iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** XI **Month of publication:** November 2025

DOI: https://doi.org/10.22214/ijraset.2025.75283

IoT-based Prepaid Smart Energy Meter and Theft Detection

Navadeep G[1], Nithin M R[2], Naveen M[3], Gonehal Manjunath[4], Mrs. Bhavya S[5]
Dept. of Electronics and Communication Engg, AMC Engineering College Bengaluru, India

Abstract: IoT-based prepaid smart energy meter with built- in theft detection to improve traditional electricity billing and monitoring systems. With the increasing demand for power and the necessity to stop power theft, the system guarantees real-time measurement, control, and communication.

An Arduino Uno microcontroller serves as the central unit, connected to an energy meter to read power usage. A relay module connects or disconnects the load automatically depending on the prepaid balance, while a GSM module facilitates remote recharge of the balance and status reporting.

A micro-switch senses unwanted cabinet opening, triggering a buzzer and sends instant notifications through GSM. An LDR-based display gives real-time indication of units consumed, balance available, and credit status. An optocoupler (4N35) provides electrical isolation and immunity to noise, safeguarding the controller circuit.

The system is cost-effective, scalable, and reliable for use in domestic as well as small industries with real-time monitoring, theft detection, and automatic recharging due to the integration of embedded hardware and IoT.

Keywords: IoT, Smart Energy Meter, Prepaid Billing, Ar- duino Uno, GSM Module, Theft Detection, Relay Control, Op- tocoupler 4N35, Energy Management.

Index Term: IoT, Smart Energy Meter, Prepaid Electricity Billing, Arduino Uno, GSM Communication, Relay Control, Theft Detection, Optocoupler 4N35, Buzzer Alarm, LDR Display, Energy Management.

I. INTRODUCTION

Electricity is one of the most essential resources that en- able economic development, industrialization, and everyday activity. The mounting consumption and theft, however, put enormous burden on energy utilities in adopting smart solu- tions. Manual reading and post-paid billing-based conventional meters are likely to introduce delays, erroneous bills, and end- user unawareness. Therefore, consumers are not motivated to optimize usage efficiency, while utilities lose revenue and poor load planning.

Internet of Things (IoT) has revolutionized device interac- tion into prospects for smart and sustainable systems. Prepaid smart energy meters are the future technology that integrates metering, billing, and communication onto one platform. Through the provision of pre-purchasing energy credit, the meters encourage wise consumption and avoid late payment. In contrast, theft detection allows for the detection of unau- thorized usage early to save utility revenue.

In this project, an Arduino Uno microcontroller is employed as the central controlling system due to its ease of use, low cost, and accessibility for programming. The system measures energy in terms of quantifiable units through a calibrated energy meter and dynamically adjusts the balance. Power supply is regulated with the help of a relay module based on available credit, with auto-disconnection at zero balance without intervention.

The GSM module enables two-way communication for remote recharge of accounts through SMS or cloud service. Instant notification of consumption, balance left, or attempted illegal opening is sent, improving transparency and security. In the case of theft detection, a micro-switch is installed in the meter case; any attempted unauthorized opening triggers a buzzer alarm and sends an alert message.

Critical information such as units consumed, balance, and system status are displayed on the LDR display. Safety is ensured by optocoupler 4N35, which provides galvanic separation of high-voltage signals and sensitive logic circuits. Support resistors protect the circuit and maintain stable operation. The proposed system not only enhances the shortcomings of traditional meters but also supports sustainable use of energy by ensuring controlled utilization and proper collection of revenues. This work shows how embedded systems and Internet of Things communication can be combined to provide an economical, secure, and scalable residential, commercial, and light industrial metering solution.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

II. PROBLEM STATEMENT

The energy sector is incessantly grappling with the prob- lems of proper billing, unauthorized consumption, and right energy usage. Manual reading is required for conventional electromechanical or static meters, which is labor-intensive and prone to errors. Post-paid billing is typically accompanied by delayed payments, revenue loss, and improper information for the consumer as well as supplier. Electricity theft using meter bypassing and tampering is a prevalent issue, resulting in significant revenue loss for the utilities. Today's smart meters, while advanced, are expensive or lack inbuilt theft detection and prepaid functionality in a single platform. It is seemingly not easily available for a cost-effective option with real-time monitoring, prepaid charg- ing, remote recharging, and theft safeguarding. The proposed system should be robust, simple to install, and work well in areas with varying network conditions. It needs to arm consumers with open consumption data and place providers in a straitjacket of supply and revenue realization.

