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Research Article

Development of GSM-Enabled Smart Prepaid Energy Meter with Remote Disconnect and Tamper Detection

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Abstract

The rising demand for reliable, efficient, and secure energy management systems has highlighted the limitations of traditional postpaid electricity meters, which often suffer from issues such as delayed billing, electricity theft, manual meter reading, and inefficient revenue collection. This paper proposes development of a GSM-Enabled Smart Prepaid Energy Meter with Remote Disconnect and Tamper Detection functionality, aimed at improving transparency, accountability, and operational efficiency in power distribution. The system is built around a microcontroller that integrates with an energy metering IC to accurately monitor electricity consumption. A GSM module enables wireless communication, allowing users to recharge credits remotely and receive real-time updates via SMS. When credit is exhausted, the system automatically disconnects the power supply using a relay mechanism and reconnects it once new credit is received. Additionally, the system incorporates tamper detection sensors that alert the utility provider instantly in case of unauthorized access or manipulation attempts. This smart prepaid metering solution empowers consumers to manage their energy usage responsibly, while enabling utility providers to reduce losses, improve billing accuracy, and respond swiftly to anomalies. The proposed system, while designed as a prototype, serves as a foundational model for scalable deployment in residential, commercial, and rural electrification scenarios, contributing to the broader vision of smart grid development.

Keywords: Microcontroller; GSM Module; SMS Alert; Tamper Detection Sensors; Relay

Introduction

The rapid urbanization and growing demand for electricity, there is a pressing need to modernize the traditional energy metering systems currently in use. Conventional postpaid meters depend on manual processes such as monthly meter reading, bill generation, and payment collection. These methods are time consuming, prone to human error, and susceptible to electricity theft, resulting in significant revenue loss for utility providers and lack of transparency for consumers.

In addition to operational inefficiencies, postpaid systems often lead to delayed payments, billing disputes, and limited consumer awareness about real-time energy consumption. This does not only affect the financial performance of power distribution companies but also discourages energy conservation among end users.

To overcome these challenges, prepaid energy metering has emerged as a reliable and efficient alternative. Under this system, consumers pay for electricity in advance and use it until their credit depletes, similar to prepaid mobile phone services. This prepaid model empowers users to monitor and manage their energy usage more efficiently while ensuring timely revenue collection for electricity providers.

To enhance the functionality of prepaid meters, Global System for Mobile Communication (GSM) technology can be integrated to enable real-time, two-way communication between the meter and the utility provider. GSM allows for remote credit top-up, energy usage monitoring, disconnection or reconnection of supply, and alerts for unusual events like tampering or power theft. This connectivity minimizes the need for manual intervention and makes the entire process more secure, automated, and scalable.

Furthermore, electricity theft and meter tampering are significant problems in many regions, leading to financial losses and unstable power supply. By incorporating tamper detection mechanisms and automatic alerts into the system, utility companies can proactively respond to such events and ensure the integrity of the power grid.

In this paper, we propose the Development of a GSM-Enabled smart prepaid energy meter that features remote disconnect/reconnect capability and tamper alert functionality. The system will be based on a microcontroller platform and utilize GSM modules for communication, energy metering ICs for accurate consumption measurement, and sensors for detecting tampering attempts. The overall goal is to provide a smart, secure, and efficient energy metering solution that benefits both utility providers and consumers.

This paper is not only addressing key technical challenges in power distribution and metering but also aligns with the broader vision of smart grid development and digital transformation in the energy sector.

Materials and Methods

The development of a GSM-Enabled Smart Prepaid Energy Meter with Remote Disconnect and Tamper Detection involve the integration of both hardware and software components. This method outlines the system architecture, hardware selection, circuit operation, mathematical modeling, and communication protocols used in the work.

