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IOT-ENHANCED SMART ENERGY METER WITH DUAL NODE MONITORING, CLOUD DATA INTEGRATION, BILLING AND ALERT SYSTEM FOR THEFT ATTEMPS

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Abstruct: The dual-node monitoring smart energy meter system powered with IoT technology establishes real-time cloud data integration, automated billing, and theft detection alert systems. Made virtually around Arm Cortex STM 32 microcontroller, sensors, and NRF24L01+ wireless modules, this particular system is capable of monitoring electrical consumption for two separate households. A receiver unit collects the data from the two nodes and sends it to the Thing Speak cloud for remote access and visualization of the data. The other most crucial aspect of the software is computing the energy used and generating the bills for that consumption while also detecting anomalies that would indicate some potential form of energy theft. The moment it detects any unauthorized activity, it generates alerts for immediate action to uphold security. As a centralized monitoring and remote-access solution with smart billing, this will improve energy management operational efficiency and form the basis for scalable deployment in residential and smart grid applications.

Keywords : *Smart Energy Meter, Internet of Things (IoT), Energy Monitoring, ThingSpeak Cloud Integration, Automatic Billing System*

I . INTRODUCTION

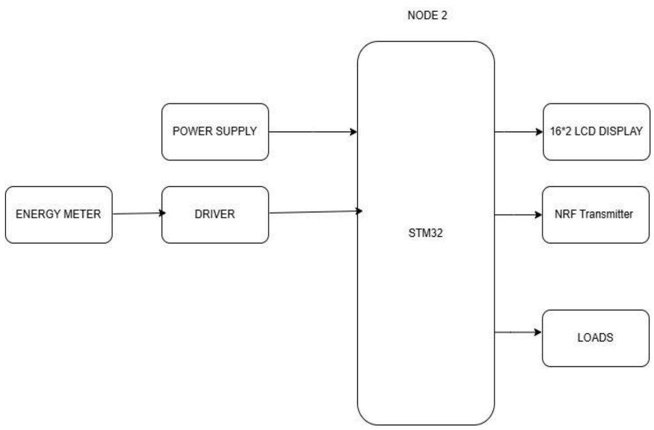
Increased urbanization and the dependence on electronic appliances have driven increased demand for electricity. Efficient energy management has become all a part of life to consume satisfactorily, lower electricity bills, and facilitate sustainable living. Traditional energy metering systems are usually manual and poorly designed with no ability to monitor a household's energy usage in real time, thus forcing the user to guess usage patterns or detect abnormal usage without these factors being recognized in a timely manner. Target problems include delaying bill generation, no centralized data storage, and limitedmodern smart environments. Moreover, this project implements an IoT-based smart energy meter system that provides the best solutions to these limitations through state-of-the-art technology, involving dual-node energy monitoring, real-time data analysis, automated billing, and theft detection security. The technology is based on stm 32 arm cortex m3 series microcontrollers, sensors, and NRF24L01+ wireless communication modules. Each energy meter serves as a transmission node that is to be installed separately into the households to monitor and calculate power usage. A central receiving unit collects data from both nodes and transmits it to Thing Speak cloud via an internet-connected module for access and visualization by users. The software algorithm calculates energy in real time, issues bills according to predefined tariff rates, and continuously checks for conditions that might indicate energy theft or tampering. Whenever it has been able to identify certain anomalies, the system automatically raises an alert, thus improving security and integrity of the energy monitoring process. This does not only give users power to control how they consume energy better, but it also enables the introduction of a scalable and secure yet economically viable alternative to conventional metering systems. Future enhancements such as a mobile app integration and machine learning-based analytics can increase this project's chances of adoption into the living environments of smart homes and community energy management networks.

