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IOT BASED SMART ENERGY MANAGEMENT AND ELECTRICAL FAULT DETECTION SYSTEM

[1] Sriramula. Srimatha, [2] V. Vinitha, [3] K. Sree Lakshmi, [4] T. Shasidhar, [5] A.Balu Kumar
[1]Assistant Professor, [2345]Students
Department of EEE
Siddhartha Institute of Technology & Sciences, Narapally
drsrimatha_eee@siddhartha.co.in, 25tq5a0204@siddhartha.org.in, 25tq5a0209@siddhartha.org.in, 25tq5a0206@siddhartha.org.in, 24tq1a0201@siddhartha.co.in

ABSTRACT

Electrical energy is used wastefully in many homes, hostels, small workshops, and commercial buildings because consumers see their consumption only once a month through the utility bill. At the same time, faults such as overloads, short circuits, earth leakage, over-voltage, and under-voltage are usually handled only by fuses and miniature circuit breakers that act after the damage has started and give no information about what went wrong. This paper presents an IoT Based Smart Energy Management and Electrical Fault Detection System that measures consumption continuously, identifies abnormal electrical conditions, isolates the affected load, and reports the event to the user in real time.

The system is built around an ESP32 microcontroller connected to a ZMPT101B voltage sensor and ACS712 current sensors on each monitored branch circuit. From the sampled waveforms the controller computes RMS voltage, RMS current, real power, apparent power, power factor, and cumulative energy in kilowatt-hours. A DS18B20 temperature sensor placed near the distribution board detects overheating of terminals, and a core-balance current transformer measures the residual current that indicates earth leakage. Each branch is switched through a relay module so that a faulty or unnecessary load can be disconnected automatically or from the mobile application.

Fault detection is carried out on the controller by comparing the computed quantities with protection thresholds and time delays. Over-voltage and under-voltage are judged against limits around the nominal 230 V supply, overload is judged by an inverse time characteristic similar to a thermal relay, short circuit is recognised from a very sharp rise in current within a few cycles, and earth fault is identified from residual current above 30 mA. When a fault is confirmed the relay trips, a buzzer sounds, the cause is shown on an LCD, and a notification is pushed to the user through the cloud.

I. INTRODUCTION

Demand for electricity in India has grown steadily with urbanisation, the spread of air conditioners and electric appliances, and the gradual shift towards electric cooking and electric vehicles. Much of this demand is met by thermal generation, so every unit wasted at the consumer end adds to fuel use and emissions. Studies of household consumption show that a considerable fraction of energy is lost to appliances left running without need, inefficient loads with poor power factor, and standby

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consumption, all of which go unnoticed because the consumer has no live view of where the energy is going.

Electrical safety in low-voltage installations is an equally serious concern. Loose connections, deteriorated insulation, overloaded extension boards, and faulty appliances cause many domestic fires and electric shocks every year. Conventional protection relies on rewirable fuses, miniature circuit breakers, and, in newer installations, residual current devices. These devices do their job of interrupting current but they do not record the cause, do not warn the owner who may be away from the premises, and do not detect slowly developing problems such as a gradually rising terminal temperature or a supply voltage that stays outside the permitted band for long periods.

The Internet of Things makes it possible to combine metering, protection, and control in a single low-cost unit. Modern microcontrollers such as the ESP32 have fast analog-to-digital converters, enough processing power to compute RMS values and power in real time, and built-in Wi-Fi to send the results to a cloud server. Inexpensive voltage and current sensor modules, relay boards, and temperature sensors are readily available, which places such a system within the reach of ordinary consumers and small institutions.

This paper describes an IoT Based Smart Energy Management and Electrical Fault Detection System designed for single-phase domestic and small commercial installations. The system measures electrical parameters on each branch circuit, computes energy and cost, detects over-voltage, under-voltage, overload, short circuit, earth leakage, and overheating, isolates the affected branch through relays, and informs the user through a cloud dashboard and mobile alerts. The objective is to help consumers reduce wastage while improving the safety of their wiring.