III. SYSTEM DESIGN OVERVIEW

A. Hardware Architecture

The hardware setup combines various sensing, control, and communication modules into one integrated system. At the heart is the Arduino Uno, which serves as the central controller and coordinates the operation of all the peripherals. It connects to an electric energy meter, from which it retrieves pulse or analog signals representing the quantity of energy consumed. This information is processed and stored to determine the units consumed and remaining balance of credit.

The relay module is connected between the load and the supply line and acts as a switch. The Arduino prompts it to connect or disconnect the load depending on the prepaid balance in order not to let the consumer spend more than the energy units bought. In remote communication, a GSM module (SIM800C) is included such that the system can send SMS messages, accept recharge instructions, and send theft alerts to the user or utility company.

To protect the meter from illegal tampering, a micro-switch is fitted within the case. When anyone tries to open the case, it triggers the switch, which makes the Arduino initiate a buzzer and automatically send a theft notification over the GSM network. A 16×2 LCD display (LDR display) is employed to display real-time parameters including the balance value, total energy consumed, system status, and any active alarms, thus making the device easy to use.

Electrical safety and signal isolation are provided through the aid of an optocoupler IC (4N35), which would not let high voltages pass to the logic circuits while still ensuring precise signal transfer. Extra resistors are carefully positioned to regulate current flow and safeguard sensitive parts from surges. The whole configuration is powered by a regulated DC power supply, which converts and stabilizes the input voltage for dependable operation. Fuses, protection diodes, and decoupling capacitors improve long-term durability and resistance to electrical noise, allowing the system to run safely and reliably in domestic or small industrial applications.

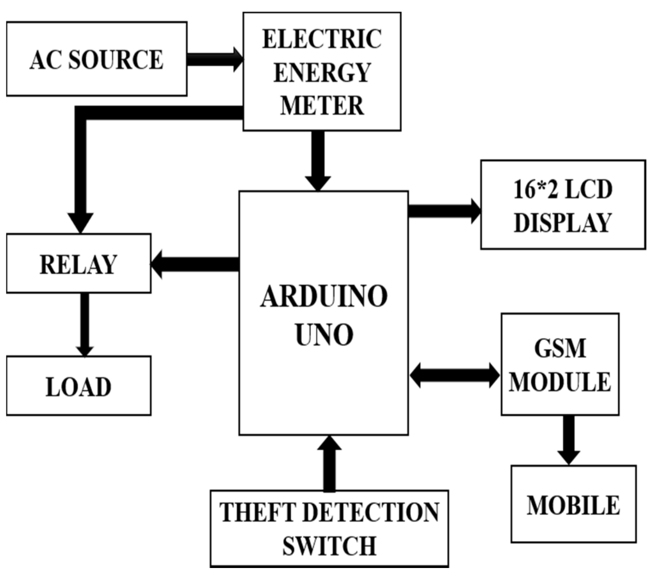


Fig. 1. Block diagram of the proposed IoT-based prepaid energy meter

B. Software Architecture

The software part is developed utilizing the Arduino IDE and embedded C language for portability and ease of devel- opment. The firmware initializes critical peripherals, declares input/output pins, configures internal timers, and reads the pulse signals or analog values from the energy meter.

A balance control algorithm continuously subtracts the units used and instructs the relay to switch off the load whenever the balance goes to zero, making prepaid operation accurate.

The GSM interface library handles parsing of SMS, verification of recharging codes, sending of usage reports, and theft alerting to end users or utility staff.

Interrupt-driven service routines manage the micro-switch, providing instantaneous reaction to unauthorized access of the enclosure through triggering the buzzer and sending a notification via the GSM module. Display drivers update the 16×2 LCD at regular intervals, showing current information about balance, units used, and system alarms without delay. Firmware strength is ensured through the use of data validation checks, error-handling routines, and watchdog timers that reset the system in the event of a software failure or extended inactivity.

