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Enhancement of Digital Energy Meter into a Smart Energy Monitoring and Abnormal Load Detection System

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ABSTRACT: The proposed project introduces design to incorporate smart energy elements in to a standard digital energy meter to apply the continuous energy monitoring and abnormal load detection features of a smart energy meter. This system incorporates ESP32 microcontroller, which is enhanced with a PZEM-004T v3.0 Energy Meter Module and an ACS current sensor to read the real-time voltage, current, power, and energy use. The system consists of a system of multiple relay controls to manage loads and a buzzer to indicate abnormal load conditions like over voltage, low voltage, overload and high energy consumption. The data obtained is shown on a LCD and can be viewed on ThingSpeak, an IoT analytics platform service to analyze and visualize data. The system also leverages machine learning capabilities on historical energy data gathered on the cloud by IoT to conduct the load forecasting. It forecasts the future power usage and allows intelligent and proactive energy control. This system is a cost-effective and reliable solution as it accurately monitors and identifies over load and can be used in smart grid and home automation applications.

KEY WORDS: Smart Energy Meter, IOT -Based Energy Monitoring, ESP32 Microcontroller, PZEM- 004T Module, ACS712 Current Sensor, Real-Time Monitoring, Energy Consumption, Voltage, current, Power, Energy, Thingspeak IOT Platform, LCD Display and Buzzer Alert system

I. INTRODUCTION

The fast growth in electricity demand, the rising interest in energy efficiency, and overloading conditions in recent years have resulted in a high demand in intelligent energy monitoring systems. Conventional energy meters, which are used in domestic and industrial markets, are constrained in their capabilities because they can only measure total energy consumption without offering real-time measurements or remote access. This complicates the analysis of consumption patterns, identification of abnormalities, and achieving efficiency in energy use by the users and the utility providers. As embedded systems and communication technologies have advanced, there has been a transition to the use of smart energy management systems with better monitoring, control, and predictive abilities. Energy monitoring systems have been radically changed as a result of the integration of the Internet of Things (IoT). The IoT provides a smooth interaction between gadgets that can be able to access, process and monitor data remotely in real-time using cloud environments. Energy data are stored and visualized in platforms such as ThingSpeak, in this project. Voltage, current, power, and energy consumption can be tracked anywhere with users enhancing decision-making and transparency. Also, features of IoT systems include remote load control, automated alerts, and system diagnostics. The intended system is able to keep track of electrical parameters in order to identify certain abnormal conditions, including overload, overvoltage, and undervoltage. Predefined threshold limits are used to determine overload by comparing the measured values with the threshold limits. In case of violation of these limits, the system sends alerts through a buzzer and cloud messages, which assists in avoiding electrical appliance damages. The system is constructed based on

ESP32 microcontroller with inbuilt Wi-Fi as a communication channel. An electrical module PZEM-004T is used to measure electrical parameters, and an ACS current sensor improves the accuracy. A LCD shows real-time information and load is controlled by relays. Moreover, a simple regression model is executed in order to predict the future energy consumption to manage the energy better. Overall, the system provides an efficient, reliable, and cost-effective solution for smart energy monitoring.

Table 1.1: Literature survey of some of the existing work :

S.No	Author Name	Description of Work	Methodology / Focus	Key Finding(s)
1	P. A. Bhoite, S. B. Patil, and R. K. Shinde	IoT-based electricity theft detection system	Uses IoT sensors and monitoring for detecting unauthorized usage	Provides real-time monitoring and improves theft detection efficiency
2	E. Ul Haq, M. Awais, and S. A. Khan	Deep CNN-based electricity theft detection	Uses smart meter data with deep learning techniques	High accuracy in identifying electricity theft patterns
3	C. Chong, K. L. Wong, and M. H. Tan	Smart energy meter with theft control	IoT-based monitoring with control mechanisms	Enables real-time tracking and theft prevention
4	M. Iftikhar, A. Rehman, and F. Khan	ML-based electricity theft detection	Machine learning algorithms for smart grid security	Improves detection accuracy and system reliability
5	S. Karajagi, P. Kulkarni, and R. Desai	IoT smart energy meter system	Real-time monitoring and theft detection using IoT	Enhances transparency and reduces energy losses