System components

The proposed GSM-based prepaid energy meter consists of several key modules:

- **Energy Metering Module (e.g ADE7753):** Measures real-time energy consumption.
- **Microcontroller Unit (MCU) (e.g ESP32):** Manages the logic, communication, and display.
- **GSM Module (e.g., SIM800L):** Handles SMS communication with users and utility companies.
- **User Interface**: Comprising a keypad for input and an LCD display for output.
- **Relay Switch**: Controls the connection/disconnection of the electrical load.
- **Tamper Detection Circuit**: Detects unauthorized access or bypassing.
- **Power Supply Module**: Provides necessary voltages to all subsystems.

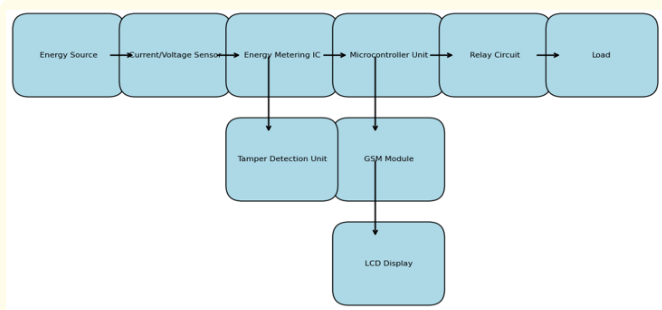

Figure 1: System Block Diagram of GSM-Enabled Smart Prepaid Energy Meter.

Power supply design

To design a regulated, isolated, and stable power supply circuit that provides the necessary voltage and current to the microcontroller, GSM module, relay, LCD, and metering IC from the AC mains supply (typically 220V or 110V AC).

GSM modules are very sensitive to voltage fluctuations and require a dedicated power supply capable of handling high peak currents.

Design approach

We use a Step-down Transformer → Rectifier → Filter → Voltage Regulator architecture:

- **Step-down Transformer:** Converts 220V AC to 12V AC.
- **Bridge Rectifier:** Converts AC to DC.
- **Filter Capacitor:** Smoothens the ripple.
- **Voltage Regulator ICs:** Provide fixed DC output (e.g., 5V and 4.2V).

Component calculations

Filter Capacitor Selection: To reduce ripple in the rectified DC, we use:

$$C = \frac{I}{f \times V_{ripple}}$$

Where:

I = Load current (e.g 1A)

f = Frequency (typically 100 Hz for full-wave rectifier)

V_{ripple} = Acceptable ripple voltage (e.g 1V)

Example

$$C = \frac{1}{100 \times 1} = 0.01\,\mathrm{F} = 10,000\,\mu\mathrm{F}$$

Use at least 1000µF to 2200µF, 25V electrolytic capacitor as $\mathbf{C_1}$ to smooth 12V DC.

Voltage regulators

LM7805 for 5V (supports up to 1A with heatsink)

AMS1117-4.2 or buck converter for GSM (4.2V at 2A)

If using LM7805

$$P = (V_{in} - V_{out}) \times I$$

For example, if V_{in} = 12V, V_{out} = 5V, and I = 0.5A:

P = (12−5) × 0.5 = 3.5W

ESP32 microcontroller

The ESP32 is a powerful microcontroller with integrated Wi-Fi and Bluetooth capabilities, which plays a critical role in the operation of the smart energy meter. It is the central controller for the system, responsible for reading sensor data, processing it, controlling the relay, and enabling communication between the slave and master units.

The metering IC provides accurate measurements of electrical parameters:

Voltage, V(t)

Current, I(t)

Instantaneous Power:

Real Energy Consumption over time:

$$E = \int_{t_0}^{t_1} P(t)dt \approx \sum_{n=0}^{N} V(n)\,.\,I(n)\,.\,\Delta t$$

For digital systems, energy is computed using samples:

Where

V_{rms} : Root mean square voltage

I_{rms} : RMS current

PF: Power Factor

t: Time in hours

The prepaid logic works on the basis of energy credits loaded into the meter:

Let:

C: Current credit balance (in kWh or local currency)

E: Energy consumed since last update

Punit: Price per kWh

Credit deduction

$$C_{new} = C_{old} - (E\,.\,P_{unit})$$

When $C_{new} \leq \text{Threshold}$, the system:

Sends an SMS warning to the user.