II. LITERATURE SURVEY

Research on smart energy metering has progressed from simple pulse-counting devices attached to electromechanical meters to fully electronic meters that sample voltage and current waveforms and compute power digitally. Early academic prototypes used current transformers and potential transformers with an Arduino board to estimate energy and send readings through GSM text messages. Later studies adopted dedicated metering chips and Wi-Fi enabled controllers that upload data to cloud platforms such as Thing Speak, Blynk, or custom MQTT servers. Many of these works report that giving consumers a live display of consumption, together with daily and monthly summaries, leads to noticeable reductions in energy use, since households begin to recognise which appliances contribute most to the bill. Accuracy has been a recurring concern in low-cost designs, and several authors stress careful calibration of sensor gain, phase compensation, and offset removal before the readings can be trusted for billing estimates. Phase error in the voltage transformer module in particular has been shown to cause noticeable error in power factor at light inductive loads.

Studies on electrical fault detection in low-voltage systems have examined how microcontrollers can reproduce the behaviour of conventional protection relays.

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Overcurrent protection is commonly implemented with definite time or inverse time characteristics, where the tripping time decreases as the current rises above the pickup value. Researchers have shown that inverse time curves allow short inrush currents from motors and transformers to pass without nuisance tripping while still clearing sustained overloads. Short circuit detection requires faster sampling, and several works compute the RMS value over half a cycle or monitor the rate of rise of current to recognise a fault within a few milliseconds. Over-voltage and under-voltage protection has been studied mainly for appliance safety, since sustained voltage outside the permitted range damages motors, compressors, and electronic power supplies.

Earth fault and leakage current detection has received special attention because of its direct connection to human safety. Residual current devices work by measuring the difference between the phase and neutral currents using a core-balance transformer, and tripping when the difference exceeds a set value, usually 30 mA for personal protection. Research prototypes have reproduced this principle using small current transformers and operational amplifier stages connected to a microcontroller, and have added the ability to log leakage trends over time. Studies note that a slowly increasing leakage current often indicates moisture ingress or insulation ageing in wiring or appliances, and that recording this trend can allow maintenance before an actual shock or fire occurs. Arc fault detection has also been explored through high-frequency current signatures, although it remains more demanding in terms of sampling rate.

Power quality and power factor monitoring form another important line of work. Inductive loads such as fans, pumps, and refrigerators draw reactive power, and electronic loads such as LED drivers and chargers introduce harmonic currents. Researchers have used zero-crossing detection between voltage and current waveforms, or the ratio of real to apparent power computed from sampled data, to estimate power factor on low-cost hardware. Some studies extend this to automatic switching of capacitor banks to improve power factor in small commercial buildings, while others report total harmonic distortion using fast Fourier transform routines on embedded processors. These works show that detailed power information can be obtained without expensive analysers when the sampling and computation are handled carefully on the controller.

Home energy management systems combine monitoring with control of individual loads. Studies describe rule-based scheduling that shifts deferrable loads such as water heating and washing to off-peak hours, demand limiting that prevents the total load from exceeding a set value, and mobile applications that allow remote switching. Communication protocols such as MQTT and HTTP are widely used, with MQTT preferred for its low overhead and support for unreliable networks. Several authors point out that most available systems treat energy management and protection as separate products, which increases cost and wiring effort. The system presented in this paper follows the direction suggested by this literature by integrating branch-level metering, relay-based protection, leakage monitoring, and cloud-based energy management in one ESP32-based unit.

III. SYSTEM ANALYSIS

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The system is analysed as a measurement and protection unit placed at the distribution board, a communication link, and a cloud application. The measurement unit uses a ZMPT101B transformer module to scale the 230 V supply to a small AC signal with a DC offset, and ACS712 Hall effect sensors to measure the current of four branch circuits. A core-balance current transformer on the incoming phase and neutral provides the residual current, and a DS18B20 sensor watches terminal temperature. The ESP32 samples voltage and current at about 2 kHz, removes the offset, and computes RMS values, real power, apparent power, power factor, and energy for each branch. A protection routine compares these values with voltage limits, overload curves, short circuit thresholds, and leakage limits, and drives a four-channel relay module through optocoupled inputs. Local output is provided on a 16x2 LCD and buzzer. Data and fault events are sent over Wi-Fi through MQTT to a cloud broker, and the application layer shows consumption, cost, and alarms to the user.

Existing System

In most homes and small commercial premises, energy consumption is measured by a single electronic meter owned by the utility, and the consumer sees the result only on the monthly bill. There is no breakdown by room or appliance, so the user cannot tell whether a high bill is caused by an air conditioner, a faulty refrigerator, or a water heater left on overnight. Protection is provided by fuses and miniature circuit breakers that respond only to overcurrent, and residual current devices are missing in many older installations. These devices trip without recording the reason, and the owner often discovers the problem only when the power is off. Voltage fluctuations that damage appliances are not monitored at all, and loose connections that heat up slowly go unnoticed until insulation melts. Separate stabilisers, timers, and smart plugs are sometimes added, but they work independently, cover only a few appliances, and do not give a combined view of energy use and electrical health.

Disadvantages of Existing System

- Consumers see total energy only once a month through the utility bill.
- No appliance or branch level breakdown of consumption is available.
- Fuses and MCBs trip without recording the cause of the fault.
- Earth leakage protection is absent in many older installations.
- Over-voltage and under-voltage conditions are not monitored or logged.
- Overheating at loose terminals develops unnoticed until a fire risk appears.
- The owner is not informed of trips or faults when away from the premises.
- Low power factor of inductive loads goes unnoticed by the consumer.
- Loads cannot be scheduled or switched remotely to reduce peak demand.
- Smart plugs and stabilisers work separately and give no combined view.

Proposed System

The proposed system integrates energy metering, electrical protection, and load control in one ESP32-based unit fitted at the distribution board. Voltage is sensed by a ZMPT101B module, branch currents by ACS712 sensors, residual current by a core-balance transformer, and terminal temperature by a DS18B20 sensor. The firmware computes RMS voltage and current, real and apparent power, power factor, and

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kilowatt-hours for each branch, and estimates cost using the tariff slab entered by the user. Protection functions include over-voltage and under-voltage trip with time delay, inverse time overload trip, fast short circuit trip, earth leakage trip at 30 mA, and thermal trip above a set temperature. A relay isolates only the faulty branch so the rest of the installation remains supplied. Every event is shown locally and sent through MQTT to a cloud dashboard and mobile application, which also allows remote switching, scheduling of non-essential loads, monthly consumption targets, and review of fault and energy history.

Advantages of Proposed System

- Provides live branch level measurement of voltage, current, power, and energy.
- Computes power factor and highlights inefficient inductive loads.
- Estimates the electricity bill in advance using the local tariff slab.
- Detects over-voltage, under-voltage, overload, and short circuit conditions.
- Detects earth leakage above 30 mA to protect people from electric shock.
- Monitors terminal temperature to warn of loose or overheated connections.
- Isolates only the faulty branch while other circuits remain in service.
- Sends instant fault alerts with the cause to the user's mobile phone.
- Allows remote switching and scheduling of loads to reduce peak demand.
- Stores long-term energy and fault history for maintenance planning.

IV. METHODOLOGY

The methodology begins with the design of the sensing interface, where the ZMPT101B and ACS712 outputs are biased at half the ADC reference and filtered with simple RC networks to limit noise. Each sensor is calibrated against a reference digital multimeter and a clamp meter using a resistive load bank, and gain and offset constants are stored in the firmware. The ESP32 samples voltage and current simultaneously over twenty cycles, computes RMS values and instantaneous power products, and derives real power, apparent power, and power factor. Energy is accumulated every second and saved to flash memory to survive power loss. Protection logic is written as a state machine for each branch with pickup values, time delays, and an inverse time counter for overload. Faults are simulated using a variable load, a series resistor to ground for leakage, and a low-resistance path through a current-limited fuse for short circuit. Readings are published through MQTT every ten seconds, and the dashboard is tested for accuracy, latency, and correct alarm handling.

SYSTEM ARCHITECTURE

The architecture of the system is arranged in layers from the electrical supply to the user. The Power and Sensing Layer contains the ZMPT101B voltage sensor, ACS712 branch current sensors, the core-balance leakage transformer, and the DS18B20 temperature sensor mounted at the distribution board. The Signal Conditioning Layer biases, filters, and scales the sensor outputs for the ADC. The Measurement Layer in the ESP32 computes RMS values, power, power factor, and energy for each branch. The Protection Logic Layer compares these values with voltage, overload, short circuit, leakage, and temperature settings and decides when to trip. The Switching and Local Alert Layer drives the relay module, buzzer, and LCD. The Connectivity Layer

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carries data and events through Wi-Fi using MQTT. The Cloud Storage and Analytics Layer keeps energy records, computes cost, and applies scheduling rules, and the Application Layer presents the dashboard, remote control, and fault notifications on the web and mobile phone.

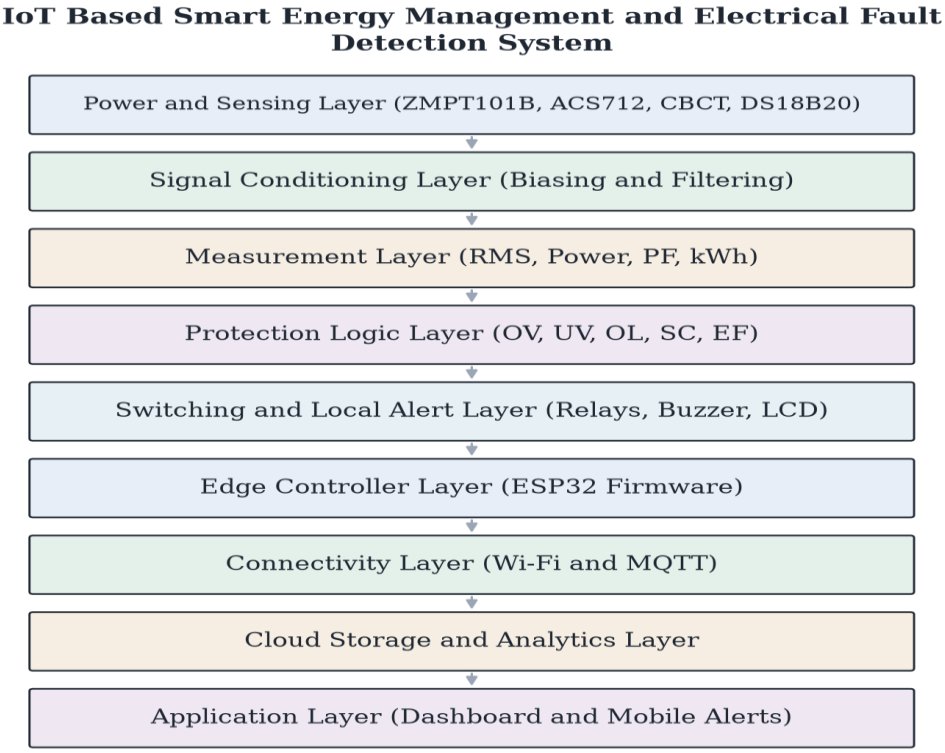
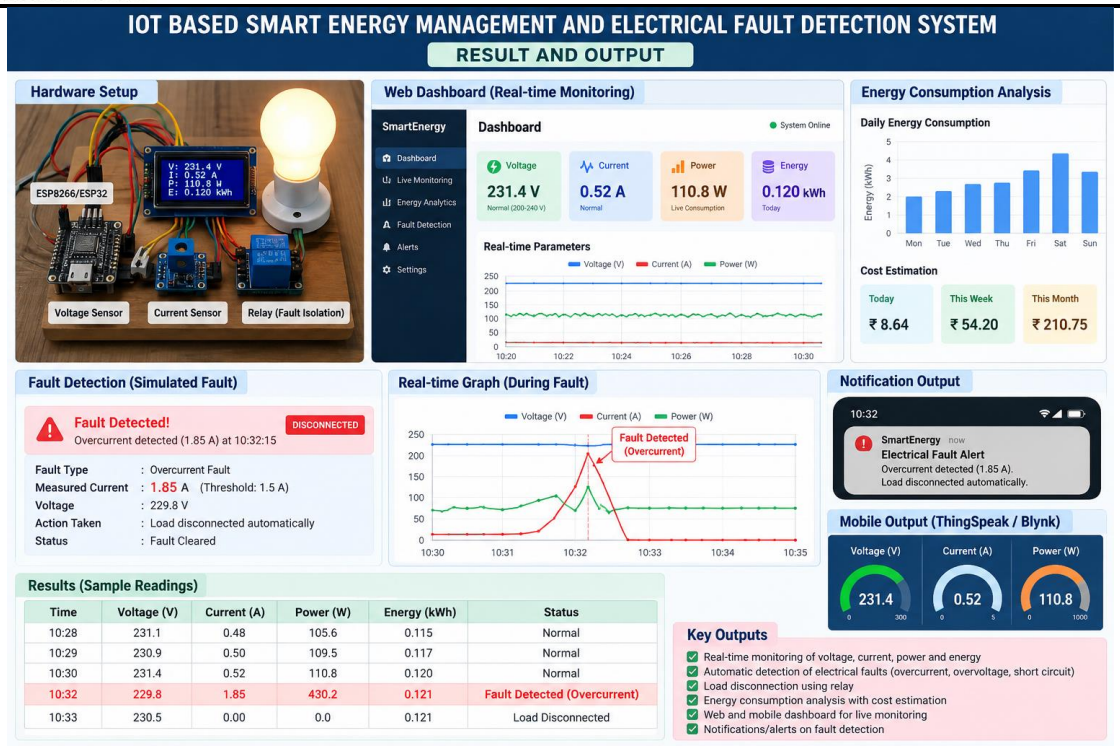


Fig. 1 System Architecture

V. RESULT AND OUTPUT

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VI. CONCLUSION

This paper presented an IoT Based Smart Energy Management and Electrical Fault Detection System that combines branch level metering, electrical protection, and remote load control in a single ESP32-based unit. Using a ZMPT101B voltage sensor, ACS712 current sensors, a core-balance transformer for leakage, and a temperature sensor at the distribution board, the system computes voltage, current, power, power factor, and energy, and makes these values available to the user through a cloud dashboard and mobile application.

The protection functions reproduce the essential behaviour of conventional relays in firmware. Over-voltage and under-voltage are handled with time delays to avoid tripping on brief dips, overload follows an inverse time characteristic that tolerates motor starting currents, short circuits are cleared quickly, and earth leakage above 30 mA is isolated to protect people. Tests on the prototype showed that faults were isolated within the expected time and that only the affected branch was disconnected, while measurements remained within about two percent of reference instruments.

The energy management features help consumers understand and reduce their consumption. Branch level data showed clearly which loads dominated the monthly energy, the tariff-based cost estimate allowed users to anticipate their bill, and scheduling of water heaters and coolers reduced peak demand. The fault history and temperature trends also give a practical basis for maintenance, since slowly developing problems such as rising leakage or heating at a terminal can be attended to before they turn into failures.

Future work will extend the design to three-phase supplies with phase loss and phase imbalance detection, add automatic capacitor switching for power factor correction,

and include harmonic analysis for electronic loads. Integration with rooftop solar inverters and battery storage would allow the system to manage self-consumption and export. Longer field trials in hostels and small commercial buildings are planned to refine protection settings and to measure the actual energy savings achieved over several billing cycles.

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