6	A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi	IoT for smart cities	Architecture and applications of IoT systems	IoT enables scalable and efficient smart grid solutions
7	G. R. Barai, S. Krishnan, and B. Venkatesh	Smart metering technologies	Functionalities and implementation of smart grids	Improves energy management and monitoring capabilities
8	A. Ghasempour	IoT in smart grid systems	Study of architecture, services, and challenges	IoT plays a key role in modern smart grid development
9	F. Chollet	Deep learning concepts using Python	Neural networks and AI modeling techniques	Provides foundation for AI-based prediction systems
10	S. Haykin	Neural networks and learning systems	Theoretical concepts of machine learning	Essential for understanding intelligent prediction models
11	T. Hastie, R. Tibshirani, and J. Friedman	Statistical learning methods	Data analysis and predictive modeling techniques	Supports advanced forecasting and analytics
12	J. Brownlee	Time series forecasting	Python-based forecasting techniques	Useful for energy consumption prediction

II. PROBLEM STATEMENT

The growth in population, industrialization and the usage of electrical appliances has posed a challenge in ensuring a stable and efficient supply of electrical energy. The traditional energy meters, which are prevalent in residential and industrial markets, are not sufficient because they do not measure real-time or have remote accessibility of energy consumption. This complicates the process of analyzing the usage trends, identifying anomalies, and regulating energy use among the users. Also, the absence of real-time monitoring and control causes wastage of energy since users are unable to monitor or control their consumption in real-time. Electricity theft is another significant problem that takes place in the form of unauthorized connection or tampering of meters leading to loss of finances and instability of the system. The old fashioned ways of identifying those problems are based on human inspections that are very slow and ineffective. Moreover, the current systems are not predictive, and it is hard to predict the future use of energy, efficiently controlling demand. Thus, a sophisticated smart energy monitoring system, which is capable of real-time data measurement, remote control, automated control, and predictive analysis, is needed. This system will be able to enhance efficiency, minimize energy losses and create reliable energy management.

III. METHODOLOGY

The system proposed is structured in order to attain real-time monitoring and detection of overloading of energy. First, the PZEM-004T module is used to measure electrical parameters, namely voltage, current, power, and energy, with an ACS current sensor used to measure the current further. The sensor values are acquired and analyzed using the ESP32 microcontroller where analysis like power consumption and energy consumption are done. The system constantly compares the current and power measured value against preset threshold values to detect abnormal conditions including overload, overvoltage and undervoltage. When an overload condition is detected then the system automatically triggers a buzzer and alerts using the cloud platform. The processed data is presented locally on an LCD where real time information is presented to the user. At the same time, the ESP32 is connected to a Wi-Fi network and sends the data to the ThingSpeak IoT platform via the HTTP protocol, which allows monitoring the device and visualizing the data in the distance. The system also offers remote load control, in which the commands sent by the cloud can be used to activate and deactivate relays to turn electrical loads ON or OFF, particularly in abnormal situations. Moreover, the cloud-based storage of historical data is employed in energy forecasting with the help of a regression-based model, which forecasts the future consumption pattern of energy. The whole process is continuous so that there is effective monitoring, detection of overload in time and better energy management.

