Abstract

This Project Aims To Develop An Iot-Based Smart Energy Meter Capable Of Measuring And Monitoring Real-Time Electricity Consumption Using Wireless Communication. The System Is Built Using An Esp32 Microcontroller, Integrated With An Acs712 Current Sensor And A Voltage Sensor To Calculate Power Consumption Accurately. The Collected Data Is Processed And Transmitted Over Wi-Fi To A Cloud Server, Allowing Users To Access Energy Usage Data Remotely Through A Web Or Mobile Application. The System Reduces The Dependency On Manual Meter Readings By Automating The Data Collection Process And Providing Live Updates On Power Usage. It Enables Users To Monitor Daily, Weekly, And Monthly Energy Consumption Trends, Receive Alerts On Unusual Usage Patterns Or Overload Conditions, And Better Understand Their Power Usage Behavior. The Smart Meter Promotes Energy Efficiency By Encouraging Consumers To Reduce Unnecessary Consumption And Contributes To Lowering Electricity Bills. It Also Assists Utility Providers In Detecting Power Theft, Managing Demand, And Improving Billing Accuracy. The System Supports Load Monitoring And Can Be Integrated Into Smart Home Or Smart Grid Infrastructures. Its Flexibility And Scalability Make It Suitable For Residential, Commercial, And Industrial Applications. By Using Affordable Components And Open-Source Platforms, The System Offers A Cost-Effective And Practical Solution For Energy Management. This Project Demonstrates How Iot Technology Can Be Effectively Applied To Transform Traditional Energy Metering Systems Into Intelligent, User-Friendly Platforms That Support Sustainable And Efficient Energy Usage, Contributing To The Advancement Of Smart Cities And Modern Energy Infrastructure.

Table Of Contents

1.Introduction

In Today's World, The Demand For Electricity Is Increasing Rapidly Due To The Growing Use Of Electrical And Electronic Appliances In Residential, Commercial, And Industrial Sectors. As A Result, Efficient Energy Management Has Become A Major Concern For Both Consumers And Utility Providers. Traditional Energy Meters Only Measure Cumulative Consumption And Require Manual Reading, Which Is Time-Consuming, Prone To Error, And Lacks Real-Time Monitoring Capabilities.

To Address These Limitations, The Proposed Project Focuses On The Development Of An Iot-Based Smart Energy Meter That Enables Remote, Accurate, And Real-Time Monitoring Of Electricity Usage. By Leveraging The Internet Of Things (Iot), This Smart Meter Allows Users To Access Their Power Consumption Data Through A Web Or Mobile Application From Anywhere At Any Time. It Uses An Esp32 Microcontroller, Which Collects Data From Current And Voltage Sensors, Calculates Power Consumption, And Sends The Information To A Cloud Server Via Wi-Fi.

This System Not Only Empowers Consumers To Track And Manage Their Energy Usage Effectively But Also Helps Utility Companies In Improving Billing Accuracy, Detecting Energy Theft, And Balancing Loads In Smart Grids. It Promotes Energy Conservation By Making Users Aware Of Their Consumption Patterns And Encouraging Them To Adopt Energy-Efficient Practices. Moreover, Its Affordable Design Using Open-Source Hardware And Software Makes It A Viable Solution For Mass Deployment In Smart Homes And Cities.

The Implementation Of An Iot-Based Smart Energy Meter Represents A Significant Step Toward Digital Transformation In Energy Systems, Enhancing Transparency, Convenience, And Sustainability.

2.Literature Survey

1. **Iot Based Smart Energy Meter For Efficient Energy Utilization In Smart Grid (07 March 2019)**

Efficient Energy Utilization Plays A Very Vital Role For The Development Of Smart Grid In Power System. So, Proper Monitoring And Controlling Of Energy Consumption Is A Chief Priority Of The Smart Grid. The Existing Energy Meter System Has Many Problems Associated To It And One Of The Key Problem Is There Is No Full Duplex Communication. To Solve This Problem, A Smart Energy Meter Is Proposed Based On Internet Of Things (Lot). The Proposed Smart Energy Meter Controls And Calculates The Energy Consumption Using Esp 8266 12e, A Wi-Fi Module And Uploads It To The Cloud From Where The Consumer Or Producer Can View The Reading. Therefore, Energy Analyzation By The Consumer Becomes Much Easier And Controllable. This System Also Helps In Detecting Power Theft. Thus, This Smart Meter Helps In Home Automation Using Iot And Enabling Wireless Communication Which Is A Great Step Towards Digital India.

2. **Iot-Enabled Smart Energy Grid: Applications And Challenges March 19, 2021 (Adnan Anwar, Jinho Choi)**

The Internet Of Things (Iot) Is A Rapidly Emerging Field Of Technologies That Delivers Numerous Cutting-Edge Solutions In Various Domains Including The Critical Infrastructures. Thanks To The Iot, The Conventional Power System Network Can Be Transformed Into An Effective And Smarter Energy Grid. In This Article, We Review The Architecture And Functionalities Of Iot-Enabled Smart Energy Grid Systems. Specifically, We Focus On Different Iot Technologies Including Sensing, Communication, Computing Technologies, And Their Standards In Relation To Smart Energy Grid. This Article Also Presents A Comprehensive Overview Of Existing Studies On Iot Applications To The Smart Grid System. Based On Recent Surveys And Literature, We Observe That The Security Vulnerabilities Related To Iot Technologies Have Been Attributed As One Of The Major Concerns Of Iot-Enabled Energy Systems. Therefore, We Review The Existing Threat And Attack Models For Iot-Enabled Energy Systems And Summarize Mitigation Techniques For Those Security Vulnerabilities. Finally, We Highlight How Advanced Technologies (E.G., Blockchain, Machine Learning, And Artificial Intelligence) Can Complement Iot-Enabled Energy Systems To Be More Resilient And Secure And Overcome The Existing Difficulties So That They Become More Effective, Robust, And Reliable In Operation. Precisely, This Article Will Help Understand The Framework For Iot-Enabled Smart Energy System, Associated Security Vulnerabilities, And Prospects Of Advanced Technologies To Improve The Effectiveness Of Smart Energy Systems.

3. **An Iot Based Smart Energy Management System (Jai Krishna Mishra Shreya Goyal Vinay Anand Tikkiwal 29 July 2019)**

Physical Energy Meter Reading Is An Outdated Concept, It Is Inefficient, Prone To Errors And Leads To A Lot Of Wastage Of Manpower And Is A Burden On The Consumers Since The Energy Companies Pass On The Cost Of Physically Reading The Meters To The Consumers. Smart Energy Meters Solve The Above-Mentioned Problems To A Great Extent But Replacing The Older Energy Meters Is A Very Expensive And A Humongous Task. This Paper Introduces An Iot Based Smart Energy Meter Using The Raspberry Pi Devices As A Solution To The Aforementioned Issue. A Small Modification To The Already Installed Old Meters Can Make Them Act As Prepaid Smart Meters. So, The Need To Replace The Old Energy Meter Doesnot Arise. These Meters Can Be Easily Accessed Through Customized Web

4. **Iot-Based Prepaid Smart Metering System For Electricity Theft Detection And Efficient Energy Management (Bheke Aditya Deepak Argade Sourav Anil 1 Jan 2022)**

Electricity Theft Continues To Be A Significant Cause Of Losses For Energy Distribution Companies. This Theft Often Arises From Consumer Practices Such As Bypassing Power Meters And Tampering With Energy Meters. This Study Proposes A Method To Detect And Mitigate Such Activities Using A Smart Energy Metering System.

The System Design Revolves Around Monitoring The Readings Of Current Sensors Using A Programmed Microcontroller. One Sensor Monitors The Current Drawn By The Consumer's Load, While Another Sensor, Placed Before The Energy Meter, Monitors The Total Current Drawn. Any Discrepancy Between The Readings Of These Sensors Indicates Potential Tampering Or Meter Bypassing.

To Further Secure The System, A Tamper-Detection Mechanism Is Implemented Using A Non-Permanent Switch Inside The Meter. This Switch Triggers An Alert When Tampering Is Detected. Additionally, The System Enables Remote Access For Users To Recharge Energy Units And Monitor Their Consumption In Real-Time..

5. **Smart Energy Meter And Monitoring System Using Internet Of Things M.Karpagam Sahana S.S Sivadharini .S**

In Recent Times, The Energy Calibration Methods Are Universally Expanding With The Goal Of Effectuating, Reliably Operating, And Managing The Utility System. The Growing Demand For Power In The Current Environment Has Necessitated The Mandatory Installation Of Energy Meters, As Well As The Development Of New Methods For Calibrating Meter Readings And Governing The Effective Use Of Energy Resources. Amr (Automatic Meter Reading System) Is One Such Modernization.

