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Artificial Intelligence & Machine Learning Based Smart Energy Meter

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Abstract: ***Energy management is an inspiring domain in developing of renewable energy sources. The major objective of an energy management system is to achieve optimum energy procurement and utilization throughout the organization, minimize energy costs without affecting production, and minimize environmental effects. The rapid growth in energy demand and the increasing integration of renewable energy sources have created significant challenges in efficient power management and consumption optimization. Traditional energy metering systems lack real-time intelligence, adaptability, and predictive capabilities, resulting in energy wastage and inefficient load management. To address these limitations, this paper presents an Artificial Intelligence and Machine Learning–based Smart Energy Management System designed to monitor, analyze, and optimize energy consumption patterns in real time.***

The proposed system utilizes smart sensors, Machine learning algorithms such as linear regression, decision trees to forecast energy demand, detect anomalies, and identify consumption trends, Artificial intelligence techniques enable automated decision-making. Experimental results demonstrate the integration of AI and ML provides scalability and adaptability, making the system suitable for residential, commercial, and industrial applications.

I. INTRODUCTION

The growing demand for electrical energy, driven by rapid urbanization, industrial expansion, and increased use of electronic devices, has placed significant stress on existing power generation and distribution systems. At the same time, concerns related to energy efficiency, rising operational costs, and environmental sustainability have made intelligent energy management a critical requirement. Conventional energy monitoring systems are largely passive in nature and provide limited insight into real-time consumption patterns, making them insufficient for modern energy management needs.

Advancements in smart grids and Internet of Things (IoT) technologies have enabled continuous monitoring of energy usage through smart meters and connected sensors. However, merely collecting data does not guarantee efficient energy utilization. The challenge lies in analysing large volumes of energy data and converting it into meaningful insights that support informed decision-making. This has led to increasing interest in the application of Artificial Intelligence (AI) and Machine Learning (ML) techniques for smart energy systems.

This project focuses on the development of an AI and ML–based smart energy management system that enhances traditional metering infrastructure by integrating data-driven intelligence. The proposed approach aims to improve energy efficiency, support proactive decision-making, and contribute to the development of sustainable and intelligent power management solutions suitable for residential, commercial, and industrial environments

I. LITERATURE REVIEW

The continuous growth in energy consumption and the increasing complexity of modern power systems have made efficient energy monitoring and management a critical challenge. Traditional energy meters are primarily designed for basic measurement and billing purposes and lack the capability to analyse consumption behaviour or support predictive decision-making. To address these limitations, an energy meter system integrated with Machine Learning and Artificial Intelligence of Things (AIOT) provides an intelligent and adaptive solution for modern energy management. In this approach, IoT-enabled smart meters equipped with voltage and current sensors continuously collect real-time energy data and transmit it to processing platforms through reliable communication networks. Machine learning algorithms analyse historical and real-time data to identify usage patterns, forecast energy demand, and detect anomalies such as power theft or abnormal consumption. These predictive capabilities enable proactive load management and help reduce peak demand stress on the power grid. Artificial intelligence enhances the system by enabling automated decision-making and adaptive control mechanisms, allowing the meter to respond intelligently to changing consumption conditions. Edge-level intelligence supports fast local analysis and immediate alerts, while cloud-based AI systems perform long-term trend analysis and optimization. The integration of AIOT improves system reliability by enabling early fault detection and predictive maintenance, reducing downtime and operational costs. Additionally, AI-driven insights provide consumers with a better understanding of their energy usage behaviour, encouraging energy-efficient practices. For utility providers, the system offers improved demand forecasting, optimized resource allocation, and enhanced grid stability. Overall, the integration of machine learning and Artificial Intelligence of Things transforms conventional energy meters into intelligent energy management systems that support smart grid infrastructure, reduce energy wastage, and promote sustainable and efficient power utilization in residential, commercial, and industrial environments.[1].The perspective of smart energy management has evolved significantly with the adoption of machine learning techniques that enable data-driven decision-making in modern power systems. As energy demand continues to grow and consumption patterns become increasingly dynamic, traditional energy management approaches are no longer sufficient to ensure efficiency and reliability. Machine learning provides the ability to analyze large volumes of energy data collected from smart meters, sensors, and connected devices, allowing systems to learn consumption behaviors and adapt to changing conditions. Through techniques such as load forecasting, pattern recognition, and anomaly detection, machine learning- based energy management systems can anticipate demand fluctuations, optimize energy distribution, and reduce peak load stress. These systems support proactive strategies such as demand response and automated control, improving overall grid stability. From a broader perspective, the integration of machine learning enables continuous improvement as models refine their predictions over time using real-world data. This intelligent approach enhances energy efficiency, minimizes wastage, and supports the integration of renewable energy sources by managing variability and uncertainty. Furthermore, machine learning-driven insights empower consumers with greater awareness of their energy usage while assisting utility providers in planning and resource optimization. Overall, smart energy management systems based on machine learning represent a key technological advancement toward sustainable, resilient, and intelligent energy infrastructures capable of meeting future power demands.[2].

