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Smart Electricity Tracking System

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***Abstract*— This research paper discusses the implementation of smart electricity system using Python libraries and Proteus simulation. The proposed system solves the issue of inaccurate meter readings, digitalized tedious and error-prone tasks and provides a pocket- friendly solution keeping in mind the middle-class and poor citizens of the nation. The system tracks the real-time consumption of electricity of the user and sends alerts basedon the preset value of the monthly bill amount. The system uses python libraries for creating graphical visualizations ofthe usage, to send real-time notifications and updates and warning message when the electricity limit reaches. Proteus used for hardware simulation of the model which using theGSM and ESP-32 module connected with the internet server to provide relevant data to the software. The GSM follows a set of protocols which allows it to communicate with other devices over the internet. The proposed smart electricity tracking system aims to ease the sudden shock of increased electric bill and provide a user-friendly, interactive and cost-efficient solution to the consumers.**

***Keywords*— Smart meter, electricity, python, proteus, tracking, tesseract OCR, GSM, ESP-32, energy**

I. INTRODUCTION

With the changing world, people have learned to become moreconscious of their choices. Be it the from the smallest thingslike the brand of a pencil to the energy consumption bill the get. Monitoring of data has become essential part of the sustainability process. The tracking of energy consumption in India is a tedious and error-prone task. The department ofelectricity sends a person to take readings from the meter which can often lead to over or under-readings, wastage of manpowerand inconvenience to the consumer. [1] To overcome the issues, the smart electricity tracking system is introduced. The system helps to track electricity consumption by presetting a user- defined limit to the daily, monthly, quarterly or yearly bill amount limit. The system analyses the energy consumption of the user and provides a graphical representation for better user interface and understanding. Python libraries like tesseract ocr, notification and plyer are used to make an interactive application which user-friendly and eases the user's life. The hardware transmitting the readings to the software code includes ESP-32, GSM (Global System for Mobile Communications) module, AC voltage detector, resistors and capacitors, to create a setup that could communicate with the software directly via Wi-fi connection. Instead of setting up a new meter box, the solution proposes to install the planned hardware to the existing manual meter box, reducing the overall cost of the project making it affordable and engaging to theconsumers. [2]

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II. LITERATURE REVIEW

Much emphasis has been paid to the integration of photovoltaic (PV) systems into the electrical grid as a means of lowering dependency on non-renewable energy sources. The key to controlling distributed energy generation is smart net-metering systems, which enable bidirectional energy transfer between PV installations and the grid. New developments in smart grid technology, such real-time monitoring and communication protocols, have improved consumer-grid interaction and streamlined energy management. Studies indicate that these systems provide financial benefits, including reduced dependence on fossil fuels and lower greenhouse gas emissions. Additionally, simulation tools such as MATLAB and Proteus play a vital role in assessing and improving the efficiency of these systems. [3]

Smart meters are crucial elements of smart energy systems, enabling efficient data collection, monitoring, and business intelligence applications. Recent advancements in smart grid technology have integrated communication frameworks like the Internet of Things (IoT) to enhance energy efficiency and decision-making. Data from smart meters supports various functions, including demand-side management, load forecasting, and predictive maintenance, across all stages of energy generation, distribution, and consumption. Additionally, the integration of artificial intelligence (AI) allows smart metersto further optimize energy distribution and improve overall grid performance. [4]

Large multimodal models (LMMs) have made significant progress, particularly in vision and language tasks like optical character recognition (OCR). Text-related visual tasks, including as text recognition, Visual Question Answering (VQA), and handwritten text recognition, have been the subject of recent evaluations of models such as GPT-4V and Gemini. A comprehensive benchmark called OCRBench has been developed to assess the OCR capabilities of LMMs and point out both their benefits and drawbacks, especially when it comes to processing non-semantic and multilingual text. Nevertheless, despite their remarkable powers, LMMs still struggle with handwritten writing and intricate mathematical formulae. [5]