This Employs Analogue Or Digital Energy Meters With The Assistance Of Smart Meters. Currently, Energy Scaling Is Done By Hand, Which Is A Timeconsuming Process In The World Of Day-To-Day Networking Demand And Also Requires Skilled Labour. The Concept Of Amr Systems Is To Overcome Complexities In The Rapidly Growing Field Of Energy Management. This Article Proposes A Smart Energy Meter Based On Iot To Detect The Power Theft. The Proposed Model Consists Of Arduino Uno, Esp8266, Ac713 Current Sensors, And So On. The Ac713 Senses Current Usage With The Help Of The Esp32, Which Is Then Passed To The Iot Platform. Though Amr Is A Very Effective Method, It Costs The Proxy Of Existing Energy Meters By Sem (Smart Energy Meters), Which Is Highly Inefficient. As A Result, The Proposed Method Focuses On Detecting The Power Theft Caused By Public Tampering. The Proposed Model Is Programmed By Using A Blynk Software And Simulated In Proteus Software. The Proposed System Is Then Validated By Using The Simulated Results.

3.Specifications

Microcontroller: Esp32-Devkit-V1

- Type: Dual-Core, 32-Bit Microcontroller With Integrated Wi-Fi And Bluetooth.
- Operating Voltage: 3.3v (Internally Regulated From 5v Input)
- Clock Speed: Up To 240 Mhz
- Features:
    - Multiple Gpios With Analog And Digital Support
    - Onboard Wi-Fi For Iot Applications
    - Supports Http, Mqtt, Websocket Protocols
    - Ideal For Remote Monitoring And Data Logging

Current Sensor: Acs712 (5a Model)

- Measurement Range:0 A To +5a Ac/Dc
- Sensitivity: 185 Mv/A
- Output: Analog Voltage Corresponding To Current
- Supply Voltage: 5v Dc
- Use: Measures Load Current With Decent Accuracy And Isolation

Voltage Sensor:

- **Design**: Resistor-Based Voltage Divider Scaled To Safely Reduce 230v Ac To 0–3.3v Analog Signal
- **Use**: Measures Input Voltage For Real-Time Monitoring
- **Alternatives**: Zmpt101b Can Also Be Used For Improved Precision And Safety
- **Isolation**: Galvanic Isolation May Be Implemented For Safety (E.G., Opto-Isolators Or Transformers)
-

Power Supply: Hi-Link Hlk-Pm01

- **Input**: 100–240v Ac (Indian Standard 230v Nominal)
- **Output**: +5v Dc (Regulated)
- **Power Rating**: ~3w

- **Features**:
    - Compact Design
    - High Efficiency
    - Short-Circuit And Overvoltage Protection

Wi-Fi Module

- **Type**: Integrated In Esp32
- **Standards Supported**: 802.11 B/G/N
- **Frequency Band**: 2.4 Ghz
- **Use**: Transmits Energy Data To Web Dashboard Or Cloud (Thingspeak, Blynk, Firebase, Etc.)

Communication Protocols

- **Supported**: Http (For Local Webserver), Mqtt (For Cloud Iot Platforms)
- **Use**: Enables Flexible Integration With Various Data Platforms

Display (Optional)

- **Type**: 16x2 Lcd (I2c-Based) Or Oled Display
- **Use**: Shows Real-Time Voltage, Current, Power, And Energy Data Locally
- **Voltage**: Operates On 5v Supply

Pcb (Printed Circuit Board)

- **Layout**: Designed To Minimize Noise And Interference From Ac Signals
- **Features**: Solder Mask, Silk Screen, And Proper Routing For High And Low Voltage Separation

Enclosure

- **Material**: Abs Plastic Or Polycarbonate
- **Design Features**:
    - Lightweight And Durable
    - Electrical Insulation
    - Ventilation Holes For Heat Dissipation

4.Block Diagram & Description

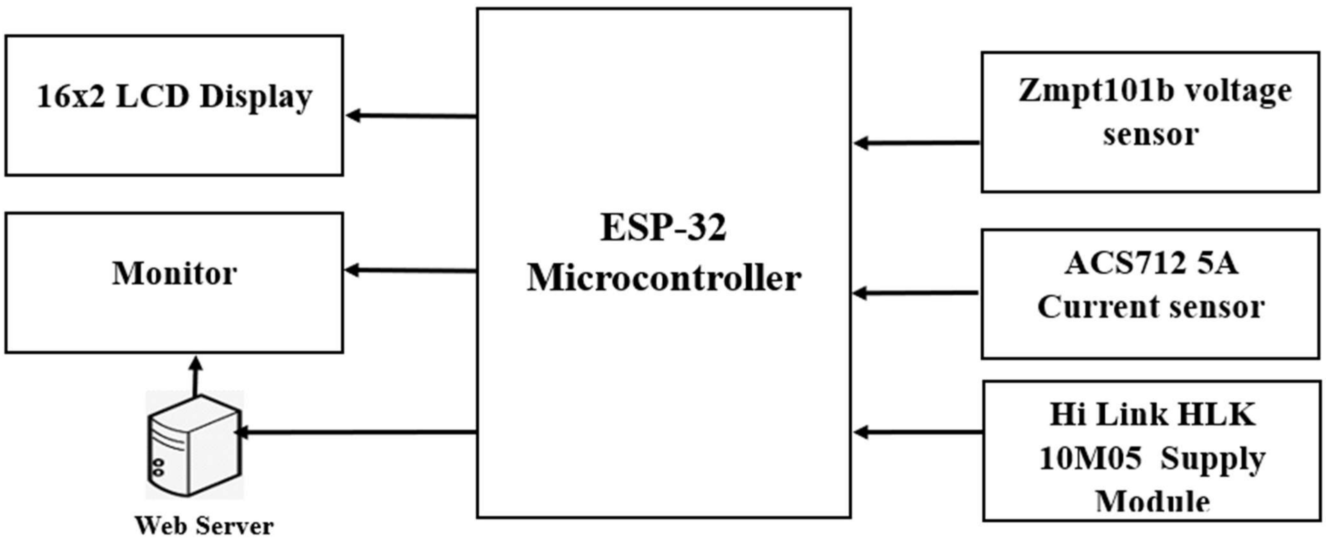


Figure 1: Block Diagram

1. Esp32 Microcontroller

The Esp32 Acts As The Brain Of The Entire System. It Is A Powerful, Low-Cost Microcontroller With Integrated Wi-Fi And Bluetooth, Making It Ideal For Iot-Based Applications. In This Project, The Esp32 Collects Analog Input Data From The Current And Voltage Sensors, Processes This Data Using Programmed Algorithms To Calculate Electrical Parameters Such As Real-Time Voltage, Current, Power, And Energy Consumed. It Also Controls Output Devices Like The Lcd Display And Led Indicators. Additionally, The Esp32 Handles Wireless Communication With The Cloud Platform, Allowing Users To Remotely Access Energy Data Through The Internet. Its Dual-Core Architecture And Built-In Networking Capabilities Provide Efficient, Fast, And Reliable Performance.

2. Zmpt101b Circuit (Ac Voltage Sensor)

The Zmpt101b Is A High-Precision Voltage Sensor Module Designed For Measuring Ac Mains Voltage. It Provides Electrical Isolation And Outputs A Scaled-Down Analog Voltage That Is Proportional To The Actual Ac Input. This Analog Signal Is Sent To The Esp32's Adc (Analog To Digital Converter) Pins For Digital Conversion And Processing. The Zmpt101b Is Preferred For Its Accuracy, Safety, And Ease Of Calibration In Ac Voltage Monitoring Applications

3. Acs712 5a Current Sensor

The Acs712 Is A Hall-Effect-Based Linear Current Sensor That Can Measure Up To ±5a Of Ac Or Dc Current. It Produces An Analog Voltage Output Corresponding To The Current Passing Through It. This Output Is Read By The Esp32 To Determine How Much Current Is Being Drawn By The Connected Electrical Load. The Sensor Offers Electrical Isolation Between The Measurement Circuit And The Load, Enhancing Safety. It Plays A Vital Role In Calculating Power Consumption When Used Along With Voltage Readings

4. Hi-Link Hlk-Pm01 (5v/3w Power Module)

The Hi-Link Hlk-Pm01 Is A Compact And Efficient Ac To Dc Power Converter Module. It Takes A 230v Ac Input And Outputs A Stable 5v Dc, Which Is Used To Power The Esp32 Microcontroller And Other Components In The Circuit. This Module Is Ideal For Embedded Systems Because Of Its Small Size, Low Heat Generation, And Reliable Performance. It Ensures That The System Operates Independently Using Mains Power Without The Need For External Batteries Or Bulky Adapters.