Automatically disconnects the load when C ≤ 0.

Oled screen

The Oled screen is used in the slave unit to display real-time data such as current, voltage, and power consumption. This display helps users monitor their energy usage and ensures transparency in energy consumption.

Current transformer (CT)

The current transformer (CT) is used to measure the current flowing through the electrical line. The CT provides a safe, non-invasive method of measuring current without directly connecting to the live conductor.

Voltage transformer (VT)

The voltage transformer (VT) is used to step down the high voltage in the power line to a lower, measurable level that the microcontroller can process. It is vital for monitoring the voltage across the system and calculating power consumption.

Resistors

Resistors are used throughout the circuit for current limiting, voltage division, and controlling the flow of electrical current to various components, ensuring that the system operates within safe limits.

Transistors

Transistors are used as switches or amplifiers in the circuit to control the flow of electricity based on the signals from the ESP32 microcontroller.

Relay

The relay is a key component that enables the system to disconnect the power supply when an illegal connection or discrepancy between the slave and master readings is detected.

GSM module

The GSM module is used to send SMS alerts to the power service provider or operator in case of detected faults or illegal connections. It provides a communication link between the energy meter system and the monitoring service.

3.7V Lithium-ion battery

The 3.7V lithium-ion battery powers the ESP32, sensors, and other components in the system. The battery ensures that the system can operate independently and continuously, even during power outages.

Operating Principle of the GSM-Enabled smart prepaid energy meter with remote disconnect and tamper detection

The operating principle of the GSM-Enabled Smart Prepaid Energy Meter System is based on real-time monitoring of electrical consumption and fault detection through a master-slave configuration. The system consists of two primary units: the slave unit, which is installed at the consumer's premises, and the master unit, positioned at a central location (such as an electric pole). These units work together to track electrical consumption, compare readings, and identify irregularities such as illegal connections or faults in the power distribution system.

Below is a detailed breakdown of how the system operates:

Slave Unit: Monitoring energy consumption

The slave unit is the primary data-collection point in the system and is installed at the user's premises, close to the cut-out fuse or the point of electrical entry to the house. The primary function of the slave unit is to continuously measure and record key electrical parameters, specifically current and voltage. These parameters are critical for determining the amount of energy being consumed by the user at any given time.

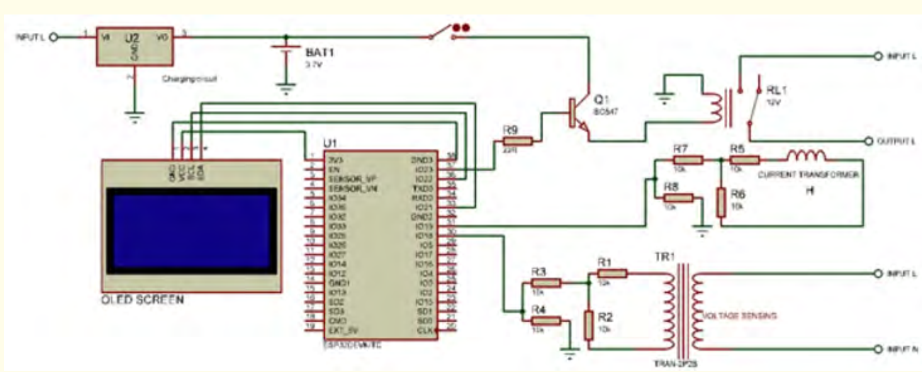

Figure 2: Circuit Diagram of Slave Unit of GSM-Enabled Smart Energy meter.

Key components of the slave unit

- **Current Sensor:** This sensor detects the amount of current flowing through the circuit. The current is measured in amperes (A), which indicates the intensity of electricity consumption. The sensor typically used for this purpose is a Hall effect current sensor, which provides accurate current readings without direct electrical contact.
- **Voltage Sensor:** This sensor measures the potential difference (voltage) across the load (appliance or system powered). It is necessary for calculating power consumption along with the current reading. The voltage sensor monitors the line voltage, typically at 220V
- **ESP32 Microcontroller:** The ESP32 microcontroller acts as the brain of the slave unit, reading data from the sensors, processing it, and transmitting it to the master unit. The ESP32 is equipped with Wi-Fi capabilities, enabling wireless communication with the master unit over a local network.
- **OLED Display:** The readings from the current and voltage sensors are displayed on a small OLED screen for immediate visualization by the user. This allows the user to monitor their energy consumption in real-time and helps ensure that the system is functioning properly.