Author has highlighted different protocols like integration of wireless sensor network, ZigBee and also IoT in his smart energy management system to monitor real-time energy consumption. Advanced strategies like model-predictive-control and dynamic energy scheduling optimize HVAC operations, reduce peak demand, and enhance energy efficiency. Key research gaps include insufficient cloud integration, optimization algorithms, load control, and scalability. Addressing these gaps, the work emphasizes the need for a scalable, real-time SEMS that incorporates advanced optimization and load control for multiple locations. [6]

The literature discusses the use of AI in automated meter reading (AMR) technology for utility photo billing, highlighting advancements in accuracy through deep learning and computer vision techniques. Various models like Faster R- CNN, SSD, and CNNs have been proposed to overcome challenges like image blur, light reflections, and rotated digits. The methods have shown promising results, such as higher accuracy, improved real-time performance, and reduced errors in detecting and recognizing meter readings. Key research focuses on developing lightweight models, optimizing performance in real-world settings, and enhancing the efficiency of meter reading systems across different environments. [7]

The study focuses on an IoT-based smart net energy meter for residential use, enabling the integration of solar photovoltaic (PV) systems in Dhaka, Bangladesh. Grid electricity usage and surplus solar power sent to national grid is easily tracked by smart system, this helps homeowners to reduce electricity cost and sell excess power. Government's automatic power tariff for billing is also included in this system which is monitored by dedicated app supporting bill payments. Hardware analysis and software simulation is done to monitor performance and also some additional features like sending notification on cases like smoke, gas and tampering is done. [8]

This study explores how Tesseract OCR can be integrated with the Laravel framework to improve text recognition capabilities in web applications. It focuses on sophisticated image preprocessing methods and effective error handling to increase both accuracy and efficiency. The results demonstrate Tesseract's strong performance in numerous practical situations, particularly with clear text images, though it also notes difficulties encountered with graphically altered and handwritten material. This research serves as a useful guide for developers interested in implementing OCR solutions. [9]

The non-commercial sector accounts for 30-40% of global electricity consumption, posing challenges in demand management as population growth drives up demand. Smart grids enable communication between utilities and end-users, improving reliability and efficiency through Demand Side Management (DSM). Techniques like Direct Load Control (DLC) and Demand Response (DR) aim to shift usage based on price signals, requiring smart meters and appliances. Various hybrid algorithms, including the proposed Hybrid Bacterial Foraging and Ant Colony Optimization (HB-ACO), enhance scheduling of home appliances to reduce electricity costs and peak-to-average ratios. The literature reveals ongoing trade-offs between cost reduction, peak management, and user comfort, highlighting the need for balanced solutions. [10]

Tajikistan's hydropower potential remains largely untapped, with less than 10% developed, despite ample resources for domestic needs and exports. The country relies heavily on hydropower, with increasing electricity production and consumption highlighting the need for better energy efficiency. Utilizing fuzzy logic and artificial intelligence can enhance predictions and management of consumption patterns, improving system reliability.

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A trapezoidal membership function categorizes winter electricity consumption into fuzzy sets, guiding decision-making through a probabilistic approach that integrates both quantitative and qualitative indicators for effective energy planning. [11]

The paper focuses on resolving the current energy tracking issues like loss of time, faulty readings, lack of knowledge of the person, incorrect billing, etc. by developing an Automatic Meter Reading (AMR) framework. The system is based on theGSM module which connects to the GSM server and sends information of the meter readings to the software application via the internet. It also predominantly uses the GPRS (General Packet Radio Service), which is a protocol for wireless communication among various connected devices. The key difference identified in the project is the use of Arduino Uno instead of ESP-32 which has been used in this project. [12]

The paper proposes a new model for smart grids using IoT (Internet of Things), machine learning, AI and cloud-based smart meters. It highlights the importance of smart meters in the smart grid system. The system proposed to have used smart meters that can refresh data every five minutes and store records hourly, daily and monthly on the cloud server. It uses ML and AI to forecast the user's energy consumption allowing them to retrospect on the usage and hence, save money and time. It follows the principle of Singular Spectrum Analysis (SSA) in the ML model for predictions. The drawback observed in the proposed system is that setting up a fully functioning smart gridwith smart meters is an expensive task. [13]