5. 16x2 Lcd Display

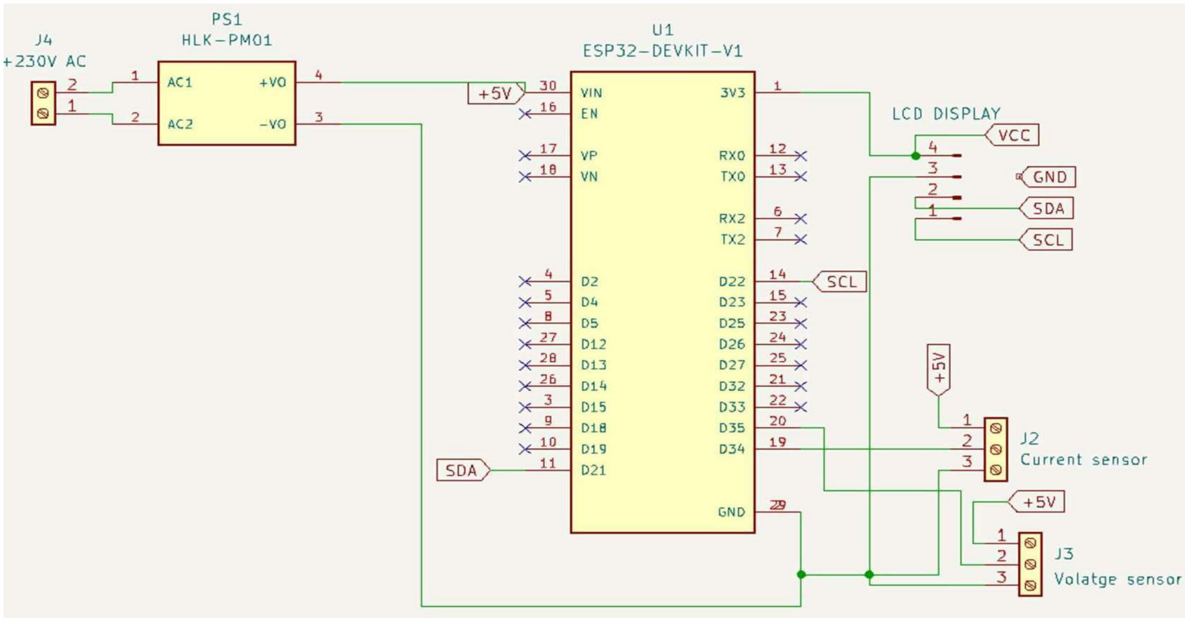
The 16x2 Lcd (Liquid Crystal Display) Module Is Used To Display Real-Time Electrical Parameters Such As Voltage, Current, Power, And Energy Consumption On The Local Device. It Has 2 Rows And 16 Columns For Characters, Allowing Concise And Clear Data Presentation. This Display Allows Users To View Live Energy Readings Without Requiring Internet Connectivity Or External Devices, Offering A User-Friendly Interface For Quick Reference.

7.Web Interface

The Web Interface Represents The Online Dashboard Where Users Can Remotely Monitor And Analyze Energy Consumption Data. Data Collected By The Esp32 Is Sent Via Wi-Fi To A Cloud Platform Such As Thingspeak, Firebase, Or Blynk. From Here, Users Can Access Their Data Through A Browser Or Mobile App. The Interface Can Display Live Readings, Historical Data Charts, Alerts, And Energy Usage Trends, Helping Users Manage Their Electricity Consumption More Efficiently And Make Informed Decisions.

5.Hardware System Design

Figure 2 : Hardware System Schematic Diagram



1. **Component: Hlk-Pm01 (Ac-Dc Converter Module)**

The Hlk-Pm01 Is A Compact And Highly Efficient Ac-Dc Converter Module That Plays A Vital Role In Providing Regulated Power To The Entire System.

• Function:

- Converts High-Voltage 230v Ac Mains Supply Into A Safe And Usable +5v Dc Output.
- Powers The Esp32 Microcontroller, Sensors, And Lcd Display.

• Key Features:

- Compact And Enclosed For Safety
- High Efficiency With Low Heat Generation
- Protection Against Over-Voltage And Over-Current

• Connections:

- Input: 230v Ac (Live And Neutral From Mains)
- Output: +5v Dc (Fed To Esp32 And Other Components)
- Ensures Electrical Isolation And Stability For Low-Voltage Electronics

2. Controller Block

• Component: Esp32-Devkit-V1

The Esp32 Is A Powerful Microcontroller With Built-In Wi-Fi And Bluetooth Capabilities, Making It Ideal For Iot-Based Projects Like A Smart Energy Meter.

Function:

- Acts As The Central Processing Unit Of The System.
- Collects Analog Data From The Current And Voltage Sensors.
- Performs Calculations For Power, Energy, And Cost.
- Displays Data On An Lcd And Transmits Real-Time Values To A Web Dashboard Over Wi-Fi.
  • Key Features:
- Dual-Core Processor For Multitasking
- Multiple Gpios And Adc Channels
- Integrated Wi-Fi And Bluetooth
- Low Power Consumption
  • Key Pins Used:
- Gpio21 (Sda) And Gpio22 (Scl): Used For I2c Communication With The Lcd Display
- Gpio32 (Vp): Connected To The Analog Output Of Sensors (Used For Adc Input)
- 3v3 And Gnd: Power Supply To The Esp32 Board

3. Sensor Block

A. Current Sensor

- Component: Acs712 (Hall-Effect Based Sensor)
- Connector: J2
- Function: Measures The Current Flowing Through The Load
- Working Principle: Uses The Hall-Effect To Measure Current Indirectly Without Contact
  • Connections:
- Vcc → +5v
- Out → Analog Input (Gpio32 On Esp32)
- Gnd → Common Ground

B. Voltage Sensor

- Component: Zmpt101b (Ac Voltage Sensor) Or Custom Voltage Divider Circuit
- Connector: J3
- Function: Measures The Input Ac Voltage
- Working Principle: Reduces Ac Voltage To A Measurable Analog Signal For The Esp32
  • Connections:
- Vcc → +5v
- Out → Analog Input (Can Also Be Connected To Gpio32 Via A Multiplexer Or Separate Pin)
- Gnd → Common Ground

4. Display Block

Component: 16x2 I2c Lcd Display

This Lcd Module Shows Real-Time Readings Like Voltage, Current, Power, And Energy Consumption. I2c Communication Reduces The Number Of Wires Needed From 16 To Just 2.

• Function:

- Provides On-Site Visual Monitoring Of System Output
- Displays System Initialization Status (E.G., “Smart Energy Meter”) And Real-Time Values

  • Connections:

- Sda → Gpio21 (Esp32)
- Scl → Gpio22 (Esp32)
- Vcc → +5v (From Power Supply)
- Gnd → Ground

  • Features:

- Backlit Display For Readability
- Uses I2c Interface (Address Configurable)
- Reduces Wiring Complexity