Enhancing energy efficiency in buildings has become a critical objective due to rising energy demand, operational costs, and environmental concerns. Conventional building energy management systems often rely on predefined schedules and manual control, which limits their ability to adapt to dynamic occupancy patterns and changing environmental conditions. A smart building energy management system that integrates Internet of Things (IoT) technologies with machine learning offers an intelligent and adaptive solution to this challenge. IoT-enabled sensors continuously monitor parameters such as energy consumption, temperature, humidity, lighting levels, and occupancy, generating real-time data across building infrastructure. Machine learning algorithms analyze this data to identify usage patterns, predict energy demand, and optimize the operation of heating, ventilation, air conditioning, and lighting systems. By learning from historical and real-time data, the system can automatically adjust control strategies to minimize energy consumption while maintaining occupant comfort. Predictive analytics enable early detection of inefficiencies and equipment faults, supporting timely maintenance and reducing energy losses. Additionally, data- driven insights provide building managers with a clearer understanding of energy performance, enabling informed decision-making and long-term optimization. The integration of machine learning and IoT transforms traditional buildings into intelligent, responsive that reduce energy wastage, improve operational, cost-effective building management.[3]The development of an IoT-enabled smart electricity meter addresses the growing need for accurate, real-time energy monitoring and improved efficiency in modern power systems. Conventional electricity meters are limited in their ability to provide continuous feedback and detailed insights into consumption behaviour, which often leads to inefficient energy usage and delayed fault identification. By integrating IoT technology, smart electricity meters can continuously measure electrical parameters such as voltage, current, power, and energy consumption and transmit this data to centralized platforms through reliable communication networks. Real-time data availability enables users to monitor their energy usage patterns more effectively and make informed decisions to reduce unnecessary consumption. Additionally, advanced data analytics can be applied to identify peak usage periods, detect abnormal consumption, and support energy optimization strategies. The smart meter also enhances system reliability by enabling early detection of faults and irregularities, reducing downtime and maintenance costs. For utility providers, IoT- enabled meters offer improved load visibility, accurate billing, and better demand forecasting, contributing to efficient grid management. Overall, the implementation of IoT-based smart electricity meters transforms traditional metering infrastructure into an intelligent energy management solution that promotes energy efficiency, operational transparency, and sustainable power utilization across residential, commercial, and industrial applications.[4].An IoT-based smart energy meter system using ML offers an efficient and intelligent solution for real-time energy monitoring and management in modern power systems. IoT- enabled smart meters continuously measure electricalparameters such as voltage, current, and power consumption and transmit the data to centralized platforms through secure communication networks. Machine learning algorithms process both historical and real-time data to identify consumption patterns, predict future energy demand, and detect anomalies such as unusual usage or system faults. By learning from user behavior and operational trends, the system provides accurate insights that support informed decision-making and energy optimization. Automated alerts and predictive analysis help users reduce energy wastage and manage peak load conditions more effectively. From the utility perspective, the integration of machine learning enhances demand forecasting, improves load balancing, and supports efficient grid management. The combination of IoT and machine learning transforms traditional energy meters into intelligent energy management systems that improve energy efficiency, reliability, and sustainability across residential, commercial, and industrial applications.[5].

II. OBJECTIVES AND METHODOLOGY

1. To Design and implementation of energy meter.

2. To Implement an unit estimation model.

3. To Detect short circuit.

4. To Integrate an energy unit model with smart energy meter using machine learning algorithm.

METHODOLOGIES:

1. Designing and implementation of Energy meter

- To Interface Microcontroller, Arduino Uno with Current sensor ACS712, Main supply and LCD display (16*2) to design energy meter.
- The Current sensor tracks power usage and sends data to the microcontroller.