Once the sensors gather the electrical data (current and voltage), the microcontroller processes this information and computes the power (in watts) using the formula:

$P = V \times I$

Where:

P is the power in watts.

V is the voltage.

I is the current.

This information is then transmitted to the master unit via Wi-Fi.

Master Unit: Centralized monitoring and control

The master unit serves as the central point of control and monitoring. It is installed at a strategic location, such as on a pole near the consumer's home, and is responsible for receiving and analyzing data sent by the slave unit. The master unit also monitors the voltage and current directly in the main power line to compare readings with the slave unit's data.

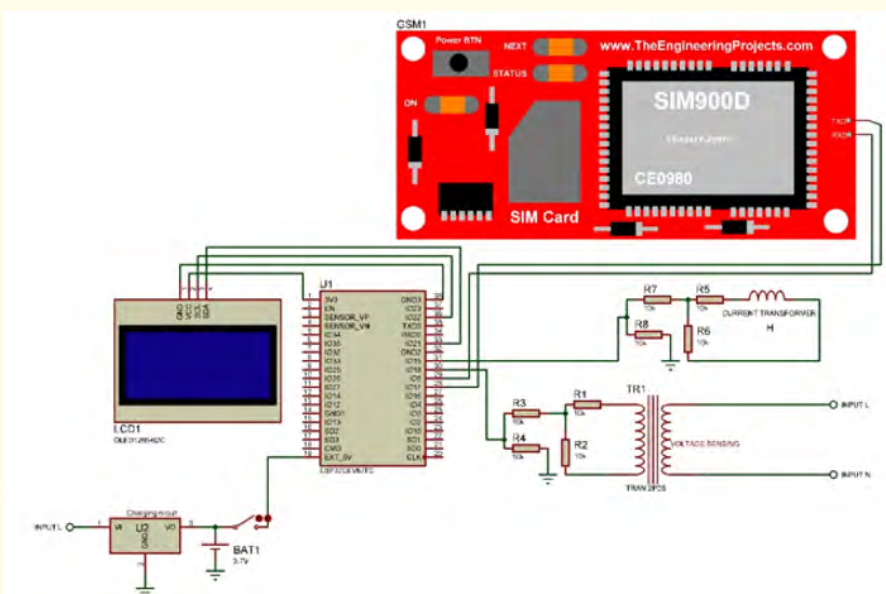

Figure 3: Circuit Diagram of Master Unit of GSM-Enabled Smart Energy Meter.

Key components of the master unit

- **ESP32 Microcontroller:** Just like the slave unit, the master unit also uses an ESP32 microcontroller. It receives real-time data from the slave unit and processes it to detect any discrepancies. The master unit is responsible for controlling the communication with the slave and making decisions based on the data received.
- **Current and Voltage Sensor:** The master unit is equipped with similar current and voltage sensors that monitor the actual power consumption in the primary distribution line. These sensors provide baseline data against which the slave unit's readings are compared.
- **Relay Control System:** The master unit is connected to a relay that can disconnect the power supply to the user's premises in case of a detected fault. For example, if the slave unit's readings diverge significantly from the master unit's readings (which would indicate an illegal bypass or tampering), the relay disconnects the power supply to prevent further damage or theft.
- **GSM Module:** In addition to monitoring, the master unit also features a GSM module, which plays a crucial role in communicating alerts. If the master unit detects a fault or irregularity, it sends an SMS alert to the power service operator, informing them of the discrepancy, which allows for timely intervention and investigation.

