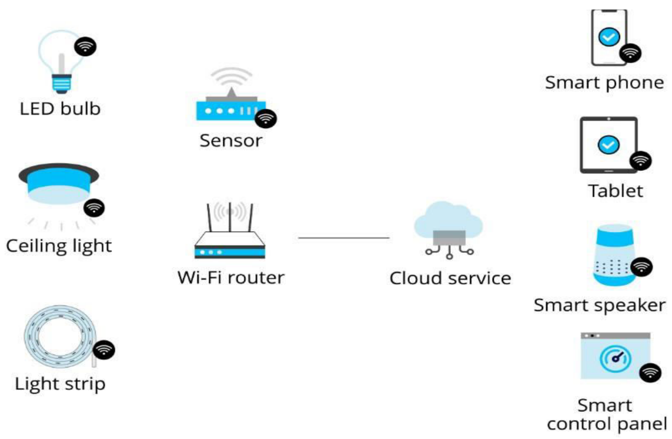

Fig 1.4:IoT in Smart Energy Management

Overall, IoT plays a significant role in modern energy management systems by providing intelligent and efficient solutions for monitoring and controlling energy usage.

1.5 SCOPE OF THE PROJECT

The scope of the IoT Energi Sense system includes real-time monitoring and control of energy usage in residential and small-scale environments. The system is designed to measure electrical parameters such as voltage, current, and power consumption and display the values to the user.

The system can be used in homes, offices, and small industries to monitor energy usage and control appliances. It helps in reducing energy wastage and improving efficiency by providing real-time data and control mechanisms.

The project also provides a foundation for future enhancements. The system can be extended by integrating mobile applications for remote monitoring and control. Cloud-based storage can be used to store energy data and perform analysis. Advanced technologies such as artificial intelligence can be implemented to predict energy consumption patterns and optimize usage.

In addition, the system can be integrated with renewable energy sources such as solar panels to promote sustainable energy usage. This makes the system suitable for modern smart homes and energy-efficient environments.

The scalability of the system allows it to be expanded for larger applications, making it a versatile solution for energy management. Overall, the project provides a strong foundation for developing advanced energy management systems in the future.

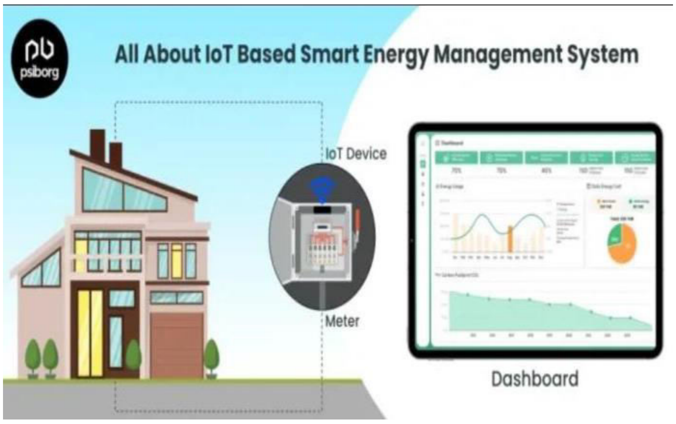

Fig 1.5: Scope of IoT Energy Management System

2. LITERATURE SURVEY

2.1 OVERVIEW OF SMART ENERGY MANAGEMENT SYSTEM

Energy management has become a significant area of research due to the increasing demand for electricity and the need for efficient utilization of resources. Traditional energy systems mainly focus on measuring total energy consumption without providing real-time insights into usage patterns. This limitation often leads to inefficient energy utilization and increased wastage.

Smart energy management systems have been developed to overcome these limitations by integrating advanced technologies such as sensors, microcontrollers, and communication networks. These systems provide real-time monitoring, analysis, and control of energy usage. According to studies, smart energy systems improve efficiency and reduce unnecessary consumption by enabling users to monitor their energy usage continuously.

Furthermore, the adoption of intelligent systems helps in achieving sustainable energy goals. These systems contribute to reducing electricity costs and minimizing environmental impact by optimizing energy usage patterns.

2.2 IoT-BASED ENERGY MONITORING SYSTEM

The Internet of Things (IoT) has transformed the field of energy management by enabling interconnected devices to communicate and exchange data. IoT-based energy monitoring systems use sensors and microcontrollers to collect real-time data and transmit it for processing and analysis.