2. Implementation of unit estimation model

- To Interface ESP32 Microcontroller with Current sensor (ACS712), Main supply and LCD display (16*2), Loads to a buzzer to design unit estimation model.
- We have used 3 loads
- Current sensor tracks power usage and sends data to the microcontroller.
- Microcontroller enables wireless communication to interface with cloud
- Remote X Y is a cloud server that helps to display the parameters.
- Free units are fixed to some Unit (10) after the use of free units billing starts

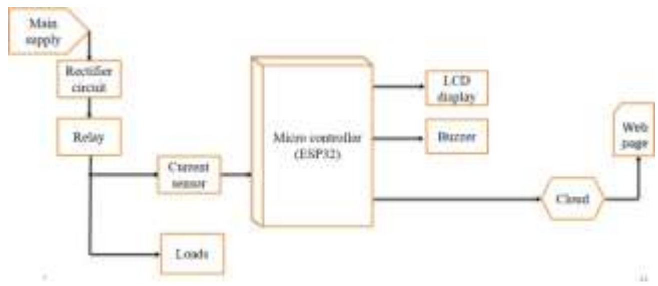
3. Detection of short circuit

- Interfacing the Rectifier circuit and relay with unit estimation model from main supply
- Relay acts as a switch and turn off during short is detected

4. Integration of energy unit model with smart energy meter using machine learning

- Random forest algorithm is used for this model
- A set of data sheet is given as a input to this algorithm uses it for classification as a tree and predict future energy usage.

III. BLOCK DIAGRAM



The block diagram illustrates a Smart Energy Meter utilizing Internet of Things (IoT), Artificial Intelligence & Machine Learning technology. An Artificial Intelligence and Machine Learning–based smart energy meter consists of several interconnected components that work together to enable intelligent energy monitoring and control. The rectifier circuit converts the incoming AC supply into a regulated DC voltage required for powering the electronic components of the system. The current sensor continuously measures the load current and provides real-time energy consumption data, which is processed by the ESP32 microcontroller, the core unit of the energy meter. The ESP32 handles data acquisition, basic calculations, and wireless communication while also interfacing with machine learning models deployed either locally or through the cloud for consumption analysis and prediction. The relay is used as a control element that allows automatic or remote switching of electrical loads based on AI-driven decisions, such as overload protection or energy optimization. The LCD display provides local visualization of key parameters such as current consumption and system status, enabling users to monitor energy usage directly at the meter. Collected data is transmitted to the cloud platform, where machine learning algorithms analyse historical and real-time data to identify usage patterns, forecast energy demand, and detect anomalies. The processed information is then presented through a webpage interface, allowing users and utility providers to remotely monitor energy consumption, receive alerts, and make informed decisions to improve energy efficiency.

IMPLEMENTATION

Artificial Intelligence and Machine Learning–based smart energy meter integrates sensing, control, communication, and intelligent data analysis to enable efficient energy monitoring and management. A rectifier circuit converts the AC mains supply into a regulated DC voltage to power the system components. The current sensor is connected to the load to continuously measure real-time current consumption, and this data is processed by the ESP32 microcontroller, which serves as the core processing and communication unit. The ESP32 performs initial energy calculations, manages data acquisition, and transmits consumption data to the cloud using its built-in Wi-Fi capability. An LCD display is interfaced with the ESP32 to provide local visualization of energy parameters and system status. A relay module is incorporated to enable automatic or remote control of the connected load, allowing the system to disconnect or regulate power based on predefined limits or intelligent decisions. In the cloud platform, machine learning algorithms analyse historical and real-time energy data to identify usage patterns, predict future consumption, and detect abnormal behaviour. The analysed data and insights are presented through a webpage interface, enabling users to remotely monitor energy usage, receive alerts, and make informed decisions to improve energy efficiency.