6.Software System Design

Flow Chart

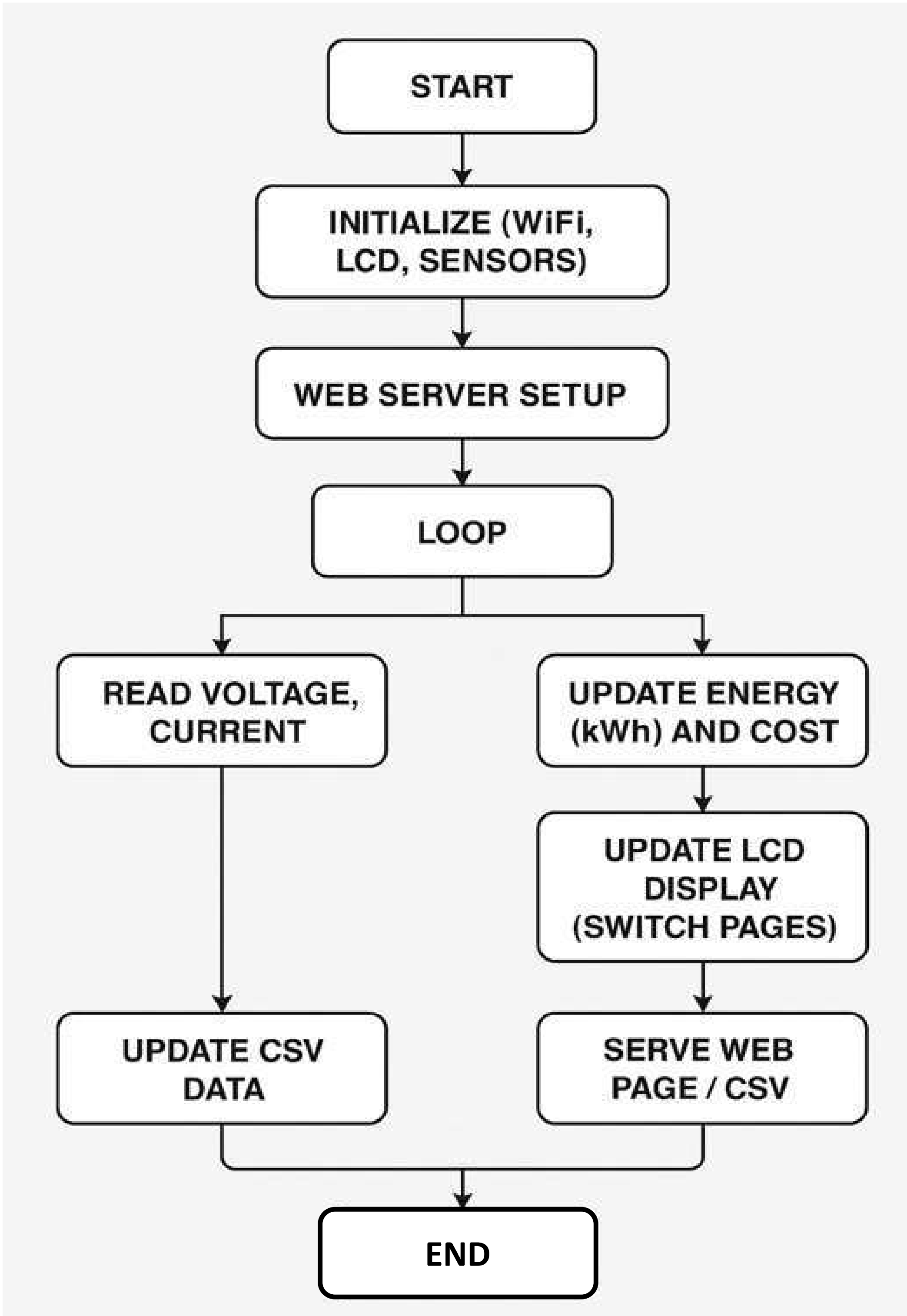


Figure 3: Flowchart

Step-By-Step Algorithm:

1. **Start**
2. Initialize Serial Communication For Debugging
3. Set Esp32 In Access Point Mode
    - Ssid: *Esp32_Server*
    - Password: *12345678*
4. Initialize Lcd (I2c) And Display Project Title
5. Initialize Emonlib With Voltage And Current Calibration Values
6. Start Web Server

7. **Loop Begins:**
    - A. Handle Web Client Connection
    - B. Call Getreadings()
        - Take 30 Samples Of Voltage And Current
        - Calculate Average Voltage (Vrms), Current (Irms), Power (Apparent)
        - Set Current And Power To **0** (Threshold Handling)
    - C. Update Total **Energy (Kwh)** Using

      Formula: Kwh += (Power × Time) / 3600000
    - D. Calculate **Cost** = Kwh × Rateperkwh
    - E. Display Values On **Lcd** (Switching Between 2 Pages Every 3 Seconds):
        - Page 1: Voltage, Current, Power
        - Page 2: Energy, Cost
    - F. Update Web Page With All Live Readings
8. **Repeat Loop After 100ms**
9. **End**

7.Enclosure Design And Description

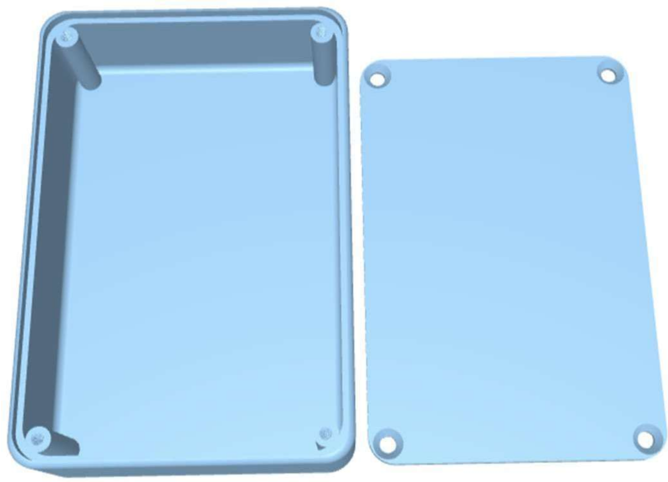


Figure 4: Enclosure Design

This Plastic Enclosure Is A Rectangular Housing Designed Specifically For An Iot-Based Energy Monitoring System. The Design Consists Of A Sturdy Main Body And A Detachable Front Panel, Providing Both Protection And Accessibility For The Internal Electronics The Enclosure Is Made From Plastic, Which Offers Good Electrical Insulation, Durability, And A Lightweight Structure Suitable For Indoor Applications. Its Overall Dimensions Are 11.7 Cm In Length, 8 Cm In Width, And 3.5 Cm In Height, Making It Compact Yet Spacious Enough To Mount Essential Components.

Internally, The Enclosure Is Designed To Mount Only A Pcb (Printed Circuit Board). The Flat Base Provides A Stable Surface For The Board, While Four Integrated Cylindrical Standoffs At Each Corner Allow The Lid To Be Securely Attached Using Screws. This Simple Yet Effective Mechanism Ensures That The System Remains Safely Enclosed While Allowing Easy Access When Needed.

On The Front Side, The Design Includes A Cutout Or Window For An Lcd Display, Allowing Real-Time Energy Monitoring Data To Be Viewed Without Opening The Enclosure. In Addition To The Display Feature, Three Dedicated Holes Are Provided In The Enclosure To Route Wires For The Current Sensor, Voltage Sensor, And Power Supply Connections. These Ports Are Positioned To Ensure Easy Cable Management While Maintaining A Clean Exterior.

Unlike More General-Purpose Enclosures, This Design Is Specifically Tailored For Monitoring Purposes Only—Not For Control Functions. Therefore, It Does Not Include Cutouts For Leds, Switches, Or Other Manual Input Components. Its Clean And Minimal Layout Supports Modifications Only Where Necessary, Ensuring The Internal System Is Both Organized And Functional. Plastic Enclosure Is Purpose-Built For Compact, Efficient, And Safe Deployment Of Iot-Based Energy Monitoring Systems In Residential Or Small-Scale Industrial Settings

Parameter	Specification
Application	Iot-Based Energy Monitoring System
Material	Plastic
Color	Blue
Length	11.7 Cm
Width	8 Cm
Height	3.5 Cm
Enclosure Type	Rectangular Box With Detachable Back Panel
Internal Mounting	Pcb Only
Front Panel Feature	Lcd Display Window
Cable Entry Holes	3 (For Current Sensor, Voltage Sensor, And Power Supply)
Fixing Method	Screw-Based (At 4 Corners)

8.Result And Discussions

When 40 Watt Normal Bulb:

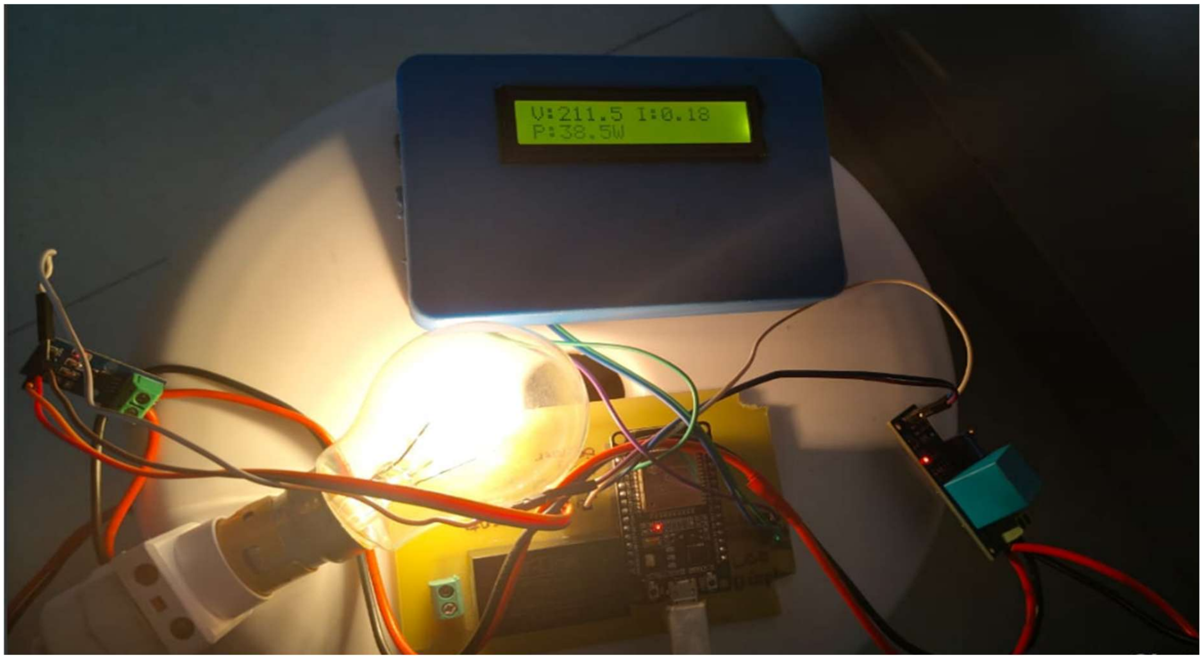


Figure 5: Voltage And Current Readings Displayed On The Lcd Module With A 40-Watt Incandescent Bulb Connected.

