IOT Based Smart Energy Meter with Fault Detection and Theft Detection

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Abstract

This paper presents the design and implementation of an IoT-Based Smart Energy Meter with Fault Detection and Theft Detection capabilities. The proposed system aims to provide accurate monitoring of electrical energy consumption while enhancing the reliability and security of power distribution networks. The system utilizes current and voltage sensors interfaced with a microcontroller to continuously measure electrical parameters such as voltage, current, power, and energy consumption. Through IoT connectivity, the collected data is transmitted to a cloud platform, enabling real-time monitoring and analysis through a web or mobile application. The system eliminates the need for manual meter reading and supports automated billing processes. In addition to energy monitoring, the system incorporates intelligent fault detection and theft detection mechanisms. Electrical faults such as overvoltage, overcurrent, and short circuits are identified in real time, and instant notifications are sent to users and utility providers to prevent equipment damage and ensure safety. The theft detection module monitors abnormal power consumption patterns and detects unauthorized energy usage by comparing measured parameters with expected values. Experimental implementation demonstrates the effectiveness of the proposed system in improving energy management, reducing power losses, and enhancing grid security. The integration of IoT technology with smart metering provides a cost-effective and scalable solution for modern energy distribution systems.

Keywords: Automation, Cloud Platform, Energy Management, Fault Detection, IOT- Based Smart Energy Meter, Power Consumption, Real-Time Monitoring, Smart Grid, Sustainable Energy System.

INTRODUCTION

The increasing demand for electricity and the need for efficient energy management have accelerated the development of smart metering technologies. Traditional energy meters require manual reading, which is time-consuming, prone to errors, and incapable of providing real-time consumption information. Furthermore, power theft and electrical faults result in significant revenue losses and operational challenges for utility providers.

The Internet of Things (IoT) offers an effective solution by enabling remote monitoring and control of electrical systems. Smart energy meters integrated with IoT technology allow users and utility companies to access real-time energy consumption data from anywhere. Additionally, advanced analytics can be used to detect abnormal conditions such as faults and unauthorized electricity usage.

This work proposes an IoT-based smart energy meter capable of monitoring energy consumption, detecting electrical faults, and identifying power theft. The system improves transparency, enhances operational efficiency, and contributes to sustainable energy utilization.

PROBLEM STATEMENT

Traditional electricity metering systems rely on manual meter reading and periodic monitoring, which often result in inaccurate billing, delayed data collection, and increased operational costs. These conventional

systems are unable to provide real-time information regarding energy consumption, making it difficult for consumers and utility providers to monitor and manage electricity usage efficiently.

LITERATURE SURVEY

Sebastian P.K. and Deepa K. (2022) proposed an IoT-based smart energy meter using Arduino Uno, ESP8266, and ACS712 sensors. The system monitors energy consumption and detects faults and electricity theft by comparing input and output current values. Data is uploaded to the Adafruit IO cloud platform for remote monitoring. [1]

Smart Energy Meter with Power Theft Detection (ICEES 2024) introduced a smart metering system that detects electricity theft by comparing energy measurements at different distribution points. The system provides real-time monitoring and alerts utility providers when abnormal energy usage is detected. [2]

Smart Energy Meter with Theft Detection and Voice Alert (ICIMA 2025) presented a theft detection system using current and voltage sensors. When unauthorized usage is identified, the system generates voice alerts and notifications, improving energy security and reducing power losses. [3]

IoT-Based Prepaid Energy Meter with Theft Monitoring and Control System (2025) focused on prepaid billing, remote monitoring, and theft detection. The system uses IoT technology to provide real-time energy tracking, efficient billing management, and remote control capabilities. [4]

IoT-Based Smart Energy Meter with Fault Detection Features and Theft Detection (2025) reviewed smart metering technologies that integrate IoT sensors, Wi-Fi/GSM communication, fault detection, and theft detection. The study also explored cloud computing and machine learning techniques for improving system performance. [5]

Most existing systems focus mainly on either fault detection or theft detection and often lack a complete integrated solution. Therefore, there is a need for an IoT-based smart energy meter that combines real-time monitoring, fault detection, theft detection, cloud connectivity, and instant alert generation in a single platform.