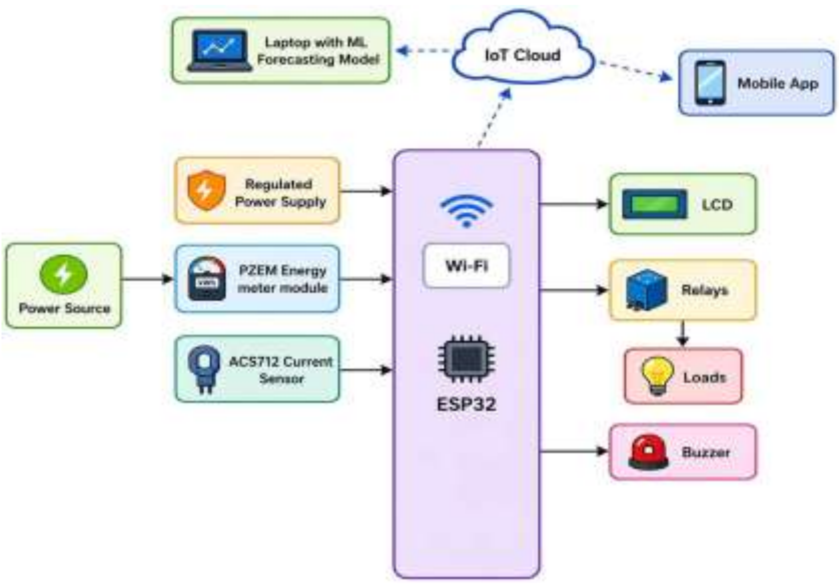


Fig. 3.1: Block Diagram Of Smart Energy Meter

IV. SYSTEM DESIGN AND IMPLEMENTATION

The connection diagram and flowchart together explain the overall design and working of the proposed system.

A. HARDWARE INTERFACING :

The connection diagram shows the integration of all the hardware components with the ESP32 microcontroller, the central processing unit of the system. ESP32 captures information through sensors, processes it, and displays it on the LCD, and sends it to the cloud via its inbuilt Wi-Fi solution. The energy meter module PZEM-004T v3.0 is connected with the ESP32 by UART communication (TX and RX pins). It can directly measure electrical parameters of voltage, current, power, and energy of the AC supply and transmit this information to the ESP32. The PZEM module is connected to the AC input and the load (say a bulb) is connected across them to be measured. A series of ACS712 current sensor is used in connection with the load to sense current on its own. It reads an analog signal to the ESP32 which assists in checking the current readings and enhancing the precision. It is also helpful in identification of abnormal conditions.

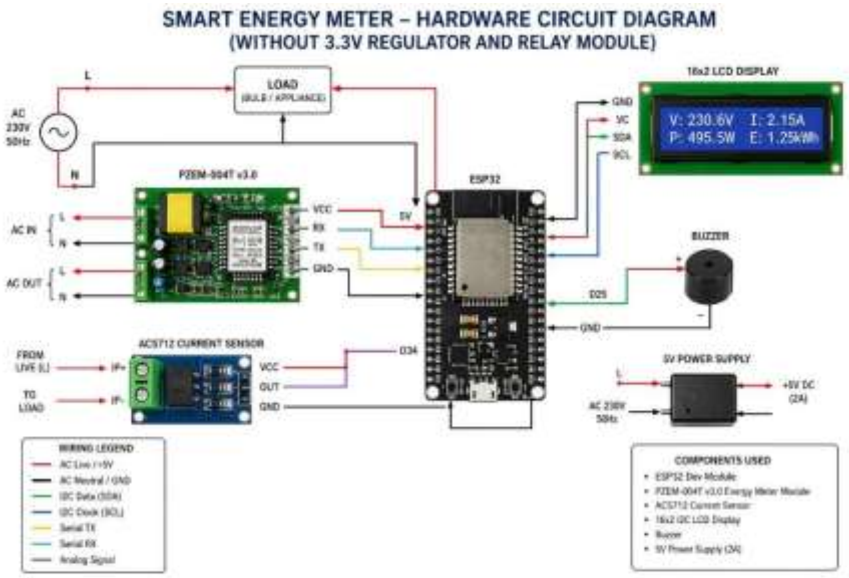


Figure 4.1: Schematic diagram

The ESP32 is connected with a 16x2 LCD display (I2C type) via SDA and SCL pins to display real-time values in terms of voltage, current, power, energy consumption and billing details. An audible alarm to trigger during abnormal conditions, such as overload, overvoltage, and under voltage, is attached to one of the ESP32 GPIO pins with a buzzer. The ESP32 transmits data that is gathered to the ThingSpeak cloud system to be remotely monitored, stored, and displayed in a graphical format. Every component will be supplied with a regulated 5V DC power supply and a common ground is used throughout the circuit to provide stable and correct operation of the system.