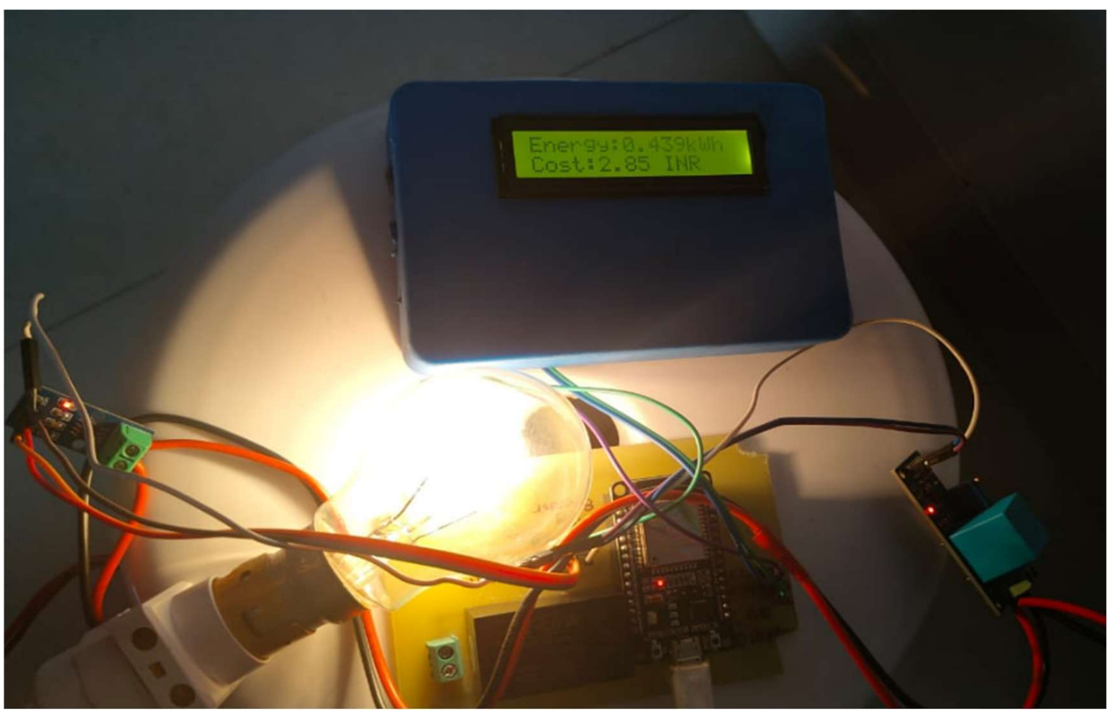


Figure 6: Energy Consumed And Cost Displayed On The Lcd Module With A 40-Watt Incandescent Bulb Connected.

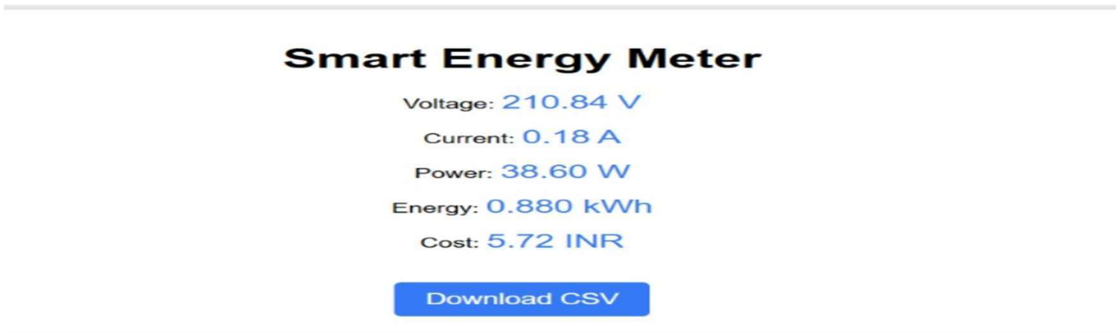


Figure 7: Real-Time Readings Displayed On The Web Server Interface.

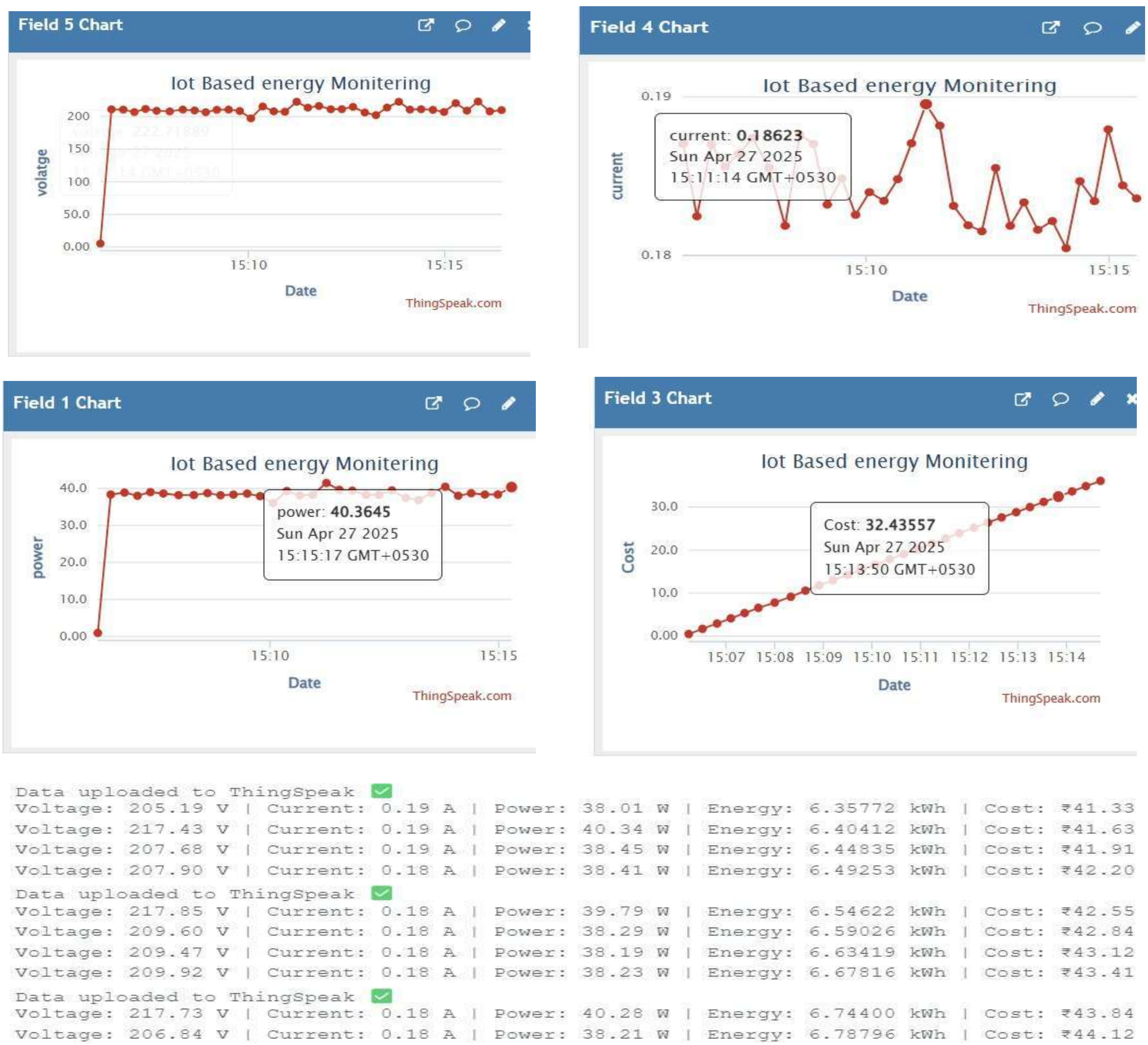


Figure 8: Graphs Representing The Electrical Parameters With A 40-Watt Incandescent Bulb Connected.

