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Smart Meter Utilizing Fuzzy Logic and IoT

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ABSTRACT- Smart systems are utilized for home applications to enhance the protection reliability and cost economy. The main challenges of a smart system are time process, decision reliability, fault classification, and the ability to connect with the Internet of Things (IoT). In this proposal, a smart system power meter will be designed using artificial intelligence (AI) and IoT. The fuzzy logic with the microcontroller and the internet application are system parameters. Results show that the cost and fault of the power are successfully classified and discovered *via* fuzzy logic to notify the customer about the situations of home power. The system manages the home power cost and protects the home's devices from damage.

Keywords: Smart power system, IoT, fuzzy logic, fault detection.

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1. INTRODUCTION

Recently, life required the design and construction of intelligent and sustainable cities that enhance reliability and give the ability to integrate with the world based on developed applications [1] [2]. Explosion utilizing the smart devices and applications that push researchers to be interested in conveniently constructing smart homes (SH) with these applications. Whereas the automated observation of the machines and instruments enables the householder to carry out missions when far away or before reaching one's destination, in other terms, the ability to control, protect, and monitor the SH can be done without the homeowner's involvement [3]. Moreover, the SH system introduces essential and reliable assistance to the elderly and disabled via utilizing a smartphone to carry out, control, and monitor purposes [4][5][6].

The Iraqi electricity grid was established over a century ago, challenging many problems and not convenient for smart cities or home applications [7]. Increasing energy demands with time was the face of the developing electricity network. Furthermore, the increase in the price of the kilowatt /hour will fatigue consumers' financial budgets [8]. The use of smart meters has become a necessity for its purpose of protection, fault prediction, control, and informing the consumer about the energy situation in the real-time process [5][9][10].

The development of energy meters is classified into three different brands: - traditional, semi-smart, and smart energy meters [11]. The conventional meters measure and display the total consumption of customer load [12]. Manual data is collected via the electricity laborer, which is the leading property of the meter. The second development was semi-smart energy metering, based on the data-collecting manual but containing control and protection. It can communicate with a homeowner for mentoring and managing the problem if it happens. The third type, the smart meter feature of this meter allows the Electricity Company to communicate with the meter and monitor and control it based on utilizing a smart grid and IoT [13].

IoT technology, one of the world's hottest technology areas, is now gradually being used in various fields. The application of this technology has been an infrastructure of most techniques in healthcare, industry, education, military, spy, environment, and sensors [14][15]. These IoT techniques have enhanced energy consumption, capability, flexibility, usability, and reachability based on improved communication between devices and data interchange during real-time processing. Moreover, the IoT is based on other technologies for data collection, such as Wireless Sensor Networks (WSNs), ZigBee, and near-field communication (NFC) [16].

The estimated number of devices lined with the network will reach 75 billion in 2025. thus, Challenges with the rapid increase in Internet devices face big data collection, secret of information during interchange, and real-time processing [17][18].

Artificial intelligence (AI) has recently been utilized for SH employment in districts of control, data processing, fault prediction, and decision-making. AI is related to many technologies, such as fuzzy logic, which are selected based on

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the environment of the applications. In quintessence, the utilization attempts of fuzzy logic regarding SHs has been flourishing and effective [19][20][21]. The FL can predict the fault and be more skilful than conventional digital or analog control systems, thereby being flexible and reliable for the input and the output data to represent system behavior[22].

2. LITERATURE REVIEW

Depending on the historical sequence, this section will mention some research related to smart home applications, smart meters, utilizing AI, and IoT applications.

[23] presented advanced power strips (APS) with reduction strategies for load based on load sensing and scheduled timers. The result showed saving energy for the devices used in an office. Data collected from the plug via wireless technique (ZigBee) was fed to the main getaway to process the data. In [24], the power is controlled based on the motion sensor and the use schedule, and the system is implemented.

They proposed a new scheme for power consumption reduction. It is called the Residence Energy Control System, and it is based on IoT and wireless sockets. The scheme features monitoring and controlling the home device by turning off all unused appliances [2].