The system architecture also features a non-volatile memory interface, enabling core information like the balance remaining and last consumption to be stored even after the loss of power. The coded base is structured and modular to make upgrades easier in the future, making it possible to integrate sophisticated features like dynamic tariff management, over- the-air firmware upgrades, and improved data logging for extended energy analytics.

C. Functional Workflow

The operation process of the suggested prepaid energy metering system starts with the power supply being activated. Upon the switching on of the supply, the microcontroller executes a series of hardware initialization procedures. The LCD display is first initialized to offer a display interface for the consumer, followed by the GSM module initialization to facilitate wireless communication for balance and alert notifi- cations. Upon successful initialization, the system announces itself ready and blanks the LCD display to show default values of units = 0 and balance = 0.

To initiate energy usage, the user must recharge the balance of the meter via mobile-based transaction. After the recharge request is authenticated, the system updates the balance, and switches ON the relay thereby energizing the load. From here onwards, the LCD keeps showing the active energy consumption (units) and the prepaid available balance.

The system continuously monitors two important parame- ters: theft of power and balance levels. • Power theft identifi- cation: When an abnormal condition is identified, for instance, the switch status showing sw = 0, the system views this as unauthorized bypassing or tapping of the meter. In this event, the system immediately sends an SMS warning using the GSM module, alerting the user or utility company of the attempted theft. • Balance monitoring: The prepaid balance is continuously compared against the pre-configured limits. If the balance goes below a warning limit (e.g., below 15 units), the user is reminded with an SMS to refill urgently. When the balance goes below a critical limit (e.g., below 5 units), another message is sent with a focus on urgent recharge needs.

In case of no theft and enough balance, the system runs in a cyclical manner where each unit drawn (Units++) decreases the respective balance (Balance–).

Thus, energy usage is directly correlated with available prepaid balance. But when the balance either gets to zero or remains below the threshold without recharging, the relay gets automatically switched OFF, disconnecting the power supply to the load. This protection guarantees electricity supply on a prepaid basis only and inhibits unauthorized use.

By applying this workflow, the system not only guarantees prepaid energy consumption but also integrates security (theft detection) and communication (SMS notification) to guaran- tee increased reliability, transparency, and user awareness. It therefore offers an intelligent, automatic solution for effective energy management in contemporary power distribution sys- tems.

IV. IMPLEMENTATION

To realize the thought process, a hands-on setup was built with the circuit shown below. An Arduino Uno is at the heart of the setup, acting as the brain of the system and performing every action. A 16×2 LCD screen was included to show the current balance, units consumed, and warning messages in real time. The power meter was coupled to the controller via a 4N35 optocoupler, separating the measurement circuit from the microcontroller in a secure way. A relay module was put between the power supply and the load (represented by a bulb) in a way that allowed the Arduino to instantly switch off the supply whenever the credit available reached zero or a tamper event was detected.