SYSTEM DESIGN AND METHODOLOGY

A. System Components

The developed system consists of:

1. ESP32: Main controller with Wi-Fi
2. ACS712: Current sensing module
3. Voltage Sensor: Voltage measurement
4. Relay Module: Load control and protection
5. LCD Display: Local monitoring
6. Power Supply: Circuit operation
7. Wi-Fi Network: Internet connectivity

B. Working Principle

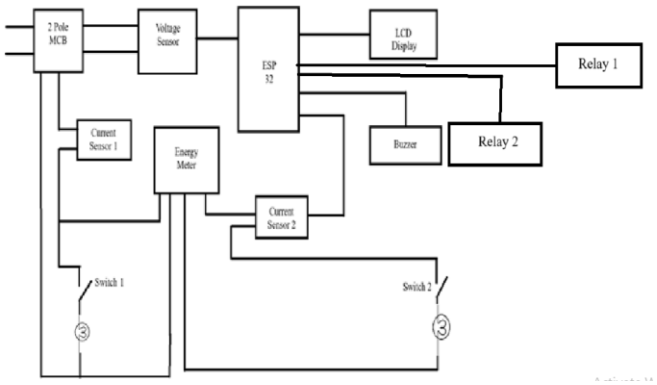

Fig 1: Block Diagram

The IoT-Based Smart Energy Meter with Fault Detection and Theft Detection operates by continuously measuring electrical parameters such as voltage and current using dedicated sensors. The sensed data is processed by the ESP32/NodeMCU microcontroller, which calculates power consumption and energy usage in real time. The measured values are displayed on an LCD and simultaneously transmitted to a cloud platform through Wi-Fi connectivity for remote monitoring.

The system continuously analyzes the collected data to detect abnormal conditions. If faults such as overvoltage, overcurrent, or short circuits occur, the system immediately generates alerts and can disconnect the load through a relay to prevent damage. For theft detection, the system compares expected and actual energy consumption values and identifies unusual current variations or unauthorized connections. When suspicious activity is detected, alert notifications are sent to the consumer and utility provider through the IoT platform. This enables efficient energy management, accurate billing, enhanced safety, and reduction of electricity theft.

RESULTS AND DISCUSSION

Case 1: Normal Operating Condition

Objective: To verify the operation of the smart energy meter under normal load conditions.

Condition:

- Load current less than 10 A.
- Difference between Meter Current Sensor (I_1) and Load Current Sensor (I_2) less than 5 A.
- No unauthorized load connected.

Experimental Readings:

	A	B	C	D	E	F
1	Timestamp	Voltage (V)	Meter Current I_1 (A)	Load Current I_2 (A)	Power	Status
2	01/05/2026 10:00:00	230	2.1	2.05	483	NORMAL
3	01/05/2026 10:01:00	231	3.5	3.42	808	NORMAL
4	01/05/2026 10:02:00	229	4.8	4.75	1099	NORMAL
5	01/05/2026 10:03:00	232	6.2	6.1	1438	NORMAL
6	01/05/2026 10:04:00	230	8.5	8.4	1955	NORMAL

Fig 2: Normal Operating Condition

Analysis: In normal operating condition, both ACS712 current sensors measure nearly the same current. The difference remains below the predefined threshold of 5 A. The ESP32 continuously monitors voltage, current, power, and energy consumption and uploads the data to the cloud platform. Since the measured current is below 10 A and no abnormal variation exists between sensors, the system classifies the condition as NORMAL.

Result: The smart energy meter successfully measured electrical parameters and transmitted them to ThingSpeak, Google Sheets, and Telegram without generating any theft or fault alerts.

Case 2: At theft Condition

Objective: To detect unauthorized power consumption by comparing currents measured at two different locations.

Condition:

- Difference between current sensors greater than or equal to 5 A.
- Current remains below overload limit.
- Illegal tapping or bypass connection simulated.

Experimental Readings:

	A	B	C	D	E	F
1	Timestamp	Voltage (V)	Meter Current I_1 (A)	Load Current I_2 (A)	Power	Status
2	01/05/2026 10:00:00	230	2.1	2.05	483	NORMAL
3	01/05/2026 10:01:00	231	3.5	3.42	808	NORMAL
4	01/05/2026 10:02:00	229	4.8	4.75	1099	NORMAL
5	01/05/2026 10:03:00	232	6.2	6.1	1438	NORMAL
6	01/05/2026 10:04:00	230	8.5	8.4	1955	NORMAL
7	01/05/2026 10:05:00	230	8	2.5	1840	THEFT
8	01/05/2026 10:06:00	231	9.2	3.8	2125	THEFT
9	01/05/2026 10:07:00	229	7.5	2.3	1718	THEFT
10	01/05/2026 10:08:00	230	8.8	3.1	2024	THEFT
11	01/05/2026 10:09:00	232	9.5	4.2	2204	THEFT

Fig 3: At theft Condition

Analysis: During theft conditions, an unauthorized load is connected before the consumer meter. Consequently, the meter-side current (I_1) becomes significantly higher than the load-side current (I_2). The current difference exceeds the threshold value of 5 A. The ESP32 identifies this mismatch and generates a theft alert. The alert message is transmitted to the Telegram bot and the theft status is stored in the cloud database.