Research indicates that IoT-based systems provide accurate and real-time information, making them more efficient compared to traditional monitoring systems. These systems allow users to monitor energy consumption remotely and control appliances using smart devices.

IoT systems consist of multiple components, including sensors, controllers, and communication modules. Sensors measure parameters such as voltage and current, while microcontrollers process the data and perform necessary calculations. The processed data is then displayed to the user or transmitted to other devices for further analysis.

Additionally, IoT-based systems support automation, enabling appliances to operate based on predefined conditions. This reduces energy wastage and improves system efficiency.

2.3 ROLE OF SENSORS AND MICROCONTROLLERS IN ENERGY SYSTEM

Sensors and microcontrollers play a vital role in the functioning of smart energy management systems. Sensors are responsible for collecting accurate data, while microcontrollers process and analyze the data.

Current sensors such as ACS712 and voltage sensors such as ZMPT101B are commonly used for measuring electrical parameters. Accurate sensing is essential for reliable energy monitoring and efficient system performance.

Microcontrollers such as ESP32 are widely used due to their high processing capability and built-in communication features. These devices act as the central unit of the system, performing tasks such as data processing, control operations, and communication.

The integration of sensors and microcontrollers enables real-time monitoring and control of energy systems, ensuring accurate data collection and efficient operation.

2.4 SMART HOME AUTOMATION AND ENERGY OPTIMIZATION

Smart home automation is an important application of IoT in energy management systems. It involves the use of intelligent systems to control household appliances automatically.

Studies have shown that automated systems can significantly reduce energy consumption by controlling appliances based on user behavior and environmental conditions. For example, devices can be turned off automatically when not in use, preventing unnecessary energy wastage.

Energy optimization techniques are also used to improve system performance. These techniques analyze energy usage patterns and suggest ways to reduce consumption. Advanced systems use machine learning algorithms to predict energy usage and optimize appliance operation.

Smart home automation improves both energy efficiency and user convenience by enabling remote control and real-time monitoring of devices.

2.5 CHALLENGER AND FUTURE TRENDS IN IoT ENERGY SYSTEM

Despite the advantages of IoT-based energy management systems, several challenges still exist. One of the major challenges is the cost of implementation, especially for large-scale systems. Although basic systems are affordable, advanced solutions require significant investment.

Another challenge is data accuracy and reliability. Sensor calibration and environmental factors can affect measurement accuracy, which may impact system performance. Ensuring reliable data collection is essential for effective energy management.

Security is also a major concern in IoT systems. Since these systems involve data transmission, they are vulnerable to cyber threats. Proper security measures must be implemented to protect user data.

Future trends in energy management include the integration of artificial intelligence, cloud computing, and renewable energy sources. AI-based systems can predict energy consumption patterns and optimize usage automatically. Cloud-based systems enable data storage and remote access, while renewable energy integration promotes sustainability.

These advancements will lead to more intelligent, efficient, and scalable energy management systems in the future.

3. PROPOSED METHODOLOGY

The poposed system overcomes the limitations of traditional energy monitoring methods—such as the lack of real-time data access, minimal automation, and limited user awareness—by integrating modern sensing, processing, and cloud technologies into a single smart solution. The system utilizes the **ACS712 current sensor** to measure load current accurately and the **ZMPT101B voltage sensor** to monitor supply voltage. These sensors continuously feed real-time data to the **ESP32 microcontroller**, which performs instantaneous power calculations using the formula:

P=V×IP = V \times IP=V×I

The ESP32, known for its high processing capability and built-in Wi-Fi functionality, ensures fast computation and seamless data transmission. This enables accurate monitoring of electrical parameters such as voltage, current, and power consumption.

For local visualization, an LCD display is incorporated to provide immediate feedback to users without requiring internet access. This feature enhances usability by allowing on-site monitoring even during network interruptions. Additionally, a relay module is integrated to enable automated or manual control of connected appliances. This allows users to switch devices ON or OFF remotely via cloud commands or locally based on predefined conditions, contributing to energy conservation and safety.

