IoT Based Smart Energy Consumption and Monitoring System

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Abstract: As a result of the exponential growth in the global human population and the heightened reliance on electrical energy, there has been a significant surge in the demand for power, leading to a substantial shortfall during periods of high demand. To effectively address the energy concerns at hand, it is imperative to undertake the modernization of the electrical infrastructure. The use of Internet of Things (IoT) technology has the potential to be applied in several situations pertaining to energy consumption and distribution. This article primarily focuses on the topics of automated invoicing, power card functionality, theft detection, power optimisation, and the provision of pertinent energy consumption data to users. An Internet of Things (IoT)-based smart energy metre system has three primary components: a controller, a Wi-Fi device, and a theft-detecting device. The theft detector sensor promptly identifies and reacts to any instances of theft or malfunction. The controller assumes a crucial role in maintaining the operational status of all the components. This technology uses internet connectivity to link energy metres, hence eliminating the need for human involvement in power maintenance via the implementation of the Internet of Things (IoT) concept. The proposed work aims to develop an Internet of Things (IoT)-based metre reading system that enables continuous monitoring of metre readings. The system allows the service provider to automatically deactivate the power source when the consumer fails to pay their monthly bill. Additionally, the system eliminates the need for human intervention, provides accurate metre readings, and helps prevent billing errors.

Keywords: Power theft detection, automated billing, smart energy metres, and the Internet of Things

I. INTRODUCTION

Currently, electricity is the indispensable resource for human existence in the planet. Every residence, workplace, organisation, and sector requires an electrical connection for their operation. As a result of the exponential growth in the global human population and the heightened reliance on electrical energy, there has been a significant surge in the demand for power, leading to a substantial shortfall during periods of high demand. To effectively address the energy concerns at hand, it is imperative to undertake the modernization of the electrical infrastructure. The use of Internet of Things (IoT) technology has the potential to be applied in several situations pertaining to energy consumption and distribution. The notion of smart cities is seeing significant advancements in the realm of Internet of Things (IoT) and digital technologies, surpassing previous iterations. Hence, it is essential to transition towards innovative and superior alternatives, such as smart grid, smart metering, and zero energy buildings, in order to reduce dependence on these resources by minimising energy use and enhancing the utilisation of renewable energies. As a result, the efficiency of power and energy management systems will be enhanced. The effective management of electrical energy usage may be achieved via the adoption of precise metering, theft detection, and the establishment of a robust tariff and billing system. Gathering metre readings is a very challenging task in the invoicing process.

The conventional method of collecting data from electrical energy metres involves a utility company visiting customer premises at regular intervals to record the metre readings. This process exhibits many limitations, including its time-consuming nature, labor-intensive requirements, increased reliance on human resources, susceptibility to human mistake, and the potential for corruption. The procedure may have disruptions as a result of adverse weather conditions. Additionally, in the event that the customer is unavailable, the billing will remain unresolved, necessitating a human operator to review the matter. India is experiencing an energy shortfall during periods of high demand. A significant power quality concern has been identified as the occurrence of low voltage during peak hours. Utility companies often use load shedding as a power management method. The need of energy conservation is very significant in the context of a growing demand for electrical energy.

The current energy billing system has a propensity for errors, duration, and labor-intensive processes. faults may occur at several stages of the energy billing process, such as faults related to electro-mechanical metres and human errors throughout the process of recording metre readings. To counteract these inaccuracies, one might use the smart energy metre. The primary aim of the proposed study is to design and implement an intelligent energy metre. The Arduino receives the pulse from the energy metre, does unit calculations, and presents the resulting value on the liquid crystal display (LCD). The reading is recorded in an integrated EEPROM, allowing it to continue the calculation even in the event of power outages. The energy meter's reading is sent to the user's mobile phone via a Wi-Fi modem as a message. The prototype system is operated by an external power source that transforms alternating current (AC) electricity into direct current (DC) power, which is then supplied to Arduino and Wi-Fi.

This article primarily focuses on the topics of automated invoicing, power card functionality, theft detection, power optimisation, and the provision of pertinent energy consumption data to users. The user has the ability to monitor energy usage units via a web page by inputting the IP address of the device. The theft detection device, which is linked to the energy metre, will alert the firm when there is any tampering or theft detected in the metre. This notification will be sent over the PLC modem, and the detected theft will be shown on the terminal window. This technology uses internet connectivity to link energy metres, so implementing the Internet of Things (IoT) idea and eliminating the need for human involvement in power maintenance. This work is structured into six parts, with the introductory portion being the first one. Section II provides a comprehensive overview of the proposed prototype of an Internet of Things (IoT) based smart energy metre system. Section III provides the specific hardware specifications of the suggested solution. The specifics of the software are elaborated upon in section IV. The experimental findings are reported in part V, followed by the presentation of the conclusions in section VI.