Result: The proposed system successfully detected electricity theft in all test cases and generated real-time notifications for monitoring authorities.

Case 3: At Fault Condition

Objective: To protect the electrical system from overload and fault conditions.

Condition:

- Load current exceeds 10 A.
- Excessive load connected to the supply.
- Current difference between sensors remains small.

Experimental Readings:

	A	B	C	D	E	F
1	Timestamp	Voltage (V)	Meter Current I_1 (A)	Load Current I_2 (A)	Power	Status
2	01/05/2026 10:00:00	230	2.1	2.05	483	NORMAL
3	01/05/2026 10:01:00	231	3.5	3.42	808	NORMAL
4	01/05/2026 10:02:00	229	4.8	4.75	1099	NORMAL
5	01/05/2026 10:03:00	232	6.2	6.1	1438	NORMAL
6	01/05/2026 10:04:00	230	8.5	8.4	1955	NORMAL
7	01/05/2026 10:05:00	230	8	2.5	1840	THEFT
8	01/05/2026 10:06:00	231	9.2	3.8	2125	THEFT
9	01/05/2026 10:07:00	229	7.5	2.3	1718	THEFT
10	01/05/2026 10:08:00	230	8.8	3.1	2024	THEFT
11	01/05/2026 10:09:00	232	9.5	4.2	2204	THEFT
12	01/05/2026 10:10:00	230	10.5	10.4	2415	OVERLOAD
13	01/05/2026 10:11:00	231	11.2	11.1	2587	OVERLOAD
14	01/05/2026 10:12:00	229	12	11.9	2748	OVERLOAD
15	01/05/2026 10:13:00	230	13.5	13.4	3105	OVERLOAD
16	01/05/2026 10:14:00	232	15	14.9	3480	OVERLOAD
17						

Fig 4: At theft Condition

Analysis: When the connected load exceeds the predefined limit of 10 A, the measured current rises above the safe operating range. The controller identifies the abnormal condition as an overload or fault. A fault alert is generated and can be used to trigger a relay for disconnecting the supply. This prevents damage to electrical equipment and improves system safety.

Result: The proposed system accurately detected overload conditions and provided immediate fault notifications, ensuring protection of the electrical installation.

Fig 5: Project Model

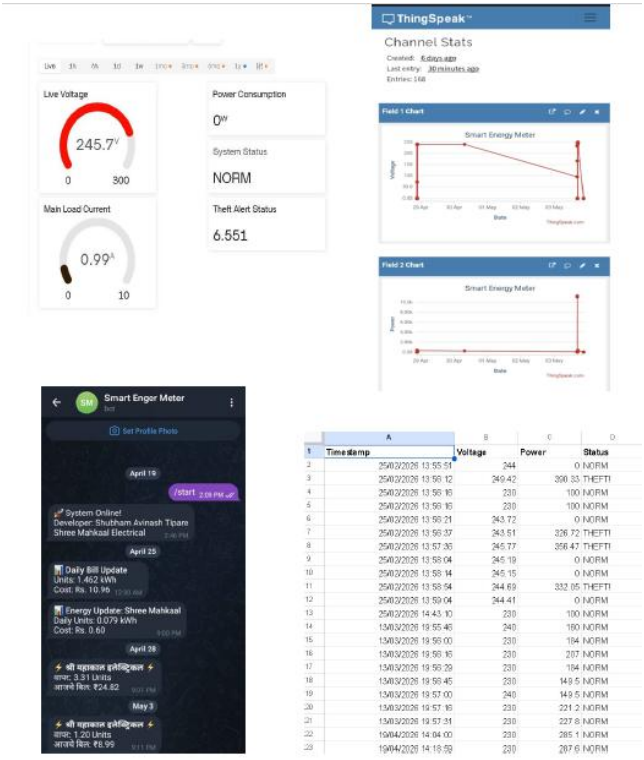

Fig 6: Reading Display Board

CONCLUSION

This IoT based "Smart Energy Meter with Fault & Theft Detection" project ensures reliable performance in real time energy monitoring, fault detection, and prevention from thefts. Using sensors, microcontrollers, and a cloud-based platform like Think Speak, this system can provide efficient energy management. The project has many advantages like improved energy efficiency, reduced losses, and potential to develop further with technological developments in IoT and smart grid technologies.

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