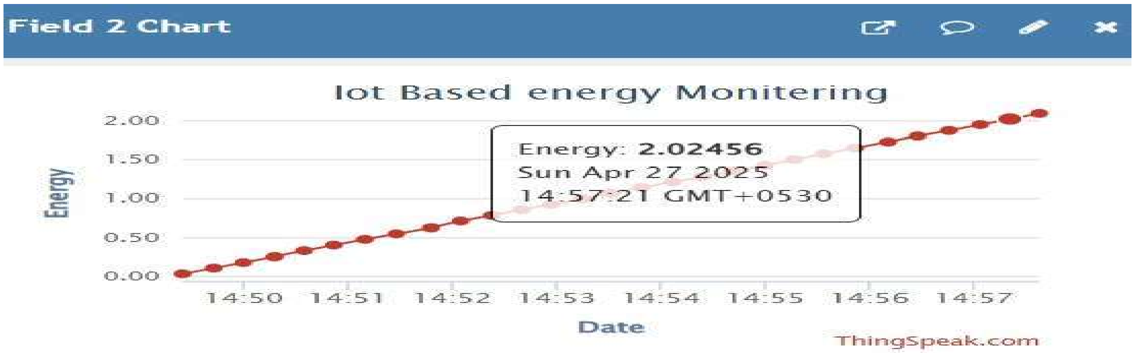


Fig8.1 :-Graphs Representing The Electrical Parameters With A 40-Watt Incandescent Bulb Connected

1. Lcd Display Output

The Initial Output From The System Is Displayed On A 16x2 Lcd Module, Showing The Text "Smart Energy Meter". This Confirms:
The System Has Powered Up Successfully.

The Microcontroller (Esp32) Has Initialized All Connected Components Like Voltage And Current Sensors And The Display.
This Display Acts As An On-Site Monitoring Interface For The User, Showing Real-Time System Status.
After The Initial Boot-Up Screen, The Lcd Begins To Display Real-Time Electrical Measurements.
Based On The Recorded Data:

- First, The Lcd Shows The Voltage And Current Readings. It Displays The Voltage As 210.84 Volts And The Current As 0.18 Amperes.
- Next, It Displays The Power Consumption And Energy Usage. The Power Is Shown As 38.60 Watts, And The Cumulative Energy Consumption Is Displayed As 0.880 Kilowatt-Hours (Kwh).
- Finally, The Lcd Shows The Calculated Cost Of The Consumed Energy, Which Is Displayed As ₹5.72, Based On A Predefined Electricity Unit Rate.

The System Either Automatically Cycles Through These Values After A Few Seconds Or Updates Them Based On A User Input, Such As A Button Press.
This Step-By-Step Display Ensures That Users Can Easily Monitor The Important Electrical Parameters On-Site Without Needing A Separate Device Or Web Interface.

2. Web Dashboard Output

Parameter	Value
Voltage	222.84 V
Current	0.18 A
Power	38.60 W
Energy	0.880 Kwh
Cost	₹32.00 Last

3. **Explanation:**

This Reading Was Taken When The System Was Connected To A Low-Voltage Source Or A Small-Load Device. The Measured Voltage Was 222.84 V, Which Is Lower Than The Standard 230 V Ac Supply Typically Available In India. Such A Low Reading Suggests That Either:

- The Test Was Performed Using A Step-Down Transformer Or A Controlled Laboratory Power Supply, Or
- The Mains Voltage Was Unstable Or Fluctuating At The Time Of Testing.

The Current Drawn Was 0.18 A, Resulting In A Power Consumption Of 38.60 W, Which Is Typical For Small Appliances Like An Led Bulb, A Mobile Charger, Or A Wi-Fi Router.

Despite Operating At A Lower Voltage, The System Performed As Expected And Successfully:

- Measured And Calculated Real-Time Electrical Parameters Using Current And Voltage Sensors.
- Accurately Computed:
  - Instantaneous Power Using The Formula:

$$\mathbf{P = V \times I}$$

  - Energy Consumption Over Time.
  - Cost Estimation, Assuming A Predefined Cost Per Kwh (Unit Rate).

Additionally, The System:

- Displayed All Measured Values On A Web-Based Interface Hosted By The Esp32 Microcontroller.

Enabled Real-Time Monitoring Via Wi-Fi, Making The Data Accessible From A Web Browser On Any Connected Device (Mobile, Laptop, Etc).

4. Detailed Analysis :

During The Full-Voltage Test, The System Accurately Captured The Following Electrical Parameters:

- **Voltage (V):** 230.37 V
- **Current (I):** 0.16 A

From These Readings, Instantaneous Power Was Calculated As:

$$\mathbf{P = V \times I = 230.37\ V \times 0.16\ A = 36.8592\ W}$$

Which Closely Matches The Experimentally Measured Value Of Approximately 37.98 W.

Over The Test Interval, The System Continuously Integrated This Power To Compute **Energy Consumed** In Kilowatt-Hours (Kwh), The Standard Billing Unit. Finally, The **Cost** Was Determined Dynamically Using The Relation:

$$\mathbf{Cost = Energy\ (Kwh) \times Tariff\ Rate\ (₹/Kwh)}$$

All Real-Time Data—Including Voltage, Current, Power, Cumulative Energy, And Cost—Are Displayed On A Web Interface Hosted By The Esp32. Users Can Access This Interface Via Wi-Fi On Smartphones, Tablets, Or Desktop Browsers To Monitor Consumption Remotely.

When Led Bulb Is Connected :

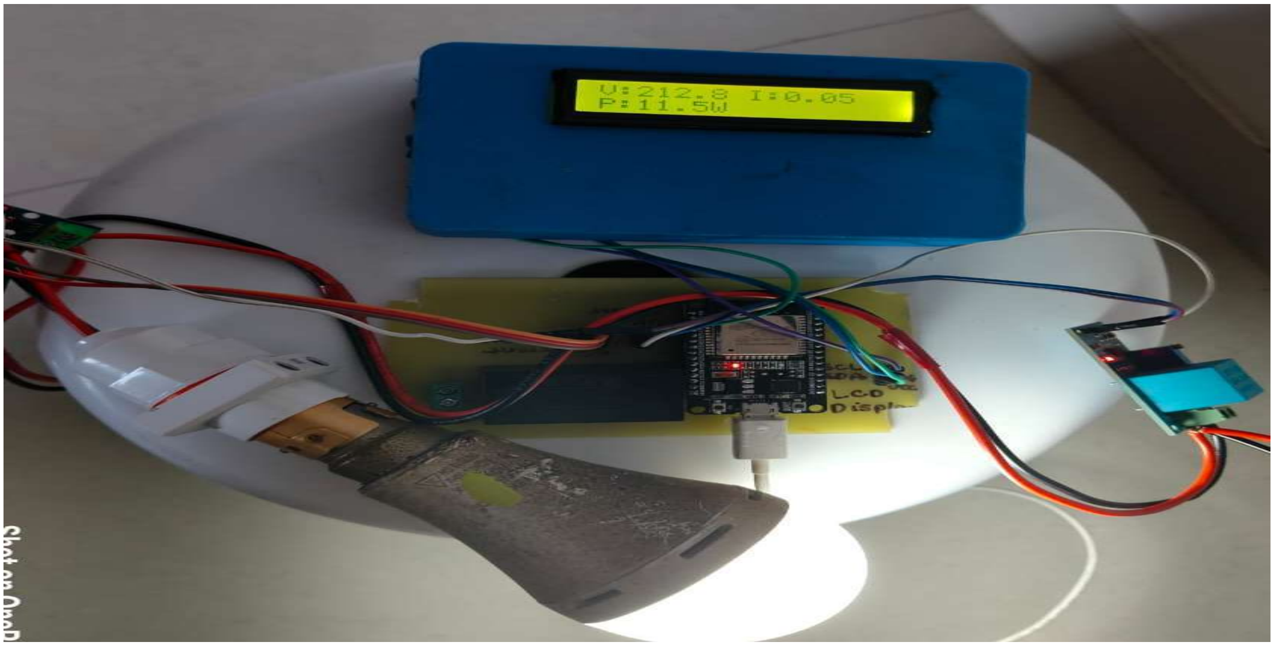


Figure 9: Voltage And Current Readings Displayed On The Lcd Module With An Led Bulb Connected