The integration of ThingSpeak cloud platform further enhances system functionality by enabling remote monitoring, real-time data logging, graphical visualization, and historical data analysis. Users can access energy consumption patterns through web or mobile interfaces, helping them make informed decisions to reduce unnecessary power usage.

One of the key advantages of this system is cost-effectiveness. By using affordable and widely available components such as the ESP32 and sensor modules, the system remains economically viable for residential applications. Its modular design also makes it scalable—additional sensors and relays can be incorporated to monitor multiple appliances or rooms without major structural changes.

Furthermore, the system supports offline capability for local monitoring and control, ensuring reliability even in the absence of internet connectivity. Its compact and adaptable architecture makes it suitable for smart homes, small industries, and educational projects.

By providing real-time insights into energy consumption, the system increases user awareness and promotes responsible electricity usage. Unlike conventional energy meters that only display cumulative readings, this smart solution empowers users with actionable data, automation features, and remote accessibility—without requiring complex installation or technical expertise.

In the long term, such a system contributes to energy efficiency, cost savings on electricity bills, and environmental sustainability by reducing unnecessary energy wastage.

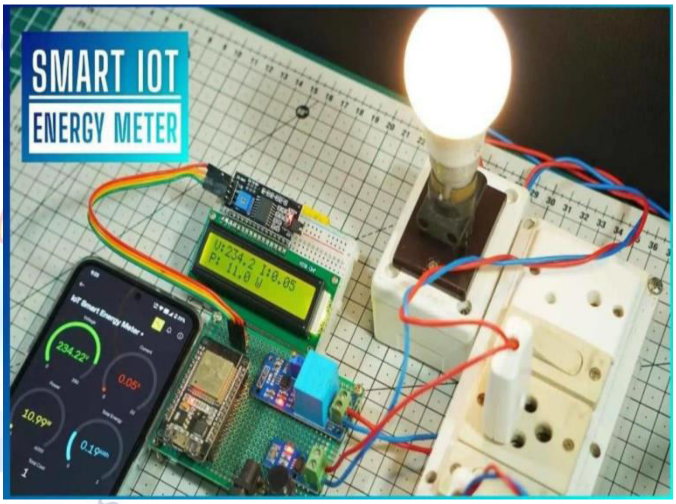

Fig 3.1 Proposed IoT-Based Energy Senses System

3.1 SYSTEM ARCHITECTURE

The proposed architecture is structured into four clearly defined layers—Input, Processing, Output, and Control—to ensure systematic operation, modularity, and reliability. In the **Input layer**, the ACS712 current sensor measures the load current, while the ZMPT101B voltage sensor monitors the supply voltage. These sensors continuously capture real-time electrical parameters from connected appliances. By isolating sensing components in a dedicated layer, the system ensures accurate data acquisition while minimizing interference and measurement errors.

The **Processing layer** is centered around the ESP32 microcontroller, which acts as the brain of the system. It performs Analog-to-Digital Conversion (ADC) to transform sensor signals into digital values. The ESP32 then computes electrical parameters such as voltage, current, and instantaneous power using the formula P=V×IP = V \times IP=V×I. Its built-in Wi-Fi capability enables seamless data transmission to cloud platforms while maintaining efficient local processing. This layer ensures fast computation, low latency, and reliable communication.

In the **Output layer**, processed data is presented both locally and remotely. An LCD display provides instant, on-site visualization of electrical parameters, ensuring users can monitor energy usage even without internet access. Simultaneously, data is uploaded to the ThingSpeak cloud platform, where it is stored, analyzed, and displayed through graphical dashboards. This dual-output approach enhances accessibility by combining real-time monitoring with historical trend analysis.

The **Control layer** incorporates a relay module that enables automated or manual switching of connected appliances. Based on predefined threshold values—such as maximum allowable current or power consumption—the ESP32 can trigger the relay to turn devices ON or OFF. This automation prevents overload conditions, reduces energy wastage, and enhances electrical safety. Users can also control appliances remotely through cloud-based commands, improving convenience and flexibility.

Overall, data flows continuously through the system in a structured sequence: sensors collect measurements → the ESP32 processes and calculates parameters → results are displayed locally and uploaded to the cloud → control actions are executed when thresholds are met. This layered design promotes modular development, making it easier to upgrade individual components without affecting the entire system. It also improves reliability, fault isolation, and scalability, making the architecture suitable for smart home and energy management applications.