B. SYSTEM FLOWCHART :

The flowchart shows the process of functioning of the smart energy monitoring system. The system starts with the start block in which the power measurement unit measures electrical parameters (voltage, current, and power) with the smart energy meter. The measured values are then transmitted to the IoT communication module which connects to the cloud server via an API. The data transmission phase then transfers the power data collected to the cloud platform where it is stored and monitored. The processing unit, which is situated in the IoT server, conducts analysis of data and uses algorithms to identify abnormal conditions like power theft. The decision block goes through to see whether the theft is detected or not. In the case where no theft is detected, the system will update the database and log normal data. In case of theft, then the system will be subjected to a tampering check where meter status flags will be examined to ascertain abnormal activity. Once confirmed, the alert system is on so as to alert the user or any concerned authority of the identified problem. Lastly, the system also updates the database by recording the theft records to be referred to and analyzed later. This process guarantees that the abnormal conditions are detected correctly and that data management of smart energy systems will be achieved.

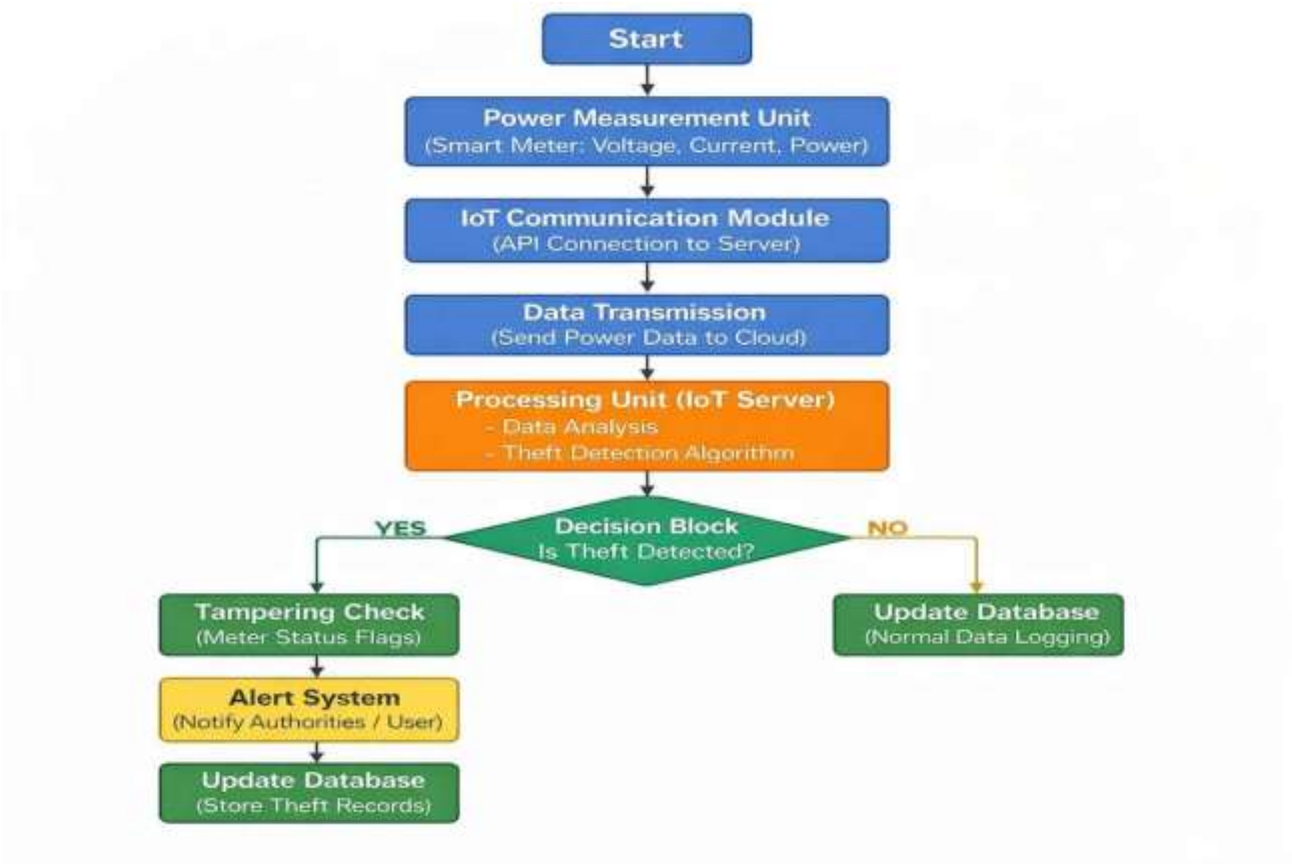
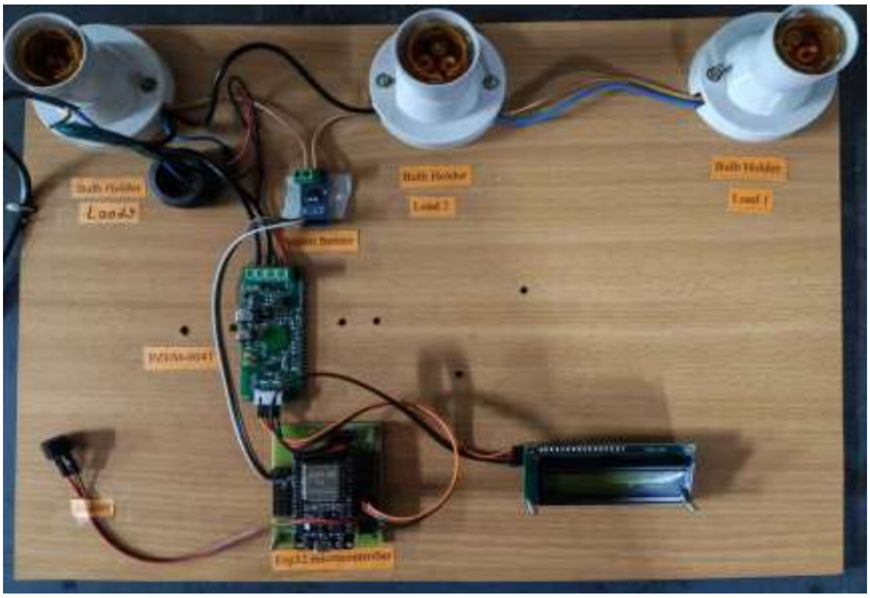