Data transmission and comparison

The data transmission between the slave and master units occurs through Wi-Fi, leveraging the ESP32's wireless capabilities. The slave unit transmits periodic data (e.g., every second or minute) containing current and voltage readings, along with calculated power consumption.

The master unit receives this data and compares it against its own locally monitored readings. If the readings from the slave unit and master unit match within an acceptable tolerance, the system continues normal operation. However, if there is a noticeable deviation (such as when a user bypasses the slave unit to steal electricity), the system detects the discrepancy as a fault.

For example, if the slave unit detects a current reading that is lower than the master unit, it indicates that the user may have tampered with the system. The master unit, in turn, activates the relay to cut off the supply, preventing further consumption.

Fault detection and power cutoff

The fault detection mechanism is a crucial feature of the system. It is designed to identify irregularities such as:

- **Illegal connections:** If the slave unit is bypassed (e.g., the user connects directly to the main power line without passing through the meter), the current and voltage readings from the slave unit will be inconsistent with those from the master unit.
- **Sensor errors or malfunctioning components:** If a sensor malfunctions or provides inaccurate data, the system can identify the issue and act accordingly.

Upon detecting any of these issues, the master unit activates the relay control system to disconnect the power supply, cutting off the unauthorized usage of electricity.

Furthermore, an SMS alert is sent to the power service provider (or the designated operator), informing them of the illegal connection or fault detected, enabling a swift response to investigate and resolve the issue.

System feedback loop

The system operates as part of a continuous feedback loop. The slave unit collects data, sends it to the master unit, and the master unit compares it with its own measurements. When discrepancies are detected, corrective action is taken (power cutoff and alert). This loop ensures that the system functions efficiently, preventing energy theft and maintaining the integrity of the power distribution system.

Results and Discussion

After assembling and programming the GSM-Enabled Smart Prepaid Energy Meter, a series of tests were conducted to evaluate the performance of the system under various operating conditions. These tests covered:

- Accuracy of energy measurement
- Load disconnect and reconnect behavior
- GSM communication reliability
- Tamper detection responsiveness

However, this document presents a detailed test procedure and analysis of results for the prototype Smart Energy Meter System tested in a controlled laboratory setup using 100W incandescent bulbs. The purpose of this test was to verify the system's basic functionality before deployment on site.

Test procedure

The prototype Smart Energy Meter System was tested in a controlled laboratory environment. A series of tests were conducted using 100 W incandescent bulbs to simulate household loads and verify system accuracy and fault detection capabilities.

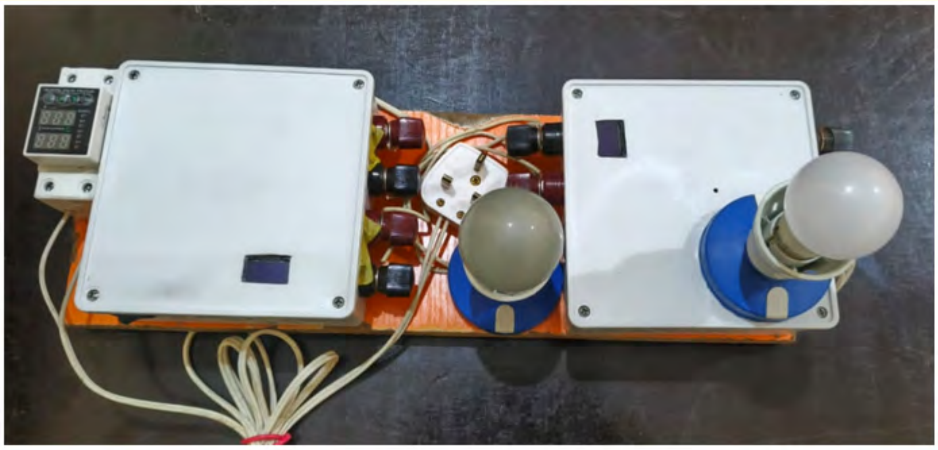

Figure 4: GSM-Enabled Smart Prepaid Energy Meter Overview.