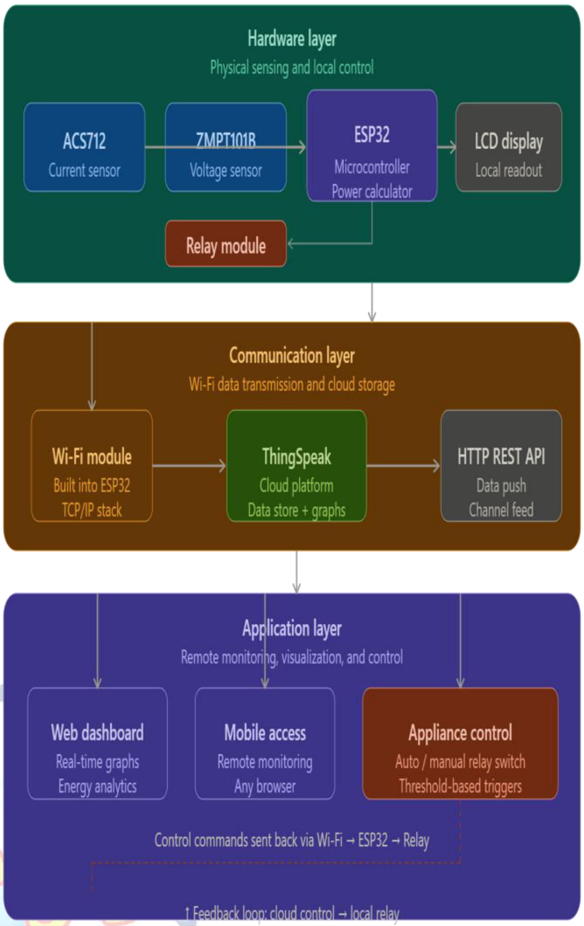

Fig 3.2 Proposed System Architecture

The IoT Energy Sense System follows a layered architecture consisting of hardware, communication, and application layers to ensure modularity, scalability, and reliable operation. In the hardware layer, the system uses the ACS712 to measure load current and the ZMPT101B to measure supply voltage. These sensors continuously generate analog signals proportional to electrical parameters, which are fed into the ESP32 microcontroller. The ESP32 performs Analog-to-Digital Conversion (ADC), calculates RMS voltage and current values, and computes instantaneous power using the formula P=V×IP = V \times IP=V×I. It also calculates energy consumption over time. The processed values are displayed locally on an LCD screen for immediate user reference, ensuring offline accessibility. Additionally, a relay module is connected to the ESP32 to control appliances either manually or automatically based on predefined threshold conditions.

The communication layer enables wireless data transmission to the cloud. The ESP32 uses its built-in Wi-Fi module and TCP/IP protocol stack to send data via

HTTP REST API to the ThingSpeak cloud platform. ThingSpeak stores incoming data, generates real-time graphs, and maintains historical records for analysis. The system also supports bidirectional communication, meaning control commands from the cloud can be sent back to the ESP32, which then activates or deactivates the relay accordingly. This feedback loop enables remote appliance control and automated energy management.

The application layer provides user interaction and monitoring capabilities. Users can access real-time energy data through a web dashboard or mobile browser interface. The dashboard displays voltage, current, power, and energy trends graphically, allowing users to analyze consumption patterns. Users can also set threshold values for automatic switching, manually control appliances, and review historical energy reports. This layered architecture ensures structured data flow from sensors to cloud and back to control units, making the system reliable and efficient for smart home energy management.

3.2 USE CASE DIAGRAM

The document does not explicitly present a graphical use case diagram; however, the primary use cases can be clearly derived from the system functionality and architecture. The system is designed to support real-time energy monitoring, automated appliance control, cloud-based data visualization, and anomaly detection. These functional behaviors collectively define the operational scope of the IoT Energy Sense System. The interactions are mainly centered around two actors: the Home User and the System itself, where the user performs monitoring and control actions while the system executes measurement, processing, and automation tasks.

One of the primary use cases is real-time monitoring of electrical parameters. The Home User can observe voltage, current, and power values locally through the LCD display or remotely via the ThingSpeak cloud dashboard. The system continuously reads sensor inputs, processes the data, and updates the display and cloud channel at regular intervals. This use case ensures transparency in energy consumption and allows users to remain aware of their real-time electricity usage without complex setup or manual measurement tools.