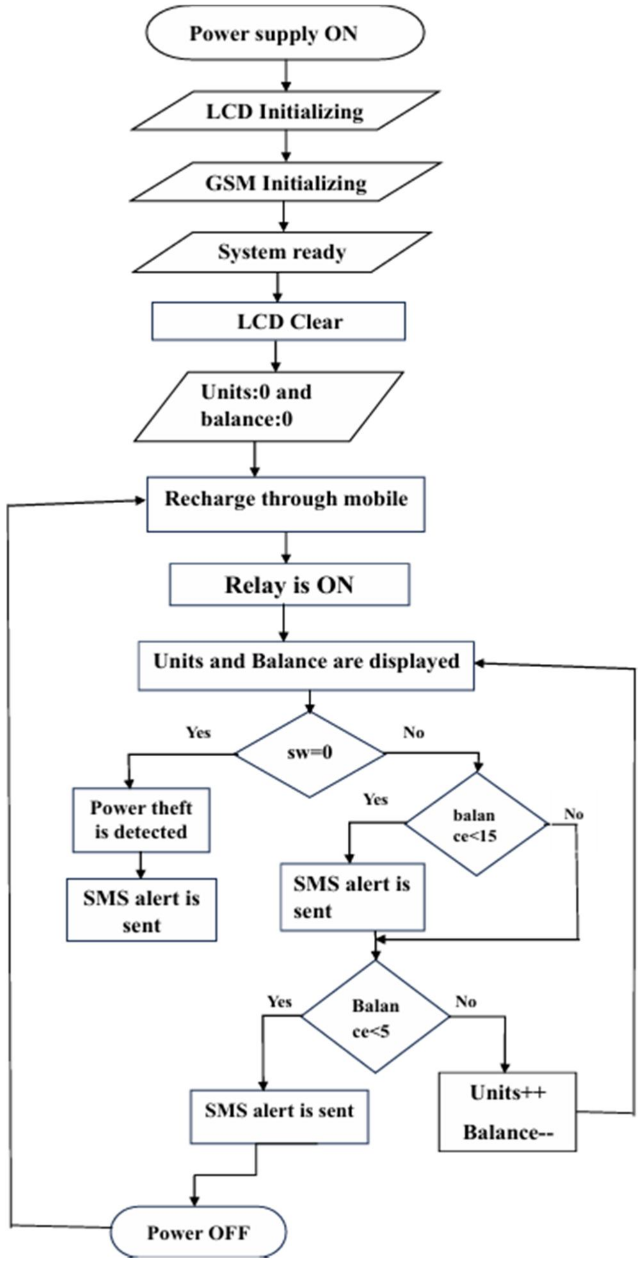


Fig. 2. Flowchart of the proposed IoT-based prepaid energy meter

The meter and user were made communicable through a GSM SIM800 module. SMS could be sent via this module to recharge the credit, view remaining balance, or send alerts for any abnormal activity. For theft detection and detection of unauthorized entry, a micro-switch was mounted inside the meter box. On activation, this switch would immediately trigger a buzzer and also send an alert to the registered mobile number. Supporting components such as resistors, fuses, and a regulated DC power supply ensured safe operation and protected the board against electrical spikes, and organized wiring kept the circuit stable and simple to debug. In the software area, the firmware was developed in Embed- ded C with the Arduino IDE and flashed into the controller. The code was programmed to count pulses from the energy meter, calculate outstandings credit, and operate the relay at balance points. Interrupts were left for fast reaction against attempted theft and pulse interrupts, while LCD display was optimized to render the display as smooth and responsive as possible. GSM operations handled recharges and status mes- sages in order to keep users updated at all times. In the tests, the system operated well under different loading conditions, shutting power cleanly at zero balance and triggering theft alerts on time. The see-through wiring, interactive software, and insulation protection made the design a good solution for prepaid energy metering and prevention of theft.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

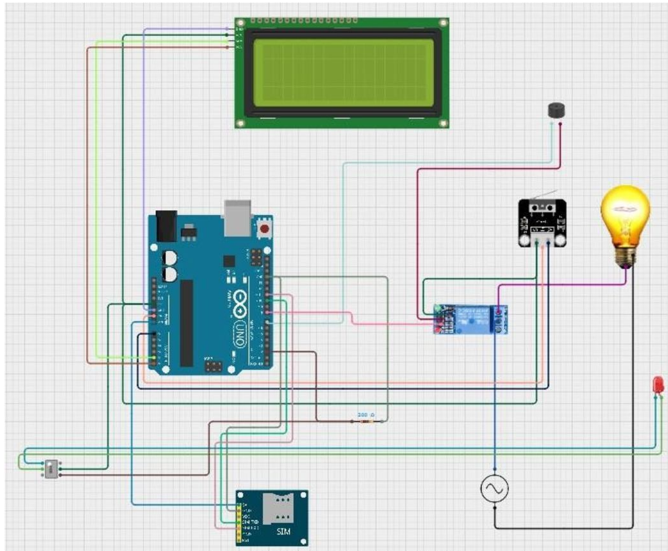


Fig. 3. Circuit diagram of the proposed IoT-based prepaid energy meter

V. ADVANTAGES AND DISADVANTAGES

A. *Advantages*

- Provides real-time consumption tracking, prepaid billing, and theft detection in one unit.
- Minimizes manual intervention and bill delays.
- Protects revenue by cutting power when the balance runs out.
- Encourages energy saving by providing real-time data to consumers.
- GSM communication enables remote recharges and im- mediate alerts.
- User safety and signal stability are provided through optocoupler and resistors.
- Easy to deploy in residential, commercial, and small-scale industrial applications.
- Modular construction is simple to upgrade to software or communication protocols.