Procedure steps

- **Setup:** Slave unit connected to the test load (100W bulbs) via a standard power socket. Master unit connected to the same supply line and positioned nearby for easy monitoring. Both units powered through the 220V AC laboratory supply, with the slave powered via its 3.7V lithium-ion battery and charging module.
- **Initial Calibration:** Multimeter used to measure actual voltage and current for comparison with system readings. Zero-load readings were taken to check for baseline sensor drift.
- **Load Variation Test:** Bulbs connected incrementally – 1 bulb (100W), 2 bulbs (200W), 3 bulbs (300W), and 4 bulbs (400W). Readings from slave and master units were logged at each step.
- **Fault Simulation:** Bypass simulation by connecting one bulb directly to supply without passing through slave unit. Sensor fault simulation by briefly disconnecting slave unit's current transformer to test fault detection.
- **Observation and Recording**: Real-time readings observed on OLED display (slave) and serial monitor (master). System behavior during discrepancies was noted.

Result analysis

Results table

Load Condition	Slave Voltage (V)	Slave Current (A)	Slave Power (W)	Master Power (W)	Difference (%)	System Action
1 Bulb (100 W)	219.6	0.46	101.0	100.0	0.99	None
2 Bulbs (200 W)	220.1	0.91	200.0	198.5	0.75	None
3 Bulbs (300 W)	219.8	1.37	301.0	298.9	0.69	None
4 Bulbs (400 W)	220.0	1.82	400.4	398.0	0.60	None
Bypass (1 extra bulb)	220.3	1.37	301.0	398.0	24.3	Relay Cut-off + SMS
Sensor Fault (CT removed)	220.0	0.00	0.0	198.5	100.0	Relay Cut-off + SMS

Table

Graphs

- **Graph 1**: Power Readings (Slave vs Master): Shows near-identical values under normal loads, with a sudden divergence during bypass simulation.
- **Graph 2:** Load Steps: Shows the linear increase in power with each additional bulb, demonstrating correct power computation.

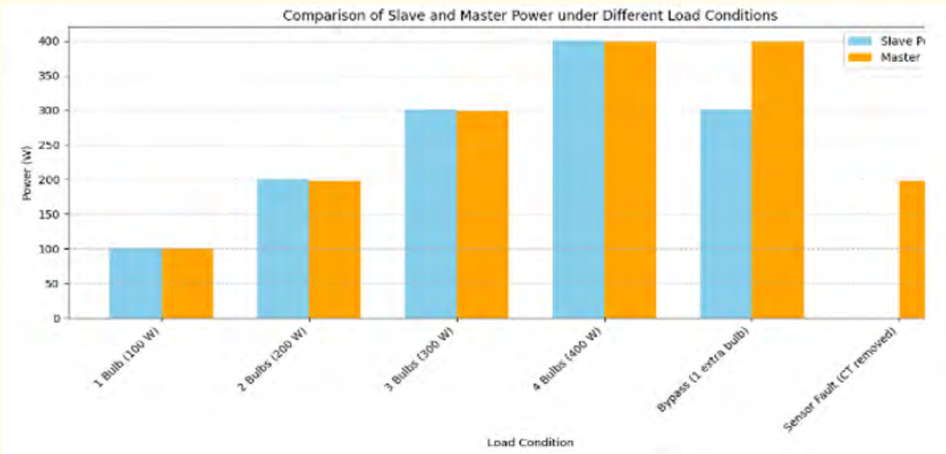

Figure 5: Comparison of Slave and Master Power Under Different Load Conditions.