Another critical use case is automatic appliance control based on predefined threshold values. The System continuously analyzes sensor data, and when the measured power or current exceeds a user-defined limit, it triggers the relay module to switch off the connected appliance. This automated control mechanism prevents overload conditions, reduces energy wastage, and enhances safety. The decision-making process occurs internally within the microcontroller, making the automation independent of constant user supervision.

The system also supports historical data analysis as an important use case. The Home User (or Admin role in extended implementations) can log into the cloud platform to view stored energy consumption records in graphical format. ThingSpeak generates time-based charts that help users identify consumption patterns, peak usage hours, and irregular behaviors. This functionality assists in making informed decisions regarding load management and energy efficiency improvements.Finally, remote access via Wi-Fi serves as a key extension of the system's capabilities. Through internet connectivity, the Home User can monitor readings, review historical data, and send control commands from any location. This extension enhances convenience and transforms the system from a basic monitoring device into a fully functional IoT-based smart energy management solution. Overall, the derived use cases demonstrate a balance between user-driven interactions and autonomous system operations, ensuring both flexibility and intelligent automation

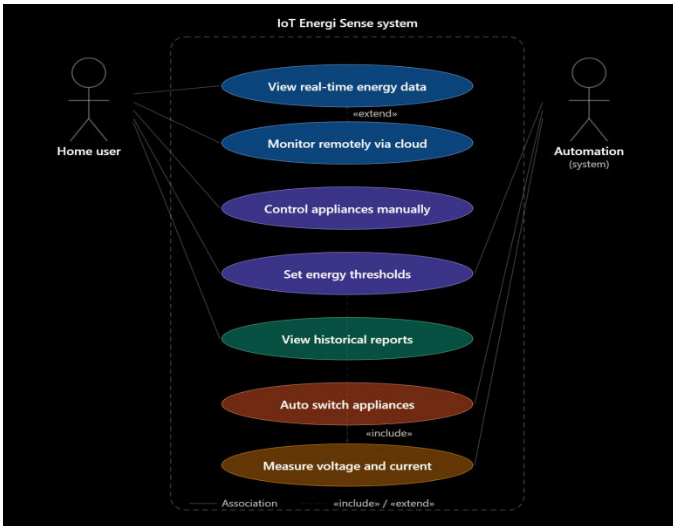

Fig 3.2 Use Case Diagram

The use case diagram represents the interaction between the system and its two primary actors: the Home User and the Automation System. The Home User interacts with the system to view real-time energy data, monitor consumption remotely through the ThingSpeak cloud platform, control appliances manually, set energy thresholds, and access historical reports. When the user logs into the dashboard, they can observe graphical representations of voltage, current, and power values, helping them understand their energy usage behavior. The ability to manually switch appliances ON or OFF provides direct control over connected loads.

The Automation System operates independently once threshold values are configured. It continuously measures voltage and current through the sensors and processes the data using the ESP32 controller. If the measured power exceeds the defined threshold, the system automatically triggers the relay module to switch off the appliance, preventing overload and energy wastage. The "Auto Switch Appliances" functionality includes the measurement process, as automatic control depends on continuous monitoring. Additionally, viewing real-time energy data extends remote monitoring capabilities since users can access system information from anywhere via the cloud. This design supports both manual intervention and fully automated operation, ensuring flexibility and intelligent control.

Furthermore, the use case model highlights the feedback mechanism between the user and the system. When the Automation System performs an action—such as switching off an appliance due to threshold violation—the updated status is reflected immediately on both the LCD display and the cloud dashboard. This ensures transparency and keeps the user informed about system decisions. In addition, anomaly detection and alert generation can be considered extended use cases, where abnormal fluctuations in voltage or current trigger warnings. These alerts enhance system reliability and safety, making the overall interaction dynamic, responsive, and suitable for smart energy management applications.