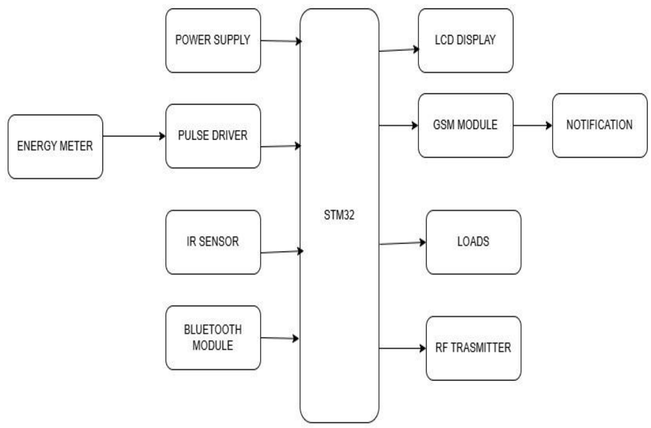
II. LITERATURE SURVEY

Many researchers and authors have copiously researched and documented the development of electrical and electronic measurements. The modern application of instrumentation systems and their practical implementation supplement the IoT K. Manjunath (2017). Webster and Eren's (2014) work has provided generalized references for sensor-based measurements and advanced instrumentation, very vital for modern energy systems. Tumanski (2014) based his research on theoretical principles relating to electrical measurement: it is knowledge of the foundation of system calibration and accuracy. Traditional measuring instruments and their operational methodologies were amplified by Golding and Widdis (2011) and Bhargava (2012). Kishore (2010) elaborates on electronic measurement techniques relevant in systems of digital nature. Rajput (2007) and Sawhney (2005) provide extensive discussions about analog and digital measuring devices, calibration methods, and error analysis. Banerjee and the Bakshi authors, besides these, comprehensively explain measurement fundamentals and methods of instrumentation systems exploiting new technologies. All these works together put in place a strong knowledge base for the design and development of IoT-based smart energy meters. They are sensor integration, wireless data transmission, energy monitoring, and security aspects such as theft detection—highly relevant for energy management solutions in the modern smart grid.

III. PROPOSED WORK

A wireless IoT full-scale smart energy measurement meter for automatic billing and theft detection in homes includes two energy meters, which act as separate transmission units for monitoring the energy used by two distinct households. Both these meters can practically measure electrical parameters using energy sensors and send such information wirelessly to a central receiving unit. A simple overview of the meters to central unit communication is given by the NRF communication modules enabling seamless communication that is reliable and power efficient. The central receiving unit is responsible for collecting consumption data collected from the two meters and then uploading it to the Thing Speak cloud platform. This further has brought real-time monitoring and storage capabilities of energy data that can then be viewed and accessed remotely by users via an interactive web page. With cloud connectivity, energy data becomes available to the user from anywhere at all times, gaining insights into their usage pattern enabling them to track and decide to avoid wastage. Automatic billing generation without human intervention is thebiggest attraction of the present system. It leads to real-time estimation of bills for consumed electricity covering the use of multiplying energy consumed, with currently prevailing tariff rates, for making such autonomic billing. This mentioned definition of "automatic" brings in a lot of prospects of human error mitigation. This automation not only saves time but also enhances quality assurance in the billing procedure. The system also incorporates anomaly detection algorithms meant for more security purposes, which monitor energy consumption data for possible irregularities like power theft or tampering with meters. For any abnormal usage of electricity, such as sudden high spikes or sudden drops in power usage, the system generates alerts in real time sending notices to users about possible theft and malfunction. Unquestionably, this is the best feature to avoid unauthorized access and ensure the integrity of data. The proposed system is scalable in future to monitor more than a single household or one or even bigger building complexes.





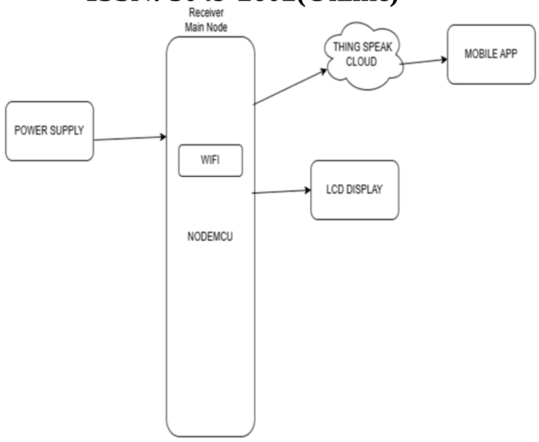


Fig 1 : Proposed System

KEY ELEMENTS:

Dual Energy Meters for Separate Households

The system encompasses two energy meters for the monitoring of power consumption from two distinct households. These energy meters are provided with energy sensors that measure the essential electrical parameters of voltage, current, and power factor. The transmitting kits (energy meters) are located in different houses and each meter collects and transmits real-time data on electricity consumption to a central node. Independent monitoring for different households. Real-time data collection for precise analysis of energy consumption patterns. Capacity to monitor individual household use.