The FL and Bat Algorithm with IoT is utilized in many applications for the smart home and smart meter, such as in [25]. [26] worked on the smart system based on utilizing the IoT, which can be amicable with a smart grid. The system consisted of Arduino, an Xbee for wireless application, and the control management via relay and other electronic parameters. The system monitors the voltage, root mean square current, power factor, apparent power, and W/h. In contrast, other authors suggested smart meters that focus on monitoring the power of the data related to current, voltage, and energy without control of the power, such as in [27].

[28] has implemented a smart metering system for monitoring data controlling energy, and power quality for the main demand of the building. The IoT is utilized for monitoring and controlling the data, and the aim of the work is energy consumption. In [29], photovoltaic power generates maladjusted power based on utilized fuzzy logic, and the system controls the problem of the over and under voltage, which was fixed. Moreover, fuzzy logic is used to detect the line's fault and its instability.

The authors in [30] presented the implementation of a smart meter for monitoring and controlling the home's load. Also, the design depends on utilizing the IoT technique and enhancing the energy consumption with a control load based on measuring the voltage and the rms current. The system controls the power using wireless technology (ZigBee), and the computer collects data from the wireless sensors to monitor and show the amount of energy saved.

Also, in [9], the presented system utilized IoT and the FL technique to save and manage the energy of the smart home. The main aims are to control the air conditioning to give the owner comfortable weather and illuminance control to save power. The results show that the FL successfully manages temperature, humidity, and illuminance to save energy for cost reduction.

Power quality in microgrids was improved by reducing the voltage harmonics and unbalanced voltages by utilizing the ANFIS [31]. [32] suggest a wireless monitoring system for measuring the three-phase currents in the building by using current sensors with ESP32 microcontrollers to transmit the data according to the Internet of Things (IoT) technique to app on the mobile phone.

The work presented in this paper focuses on monitoring, predicting, and protecting based on utilizing IoT and fuzzy logic techniques. The data will be displayed on the owner's LCD and cellphone. Moreover, the fuzzy will predict and classify the power sources' situations and detect faults. In contrast, the MC will process the control based on the FL decision to shut down the power and notify the owner.

Section one and two showed the introduction and the literature review. Section three focuses on the proposal methodology. The description of the system parameter is mentioned in section four, and the discussion of the simulation results and the experiment work is displayed in section five. The conclusion of the work is shown in section six.

3. PROPOSAL METHODOLOGY

The methodology of the work will be based on two parts; the first section focuses on the simulation of the fuzzy conditions and parameters for successfully confirming the selected conditions with system design based on utilized MATLAB. The second part is the design of the FL within the microcontroller and connecting the system with mobile based on utilizing IoT. *Figure 1* shows the integrated work of this proposal.

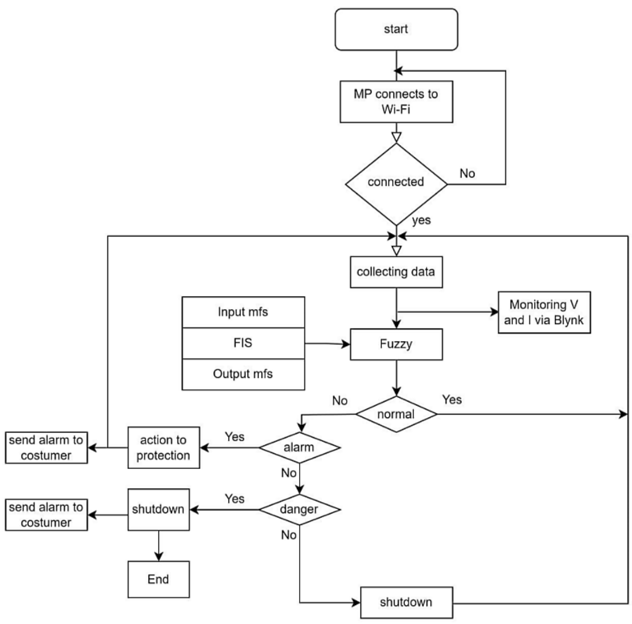

Figure 1. Integrated flowchart of the proposal

4. SYSTEM CONSTRUCTED

The system was implemented based on voltage and current sensors, and the data collected from these sensors will be fed to the microcontroller (AT332). The fuzzy IoT connection and the other conditions were designed within the MC Arduino code. The sensor MC and other parameters of the device will be described below.

4.1. Sensors and Interface Items

ZMPT101B is an AC voltage sensor for a single-phase voltage that works with the transformer-based principle, as shown in *figure 2* [33]. The main features of the sensor are good uniformity for power and voltage, high accuracy, and the ability to measure more than 250v, which is convenient for system conditions; the formula used with this sensor to give the actual value is shown in *equation (1).*

$$voltage = readValue \times 5.0 / 1023 \times \text{sensitivity value} \qquad (1)$$

Where 5.0 is the maximum voltage the sensor can measure, and 1023 is the maximum value returned by the analogRead () function [34].

The sensor ACS712 is the current sensor that was utilized to collect current data and feed it to the MC, as shown in *figure 3*. It works based on the Hall Effect to measure the current passing through the cable. The range of this sensor is convenient for this proposal, and its maximum sensed reach is 60A, as mentioned in the sensor datasheet. The main features of this sensor are: low noise, high response to current changes, and zero hysteresis of magnetic effect [35]. The formula used to calculate the actual value of the current is shown in *equation (2).*

$$current = \{(Readvalue / 200) - 514\} \times \text{sensitivity value} \ (2)$$

Where 200 is the number of samples taken, 514 is the offset value to compensate for the zero-current output [34].

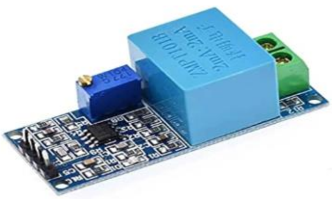

Figure 2. Voltage Sensor (ZMPT101B) [34]

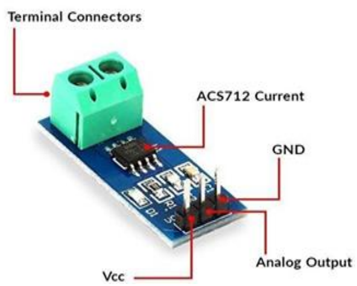

Figure 3. Current Sensor (ACS712) [34]

4.2. Microcontroller

The proposal focuses on utilizing the IoT; thus, the selection of the MC should include the ability to use Wi-Fi applications based on the motive for using the MKR1000 for this project. It can program by the Arduino IDE board supplies at 5 V, contains 8 pins for the digital I/O and 7 pins for analog I/O, Flash Memory is 256 KB, and SRAM is equal to 32 KB as shown in *figure 4 [36].*

Figure 4. MKR1000

Other parameters that implement the system are the relay and the LCD. A relay module is the interface between the MC and the field of power. Moreover, they will monitor data with real-time processes. The owner is near the system and can read all the data and the situation of the power related to the power of the home. The integrated system after construction is shown in *Figure 5.*

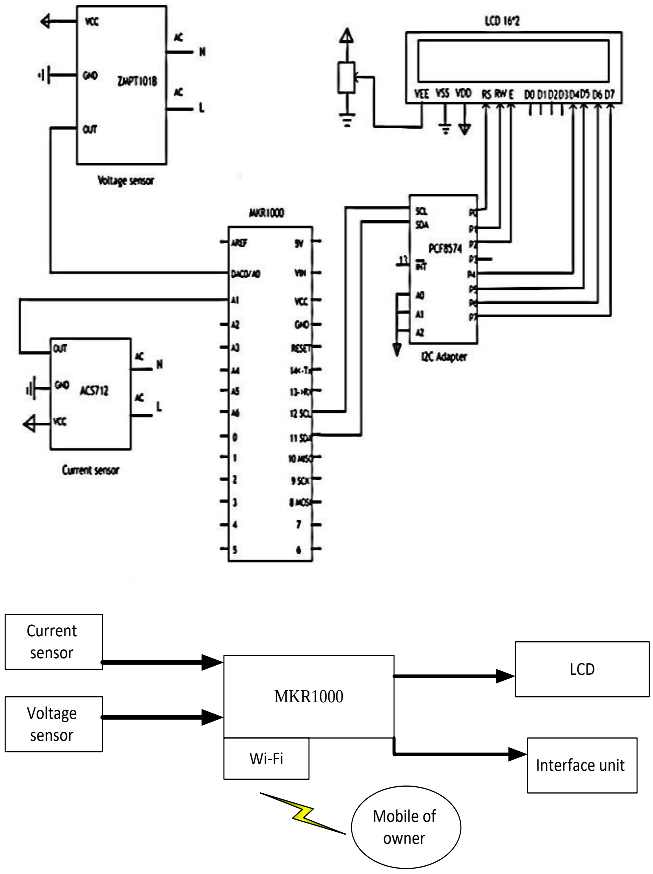

Figure 5. Integrated System

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5. RESULTS AND DISCUSSION

5.1. Fuzzy Design and Results

Fuzzy logic converts the physical environment to logic based on classifying and predicting (defuzzification) situations related to an input parameter (fuzzification). The rule inference and other parameters (FIS) have been designed based on the imagination about the output needed and the experience of the condition of the designer.

In this research, FL logic was designed with three inputs, 48 rules, and utilized Mamdani FIS and one output, as shown in *figure 6*.

A machine of 220 V was built to keep the voltage level during the lifetime of different instrument. It is well known that if the voltage range is under the proposed range, the amperage of the machine rises, which may cause breaking down of the machine or fusing of components. On the other hand, if the voltage is over the normal range, this causes the machine to work faster and subsequently lead to damage or shorten the machine's life.

Figure 7(a) shows the fuzzy logical structure of the first fuzzification the four situations of the voltage represented by (a) under_V (b) normal_V; (c) alram_Vz, and (d) ander_V, while membership functions used are Z- Shaped, Trapezoidal, Triangular, and S-Shaped, respectively. The system predicts the voltage when exceeds 220 v by alarming owner so suitable action to be taken to protect the home from damage Over-current is a case where a current is higher than the estimated current. The number of machines used and season leads to change in the utilized current value. A second input with four MFs was designed based on the experience and the estimated current range used with different seasons as shown in *figure 7(b)*. the second input is classified as normal_A, Med_A, High_A, and V.High_A. The membership's functions are Z-Shaped, Triangular, Triangular, and S-Shaped, respectively.

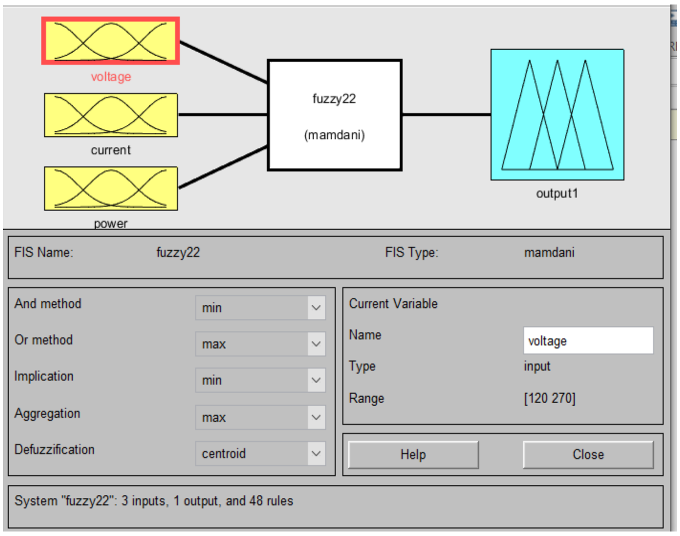
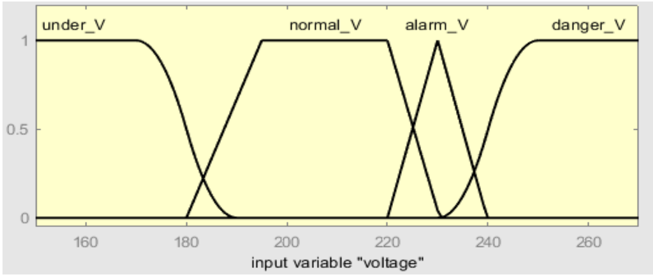
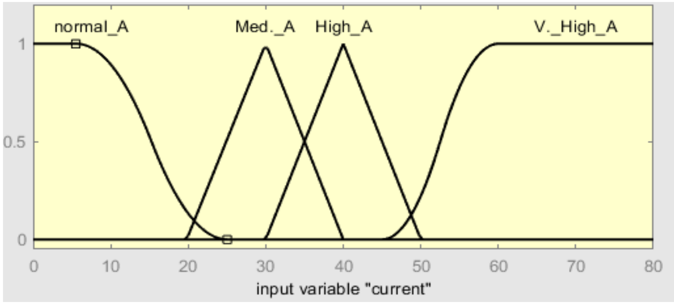


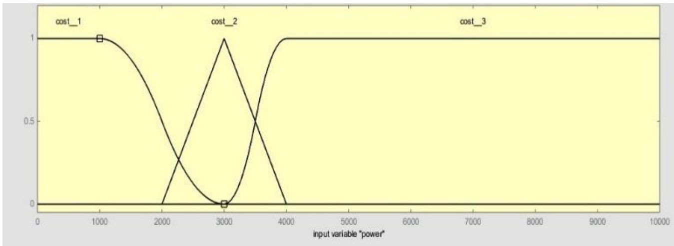
Figure 6. MATLAB windows of the fuzzy logic controller



(a)



(b)



(c)

Figure 7. (a) Voltage membership functions, (b) Current membership functions, (c) Power membership functions

Power per hour (P/h) was calculated via utilization of the current and voltage value, which is the third input for FL; that formula of P/h is shown in *equations (3)* and *(4)*. One watt of electrical power is maintained for one hour, equal to 3600 joules.

$$\text{Power} = \text{voltage} * \text{current} / 1000 \quad (3)$$

$$\text{Power/hour} = \text{power}/3600 \quad (4)$$

The P/h parameter is classified based on the price of the Iraqi policy for the Ministry of Electricity. The main condition of that policy is double the cost after 1000 units. Based on that, it rises rapidly, increasing the cost to the consumer. Thus, the input of the P/h is classified as cost 1, cost 2, and cost 3, the memberships function is Z- Shaped, Triangular, S-Shaped, respectively. Figure 7-c shown the P/h memberships function. These rules of FL are the leading force of the system which is constructed as a string of if.......then statements. Their function in FL systems is analogous to divert roles in conventional control systems. The 48 rules of the system are designed based on experiences, theoretical thinking, and deduction of power behavior. The design focuses first on the danger zones related to (under and over-voltage, over-current, and high cost). While, the alarm zones is notifying the owner if the voltage, current, and cost start to rise over normal values, as shown in the *table 1*. The system will inform the owner about the P/h situation when it increases. The 48 rules described in *table (1)* for this proposal

The output of the FL implemented based on four membership functions to give the cases as normal, alarm1, alarm2, alarm3, and danger; the alarm zone was divided into three situations to enhance the fault classification accuracy, as shown in *figure 8*.

Table 1. Fuzzy rules

Input		Output		
Current	**Voltage**	**Cost 1**	**Cost 2**	**Cost 3**
Normal	Under_V	Danger	Danger	Danger
Normal	Normal	Normal	Alarm_1	Alarm_3
Normal	Alarm	Alarm_1	Alarm_2	Alarm_3
Normal	High_V	Danger	Danger	Danger
Medium_A	Under_V	Danger	Danger	Danger
Medium_A	Normal	Alarm_1	Alarm_2	Alarm_3
Medium_A	Alarm	Alarm_2	Alarm_3	Alarm_3
Medium_A	High_V	Danger	Danger	Danger
High_A	Under_V	Danger	Danger	Danger
High_A	Normal	Alarm_1	Alarm_2	Alarm_3
High_A	Alarm	Alarm_2	Alarm_3	Danger
High_A	High_V	Danger	Danger	Danger
Very_High_A	Under_V	Danger	Danger	Danger
Very_High_A	Normal	Danger	Danger	Danger
Very_High_A	Alarm	Danger	Danger	Danger
Very_High_A	High_V	Danger	Danger	Danger

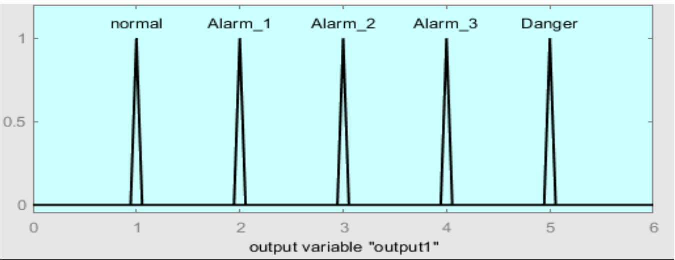


Figure 8. Output membership functions

All the processes of designing FL have been done via MATLAB Simulink to ensure that the FL gives the required output and classification based on the rulers' inference. Moreover, the entire design was implemented within Arduino code IDE to construct the smart meter system.

5.2. Result of the proposal

The 48 rules and MFs (input and output) are realized by Mamdani FIS for fault detection and notify the owner about electricity and cost situations. The results from testing with different states (normal value overall, under and over-voltage, and the over-current) showed the FL is successful in defining these faults. Moreover, the system monitors the real-time process of the data via display and the IoT (cell phone). The data collating from the field related to voltage and current used equations 1 and 2. At the same time, the P/h calculated within the MC, as mentioned in the previous section, is based on the equation utilized (4). After the collection and calculation processes, the data is applied to the FL for analysis and to identify the correct decision for predicting the fault or describing the situation of the three parameters—the data monitoring on the system via LCD, as shown in *figure 9*.

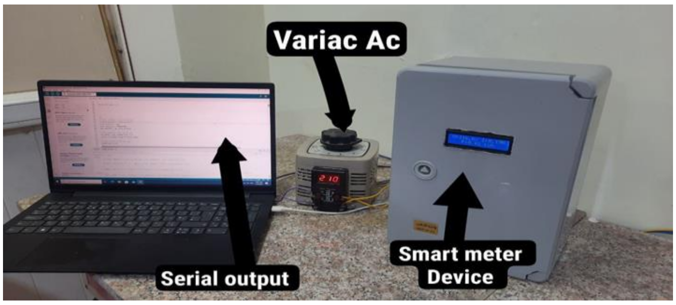
The FL has many limitations connected with accuracy and decision precision. The memberships of FL are depending on the experiment and testing which reflect the precision. Moreover, the selection of rules MFs numbers, and the range of MFs that lead to enhance the accuracy of the results.

Figure 9. LCD monitor data of the system

Sources of empirical errors of measurement are the sensor utilized, system design, testing pieces of equipment, and data fusion processing within the system. to avoid these mistakes, flowed these steps: sensors selected based on other research used, checked the data reading via more than one measuring device to ensure reading precision, and utilized the maximum accuracy with the code design for data collection. Previous processes will reduce the error source and give acceptable accuracy for fault detection as shown in the figures below.

Many tests were performed after the system and connected with cell-phone via IoT. Proposed system was monitored data collecting from the sensors, detecting current and voltage cases, and notified the owner. *Figure 10* presents various situations for the power that links with normal, alarm, and danger cases for the voltage.

The system was examined to ensure it can give correct responses about the input data using (variac) and show the response for the results via serial port, LCD, and Blynk, as shown in *figure 10 &11*. Figure 10 showed the integrated system was verified, and based on the change; the input parameter results were changed to describe the correct case of the data.



(a) Smart system test

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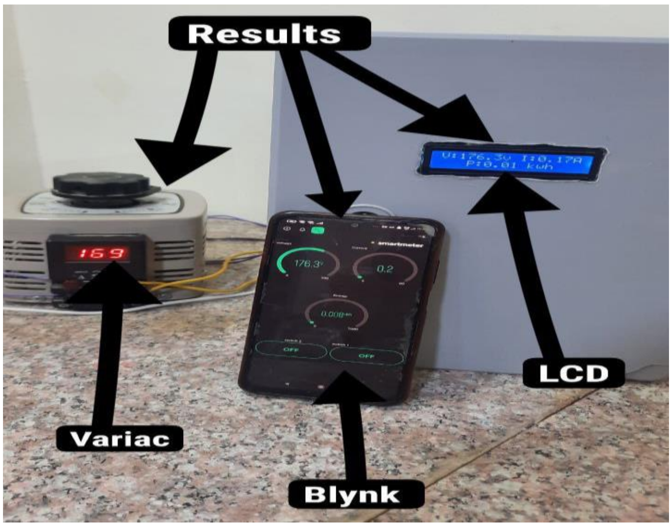
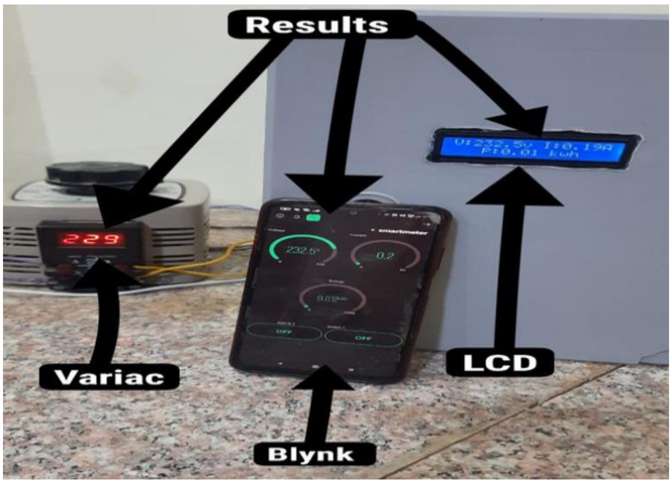


(b) Danger

(c) Normal



(d) Alarm

Figure 10. Experimentation (a) smart system test (b) Danger (c) Normal (d) Alarm

The implemented system notifies the owner when the voltage is in the alarm and danger zones. Moreover, system enables the relay to do for protection if been in alarm or danger zones. Thus, the system behavior detects the fault case established on using the FL which is built within the microcontroller. Also, the data of the serial port of microcontroller which are proving system takes the correct decision after fault detection as shown in *figure 11*. This figure shows the real-time processing of the data for normal and fault detection (under voltage, normal, alarm, over-vulgate) all are shown in *figure 11(a, b, c, d).*

Figures 11(a) and (b) show the normal case, while *figure 11-c* shows the alarm situation. The danger zone of the system is shown in *figure 11-d*.

```
voltage: 220.43 v
current: 0.12 A
Power :0.01 kwh
Input:
        Voltage: under_V-> 0.00, normal_V-> 0.96, alarm_V-> 0.00, danger_V-> 0.00

        Current: normal_A-> 1.00,  Med_A-> 0.00,  High_A-> 0.00,  Very_High_A-> 0.00

        Power: cost1-> 1.00, cost2-> 0.00, cost3-> 0.00, Very_High_cost-> 0.00

output:1.00
        Risk: Normal-> 0.96, Alarm_1-> 0.00, Alarm_2-> 0.00, Alarm_3-> 0.00, Danger-> 0.00
```

(a) case 1

```
voltage: 225.76 v
current: 0.22 A
Power :0.01 kwh
Input:
        Voltage: under_V-> 0.00, normal_V-> 0.45, alarm_V-> 0.15, danger_V-> 0.00

        Current: normal_A-> 1.00,  Med_A-> 0.00,  High_A-> 0.00,  Very_High_A-> 0.00

        Power: cost1-> 1.00, cost2-> 0.00, cost3-> 0.00, Very_High_cost-> 0.00

output:1.00
        Risk: Normal-> 0.45, Alarm_1-> 0.00, Alarm_2-> 0.00, Alarm_3-> 0.00, Danger-> 0.00
```

(b) case 2

```
voltage: 230.40 v
current: 0.17 A
Power :0.01 kwh
Input:
        Voltage: under_V-> 0.00, normal_V-> 0.01, alarm_V-> 0.96, danger_V-> 0.02

        Current: normal_A-> 1.00,  Med_A-> 0.00,  High_A-> 0.00,  Very_High_A-> 0.00

        Power: cost1-> 1.00, cost2-> 0.00, cost3-> 0.00, Very_High_cost-> 0.00

output:3.02
        Risk: Normal-> 0.01, Alarm_1-> 0.02, Alarm_2-> 0.00, Alarm_3-> 0.00, Danger-> 0.02
```

(c) case 3

```
voltage: 89.56 v
current: 0.21 A
Power :0.01 kwh
Input:
        Voltage: under_V-> 1.00, normal_V-> 0.00, alarm_V-> 0.00, danger_V-> 0.00

        Current: normal_A-> 1.00,  Med_A-> 0.00,  High_A-> 0.00,  Very_High_A-> 0.00

        Power: cost1-> 1.00, cost2-> 0.00, cost3-> 0.00, Very_High_cost-> 0.00

output:5.00
        Risk: Normal-> 0.00, Alarm_1-> 0.00, Alarm_2-> 0.00, Alarm_3-> 0.00, Danger-> 1.00
```

(d) case 4

Figure 11. Serial port shows different cases of the FL output, and data describe (a) case 1, (b) case 2, (c) case 3, (c) case 4

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Blynk is one of the IoT applications that can be utilized via iOS and Android. This application has two options based on the library's kind; the first is the free type, and the second is the application of the uses after pay. In this proposal, Blynk uses it to monitor the data of house owners and generate an alarm tone if the data exceeds the condition limit. Thus, the free type of the Blynk was utilized, as shown in *figure 12*.

(a) Blynk dashboard

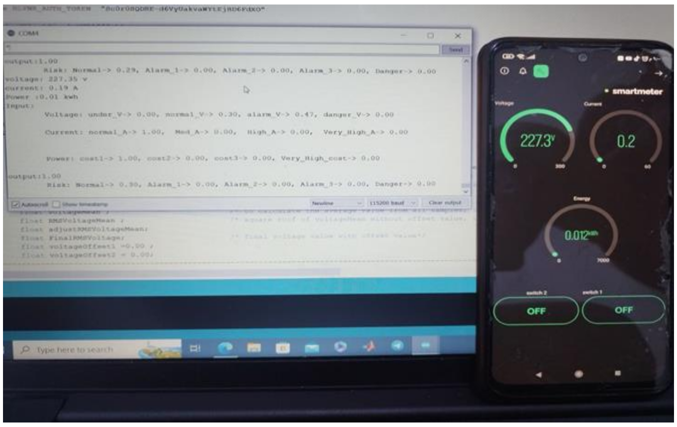

Figure 12. (a) Blynk dashboard (b) serial port and Blynk dashboard with same results

6. CONCLUSIONS

Smart applications are the daily life requirements that are convenient in a smart city; therefore, the smart meter is one of these applications needed for fault detection and home protection from the problems caused by the power supply. A smart meter was designed and implemented based on the classification and identification of the fault via FL. Moreover, the system predicts the fault and can take some action to prevent damage in a home. The IoT allowed the system to notify the owner about the data situation and alarm the owner. Based on many tests, the system successfully discovered the power supply's fault, sent an alarm to the owner, and took action to disconnect the power source.

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