In addition to monitoring and automation, the use case diagram also reflects the system's capability for configuration and continuous improvement of energy management strategies. The Home User can modify threshold values, adjust monitoring intervals, or reconfigure appliance control settings based on observed consumption patterns from the ThingSpeak dashboard. This adaptive interaction enables users to optimize energy usage over time rather than relying on fixed settings. Moreover, the integration of the ESP32 ensures seamless communication between sensing, processing, and control components, allowing real-time updates and immediate execution of commands. This additional configurability strengthens the system's role as an intelligent and user-centric energy management solution, combining awareness, automation, and remote accessibility in a unified framework.

3.3 CLASS DIAGRAM

No explicit class diagram appears in the document, likely because the project is primarily hardware-focused and implemented using embedded C, which does not strictly follow full object-oriented programming (OOP) principles. However, for documentation and design clarity, the system can be represented using an inferred class diagram that models its logical structure in an object-oriented manner. This conceptual 34 odelling approach helps in understanding system modularity, component interaction, and future scalability, even if the actual implementation is procedural in nature.

The first Inferred class Is the **Sensor** class, which represents both voltage and current sensing components. It may include attributes such as voltage and current values, along with calibration parameters and sensor status. The primary method, readData(), would be responsible for acquiring raw analog signals and converting them into usable electrical parameters. In a refined model, this class could be further specialized into CurrentSensor and VoltageSensor subclasses, each implementing specific measurement and conversion logic. This abstraction improves code maintainability and separates sensing logic from processing functions.

The **ESP32Controller** class acts as the core processing unit of the system. It receives input data from the Sensor class and performs operations such as ADC conversion, RMS calculation, and power computation through a method like calculatePower(). It also contains methods such as controlRelay() to manage appliance switching and manageWiFi() to handle internet connectivity. This class essentially coordinates all other modules and serves as the central controller in the software architecture. Since it interacts directly with sensors and output components, it forms the backbone of the inferred object-oriented model.

The **Display** and **Relay** classes represent output and control components. The Display class includes methods like updateLCD() and updateCloud() to present processed information either locally or on the cloud platform. The Relay class includes switchON() and switchOFF() methods to manage appliance states. These classes are aggregated by the ESP32Controller, meaning they are part of the controller's operation but can be conceptually treated as separate modules. This aggregation ensures modular design and allows easy replacement or enhancement of display and control mechanisms without affecting core processing logic.

Finally, the **CloudService** class models interaction with the ThingSpeak platform. It contains methods such as uploadToThingSpeak() for sending processed data to the cloud and retrieveData() for accessing stored information. In terms of relationships, there is a dependency relationship between Sensor and ESP32Controller, as the controller depends on sensor data for processing. There is also an aggregation relationship between ESP32Controller and Display/Relay components, since the controller manages their operations. Overall, although the actual system may not be fully object-oriented, this inferred class structure provides a clear and organized representation suitable for academic documentation and future software expansion.

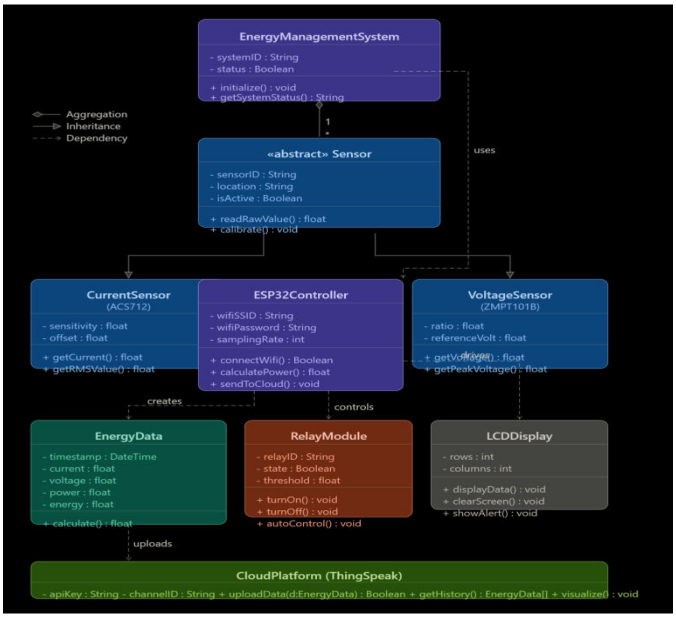

Fig 3.3 Sequence Diagram

The class diagram illustrates the object-oriented structure of the IoT Energy Sense System. The central class, EnergyManagementSystem, manages overall system operations and maintains system status. It aggregates sensor components and coordinates interactions between hardware and software modules. An abstract Sensor class defines common attributes such as sensor ID, location, and activity status, along with methods for reading raw values and calibration. The CurrentSensor (ACS712) and VoltageSensor (ZMPT101B) classes inherit from this abstract class and implement specialized methods to calculate RMS current, peak voltage, and other electrical parameters.