IV. RESULTS

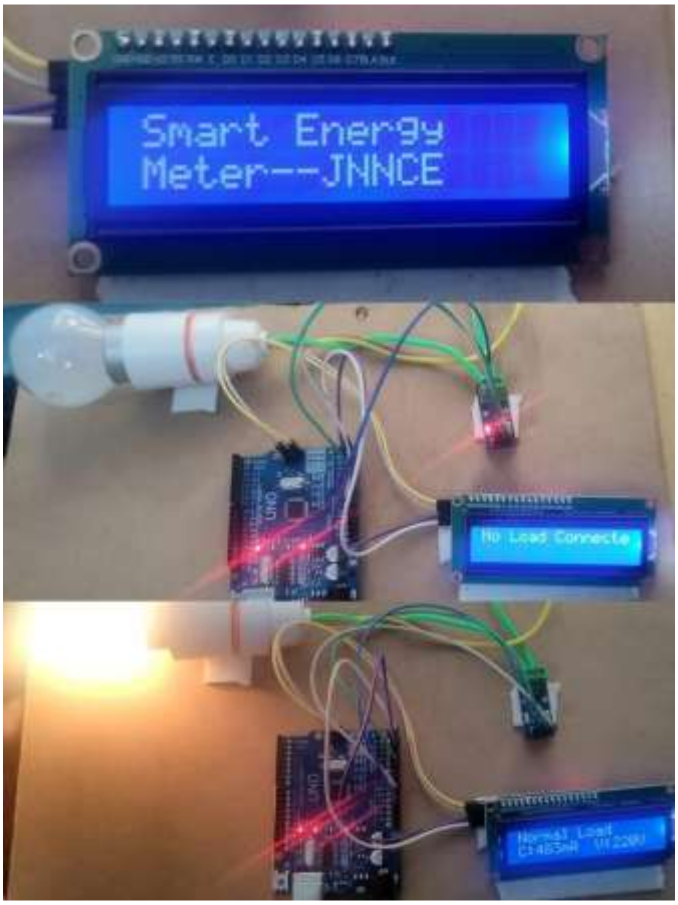


FIG-1: Energy Meter

The energy meter that detect load connected and if it is a normal load displays current and voltage reading when connected to main supply.

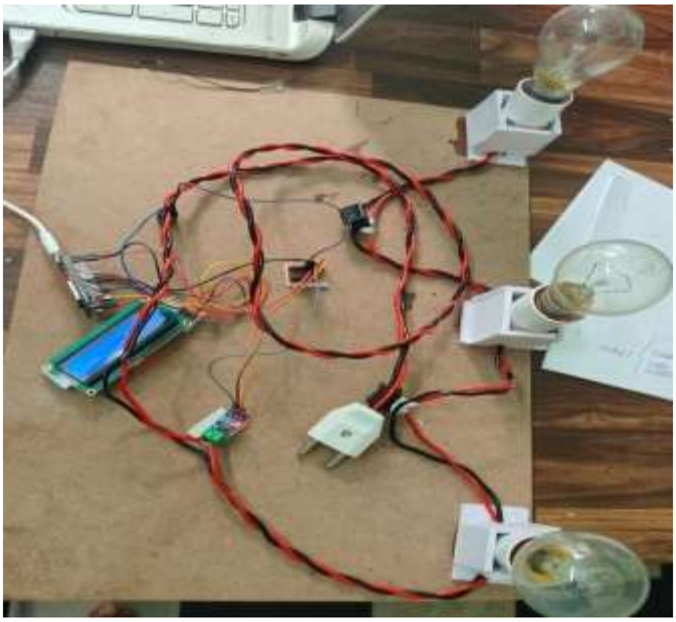


FIG-2: Unit estimation model

The figure 2 shows the unit estimation model which we have used for the implementation of our project. Unit estimation model can display number of load turned on, total available free units, available free units and generated bill.

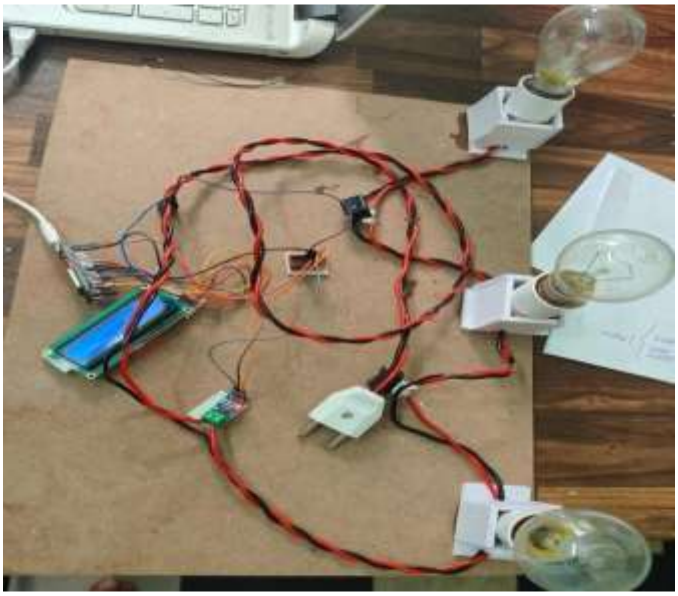


FIG-3: Smart energy meter that can detect short circuit

Above figure 4 represent an Smart energy meter integrated by Artificial intelligence & Machine learning that can estimated current, voltage, power usage, future usage units and provides billing.