II. LITERATURE SURVEY

The integration of Internet of Things (IoT) technologies with energy monitoring and management systems has gained significant attention in recent years due to its potential for improving energy efficiency, reducing costs, and promoting sustainability. Several studies have explored the development and implementation of IoT-based smart energy solutions.

Bhandari et al. (2021) proposed an IoT-based electricity monitoring system using NodeMCU and ThingSpeak cloud platform to track real-time energy consumption in households. Their system utilized current sensors and IoT modules to transmit data to the cloud, enabling users to monitor and analyze their energy usage patterns through a web interface. Anusha et al. (2022) developed a smart energy meter using ESP32 and cloud integration to monitor and control home appliances remotely. Their system employed a current sensor to measure energy consumption and an ESP32 microcontroller to transmit data to the cloud. Users could access energy usage information and control connected devices through a mobile application. Ullah et al. (2023) implemented an IoT-enabled smart energy management system with machine learning algorithms for predictive analysis and optimization. Their system integrated energy meters, IoT modules, and cloud computing to collect and analyze energy consumption data. Machine learning models were employed to forecast future energy demand and provide recommendations for optimized energy usage.

Hafeez et al. (2020) developed an IoT-based smart home energy management system using Arduino and Raspberry Pi. Their system monitored energy consumption, controlled appliances remotely, and integrated with renewable energy sources to optimize energy usage and reduce costs. Saleem et al. (2021) proposed an IoT-based smart energy monitoring and control system for industrial applications. Their system utilized IoT sensors and cloud computing to monitor energy consumption in real-time, identify inefficiencies, and implement energy-saving strategies through automated control systems.Kumar et al. (2020) designed an IoT-enabled smart energy meter for residential and commercial buildings. Their system employed IoT sensors, cloud computing, and data analytics to provide detailed energy consumption insights and enable remote monitoring and control of electrical loads. Ahmed et al. (2022) presented an IoT-based smart energy management system for smart cities. Their system integrated IoT sensors, edge computing, and cloud platforms to monitor and optimize energy consumption across various sectors, including buildings, transportation, and public utilities. Mahmood et al. (2021) developed an IoT-based smart energy monitoring system for microgrids. Their system utilized IoT sensors, cloud computing, and machine learning algorithms to monitor energy generation, consumption, and storage in microgrids, enabling efficient energy management and integration of renewable energy sources.

Shawon et al. (2020) proposed an IoT-based smart energy monitoring and control system for smart buildings. Their system employed IoT sensors, cloud computing, and machine learning algorithms to monitor energy consumption, identify energy-saving opportunities, and implement automated control strategies for HVAC systems and lighting. Sivakumar et al. (2022) developed an IoT-based smart energy monitoring and management system for industrial applications. Their system utilized IoT sensors, cloud computing, and data analytics to monitor energy consumption in real-time, identify inefficiencies, and implement energy-saving strategies through automated control systems and predictive maintenance.

III. PROPOSED METHODOLOGY

Hardware Components:

➢ Energy Measurement Devices:
- Energy/Power Meters: To measure energy consumption of the entire system or specific loads.
- Current/Voltage Sensors: Non-intrusive sensors to measure current and voltage levels.

➢ Microcontroller/Processing Unit:
- Arduino, Raspberry Pi, ESP32, etc.: To collect data from sensors, process it, and transmit to the cloud.
- Analog-to-Digital Converters (ADCs): To convert analog sensor signals to digital data.

➢ Communication Modules:
- Wi-Fi Module (e.g., ESP8266): For wireless internet connectivity and data transmission.
- Ethernet Module: For wired internet connectivity in industrial/commercial settings.

➢ User Interface:
- LCD Display: For local monitoring and control of the system.
- Relay Modules: To control and switch on/off connected appliances/loads.

Software Components:

➢ Embedded Software:
- Programming languages (C/C++, Python, etc.) for microcontroller/processing unit.
- Libraries for sensor data acquisition, communication protocols, and cloud integration.

➢ Cloud Platform:
- IoT Cloud Services (e.g., AWS IoT, Microsoft Azure IoT, Google Cloud IoT).
- Time-series databases (e.g., InfluxDB, TimescaleDB) for storing and processing energy data.
- Data Analytics Tools (e.g., Apache Spark, TensorFlow) for data analysis and machine learning.