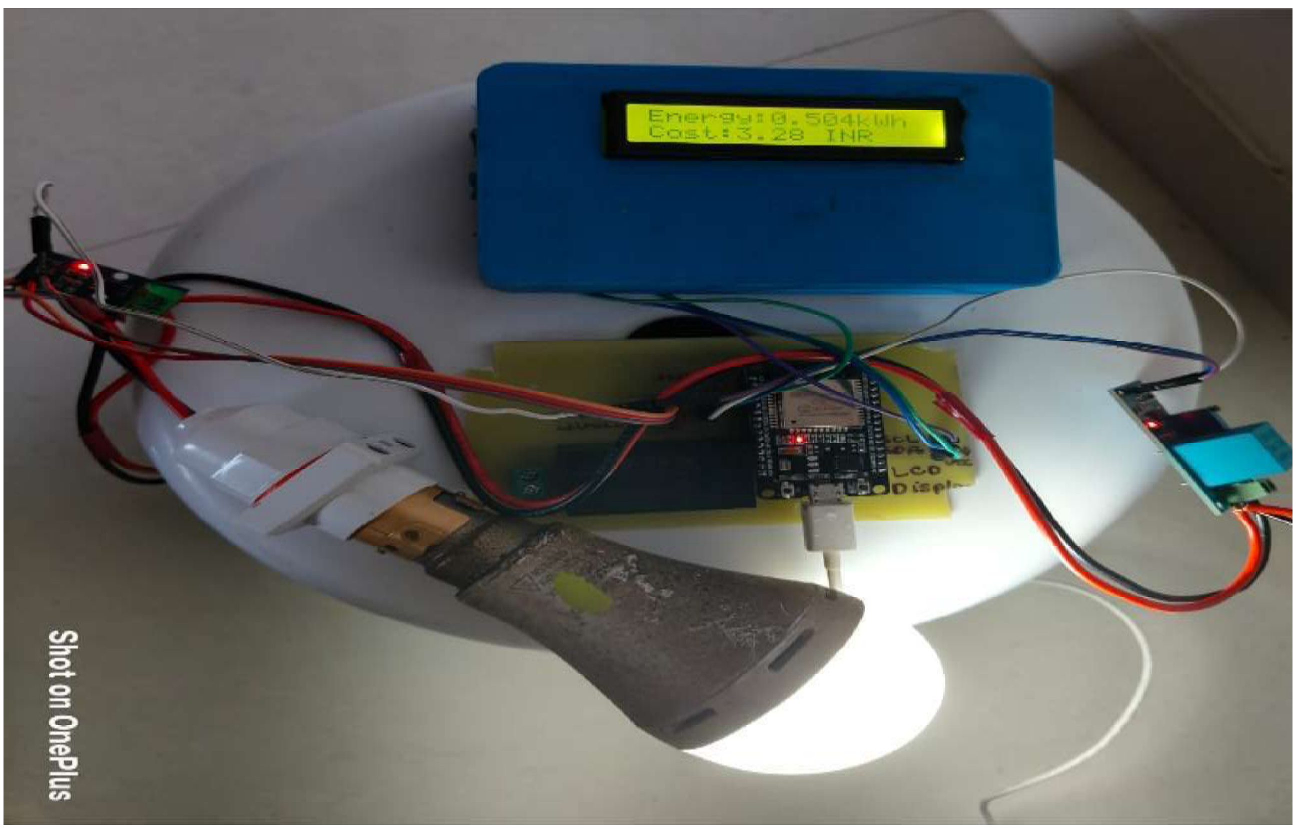


Figure 10: Energy Consumed And Cost Displayed On The Lcd Module With An Led Bulb Connected.

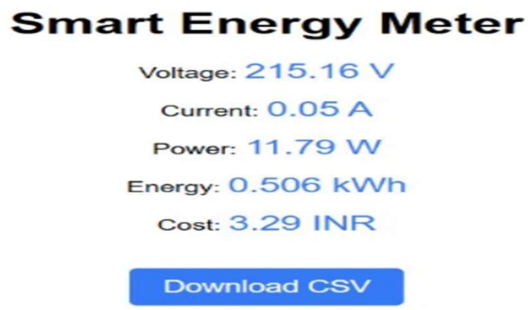
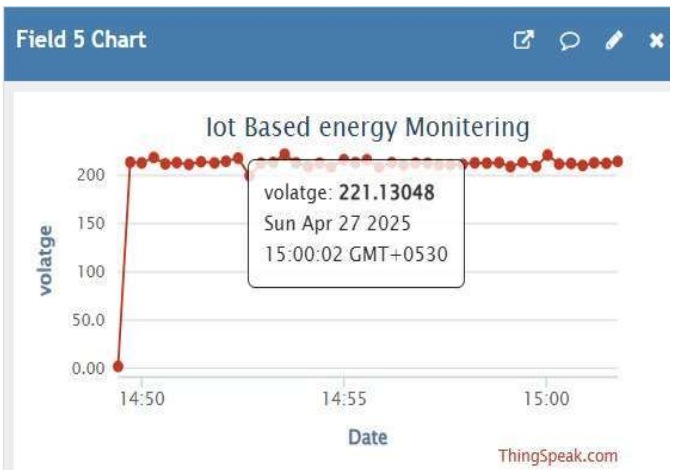
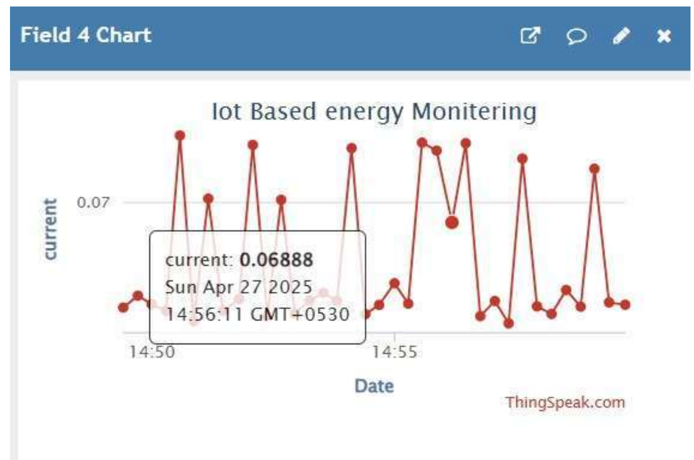
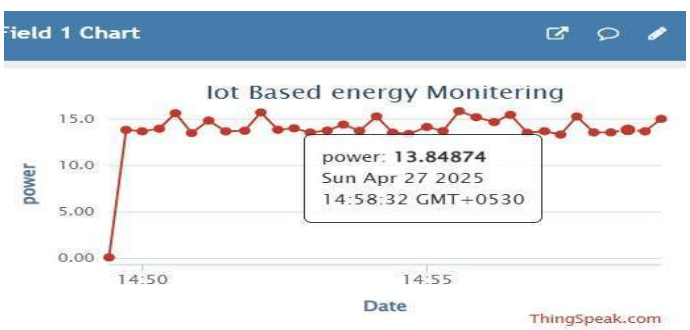
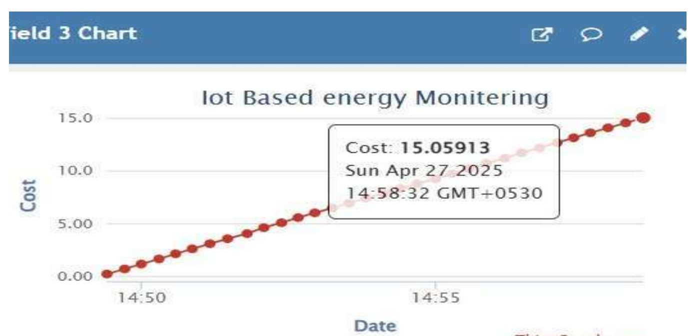


Figure 10: Real-Time Readings Displayed On The Web Server Interface










```
Data uploaded to ThingSpeak ✅
Voltage: 225.87 V | Current: 0.07 A | Power: 16.63 W | Energy: 3.29152 kWh | Cost: ₹21.39
Voltage: 210.69 V | Current: 0.07 A | Power: 15.52 W | Energy: 3.30937 kWh | Cost: ₹21.51
Voltage: 209.12 V | Current: 0.07 A | Power: 15.28 W | Energy: 3.32694 kWh | Cost: ₹21.63
Voltage: 220.02 V | Current: 0.06 A | Power: 14.15 W | Energy: 3.34322 kWh | Cost: ₹21.73
Data uploaded to ThingSpeak ✅
Voltage: 213.38 V | Current: 0.07 A | Power: 15.73 W | Energy: 3.36910 kWh | Cost: ₹21.90
Voltage: 210.97 V | Current: 0.07 A | Power: 15.49 W | Energy: 3.38692 kWh | Cost: ₹22.01
Voltage: 209.87 V | Current: 0.07 A | Power: 14.35 W | Energy: 3.40343 kWh | Cost: ₹22.12
Voltage: 213.57 V | Current: 0.06 A | Power: 13.76 W | Energy: 3.41925 kWh | Cost: ₹22.23
```