Figure 4.2: Workflow diagram

V. RESULTS AND DISCUSSION

Fig. 4.1 :Hardware Prototype Of Smart Energy System



a) Smart energy meter

S.NO	LOAD	CURRENT
1	60 Watts	0.27AMP
2	60+100=160Watts	0.61 AMP
3	60+100+60=220Watts	0.95AMP

Case-1: Normal Operation, load=60w

At the load of 60 W, the value of current is 0.27 A. The load falls within the predetermined threshold limits and therefore, there is no case of underload, overload and overvoltage. Thus, the system works as usual and nothing is noticed that interrupts the power supply.

Voltage

Fig. 4.2: voltage measurement and graph

When supply is turned on, at 11:41 voltage increases slowly and attains the value of 230 V.. This is the normal voltage at which the system functions. When the system is turned off, at 11:44, the voltage becomes 0 V, which means that the supply is completely disconnected.

current

Fig. 4.3: current measurement and graph

When the supply is turned ON, the current at first is equal to 0 A, meaning that there is no power flowing. When the system begins to work the current slowly grows, at 11:41, indicating that the load is connected to the supply. The current increases to 0.27 at a load of 60W and the rest of the graph illustrates that various loads on system are taken.

Power

Fig. 4.4 power measurement and graph

With the supply set On, at 11:40, the power starts to rise slowly, indicating that loads are being added to the supply. The system is increased to 60W of connecting load 1, at 11:41 to 11:43 and the rest of the graph indicates that varying loads were applied to the system.