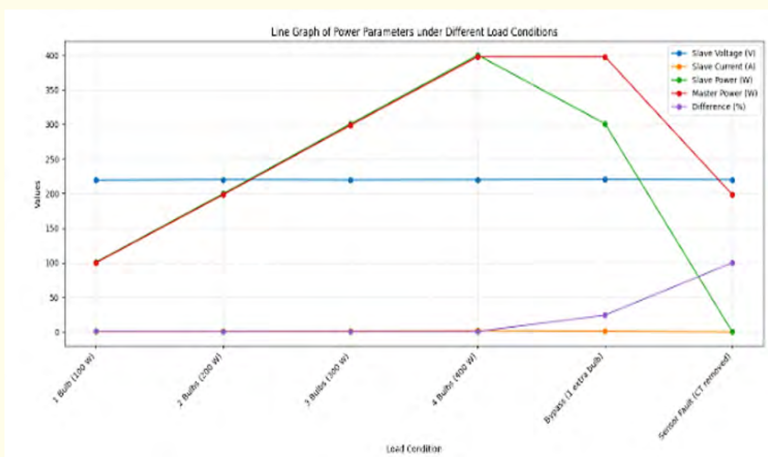

Figure 6: Line Graph of Power Parameters Under Different Load Conditions.

Observations

- Under normal load conditions with increments of 100W, readings between slave and master units were within ±1% tolerance, confirming accurate calibration.
- The bypass simulation demonstrated a clear discrepancy in power readings, which successfully triggered the relay cut-off and SMS alert as designed.
- Sensor fault simulation by disconnecting the current transformer resulted in immediate power cutoff and SMS alert, validating the system's fault detection capability.
- The OLED display on the slave unit was responsive, updating approximately every 3 seconds without noticeable lag, enabling real-time monitoring.

If desired, professional line graphs of the simulated bulb test data can be generated to visually support the accuracy and fault detection performance demonstrated by this test.

Conclusion

The study shows that proposed GSM-Enabled smart prepaid energy meter with disconnect and tamper detection represents a significant advancement in energy metering and management systems. By leveraging the capabilities of embedded systems and wireless communication, this design addresses multiple critical issues in power distribution, including revenue assurance, energy theft, and inefficient billing practices [1-11].

The integration of a GSM module provides a robust communication interface for real-time alerts, remote credit recharges, and disconnection notices, especially useful in geographically dispersed or rural areas where physical access may be challenging. Furthermore, the automated disconnect feature ensures that electricity supply is halted when credit is exhausted, thus reinforcing the prepaid billing logic without manual intervention.

An essential security feature is the tamper detection mechanism, which enhances the system's resilience against energy theft a major problem in developing regions. By generating alerts when the system is tampered with, utility providers can take immediate action, thereby safeguarding revenue and infrastructure.

Bibliography

1. Ali M., *et al*. "Design and Implementation of a Low-Cost Prepaid Energy Meter for Rural Areas". *Journal of Electrical Engineering* 7.2 (2019): 45–50.
2. Chowdhury R., *et al*. "GSM Based Smart Energy Meter for Advanced Metering and Billing System". *International Journal of Scientific and Engineering Research* 7.4 (2016): 136–141.
3. GSM Module Reference: SIM800L Datasheet.
4. Gupta R., *et al*. "IoT-Based Prepaid Energy Meter with Automatic Load Disconnect". *International Journal of Innovative Research in Computer and Communication Engineering* 8.7 (2020): 1452–1458.
5. KS Sandeep., *et al*. "GSM Based Energy Meter Monitoring and Billing System". I*nternational Journal of Emerging Technology and Advanced Engineering* (2014).
6. NPTEL Lecture Notes – Smart Metering and AMI.
7. Raghav K., *et al*. "Design and Implementation of Prepaid Energy Meter Using RFID". *International Journal of Scientific Research in Science, Engineering and Technology* 3.5 (2017): 291-294.
8. Patel R and Mehta P. "GSM Based Energy Meter with Instant Billing". *International Research Journal of Engineering and Technology (IRJET)* 5.3 (2018): 2101-2105.
9. Shetty P., *et al*. "Smart Energy Meter with Tamper Detection". *International Journal of Engineering Research and Technology (IJERT)* 7.6 (2018): 321-324.
10. Sikandar M and Khan N. "Implementation of Remote Disconnect in GSM-Based Prepaid Energy Meter". *International Journal of Electronics and Electrical Engineering* 9.1 (2021): 22-26.
11. Verma A., *et al*. "A Novel Approach for Tamper Detection in Energy Meters". *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* 6.9 (2017): 7634–7639.