B. *Disadvantages*

- GSM connection is unreliable in regions of poor signal strength.
- More initial price due to several modules compared to traditional meters.
- Requires relay, sensor, and power supply maintenance for long-term reliability.
- Low storage capability of Arduino restricts extensive data logging.
- GSM continuous operation may be costly.

VI. CONCLUSION

The Theft Detection IoT-based Prepaid Smart Energy Meter provides a reliable and practical solution for modern energy management. With the integration of prepaid billing, theft detection, and real-time communication, it is transparent and operationally effective. Arduino Uno usage makes develop- ment low cost and accessible, and 4N35 optocoupler provides electrical isolation between high and low voltage portions. Testing ensures that the system rightly records units, depletes balance, and cuts supply when credit is exhausted. Theft detection along with instantaneous alerts increases safety against unauthorized access. The unit promotes eco-friendly energy practices by motivating users to regulate usage and pay upfront. Its scalability makes it a good candidate for extensive use in both domestic and small-scale industrial settings.

VII. FUTURE SCOPE

Future development may be in the form of adding a cloud- based dashboard to access analytics and historical trends. A mobile app would offer an even more interactive environment for recharging, notifications, and energy reports. The inclusion of Wi-Fi, LoRa, or NB-IoT modules would provide greater communication range and reliability, especially in rural areas.

Dynamic tariff capability would allow maximum use of electricity in peak and off-peak periods. Inclusion with solar panels as a source of renewable energy can give hybrid billing platforms. Anomaly detection and predictive maintenance may be added with the help of artificial intelligence. Three-phase metering and industrial-grade relay support would add to its usage. Enhanced encryption techniques can further improve data security against cyber attacks.

VIII. RESULTS AND OUTPUT

The performance of the IoT-based Prepaid Smart Energy Meter with Theft Detection system shows it works perfectly well from the time of booting until communication is achieved. Once powered up, the LCD screen will first display welcome and initialization messages, with some examples being "WEL- COME T SMART ENERGY METER" and "Initializing...
Please wait", indicating the system is setting up its internal modules. When initialization is complete, the system indicates this with "SMART ENERGY METER INIT OK", which displays that the Arduino controller, GSM and relay modules are now starting. The display will then show the balance, as well the energy consumption at the time, such as "Bal: 50.00 Used: 0.0u", for example, indicating the user has 50 balance and has yet to consume any units.