The ESP32Controller class plays a crucial role in system coordination. It contains Wi-Fi credentials, sampling rate configurations, and methods for connecting to the network, calculating power, and sending data to the cloud. It interacts with the RelayModule to control appliances and with the LCDDisplay to show local readings. The EnergyData class stores processed values such as timestamp, voltage, current, power, and energy before uploading them to the cloud platform. The RelayModule class includes attributes for relay ID, state, and threshold values, along with methods for turning appliances ON, OFF, and performing automatic control. The LCDDisplay class manages local visualization functions such as displaying data, clearing the screen, and showing alerts.

Finally, the CloudPlatform class represents integration with ThingSpeak, handling API keys, channel IDs, data uploads, historical retrieval, and visualization functions. The relationships between these classes demonstrate aggregation, inheritance, and dependency structures, ensuring modular development and future scalability. Overall, the class diagram provides a clear blueprint for implementing the system in an object-oriented programming environment.

In addition, the diagram emphasizes clear separation of responsibilities among classes, which enhances maintainability and extensibility. For example, any modification in sensing logic—such as adding a new type of sensor—can be achieved by extending the abstract Sensor class without altering the core processing logic of the ESP32Controller. Similarly, changes in cloud service providers can be managed within the CloudPlatform class without affecting other modules. This loose coupling between classes ensures that the system remains adaptable to future technological upgrades or functional expansions.

Moreover, the defined relationships reflect real-world interactions within the system. Inheritance between Sensor and its subclasses promotes code reuse and polymorphism, allowing uniform handling of different sensor types. Aggregation between ESP32Controller and modules such as RelayModule and LCDDisplay shows that these components are part of the controller's operation but maintain independent functionalities. Dependency relationships between EnergyManagementSystem and other classes illustrate centralized coordination while preserving modular design. Together, these structured relationships ensure that the class diagram not only models the system logically but also supports efficient implementation and long-term scalability.