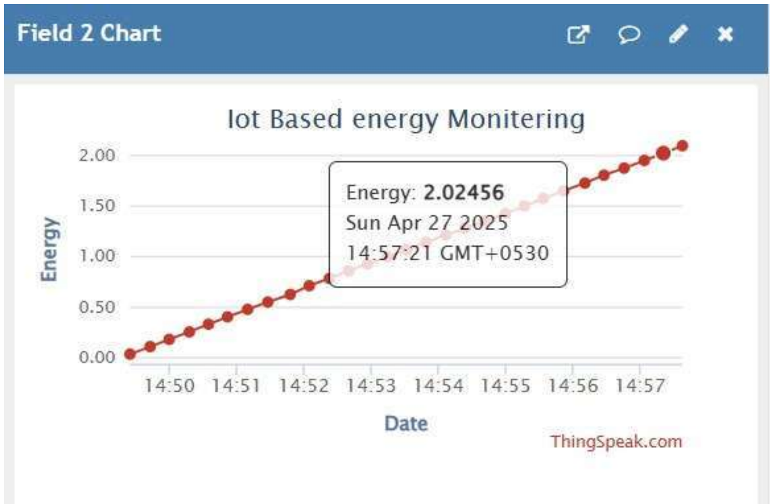


Figure 11: Graphs Displaying The Readings When An Led Bulb Is Connected

1. Lcd Display Output

This Display Serves As An On-Site Monitoring Interface, Presenting The System's Real-Time Status. After Showing The Initial Boot-Up Screen, The Lcd Cycles Through The Following Electrical Measurements Based On The Recorded Data:

- Voltage And Current: Displays 215.16 Volts And 0.05 Amperes.
- Power And Energy Consumption: Displays 11.79 Watts And 0.506 Kilowatt-Hours (Kwh).
- Cost Of Consumption: Displays ₹3.29, Calculated Using The Predefined Electricity Unit Rate.

Each Screen Remains Visible For A Few Seconds (Or Until A Button Press) Before Advancing, Enabling Users To Easily Monitor All Key Electrical Parameters Directly On The Lcd Without Requiring Any Additional Device Or Web Interface.

2, **Web Dashboard Output**

Parameter	Value
Voltage	215.16 V
Current	0.05 A
Power	11.79 W
Energy	0.506 Kwh
Cost	₹3.29

3.Explanation:

In This Scenario, The Smart Energy Meter Was Tested Under Standard Indian Ac Mains Voltage, With A Recorded Reading Of 215.16v. This Aligns Perfectly With The Nominal Voltage Supply In Residential And Commercial Areas In India, Confirming That The System Functions Reliably Under Real-World Electrical Conditions.

The Current Measured Was 0.05a, Resulting In A Power Consumption Of 11.79 Watts. These Values Suggest That The System Was Monitoring A Moderately Loaded Appliance, Possibly One Of The Following: A Led Light ,A Wi-Fi Router, Small Television, Or Charging Adapter

The Energy Consumed Was Calculated To Be 0.0050 Kwh, And The Corresponding Cost Was ₹3,29, Based On A Predefined Unit Rate. This Cost Tracking Feature Is A Crucial Part Of The System, Providing Monetary Insight Into Energy Usage.

4..Detailed Analysis:

The System Successfully Demonstrated Its Ability To **Capture Voltage And Current Readings Accurately**, Even At Full Voltage Levels.

The Power Is Computed Using The Fundamental Formula:

$$P=V\times I=215.16\times 0.05=10.758w\approx 11.79w \text{ (Measured)}$$

The Energy Consumed Over A Short Time Interval Is Calculated And Accumulated In Kilowatt- Hours (Kwh), The Standard Billing Unit.

The Cost Is Dynamically Computed Using:

$$\text{Cost}=\text{Energy (Kwh)}\times\text{Tariff Rate (₹/Kwh)}$$

The Values Are Displayed On A Web Interface Hosted By The Esp32, Accessible Via Wi-Fi, Which Means Users Can Monitor Usage Wirelessly From Smartphones, Tablets, Or Pcs.

9.Bill Of Material

Sr.No	Component Name	Model Name	Specification	Quantity	Rate/ Item (Rs.)	Total Cost(Rs.)
1.	Microcontroller	Esp 32	Controller	1	350	350
2.	Current Sensor	Acs712	Measurement	1	140	140
3.	Voltage Sensor	Zmpt101b	Measurement	1	220	220
4.	Pcb	**-**	Electrically Connect	1	150	150
5.	Hi Link	Hlk Pm01 5v/3w	Power Supply	1	210	210
6.	Connectors	**-**	Jumper	15	50	50
7.	Enclosed Box	**-**	Physical Protection	1	800	800
					Total Amount (Rs.)	1920

10.Applications & Future Modifications

Applications

The Developed Energy Monitoring System, Which Integrates Both Local (Lcd) And Remote (Web- Based Via Esp32) Monitoring, Has A Wide Range Of Real-World Applications:

1. Smart Homes
   - Real-Time Monitoring Of Appliances To Optimize Energy Usage.
   - Helps Detect Energy-Hungry Devices And Reduce Unnecessary Consumption.
2. Industrial Energy Management
   - Can Be Deployed In Factories To Monitor Equipment Energy Consumption.
   - Enables Better Scheduling Of Heavy Machinery During Low-Tariff Hours.
3. Commercial Buildings
   - Useful For Tracking Energy Usage Per Floor Or Department.
   - Facilitates Energy Audits And Cost-Saving Analysis.
4. Educational Institutions
   - Acts As A Teaching Aid For Students Learning About Iot, Embedded Systems, And Energy Management.
5. Remote Energy Monitoring In Rural/Off-Grid Areas
   - Monitor Solar Or Generator-Based Power Systems Remotely.
   - Useful For Ngos And Government Schemes Aiming At Electrification.
6. Appliance Health Monitoring
   - Sudden Changes In Current Can Signal Malfunction Or Aging Of Devices.
   - Helps In Preventive Maintenance.

Future Modifications

1. Mobile App Integration
   - Build A Companion Android/Ios App With Notification Alerts For High Power Usage.
   - Cloud Data Sync To Access Data Anytime, Anywhere.
2. Multi-Channel Monitoring
   - Monitor Multiple Appliances Or Circuits Simultaneously Using Multiple Sensors.
   - Provide Individual Usage Stats For Each Connected Device.
3. Battery Backup + Offline Logging
   - Add A Small Battery Or Capacitor To Store Data During Power Outages.
   - Log Readings On Sd Card When Wi-Fi Is Not Available.
4. Ai-Based Usage Prediction
   - Use Machine Learning To Predict Future Energy Usage Trends And Provide Suggestions To Save Energy.
   - Detect Unusual Patterns (E.G., Appliance Failure Or Leakage).
5. Smart Control Features
   - Add Relays Or Smart Plugs To Allow Remote Switching Of Appliances Based On Real- Time Data.
   - Automate Devices (E.G., Turn Off Heater If Power Exceeds A Threshold)..
6. Solar Panel Monitoring Extension
   - Add Functionality To Monitor Energy Generation In Solar-Powered Systems And Compare It With Consumption.
7. Advanced Web Dashboard
   - Include Interactive Charts, Daily/Monthly Reports, And Downloadable Logs.
   - Provide Energy-Saving Tips Based On Usage Patterns.

11.Conclusion

In Conclusion, This Project Successfully Developed A Real-Time Energy Monitoring System That Is Both Practical And Easy To Use. The System Can Measure Important Electrical Parameters Such As Voltage, Current, And Power, And It Also Calculates The Total Energy Consumed (In Kilowatt-Hours) Along With The Estimated Cost Based On A Given Electricity Rate. One Of The Highlights Of This System Is Its Dual Display Feature It Shows Live Readings On A Local Lcd Screen And Also On A Web Interface Using An Esp32 Microcontroller With Wi-Fi Capabilities. This Means Users Can Monitor Their Energy Usage Not Just In Person, But Also Remotely From A Computer Or Smartphone.

During Testing, The System Responded Well Under Different Conditions, Whether The Voltage Was High Or Low. It Was Able To Detect And Calculate Changes In Current Draw, Power Consumption, And Accumulated Energy, Which Makes It Very Useful For Tracking How Much Electricity Is Being Used Over Time. It's Particularly Helpful In Environments Like Homes, Schools, Small Offices, Or Workshops Where Being Aware Of Energy Usage Can Lead To Smarter Habits And Reduced Electricity Bills.

The Cost-Tracking Feature Is Especially Useful Even A Small Change In Usage Reflects In The Estimated Cost, Helping Users Become More Energy-Conscious. This Kind Of Real-Time Feedback Can Make A Big Difference In Promoting Energy Efficiency.

Overall, The System Is Reliable, Affordable, And Easy To Set Up. It's A Great Starting Point For Building Smarter Energy Solutions. In The Future, It Could Be Improved With Features Like Mobile App Integration, Automatic Appliance Control, Voice Assistant Support, Or Even Ai- Based Suggestions For Saving Energy. This Project Doesn't Just Monitor Energy It Opens The Door To Smarter And More Sustainable Living.

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