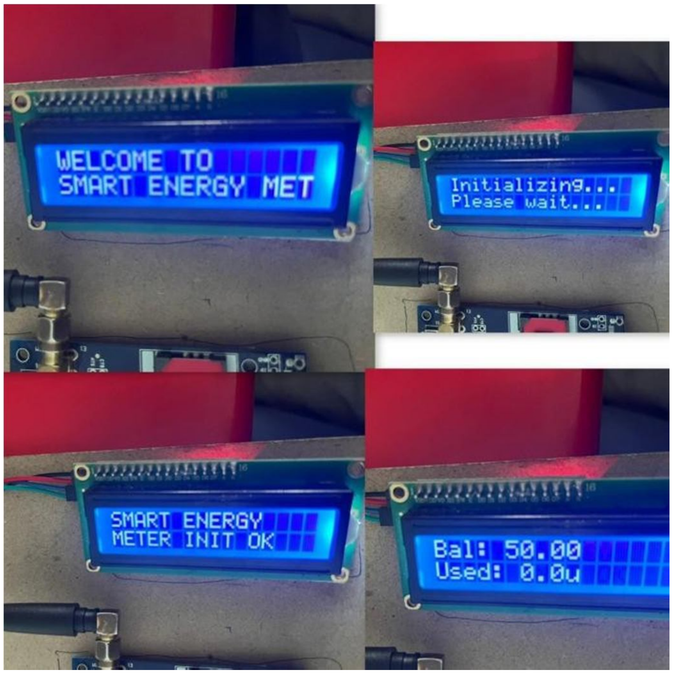


Fig. 4. LCD diplay

The system allows the user to recharge the meter remotely by sending an SMS command that is formatted correctly, in order for the system to accept the command, which for example would be: RECHARGE 100 PIN1234, meaning the user is recharging the balance by 100, and the user must enter their PIN, which is a fictitious one at this stage. When the balance is recharged successfully, a confirmation message is sent back stating "Recharged 100. Bal: 100", which means the balance after the recharging period that is displayed could either be the original balance of 50 + 50, or a number from the recharge process that is equal to the new balance reflected.In the event that the user enters an invalid amount or incorrect format, an error message is shown on the LCD like "invalid amount" or "format: RECHARGE PIN1234." When unauthorized tampering or opening occurs, the system immediately displays the alert message "Theft Detected!" to notify the owner/utility. When the prepaid balance reaches a particular threshold to indicate a low-balance warning (e.g., low balance: 5. Please recharge your smart energy meter.).

These findings illustrate that the prototype reliably and effectively completes smart energy metering tasks including real-time unit monitoring, and automatic relay cutoff during low-balance, GSM based recharge, and theft alert functions.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