The paper proposed an energy tracking meter using Nb-IoT communication module, ESP-8266 wi-fi module, Raspberry-pi and cloud. This new system is better than the traditional system of DR, OREM and SLN by 7.42, 27.83, and 20% respectively. It sends a reminder SMS to the user to pay the bill preventing fine or extra charges for the customer. The system mainly sends data to the electricity service provider who may cut off the electricity supply if the bill is not paid on time. The use of Nb-IoT limits the application's use to cellular connectivity, using low power and transfers less amount of data. [14]

III. METHODOLOGY

This section breaks down the methods, frameworks and technology stack used throughout the development of the project. It explains the steps we took for designing, implementing, and testing the system

1. System Requirements and Analysis:

The first phase of development concentrated on gathering the system's requirements. Based on the google form surveyand the POEMS framework, [15] we identified important requirements like presetting bill amount limit, pictorial representation of the usage, tracking consumption of every appliance, budget-friendly and setting up notification systems. Using these requirements, we then created a high- level design for the system.

- Functional Requirements: The system needed to allow consumers to preset the electricity consumption value, monitor usage and send real-time notifications. The user interfaces are designed to be intuitive and easyto use for the consumers.
- Non-Functional Requirements: The project prioritized system performance, scalability, data security, and responsiveness to ensure that the systemcould efficiently manage many consumers.

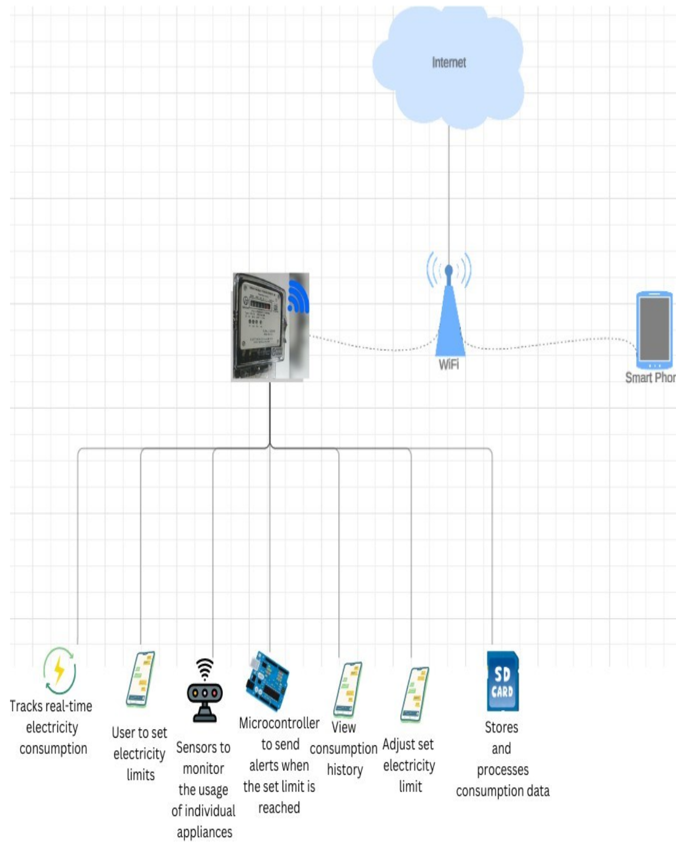

Fig.1 System Architecture Overview

2. System Design Using Python:

The "Electricity Bill Tracker" prototype simplifies the management of power consumption by integrating multiple Python packages. The system extracts data from uploaded photos of utility bills using Pytesseract and OpenCV for Optical Character Recognition (OCR). A secure login system is utilized for user registration and authentication, and an interactive graphical user interface (GUI) is created using Tkinter. Email notifications are handled via SMTP, which alerts users of account updates and excessive electricity usage. Additionally, the system uses Matplotlib for data visualization, creating graphs similar to bar charts to show consumption trends over time. Although the prototype works well, there is room for improvement, particularly in the email distribution system and the addition of additional data analytics elements to improve user insights.

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Ensuring safe access, the system starts with user registration and login. Users upload an image of their electricity bill after successfully logging in, and OpenCV and Pytesseract are used to extract data from the image. After the gathered data is examined, SMTP notifies the user via email if the amount of electricity used above 500 kWh. Additionally, the system uses Matplotlib to create visual representations of trends in electricity usage. Despite its success, new analytical analytics and an improved email distribution system should be added in the future to provide better user insights.