➢ Web/Mobile Applications:
- Front-end frameworks (e.g., React, Angular, Flutter) for user interfaces.
- Back-end frameworks (e.g., Node.js, Django, Spring) for server-side logic and API integration.
- Visualization Libraries (e.g., D3.js, Chart.js) for data representation and dashboards.

Implementation Methodology:

➢ Sensor Integration:
- Connect energy meters, current/voltage sensors to the microcontroller/processing unit.
- Calibrate sensors and configure data acquisition parameters (sampling rate, resolution, etc.).

➢ Data Processing and Transmission:

- ○ Program the microcontroller to read sensor data, perform necessary calculations, and format the data.
- ○ Establish internet connectivity using Wi-Fi or Ethernet modules.
- ○ Implement protocols (e.g., MQTT, HTTP) for secure data transmission to the cloud platform.

- ➢ Cloud Integration and Data Storage:
- ○ Set up an IoT cloud service and configure device communication and authentication.
- ○ Implement data ingestion pipelines and store energy data in time-series databases.

- ➢ Data Analysis and Visualization:
- ○ Develop data processing and analysis pipelines using tools like Apache Spark, TensorFlow.
- ○ Apply machine learning algorithms for predictive analytics, anomaly detection, and optimization.
- ○ Build web/mobile applications with data visualization dashboards and user interfaces.

- ➢ Energy Management and Control:
- ○ Integrate appliance control mechanisms (e.g., relay modules) with the system.
- ○ Develop algorithms and rules for automated energy management and appliance control.
- ○ Enable remote monitoring and control of the system through web/mobile applications.

- ➢ Testing, Deployment, and Maintenance:
- ○ Conduct extensive testing of the system in a controlled environment.
- ○ Deploy the system in the target residential, commercial, or industrial setting.
- ○ Implement security measures (e.g., encryption, authentication) for data protection.
- ○ Regularly maintain and update the system components, software, and algorithms.

The methodology involves integrating various hardware and software components, leveraging IoT technologies, cloud computing, and data analytics techniques to create a comprehensive smart energy consumption and monitoring system. This system enables real-time monitoring, data-driven decision-making, energy optimization, and remote control capabilities, ultimately leading to improved energy efficiency and cost savings.

IV. HARDWARE DETAILS

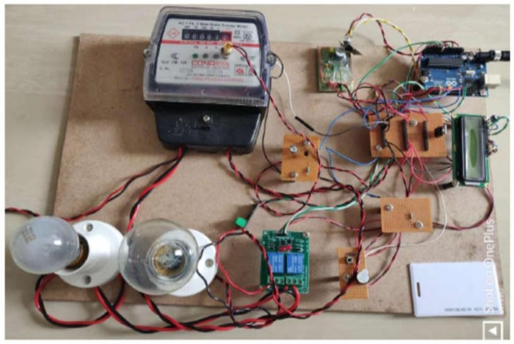
The prototype system consists of a server maintained by the power utility and energy meters provided to each consumer. The server, energy meters, and Wi-Fi modules communicate with each other through a Wi-Fi network.

The energy meter comprises an ATmega328 microcontroller, an ADE7751 energy measurement chip, a current transformer, a potential transformer, an LCD display, and a relay. The energy consumption is measured by counting the output pulses from the energy measurement chip using interrupts. The microcontroller communicates with the Wi-Fi module using AT command set. The microcontroller is programmed using Embedded C language to connect with the server.

Digital Electronic Energy Meters:
Digital electric meters utilize digital signal processors or high-performance microcontrollers. Similar to analog meters, voltage and current transducers are connected to a high-resolution analog-to-digital converter (ADC). The ADC converts the analog signals to digital samples, which are then multiplied and integrated by digital circuits to measure the energy consumed.

The microcontroller also calculates the phase angle between voltage and current to measure and indicate reactive power. It is programmed to calculate energy according to the tariff and other parameters like power factor, maximum demand, etc. It stores these values in a non-volatile EEPROM memory.

The microcontroller contains a real-time clock (RTC) for calculating time for power integration, maximum demand calculations, and timestamping specific parameters. It interacts with a liquid crystal display (LCD), communication devices, and other meter outputs. A battery backup is provided for the RTC and other critical



peripherals.

V. CONCLUSION

IoT-based smart energy consumption and monitoring systems leverage sensors, connectivity, cloud computing and data analytics to provide detailed insights into energy usage. This empowers consumers and utilities to make informed decisions, reduce wastage, and shift towards sustainable energy practices. The integration of IoT technology has the potential to significantly enhance energy efficiency, conservation efforts, and cost savings across residential, commercial, and industrial sectors.

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