Energy

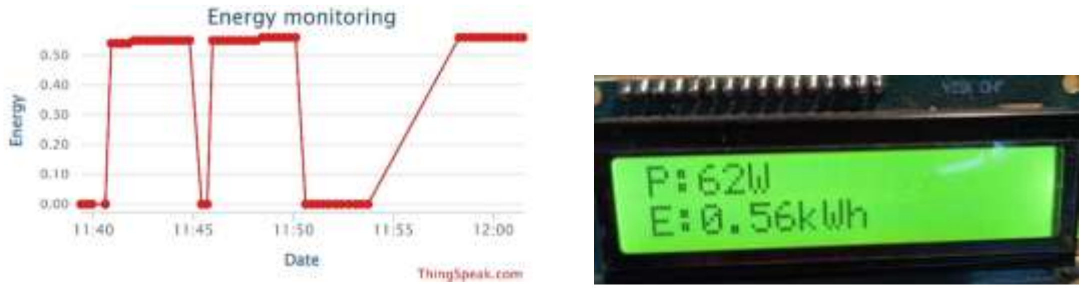


Fig. 4.5: Energy measurement and graph

Upon switching on the system, at 11:40, the energy value begins to rise indicating that power is being utilized by the loads attached. The energy increases gradually to approximately 0.5 kWh, which is constant use over time. The fact that the energy decreased to 0 kWh, at 11:45, suggests that the system has been turned off. Once again after the reactivation of the switch the energy again rises to a similar amount, portraying the resumed consumption.

Bill

Fig. 4.6: Bill measurement and graph

In the case of the system being switched ON, at 11:40 and load1 connected the bill value initially shoots up to 2.8 which means that energy is being consumed and cost is being accrued. The bill then stands virtually unchanged over a small time span, indicating a consistent use, but no drastic difference in use.

Case-2: Normal Operation, load=60W + 100W

When the load-60w+100w=160 W, the measured current is 0.61 A. The load does not exceed the predetermined threshold limits, so there are no instances of underload, overload, and overvoltage. Thus, the normal functioning of the system is observed, and there is no notice of the power supply interruption.

Voltage

Fig. 4.7: voltage measurement and graph

On switching the supply ON, at 11:46, the voltage is gradually increased, up to the value of 230 V.. This is the normal operating voltage of the system. At the time the system is switched off, 11:49, the voltage goes to 0 V, which implies that the supply is fully disconnected.

Current

Fig. 4.8: current measurement and graph

When the supply is turned on, the current is at first 0 A which shows no flow of power. As the system starts operating, the current gradually increases, at 11:46, showing the connection of load to the supply. The current increases to 0.61 with load of 160W and the rest of the graph indicates that various loads on the system cause changes in current.

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Power

Fig. 4.9: power measurement and graph

Since the supply is turned on, at 11:46, the power starts to rise slowly which indicates that loads are being put to the supply. The power rises to 160W of connecting load 2, at 11:46 and the remaining graph shows that different loads applied to system.

Energy

Fig. 4.10: Energy measurement and graph

When the system is switched ON, at 11:46, the energy value starts increasing, showing that power is being consumed by the connected loads. The power gains gradually to approximately 0.5 kWh, which is constant use during the time. An abrupt reduction of the energy to 0 kWh, at 11:50, means that the system has been turned OFF.

Bill

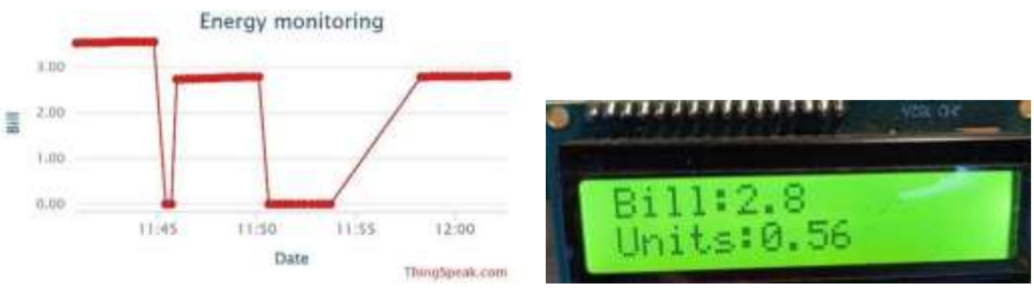

Fig. 4.11: Bill measurement and graph

At 11:46 and load 2 the bill value initially increases rapidly to 2.8 at onset of switching of the system showing that energy consumption has commenced and cost is being accumulated. The bill will then almost hold stable during a short period exhibiting a constant usage without a dramatic shift in consumption.