Communication via NRF Modules

The energy meters send information from the receivers to the central node using the NRF24L01+ wireless modules. These modules allow low-power communication across short to medium distances, ensuring reliable performance. The modules are therefore able to transmit energy consumption data from both meters to the central node without any wires or additional infrastructure. Wireless installation will be easy as pie. High efficiency in data transfer, with low power footprints. High- fidelity communication from the meters to the central.

Central Receiver Node

Truly an intelligent system brain; this central receiver is capable of receiving message readings from two transmitters, processing them, and uploading to Thing Speak cloud for remote storage and monitoring. It holds all data, which can then be accessed by a user for real-time insight into energy consumption. Centralize all the data from all different meters. Cloud integration to access energy consumption data remotely. Centralized monitoring for the convenience of access and collection by the user.

Cloud Data Integration (ThingSpeak)

The existing system centralizes everything on an online portal within the cloud known as Thing Speak. It was used for storage and processing data that concern energy consumption. Thus, it provides real-time intelligence with historical trends of consumption seen by the user through a web interface as uploaded. Thus, this is an efficient cloud-based solution for the monitoring of many households or buildings without any local storage. Being Monitored in Real Time from Anywhere. User Access Data Visualization Tools for Energy Consumption Monitoring. Architecture that scales so that it can easily accommodate added units or deployment at a large scale.

Automatic Bill Generation

The electricity bill in the automatic bill generation algorithm of the system is prepared as per the real- time energy consumption data. The actual energy consumed multiplied by the applicable tariff rates will automatically generate the bill that would be accurate without human intervention. Automatic bill generation ensures continuous billing with fewer chances of being marred by manual errors thus giving a clear advantage to the user. Bills are computed in real time based on consumption. No human intervention is actually needed for bill generation, thus eliminating human errors. The whole billing process will be visible to the users as they monitor their usage and analyze costs.

Theft Detection and Anomaly Alerts

A very important feature of an IoT-enabled energy meter is the device's theft detection scheme. It monitors the energy consumption behaviors thoroughly for any anomalies and indications that seem to point toward theft or tampering of the meters for days, months, or years. The system instantly alerts the user/administrator of a sudden coinciding occurrence of anomalous consumption activity as spikes or dips in energy usage in terms of a possible theft situation. Real-time monitoring to highlight unusual energy consumption patterns. Automated alerts will be generated for theft detection or tampering. Additional security would be provided so that unauthorized usages of energy do not occur.

User Interface and Remote Monitoring

This user interface attempts to enhance accessibility to energy consumption data using the ThingSpeak web portal. Users can then access live usage, historical data, and billing information quickly via a clear and self-explanatory dash within this interface. Thereby, this interface is empowering users for real-time monitoring of electricity use, setting alerts, and making informed decisions based on real-time data intended to optimize energy consumption and cut costs. Visualize real-time data. Allows for tracking historical consumption to help in making informed decisions. Simple user interface for monitoring and management purposes.

Scalability and Future Integrations

The scalability of the entire system is perhaps its main advantage: it has architecture to support multiple house types or square footage, big residential complex works. While scaling up, it is quite easy to incorporate additional energy meters or receiver units; hence, it is amenable to deployment within smart grid systems. Future applications could perhaps be run on a mobile app platform, include advanced predictive analysis, or integrate energy-management feedback with renewable energy systems like solar panels or wind turbines. Scalable design for large-scale applications. Integrate with renewable sources in future. Flexibility for future upgrades such as mobile app support and predictions using machine learning techniques.

IV. METHODOLOGY

System Overview

The development of the proposed smart energy meter system is meant to include dual transmitting nodes where the power measurement taken from two separate households can be done and stored. These nodes collect an amount of energy consumed, which can then be wirelessly transmitted to a central node receiver for pushing the data directly onto the ThingSpeak cloud. Thus, providing real-time monitoring, automatic billing, and remote access to the system. This project requires use of all components including STM32 Cortex-M3 Series,sensors, NRF24L01 wireless modules, and an ESP8266 WiFi module for appropriate communicational needs and cloud integration.