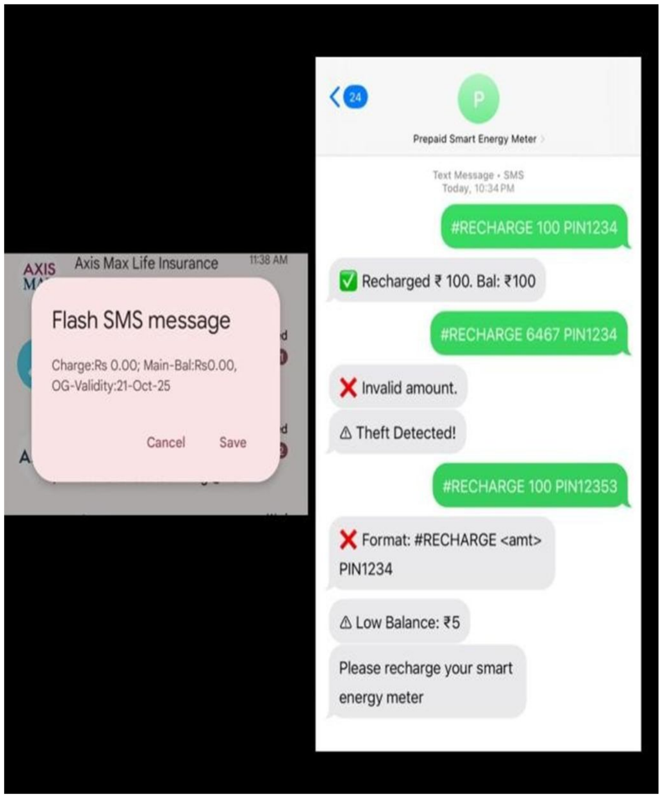


Fig. 5. Recharge and Notification's to the users

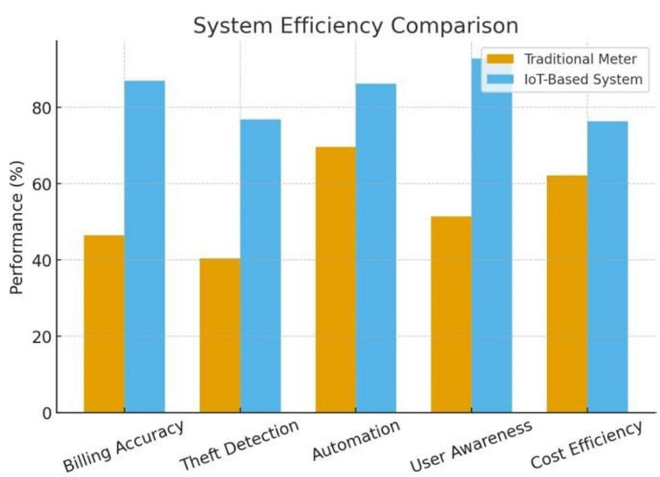


Fig. 6. System Efficiency Comparison

The System Efficiency Comparison graph illustrates the IoT-based prepaid meter against a conventional energy meter based on important parameters including billing accuracy, automation, theft detection, and customer awareness. The IoT system excels in every area as it is monitored in real time with automatic control. Although its upfront cost is slightly more, it guarantees correct billing, transparency, and better energy management and is thereby proven more efficient than traditional systems.

Power Theft Detection Over Time illustrates the response of the system to unauthorized tampering with the meter. The alarm signal is zero in normal conditions and one when theft is indicated. This takes place when the internal micro-switch is activated, which triggers an instantaneous buzzer alarm and GSM notification. The graph indicates the rapid response of the system, providing security and effective power theft prevention.

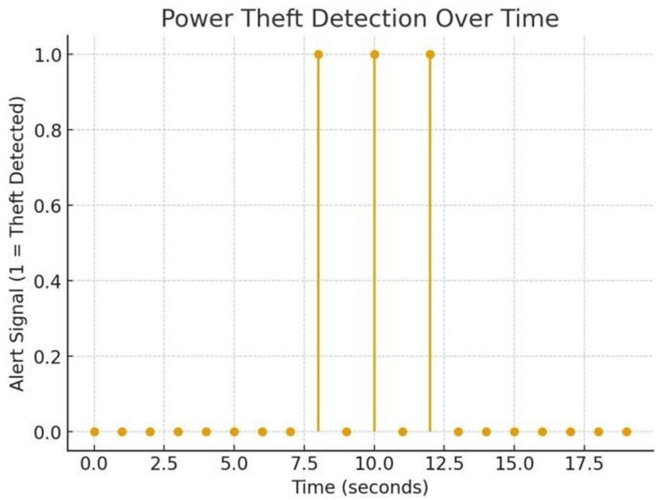


Fig. 7. Power Theft Detection Over Time

REFERENCES

[1] B. Shravani, G. Sai Deepthi, C. Nikhilesh Vijay, K. Wajida Sultana, G. Sadha Muskan, and C. Rakesh, "IoT Based Prepaid Energy Meter," Int. J. Res. Eng. Sci. (IJRES), vol. 11, no. 4, pp. 255–258, Apr. 2023.

[2] Prof. Sandhya Ahire, Dipali Bangar, Utkarsha Nagargoje, and Amit Phadatare, "IOT Based Prepaid Energy Meter," Journal of Emerging Technologies and Innovative Research (JETIR), vol. 10, no. 3, pp. 340– 347, Mar. 2023.

