**1. Project Overview and Objectives**

* **Aim**: The project focuses on developing an Internet of Things (IoT)-based smart energy meter to track and manage energy consumption in real time, helping users make informed decisions toward energy conservation.
* **Key Components**:
  + **ESP32 Microcontroller**: Serves as the central processor for gathering data from various sensors and facilitating data transmission.
  + **Sensors**: Includes ZMPT101B voltage sensor for voltage measurement and SCT103 Hall effect sensor for current measurement.
  + **LCD Display**: Displays energy data in real time to provide immediate visual feedback to users.
  + **ThingSpeak Platform**: Facilitates remote data monitoring, storage, and visualization, allowing users to access and analyze their energy usage from any location.

**2. Introduction and Background**

* **Growing Need**: Increasing energy demands and urbanization have underscored the importance of effective energy management solutions. Smart energy meters provide insights into usage patterns, which can help reduce unexpected costs and promote sustainability.
* **Challenges**: Traditional meters lack real-time data feedback and require manual data collection, which is prone to errors and inefficiencies.
* **Solution**: By utilizing the ESP32 microcontroller, Hall effect, and voltage sensors with ThingSpeak, this project aims to overcome these limitations by enabling real-time data access, visualization, and control.

**3. Theory and Methodology**

* **Smart Metering Advantages**:
  + **Real-time Monitoring**: Enables continuous tracking of energy consumption for more responsive energy management.
  + **Enhanced Consumer and Utility Control**: Provides utilities and consumers with detailed insights, enabling better regulation of power distribution.
  + **Applications in Billing**: Smart meters streamline bill generation, simplify recharging for pre-paid services, and reduce billing discrepancies.
* **Applications for Resource Conservation**:
  + Helps users monitor energy usage trends and adjust behaviors to reduce consumption and cost.
  + Supports utilities in better resource allocation, reducing environmental impact by minimizing unnecessary energy use.
* **ThingSpeak Integration**: ThingSpeak serves as the cloud-based platform that stores and analyzes the data, offering remote access and visual representation of energy usage.

**4. Hardware Description**

* **ESP32 Microcontroller**:
  + Acts as the system's brain, coordinating data collection and transmission. It has built-in Wi-Fi, allowing seamless data transmission to ThingSpeak.
* **Sensors**:
  + **SCT103 Hall Effect Sensor**: Measures current by detecting magnetic fields, providing current data necessary for power calculation.
  + **ZMPT101B Voltage Sensor**: Measures line voltage, essential for accurate calculation of power consumption.
* **16x2 LCD Display**: Uses I2C communication protocol for efficient data display, presenting voltage, current, and energy usage metrics in real-time.
* **Data Preprocessing and Calculation**:
  + Preprocessing ensures compatibility with the Arduino’s input range.
  + Key calculations include power in kilowatts, energy units, and cost in currency (Rupees) based on predefined rates.

**5. Software Functionality and ThingSpeak Integration**

* **Data Collection and Transmission**:
  + The ESP32 collects voltage and current data, which are processed to calculate power and energy usage.
  + Processed data is displayed on the LCD screen and periodically sent to ThingSpeak for remote monitoring and analysis.
* **ThingSpeak Platform**:
  + Offers real-time data visualization and user control over energy pricing.
  + Provides cost estimation by applying user-defined unit rates, allowing for flexible simulation of different pricing scenarios.
  + Graphical representation of data (voltage, current, power consumption) enhances user understanding of consumption trends.
  + **Adjustable Pricing Feature**: Users can simulate fluctuating utility rates by modifying the cost per unit within ThingSpeak, allowing a personalized analysis of how price changes affect expenses.

**6. Working Mechanism**

* **Data Flow**:
  + Sensors continuously monitor voltage and current, sending data to the ESP32.
  + ESP32 processes the data, calculates the power, energy, and cost, then displays these metrics on the LCD.
* **Power and Cost Calculations**:
  + **Power Calculation**: Power (kW)=Voltage×Current1000\text{Power (kW)} = \frac{\text{Voltage} \times \text{Current}}{1000}Power (kW)=1000Voltage×Current​
  + **Energy Units**: Units=Power×33600\text{Units} = \text{Power} \times \frac{3}{3600}Units=Power×36003​
  + **Cost in Rupees**: Cost=Units×6.77\text{Cost} = \text{Units} \times 6.77Cost=Units×6.77
* **Data Transmission to ThingSpeak**:
  + Data is continuously transmitted to ThingSpeak via Wi-Fi, enabling remote monitoring.
  + ThingSpeak performs additional analysis, presenting data as graphs for pattern recognition and anomaly detection.
  + **Graphical Analysis**: Charts visualize trends in power, voltage, and current, helping identify high-consumption periods and enabling proactive energy-saving measures.

**7. Results**

* **Data Visualization on ThingSpeak**:
  + The ThingSpeak platform provides users with access to detailed graphs and tables for voltage, current, power, and cost data. These visualizations offer insights into peak usage times and consumption trends.
  + The LCD display provides immediate, on-site feedback, while ThingSpeak supports remote, in-depth analysis.
* **User Insights**:
  + Users can monitor their energy consumption and understand how usage patterns impact costs. By simulating different rates, they can adjust their habits to optimize savings.
* **System Efficiency**:
  + The integrated components effectively monitor energy in real-time, enabling better management and awareness of power usage. This setup empowers users to adopt more sustainable energy practices.

**8. Conclusion and Future Scope**

* **Summary of Contributions**:
  + The smart energy meter provides immediate and remote access to energy data, fostering sustainable energy consumption habits through real-time monitoring and analysis.
  + **Cost Awareness**: The customizable pricing feature empowers users to assess the impact of energy costs dynamically.
* **Future Enhancements**:
  + **Intelligent Alerts**: Adding notifications to alert users when consumption surpasses predefined limits, encouraging timely action to reduce wastage.
  + **Integration with Renewable Sources**: Incorporating renewable energy options, such as solar, to further optimize energy management.
  + **Predictive Analytics**: Developing algorithms to forecast usage patterns, helping users proactively adjust to expected consumption levels.
  + **Enhanced User Interface**: Improving the user interface on ThingSpeak for better accessibility and interaction, making energy data more actionable for consumers.
* **Long-Term Vision**: Smart energy meters hold potential for creating environmentally friendly, resource-efficient communities by promoting awareness and responsible energy use. Their continued evolution is likely to support a more sustainable future in both residential and commercial spaces.