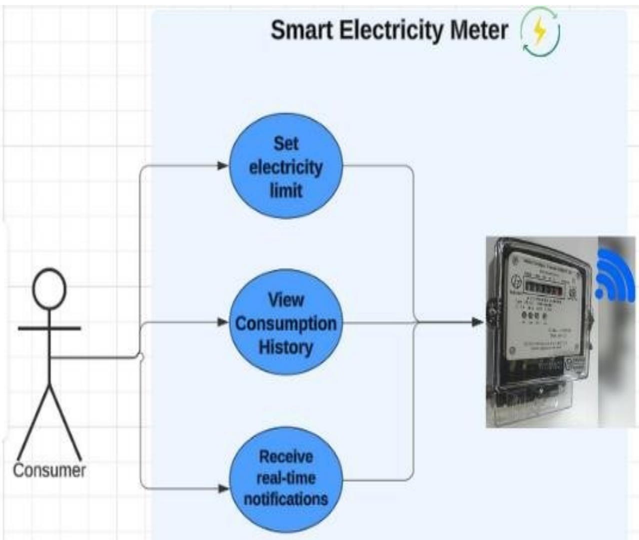

Fig.2 Use Case diagram

3. Implementation in Proteus:

3.1 ESP-32
The ESP-32 (or Espressif32) module is a power-efficient, compact-size and budget-friendly microcontroller chip with a 32-bit LX6 microprocessor that enables wireless connections via Wi-Fi and Bluetooth. The module is used in this project to execute the connection between the user's device (likely a mobile phone) and the smart electricity meter system. The module allows the system to connect to the internet and enable various facilities like data storage (AWS) and automations (IoT). [17]

3.2 GSM Module
The GSM or Global System for Mobile Communication module allows a device to connect to the wireless GSM cellular networks. It is responsible for establishing and maintaining the connection between the device and the wireless networks. It enables data transfer, that is voice calls and messages, to another device on the network. It is a crucial component in home automation and IoT systems. In this project, the module is used to send meter readings data to the software application on the user's device. [18]

3.3 AC Voltage Detector
As its name suggests, the AC (alternate current) voltage detector primary purpose is to locate or detect the flow of AC currents inthe circuit. It typically consists of a sensor, often a neon bulb or a small LED, that lights up when it comes into contact with a live wire. These detectors are essential tools for electricians and technicians to ensure safety and prevent accidents when working with electrical circuits. [19]

3.4 Resistors and Capacitor

Resistors and capacitors are fundamental electronic components. Resistors oppose the flow of current, while capacitors store electrical charge. They are used together in various circuits to control the flow of current, filter signals, and create time-dependent behaviors. Their values and combinations determine the overall characteristics of a circuit.

User Interface Development:
The user interface was created using Java Swing, enabling the development of a graphical interface for event management. Key components included buttons, text fields, and labels, all organized using layout managers like BorderLayout and GridLayout.

Testing and Validation:
The system underwent thorough testing to verify that it met the requirements and functioned correctly in different scenarios. We conducted both unit testing and integration testing:

- Unit Testing: The components, that is, the UI, hardware and algorithms were tested individually in units for debugging purposes.
- Integration Testing: After verifying the individual components, integration of components was done to ensure the system functioned seamlessly as a whole. This ensured that the prototype was able to collect, process and transmit the meter counting data seamlessly over the GSM server network, along with the proper analysis of the data for visualizations and real-time alerts. [20]

IV. CONCLUSION

The Smart Electricity Tracking System showcases the effective application of Python libraries and Proteus simulation to create a modular, scalable, and maintainable project. By utilizing Python's extensive libraries, such as, tesseract OCR, notification, NumPy, pandas and matplotlib, the system offers a strong solution for monitoring electricity consumption and sending real-time alerts and updates. The project underwent thorough testing to ensure reliability, and future enhancements will aim at integrating cloud capabilities and increasing the efficiency and features by using machine learning and artificial intelligence.

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