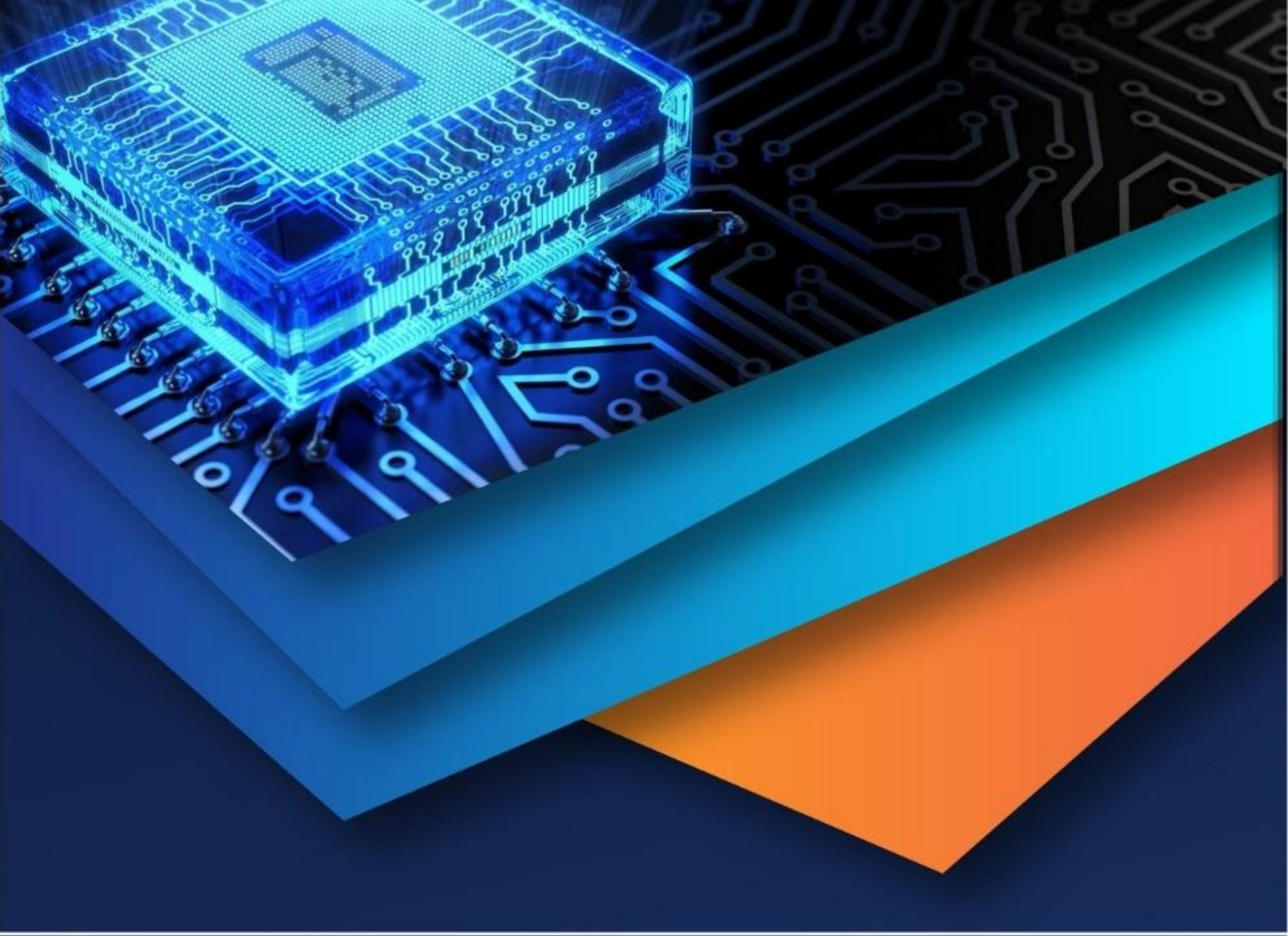
[3] M. S. Kinake, S. B. Deotale, A. R. Mirase, S. H. Padhen, and D. V. G. Neve, "Prepaid Energy Meter using GSM Technology," International Journal of Research Publication and Reviews, vol. 3, no. 5, pp. 3536– 3541, May 2022.

[4] D. S. Ramani, S. I. Kiran, S. Raviteja, and B. P. Kumar, "IoT Based Electricity Energy Meter," International Journal of Computer Science and Mobile Computing, vol. 11, no. 1, pp. 153–158, Jan. 2022.

[5] Afreen, M. S. Vishnu, and P. Prashanth Kumar, "IoT-Based Prepaid Energy Meter," International Journal for Research in Applied Science and Engineering Technology (IJRASET), vol. 11, no. III, pp. 1125–1134, Mar. 2023.

[6] S. Barkale, P. Jadhav, S. Bagul, and S. Bhosale, "IoT Based Smart Energy Metering with Blynk Application," International Journal of Trend in Scientific Research and Development (IJTSRD), vol. 7, no. 2, pp. 814– 819, Apr. 2023.

[7] D. V. Ranganayaki, N. Kumar S, S. M, and M. Mahaprabhu, "IOT Based Prepaid Energy Meter," International Journal of Creative Research Thoughts (IJCRT), vol. 9, no. 7, pp. 219–224, Jul. 2021.



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY