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Single Phase Smart Energy Meter

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Abstract: The IoT-Based Single Phase Smart Energy Meter is developed for real-time monitoring and control of residential electrical energy usage. The proposed system employs an ESP32 microcontroller along with sensing modules to measure important electrical parameters including voltage, current, power, and energy consumption.The collected information is displayed on an LCD screen and can also be accessed remotely through Wi-Fi and GSM communication. The smart meter has some useful features such as real time monitoring, overloaded protection, prepaid billing, SMS alerts and remote load control. If there are abnormal conditions like over voltage, under voltage, overload or insufficient prepaid balance, the relay and contactor mechanism will automatically disconnect the power supply. The system also includes a wireless dashboard for simple monitoring and control. This project is a low cost, user-friendly, accurate and suitable for modern residential energy management systems. Users can reduce electricity waste, improve safety and better manage energy consumption.

Keywords: *ESP32, IoT, GSM, Real-Time Monitoring, Smart Energy Meter, Energy Management.*

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I. INTRODUCTION

Electricity is one of the most important ingredients of daily life. With the increasing usage of electrical appliances, the need for proper monitoring and management of electricity consumption has also increased. Conventional energy meters only measure the total energy consumption and require manual meter reading which may lead to human errors and delayed billing.

To overcome these problems smart energy meters are being developed with the help of modern technologies like IoT (Internet of Things), wireless communication and microcontrollers. A smart energy meter can monitor electrical parameters in real time and can automatically send data without manual intervention.

In this project a Single Phase Smart Energy Meter is developed using ESP32 microcontroller, voltage sensor, current sensor, GSM module, relay module and LCD display. The system is continuously measuring electrical parameters including voltage, current, power, and energy usage. The measured information is presented locally on the LCD and can be remotely monitored via a web dashboard and SMS communication.

The proposed system also incorporates advanced electrical protection features such as overcurrent protection, high-voltage protection, low-voltage protection, prepaid billing, and automatic power disconnection. These features help improve electrical safety and reduce electricity wastage. The proposed smart energy meter is affordable, efficient, and suitable for residential applications. It helps users monitor their electricity usage, control loads remotely, and make better decisions for energy saving.

II. LITERATURE REVIEW

Many researchers have worked on improving traditional electricity meters by introducing smart monitoring and

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wireless communication technologies. Conventional meters required manual reading, which was time-consuming and less efficient. Smart energy meters solve these problems by providing automatic monitoring, remote access, and real-time data transmission.

➢ *Sinha, D., & Verma, S. (2019)*

- Title: Smart Meter with Remote Load Control Using IoT
- Journal: International Journal of Smart Grid Applications

This study introduced a smart meter system with remote load control using IoT technology. The ESP32 microcontroller was used to transmit electrical data to an online platform, while a relay module controlled electrical loads remotely. The system improved user safety and supported prepaid energy management.

➢ *Raut, P., &Deshmukh, T. (2020)*

- Title: Wi-Fi Based Smart Meter for Domestic Power Monitoring
- Journal: IRJET

This research focused on a Wi-Fi-enabled smart meter using ESP32 for domestic energy monitoring. The system stored and monitored energy data continuously and helped users analyze their electricity consumption patterns for better power management.

➢ *Ahmed, M., et al. (2021)*

- Title: Digital Energy Meter with Automated Billing Using ESP32
- Journal: IEEE Access

The researchers developed a digital energy meter with automated billing features. The ESP32 calculated electrical parameters and transmitted data to a utility server. The system improved billing accuracy and increased transparency in energy usage.

➢ *Deshpande, R., & Kale, S. (2020)*

- Title: Development of ESP32-Based Prepaid Smart Energy Meter
- Journal: International Journal of Electrical Automation

This paper presented a prepaid smart energy meter using ESP32 and relay control. The system automatically disconnected the power supply when the prepaid balance was exhausted and sent recharge notifications to the user.

➢ *Objectives*

- To design and implement an IoT-based smart energy meter for real-time electrical energy monitoring.
- To accurately measure electrical parameters such as voltage, current, power, and energy consumption using sensing modules.
- To provide wireless monitoring using Wi-Fi and GSM communication technology.
- To implement prepaid billing and automatic power cutoff features.
- To provide overcurrent, high-voltage, and low-voltage protection.
- To reduce electricity wastage and improve energy efficiency.
- To enable remote load control using SMS commands and a web dashboard.

III. MATERIALS SELECTION

➢ *Main Components & Selection Reason:*

- *Microcontroller:*

✓ ESP32 Dev Module: We chose ESP32 because it has two cores, built-in WiFi and Bluetooth and more ADC pins than Arduino. It is also very affordable. Can handle both WiFi and GSM.

- *Voltage Sensor:*

✓ PZEM004T Module: This sensor is very accurate. Has an isolated output, which is safer than using a resistor divider for 230V mains. It can also measure up to 250V AC.

- *Current Sensor:*

✓ SCT-013-030 CT Sensor:We picked this sensor because it is non-invasive and does not require breaking the wire. It can measure up to 30A which covers home loads and provides isolation.

- *Display:*

✓ 16x2 LCD with I2C: We chose this display because it uses I2C, which needs two pins saving ESP32 pins. It also uses power.

- *GSM Module:*

✓ GSM A7670C Module : This GSM module is very cheap. Works with any SIM. It supports both SMS and GPRS. Has a small size. It can work with Li-ion batteries.

- *Relay Module:*

✓ 5V 4-Channel Relay: This relay module is opto-isolated. Can switch 10A loads. It has four channels, which allows us to control appliances separately.

- *Contactor:*

✓ 25A 230V AC Contactor: We used this contactor for supply cutoff. Relays cannot handle house loads so we used this for overload and tamper protection.

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- *Power Supply:*

✓ 5V, 2A AC Adapter: This power supply is. Converts 230V AC to 5V DC. It is safe and powers ESP32, sensors and LCD.

➢ *Supporting Materials*

- PCB/Zero PCB:We used PCB for safe connections instead of breadboard.
- Enclosure:ABS plastic box: This enclosure is. Protects from shock.
- Wires:1.5 sq.mm for loads, jumper wires for signals. We used color-coded wires.
- CT Burden Resistor: 33Ω built-in for SCT-013. This resistor converts current to voltage for ESP32 ADC.

➢ *Selection Criteria*

We selected components based on their cost-effectiveness, availability, safety for 230V AC measurement, power consumption and compatibility with ESP32. We preferred -invasivesensors to ensure electrical isolation and user safety.

➢ *Flow Chart*

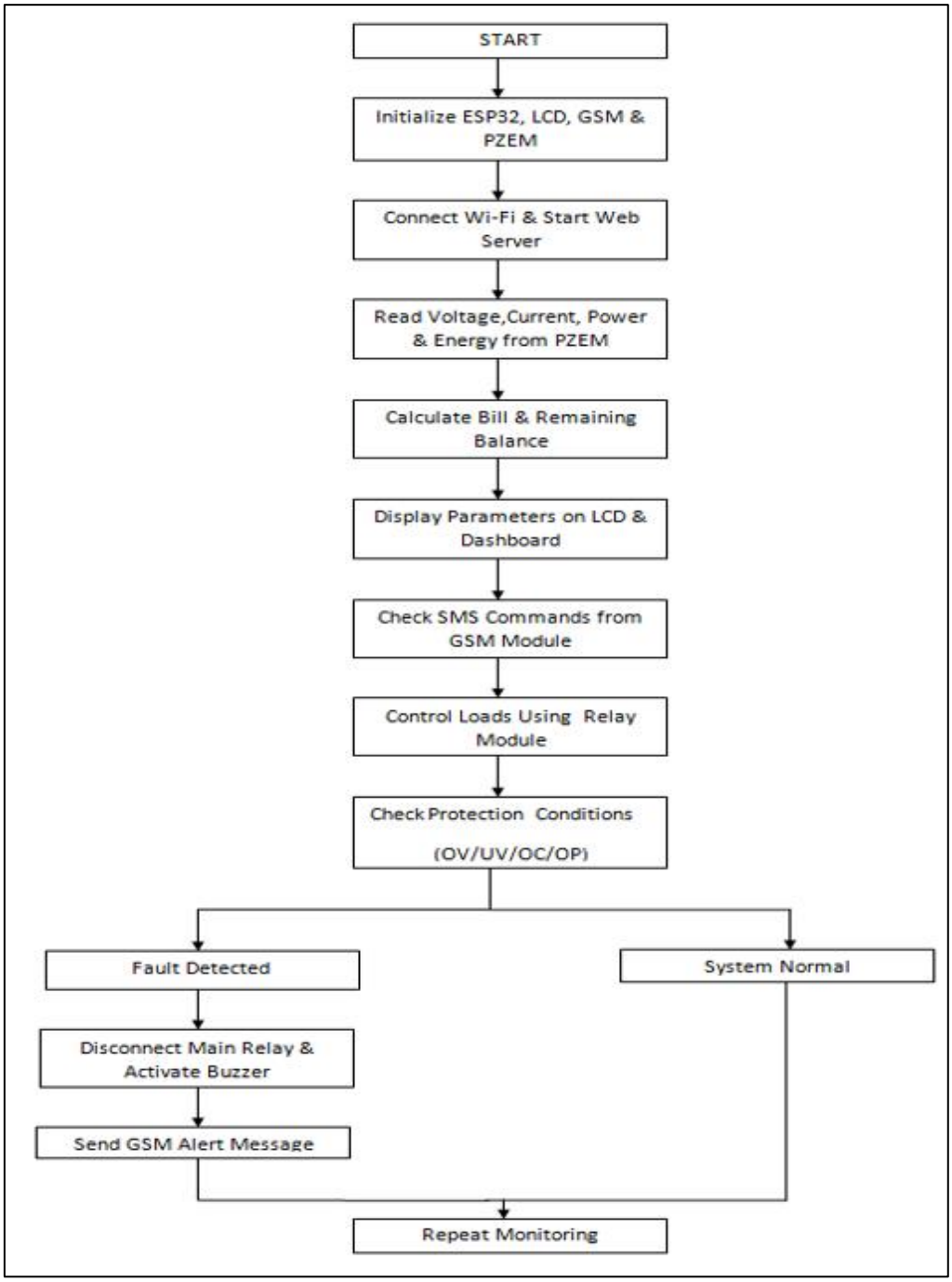

Fig 1 Flow Chart

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➢ *Circuit Diagram*

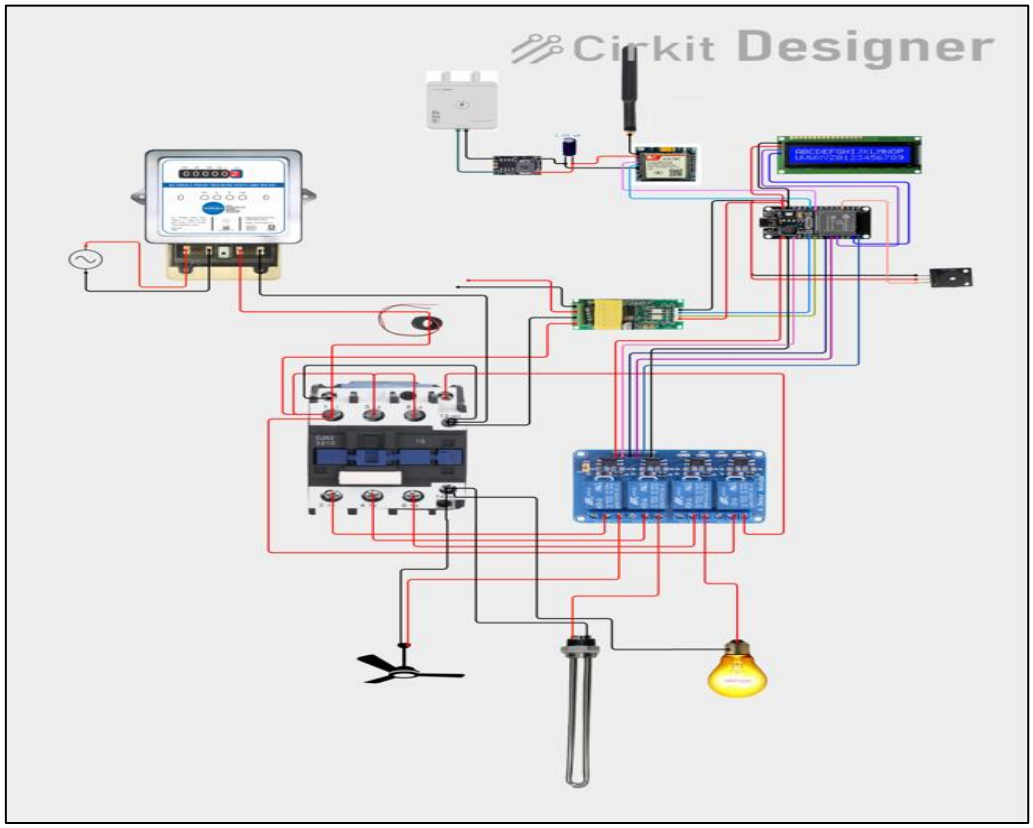

Fig 2 Circuit Diagram

➢ *Block Diagram*

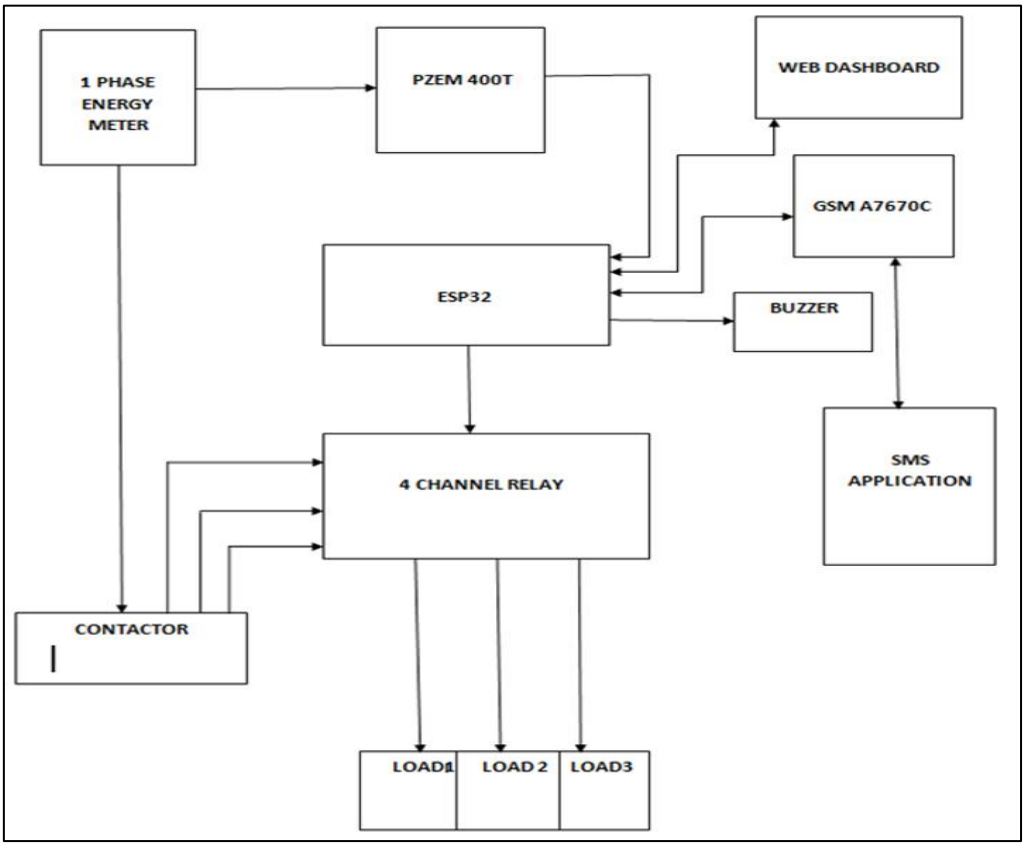

Fig 3 Block Diagram

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IV. COMPONENTS USED IN OUR PROJECT

- Relay module: In our project we are using SRD-05VDC-SL-C relay. As it is an electronic switching device which are used totrigger after deducting signals.
- Current sensor (CT):It is a sensing device that tells you how much current is flowing in a wire or conductor. It also detects overcurrent, short circuits which can cause damage.
- Voltage sensor: It is also a sensing device which helps you to detect, monitor low power voltage in your supply. It also work as a safety device.
- Micro-controller (ESP32):4. Microcontroller (ESP32): The ESP32 is the main controlling unit of the proposed system. It is a low-cost and low-power microcontroller integrated with built-in Wi-Fi and Bluetooth features, enabling wireless communication, real-time monitoring, and smart control operations.
- LCD (16*2):(Liquid crystal display):It is used in our project by displaying real time data of voltage and current sensors.
- GSM (A7670C): It works as a mobile, phones but without keypad and screen. In our project it is used to send SMS when the voltage is high.
- Energy meter : its just a device which is used to count how much electricity we used .

- *Hardware Testing*

Fig 4 Hardware Testing

V. RESULT AND DISCUSSION

The hardware prototype of Smart Energy Meterproject was assembled as per the circuit diagram. Tested with standard domestic loads for our Smart Energy Meterproject. All components functioned as intended for our Smart Energy Meter project.

- System Functionality: 1. All hardware modules operated successfully according to the designed circuit and embedded program implemented in the ESP32 microcontroller. The proposed IoT-Based Single Phase Smart Energy Meter with GSM Enabled Prepaid Billing and Protection System accurately monitored electrical energy consumption, displayed real-time data on the LCD display, and transmitted information through GSM communication without requiring manual intervention.
- Accuracy: Readings from the prototype for our Smart Energy Meter project were compared with an energy meter. Error was found to be <2%, which is within acceptable limits for domestic applications for our Smart Energy Meter project.
- Communication: The GSM module reliably sent SMS alerts for bill. Overload conditions within 3-5 seconds for our Smart Energy Meter project. TheLCD also indicated alerts for our Smart Energy Meter project.
- Load Control: The relay and contactor mechanism effectively isolated loads during overload for our Smart Energy Meter_ project preventing damage. This adds a safety feature absent in meters for our Smart Energy Meter project.
- Cost Effectiveness: The Smart Energy Meter project was implemented using cost, easily available components like ESP32, PZEM004T, A7670C GSM.
- Limitations:The A7670C module relies on 3g and 4g networks, which are being phased out for our Smart Energy Meter project.

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➢ *Advantages*

- Real-time energy monitoring.
- Accurate digital billing.
- Wireless monitoring through Wi-Fi and GSM.
- Remote load control.
- Overvoltage and overload protection.
- Automatic prepaid billing system.
- Reduced electricity wastage.
- Improved electrical safety.
- Low-cost implementation.
- Easy to operate and maintain.

➢ *Future Scope*

- Development of a dedicated mobile application.
- Cloud-based data storage and analytics.
- AI-based energy prediction system.
- Smart home automation integration.
- Solar energy monitoring support.
- Three-phase smart energy meter development.

VI. CONCLUSION

The proposed IoT-Based Single Phase Smart Energy Meter with GSM Enabled Prepaid Billing and Protection System was successfully designed and implemented using an ESP32 microcontroller, PZEM-004T sensor module, GSM module, relay control unit, and IoT communication technology. The system is capable of continuously monitoring important electrical parameters such as voltage, current, power, and energy consumption in real time.The developed system also incorporates advanced protection mechanisms including overcurrent protection, high-voltage protection, low-voltage protection, prepaid billing, and automatic power disconnection during abnormal conditions. Wireless monitoring through Wi-Fi and GSM communication enhances user accessibility, remote monitoring, and efficient energy management. Experimental testing demonstrated that the proposed system operates reliably and accurately for residential energy monitoring applications. The project provides a low-cost, efficient, and user-friendly solution for smart energy management. The implementation of IoT technology in the proposed system contributes toward improved electrical safety, reduced energy wastage, and modern smart home automation.

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