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Hardware Architecture

The basic components of the system include three elements, two being transmitter units and one central receiver. Each unit is made from an STM32 ARM Cortex-M3 microcontroller,sensors, an NRF24L01 module, and an LCD display. This arrangement itself demonstrates the consumption of energy at their respective locations. The central receiver node has an NRF module for receiving data from both transmitters within it, while an ESP8266 module uploads the data to ThingSpeak Cloud.

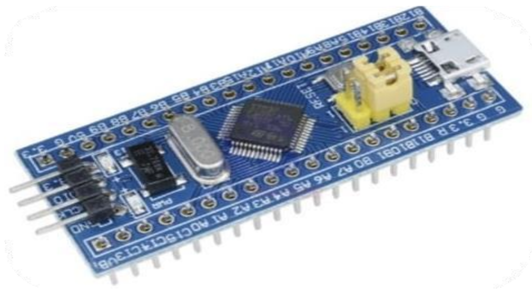

Fig 2 : STM32 ARM Cortex-M3 Series Sensor Interfacing and Data Acquisition

Each Transmitter node receives pulse signals from a real energy meter, which monitors the energy consumed by the Lamp load. These pulses are fed into an optocoupler, converting them into an analog signal. The analog data is then processed by an Analog-to-Digital Converter (ADC), converting it into a digital format before being sent to the STM32 microcontroller. The STM32 facilitates dual-node monitoring, cloud data integration, automated billing, and alert messaging upon tamper detection to ensure system security and efficiency.

Wireless Data Transmission by NRF24L01

This is the communication from one of the two receiver units to the wireless transmitter. An NRF24L01 unit will be used to establish the wireless communication between the transmitter and receiver units. The transmitters will all have their separate addresses to allow effective distribution of data. Data records the sensor's content into stored packets defining a meter ID, energy use, timestamp, and sends it to a central receiver, whilst another NRF module in the center is all geared up to take incoming pages.

LCD Display Interface

Each transmitter unit includes a 16x2 LCD, allowing displays of real-time power consumption and energy units. Immediate feedback is provided to the user concerning the units consumed and the computed bill based on usage. This feature enables real-time localized monitoring without any internet connectivity.

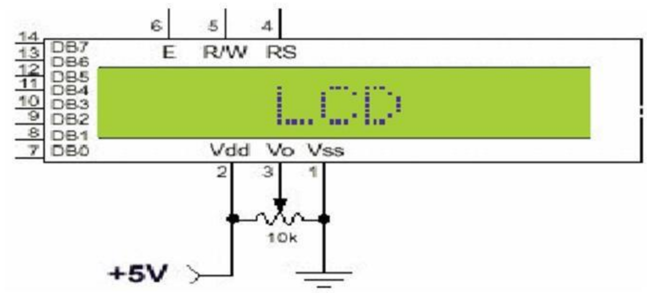

Fig 3 :16x2 LCD Basic Wiring

Billing Computation Logic

In-built billing algorithm allows the system automatically to generate the amount payable as energy consumed. The standard rate multiplied by consumption will account for the generation of the bill. The exact charge amount can be revealed on the LCD and uploaded to the cloud. It automizes reading and billing, hence increasing efficiency and accuracy.

ThingSpeak Dashboard for Remote Monitoring

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The cloud platform is called ThingSpeak, which is using its energy consumption data storing and visualizing mechanism. Every transmitter has an individual field into a ThingSpeak channel. The dashboard, therefore, displays all those real-time graphs and statistics that can allow a user to analyze the energy trends and patterns, and remote access enables monitoring but not limited to http://www.thingspeak.com. Users then have the convenience of monitoring their usage from anywhere with an internet connection.

System Testing and Validation

The whole system is tested on various load conditions to get the accurate measurements and data transfer. Calibration of these sensor readings is done against commercial energy meters in orderto ensure accuracy. The consistency of cloud integration under uniform cloud conditions is ensured by testing the reliability of the NRF communication and the Wi-Fi data upload. Overall system performance is evaluated for stability, latency, and usability.

SOFTWARE IMPLEMENTATION

We discuss smart meters based on IoT, incorporating firm IoT software implementation modules for real-time monitoring of energy, communication among nodes, data processing, and interfacing to the cloud. It includes building firmware for energy meters and the receiver node on Arduino, with NRF modules for communication, and the system's compatibility with ThingSpeak for visualization and storage purposes. Important parts regarding the software of this system are covered in this section.