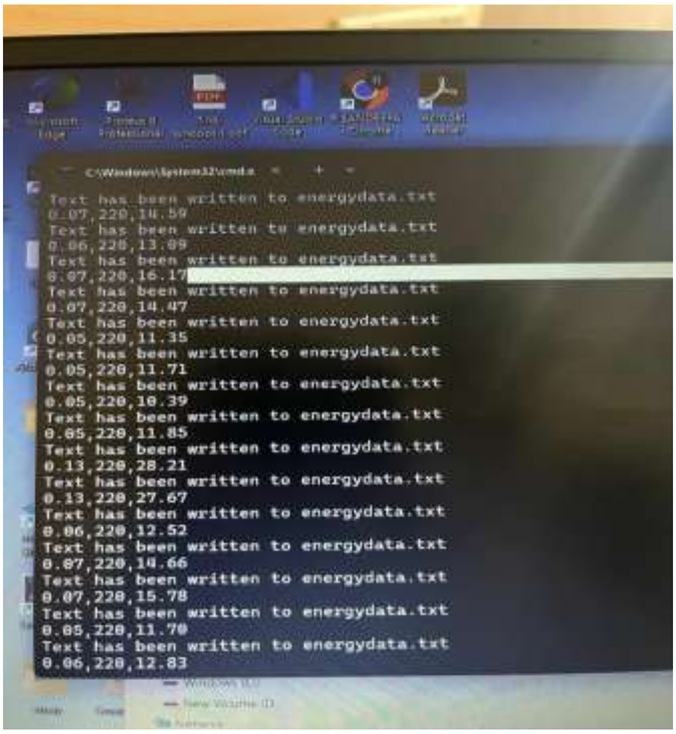


FIG-4: Set of inputs

We are provided with a set of data sheet that contain current, voltage of some about 500 data.

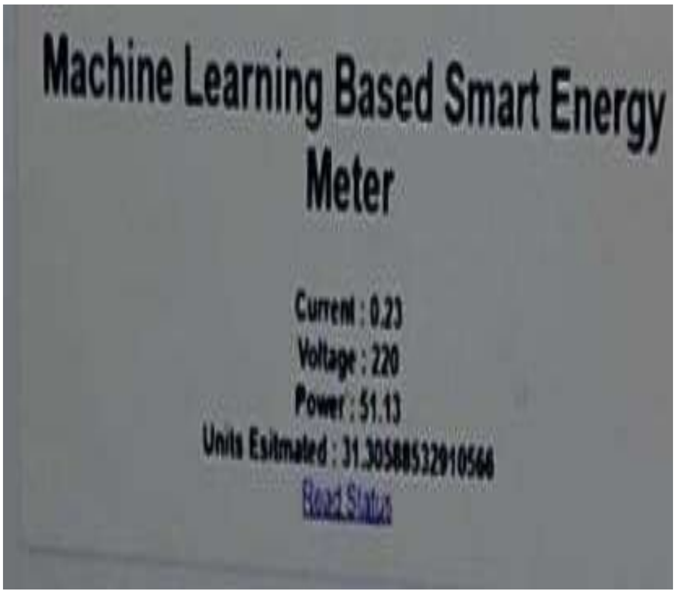


FIG-5: Estimated Output

Figure contain Current, Voltage and Power reading which is varying based on load that we switch on and from data set the future units are estimated and bill is generated.

V. CONCLUSION

In this paper, we presented an approach how the Artificial Intelligence and Machine Learning–based smart energy meter represents an effective advancement over traditional metering systems by enabling intelligent monitoring, analysis, and control of energy consumption. The system provides accurate insights into usage patterns, supports demand prediction, and enables timely detection of abnormal conditions. Additionally, remote monitoring and visualization improve user awareness and operational transparency.

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