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Case-3: Over load Operation, load=60W + 100W + 60W

When the load is 60 W + 100 W + 60 W = 220 W, the measured current is 0.95 A. As the load is larger than the preset threshold limit, then there is an overload condition. Consequently, the buzzer will be ON and the LCD will show OVERLOAD.

Voltage

Fig. 4.12: voltage measurement and graph

When the supply is turned on, at 11:55 the voltage slowly increases and attains the value of 230 V.. This voltage level is normal in terms of the system.

Current

Fig. 4.13: current measurement and graph

When the supply is turned ON, the current will be zero Ampere for some time, suggesting that there is no flow of electrical energy. When the system begins to work, the current increases steadily, reaching 11:55, suggesting that load has been connected to the supply source.

Power

Fig. 4.14: power measurement and graph

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The power starts increasing gradually when the switch to the supply is turned ON at 11:55, indicating that loads have been connected to the source. The load of 224W for connecting load 3 is achieved at 12:10.

Energy

Fig. 4.15: Energy measurement and graph

When the system ON, starting from 11:55 onwards, there is an increase in the energy value, thus proving that there is consumption of energy due to load connection. The energy value increases continuously till 0.5kWh.

Bill

Fig. 4.16: Bill measurement and graph

Once the system is turned ON, the bill value starts increasing from zero to 2.8 units at 11:55 and at Load 3 because energy consumption begins and the costs have begun accumulating. Thereafter, there is very little change in the bill because its value stabilizes.

b) **Buzzer response**

1b. Voltage Condition

S.No.	**Condition**	**Buzzer Response**
1.	Undervoltage (voltage < 160)	Buzzer ON
2.	Overvoltage (voltage > 260)	Buzzer ON
3.	Normal voltage range(160 ≤ voltage ≤ 260)	Buzzer OFF

1. Undervoltage (voltage < 160 V)

The state where the voltage is less than 160 V is known as undervoltage.

It affects the performance of various appliances including motors, fans, and electronic components. The operation of the buzzer becomes active as it indicates that the supply voltage is low and requires attention.

2. Overvoltage (voltage > 260 V)

The condition where the voltage is higher than 260 V is known as overvoltage.

It poses a threat to the appliances due to which their lifespan gets shortened. This state causes the buzzer to operate so that it warns the users about the presence of high voltage.

3. Normal Voltage Range (160 V ≤ voltage ≤ 260 V)

If the voltage exists within the range of 160 V to 260 V, then it is considered a normal situation.

As it lies within the safe range of voltage, it does not affect the performance of any equipment. This state keeps the buzzer in the off position.

2b. Power Condition:

S.No.	Condition	Buzzer Response
1.	Overload (power > 180 W)	Buzzer ON
2.	Normal power range (power ≤ 180 W)	Buzzer OFF

When the power usage is greater than 180 watts, then there is a case of overload. This could be harmful to appliances and wiring, and hence, the buzzer switches ON to warn the person. When the power is equal to or less than 180 watts, then the buzzer stays OFF

3b. Current Condition:

S.No.	Condition	Buzzer Response
1.	Overcurrent (current > 1.5 A)	Buzzer ON
2.	Normal current (current ≤ 1.5 A)	Buzzer OFF

In case the current goes beyond 1.5 A, then this is an overcurrent situation, and hence the buzzer will be turned ON.

If the current stays below 1.5 A, then it is within the acceptable level, and thus the buzzer will be OFF.

Fig. 4.17: over load condition on display

c. Load Prediction

Finally, the created system proves its effectiveness as an intelligent energy monitoring and protection method by deploying an IoT platform using the ESP32 microcontroller. The system monitors the electrical parameters including voltage, current, power, and energy consumption using the PZEM sensor module. In turn, the acquired information is presented to the user on the LCD screen and transferred into the ThingSpeak cloud platform.

Furthermore, during the experiment, the system was able to detect various faults in terms of over-voltage, under-voltage, and overload. If any faults were detected, then the controller would activate a buzzer alarm and isolate the load using relays, protecting electrical appliances. Therefore, it can be claimed that the proposed method of protection is operational and meets the project requirements.