Arduino Programming for Energy Meters

Every energy meter uses the STM 32 microcontrollers. The program continuously collects readings. Through its analog-to-digital converter (ADC), converting them into usable electrical values V, A, and W in almost real time using embedded mathematical formulas. The wired calculation data is further formatted for wireless transmission. The Arduino sketch contains the control logic for the NRF24L01 module, which is used for wireless data transfer. This software layer is embedded so that the transmitting units, energy meters, can perform autonomously and efficiently send their data to the central receiver node.

Communication Protocol with NRF Modules NRF24L01transceivers are used for the communication between the energy meters (transmitters) and receiver node. Configuration settings such as address pairing, frequency settings,
and optimizations of data rate are included in the software on both transmitter and receiver ends to facilitate reliable communication. Each energy meter has been given a unique identifier, and the NRF module is programmed to work in transmitting mode. While on the other end of the receiver, you have an NRF module that is listening to packets coming in from both meters. This wireless communication layer becomes important in providing a stable and interference-free data link to send the information in real time.

Central Receiver Node Firmware

The receiver node accepts data from both transmitting energy meters, processes it, and forwards it to the cloud. The node initializes the NRF module into receive mode, listening constantly for incoming data, decoding the received power consumption values, and then preparing the data for upload to the cloud. The node can also include provisions for detecting errors so that whatever data packets that reach it would undergo verification-to ensure they are complete and valid-to enable their forwarding to the ThingSpeak server. Logic for multiple sensor inputs and time stamping for organized data logging is included in the software.

Cloud Integration with ThingSpeak

This is an energy-centric cloud platform for storing, analyzing, and visualizing meter readings. The receiver node can connect via generic Wi-Fi modules such as ESP8266 or built-in Wi-Fi modules such as NodeMCU. The application utilizes the ThingSpeak API for authentication and for the transfer of data into respective fields in the cloud channel. Each channel data field corresponds to a single parameter: voltage, current, power, or cumulative consumption. The periodicity applied in the software implementation allows the consumer to monitor data in real time through a web interface or mobile app from ThingSpeak.

Theft Detection and Alert System

An integration of an anti-theft detection system has been incorporated to provide more security. Consumption is monitored over time and checked against the expected usage baselines. Any atypical events, such as a sudden rise in electricity consumption or signal loss from a meter, will mark the event as suspected theft or tampering.The system utilizes an IR sensor to monitor meter integrity, instantly identifying tampering events. If a breach is detected, an alert message is sent via GSM module, and a buzzer activates to notify users of potential threats. Automated alerts ensure real- time responsiveness, allowing timely action to prevent unauthorized modifications or meter bypass attempts.RESULTS AND DISCUSSION

The performance of the IoT-based dual smart energy meter system for real-time energy measurement, data transmission, billing, and cloud integration worked satisfactorily. The transmitter units measured energy consumption and calculated energy usage in kWh via STM 32 microcontrollers. Data was wirelessly transmitted to the central receiver through NRF24L01 modules, which later uploaded the collected data to the ThingSpeak cloud via the ESP8266 Wi-Fi module.