4. RESULTS

4.1 OUTPUT DESIGN

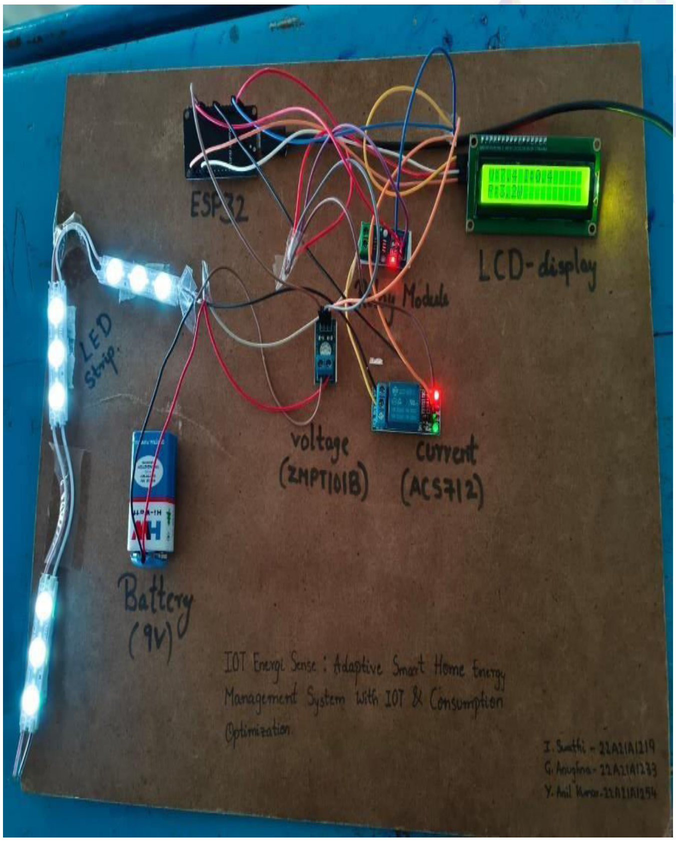

Fig 4.1: Output Result

Fig 4.2: Graphical Analysis

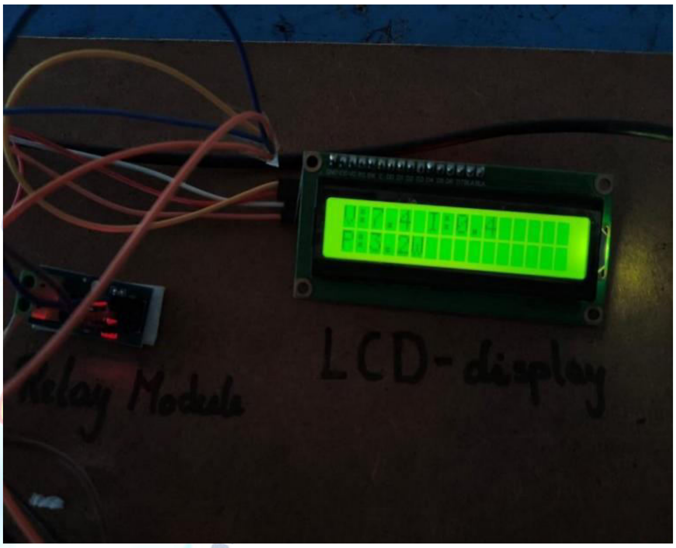

Fig 4.3: System Screenshots

5. CONCLUSION

The IoT Energi Sense: Adaptive Smart Home Energy Management System has been successfully designed, developed, and implemented as an efficient solution for real-time energy monitoring and control. With the increasing demand for electricity and the need for efficient energy utilization, this project provides a practical approach to reducing energy wastage and improving user awareness. The system integrates various hardware components such as the ACS712 current sensor and ZMPT101B voltage sensor to measure electrical parameters accurately. These sensor values are processed by the ESP32 microcontroller, which acts as the central unit of the system.

The ESP32 performs real-time calculations of power consumption by analyzing voltage and current values, and the results are displayed on an LCD screen. This continuous monitoring allows users to understand their energy usage patterns and identify areas where energy can be saved. Additionally, the inclusion of a relay module enables control of electrical appliances, allowing users to switch devices ON or OFF based on their requirements. This feature plays a crucial role in reducing unnecessary power consumption and enhancing energy efficiency.

One of the major strengths of this system is its simplicity and cost-effectiveness. The use of easily available components and straightforward design makes it accessible for small-scale applications such as homes and offices. The system does not require complex infrastructure or high investment, making it suitable for widespread adoption. Furthermore, the project demonstrates the effective application of IoT concepts in real-world scenarios, showing how smart systems can improve daily life.

The system also ensures reliable performance through continuous operation and accurate data processing. The integration of hardware and software components has been successfully achieved, resulting in a stable and efficient system. Overall, the project meets its objectives by providing a smart, reliable, and user-friendly energy management solution. It contributes to energy conservation and supports the development of smart home technologies.

FUTURE ENHANCEMENT

Although the current system performs effectively in monitoring and controlling energy usage, there are several opportunities for further enhancement and improvement. One of the major future developments is the integration of a mobile application that allows users to monitor and control their appliances remotely. This would increase convenience and provide greater flexibility in managing energy consumption.

Another important enhancement is the implementation of cloud-based data storage. By storing energy usage data on the cloud, users can access historical records, analyze consumption patterns, and make better decisions. This can also enable advanced features such as graphical representation of energy usage and real-time alerts.

The system can also be improved by incorporating artificial intelligence and machine learning techniques. These technologies can be used to predict energy consumption patterns, suggest optimization strategies, and automate appliance control based on user behavior. This would make the system more intelligent and adaptive.

In addition, the system can be expanded to support multiple appliances and larger environments such as industries and commercial buildings. This would require scaling the hardware and improving system capacity. Integration with renewable energy sources such as solar panels can also be considered to promote sustainable energy usage.

Furthermore, advanced features such as voice control using smart assistants can be added to enhance user interaction. Security features can also be implemented to protect the system from unauthorized access. By incorporating these improvements, the IoT Energi Sense system can evolve into a more advanced and comprehensive smart energy management solution.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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