Moreover, the IoT technology embedded in the system allows for remote monitoring and control of electrical loads. The obtained data stored on the cloud can be used for further analysis and forecasting purposes. As an illustration, one can apply the Artificial Intelligence method that uses Linear Regression. Based on the collected data, the model calculates the predicted value of power consumption.

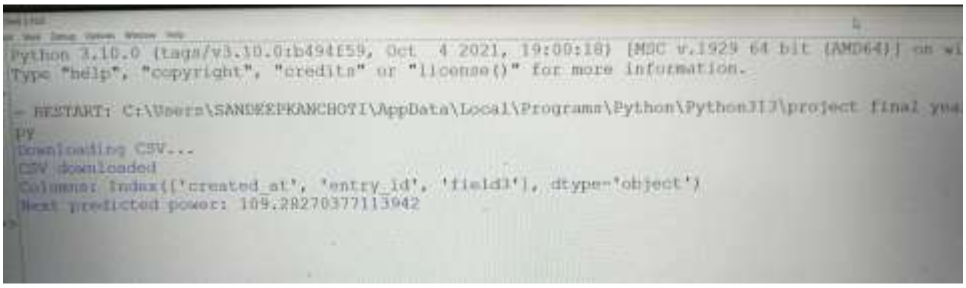

Fig. 4.18: Load Prediction result on Python idle

VI. CONCLUSION

In this project, we are trying to show how an IoT-based energy smart meter having the capacity to monitor and protect can be designed and implemented. For the purpose, we use the ESP32 along with the PZEM-004T module. These devices enable us to collect the value of parameters like voltage, current, power, and energy in real time. Moreover, we also get the values displayed on the LCD screen, which can be visualized through a web application on ThingSpeak.

We have also included protection in the system in case there is any abnormal situation, like the presence of overload, overvoltage, and under-voltage. Once the abnormal condition occurs, the system generates an alert using the buzzer and then disconnects the load to protect it from any harm.

Moreover, by implementing a basic linear regression technique, we have been able to forecast future energy consumption by considering past energy values.Overall, the proposed system is quite efficient, reliable, and economical and can be very helpful in smart energy monitoring tasks.

VII. REFERENCES

1. Smart Meters and their Application for Load Forecasting:

Conference 2023 2nd International Conference on Emerging Trends in Electrical, Control, and Telecommunication Engineering (ETECTE), November 2023

2. P. S. G. de Mattos Neto et al., “Energy Consumption Forecasting for Smart Meters Using Extreme Learning Machine Ensemble,” Sensors, vol. 21, no. 23, p. 8096, Dec. 2021, doi: 10.3390/s21238096.

3. Win Hlaing, Somchai Thepphaeng, Varunyou Nontaboot , Natthanan Tangsunantham, Tanayoot Sangsuwan, “Implementation of WiFi-Based Single Phase Smart Meter for Internet of Things (IoT)”, 5th International Electrical Engineering Congress, March 201

4. M.Karpagam “IoT Based House Hold Security Systems”, International Journal of Advanced Research Trends in Engineering and Technology. Vol 4 Special Issue, March 2017

5. N. H, Azmi, N. A M. Leh, and N. A Kamaruzaman, "Modeling of energy meter using MATLAB/Simulink," in 2018 9th IEEE Control and System Graduate Research Colloquium (ICSGRC) , 2018, pp, 75-80: IEEE

6. A Rhesri, R Bennani, Y, B, Maissa, L Hajjaji, A Tamtaoui, and H, Dahmouni, "Development of a low-cost Internet of Things architecture for energy and environment monitoring in a University Campus,"2023 lOth International Conference on Future Internet of Things and 2023 10th International Conference on Future Internet of Things and Cloud (FiCloud) Cloud (FiCloud), 2023, pp, 181-185: IEEE

7. J. K, Mishra, S. Goyal, V. A Tikkiwal, and A Kumar, "An loT based smart energy management system," in 2018 4th international 2018 4th international conference on computing communication and automation (ICCCA) conforence on computing communication and automation (ICCCA) , 2018, pp, 1-3: IEEE

8. M. H. Shah, S. Khan, A Khan, L Khan, and S.M. Eldin, "Sustainable energy management using the Internet of Things (loT)," Plos one, voL 18, no. 6, p. e0283754, 2023.

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