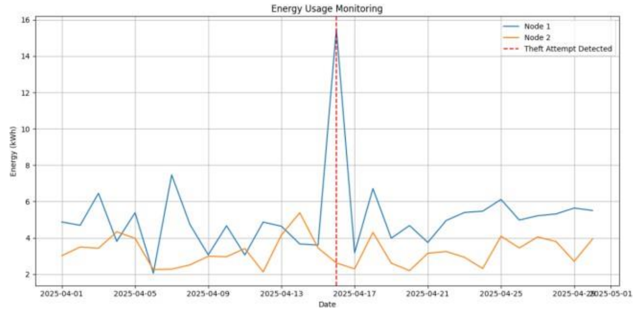

Fig 4 :Energy Usage Monitoring

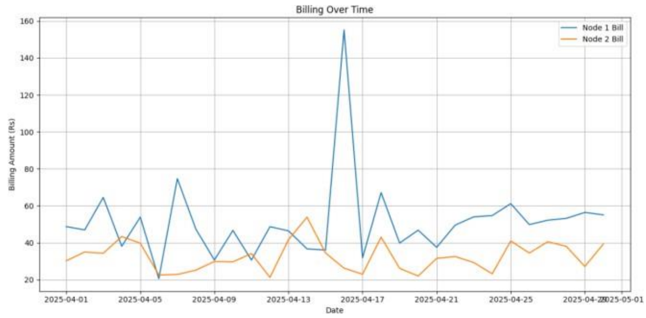

Fig 5 : Billing Over Time

Node 1 Usage (kWh)	Node 2 Usage (kWh)	Node 1 Bill (Rs)	Node 2 Bill (Rs)	Theft Alert
5.23	2.88	52.30	28.80	No
5.04	3.25	50.40	32.50	yes
4.67	2.73	46.70	27.30	No
4.90	3.10	49.00	31.00	No
5.11	2.89	51.10	28.90	No

Table 1 : Node-wise Energy Usage and Billing

The system was providing accurate readings amid varying load conditions and was consistent in performance over a typical communication range of 40-50 meters. Visualization of real-time data on ThingSpeak confirmed proper cloud synchronization: clear graphs depicting energy- consumption trends and billing status over two households. Billing automatically calculated using a fixed tariff rate and shown on de-localized LCD screens allowed the user to view their usage and costs simultaneously. Comparison charts will indicate that House A used slightly more energy than House B, most probably because it has more appliances; the bar graphs summed up the usage per day efficiently. With great functionality and easy-to-use monitoring, some shortcomings were found: it was dependent on internet access for real- time updates for the cloud and had minor deviations in sensor accuracy when compared with commercial meters. In any case, the project demonstrated the feasibility of integrating IoT with energy metering systems to provide scalable, low- cost, and easy-to-access smart energy management solutions.

CONCLUSION

To facilitate cloud data integration along with the automated billing system and the theft alert system within the infrastructures for manual monitoring in the contemporary energy management, the dual- nodes monitored IoT smart energy meter requires further improvements. The system was made to overcome various inconveniences of classical energy meters with hardware components like Arduino microcontrollers, energy sensors, and NRF24L01 wireless module and an enabling software environment to get cloud working into it. This project allows real-time monitoring of power consumption of two independent sources, wireless transmission to a central receiving node, and uploads recorded data to the ThingSpeak cloud for remote access and visualization. IoT implementation on the other hand ensures transparency and accuracy while empowering consumers with data-driven insights to use electricity more optimally. Automatic bill computation would thus be a recent advancement without manual taking of readings; the theft detection module adds a layer of security monitoring anomalies in consumption patterns and calling to the user's attention probable tampering or even energy theft.

With all this, the scalable mean added households would quite easily be integrated into the system, and renewables like solar panels could enter into the configurations. Future developments could include a mobile app, predictive analytics, and machine learning functionalities to enhance further its usability and performance. This smart energy metering system has made it clear how IoT and wireless communication can change traditional utility management experiences into dazzlingly bright, connected, and easy experiences. It thus provides one of the best frameworks for use ineither residential or commercial applications for efficient energy utilization, cost-saving, and better user awareness. Successful implementation of this project brings us one step closer to the built environment of smarter cities with greener communities balanced with technology and sustainability.

FUTURE SCOPE

The IoT-based smart energy meter system is now a rule for further upgrades and enhancements and scalability in the near future. One direction to appreciate would be where the advanced analytical engine could give users insight into decision- making concerning the valuable insight into energy consumption behaviour. On the other hand, predictive analysis may extend support to predict the future trends of usage and allow the users to participate in managing energy actively. Hence, energy-saving recommendations could be proposed based on user behaviour while contributing to household sustainability. In that regard, another notable enhancement could focus on a mobile app to guarantee maximum user participation, providing real-time energy data access, billing information, notifications, and controls from anywhere. Such changes made to work through multiple energy meters scattered throughout different homes or buildings would greatly assist centralized energy consumption monitoring, especially in apartments, commercial complexes, and smart grid scenarios. Adding integrated Renewable Energy Sources (RESs), such as solar panels, will enable consumption and generation monitoring for sustainable energy management. These machine learning algorithms can be smart enough to detect consumption anomalies, optimize load distribution, and improve fault detection accuracy for thefts or technical faults. In that manner, with the injection of the suggested functionalities settled with an enhanced interface, this system transforms into a robust yet intelligent and scalable framework directed towards modern energy management, both for residential and industrial applications.

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