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DESIGN AND IMPELEMETATION OF SMART ELECTRICAL POWER METER FOR THE IRAQI ELECTRICAL NETWORK

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Abstract: Consumption of electrical energy is one of the biggest challenges for the countries around the world. Most of the developing countries, including the Republic of Iraq, consume more electrical energy than they produce , leading to power outages during peak hours due to excessive energy demand. Therefore, there is a need to reduce the consumption of electrical power to overcome this issue. In this study, A novel design of digital smart power meter will be used for the Iraqi electrical network is proposed to eliminate the problem. Najaf City was elected as a case study. The smart digital power meter is used to measure the electrical power consumption and adjust the rate dynamically based on the time of day. The meter's readings will be transferred to the distribution station by integrating a global system for mobile communication (GSM) module into the meter. Based on the results, the designed system offers many advantages. The system helps prevent the use of unnecessary devices during peak hours, assisting consumers in balancing the daily electricity load. Additionally, the implemented system introduces a cost-effective method for calculating power consumption, proving to be more efficient than the current meter system used by Iraq's Ministry of Electricity, which relies on energy readers. The designed system also reduces fraudulent meter readers who collect money from citizens. By utilizing the proposed system, a live database will be created for each household, enabling the Ministry of Electricity to enhance consumption management and electricity generation across Iraq. Furthermore, the smart meter itself is highly cost-effective, being significantly cheaper than conventional power meter reading devices.

Keyword: Electrical Energy; Electrical Networks; Smart Meters; Power Consumption; Arduino UNO.

1. INTRODUCTION

Electrical energy has been considered as an economic backbone for each country in the world. Developing countries consumed electrical energy larger than electrical energy which generated a shutdown in an electrical network during rush hours due to excessive consumption of electrical energy. Usually, Ministry of Electricity (MoE) in Iraq cannot handle the huge demand on the electricity because of the generated power cannot reach the real consumed power by consumers. So, to provide the electricity to all regions in Iraq country, the ministry depends on (scheduled load shading: which means cutting the electrical power in region to provide the electricity in other regions and so on [1]. Hence, there is a need to decrease consumption of electrical power to avoid this issue [2]. The process of fees collection in most countries in middle east including the Republic of Iraq is a complex process depends basically on power meter readers. A power meter reader is a person appointed by the ministry of electricity which read the number of units that consumed from each house in Iraq regions every two months, and they have cost the ministry of electricity extra money for their job. Likewise, the cost of building the alive system that can be used by the ministry of electricity to build a database that can recognize how much power each house in Iraq consumes is a very complicated process and cost a million dollars. The main research question driving this project is: How can an IoT-based power meter improve billing accuracy, optimize electricity consumption, and support load balancing in the Iraqi power grid? The hypothesis of this research is to encourage consumers to shift their energy usage to non-rush hours, thereby reducing excessive demand during peak times, which dynamically adjusts electricity tariffs based on peak and off-peak hours, by implementing an IoT-enabled smart meter system. This design is expected to minimize scheduled load shedding, provide a cost-effective, automated billing system that eliminates the need for manual meter readings, and enhances the overall efficiency of the electrical grid.

In this paper , a proposed digital smart power meter is designed to address and eliminate and mentioned problems. The meter determines the cost of units that are consumed in normal usage hours at a specific price and the cost of units which are consumed in the rush hours at a higher price. The conducted smart meter will achieve load balance to the national Iraqi network by the Iraqi citizens. Hence, the overload cases during rush hours will be dissipated and moved to the normal usage hours by the citizens by Iraqi citizens due to the cost of units during rush hours is more than its cost in normal hours.

2. RELATED WORK

In recent years, the development of IoT-based electrical power meters has been a focal point in enhancing energy monitoring and management systems. For Example, to offer a cost-effective solution for utility companies, a method to convert traditional electromechanical meters into digital power meters within an Automated Meter Reading (AMR) system introduced is used by integrating an optical encoder, the system enables tamper detection and automatic data transmission [3]. Like the previous work, an IoT-based smart system was designed for monitoring electrical energy consumption by utilizing the MQTT protocol, microcontrollers, and sensors. The system shows real-time data on current, voltage, energy consumption and active power, facilitating the management of efficient energy [4]. A proposed smart meter system employing the ADE7757 power sensor module and Node-MCU ESP-32 was designed. This system uses AppSheet platform to log energy consumption data to cloud storage, providing consumption analytics and digital displays to reduce their energy usage and help consumers manage effectively[5]. Additionally, an IoT-based smart grid monitoring system was developed to enhance energy efficiency. The system uses an Arduino Uno microcontroller, the NodeMCU Wi-Fi module , and voltage and current sensors to provide real-time energy management and monitoring [6]. These studies collectively revolutionize energy consumption monitoring and management by providing the potential use of IoT-based smart meters, showing benefits like enhanced accuracy, real-time data access , and improved load control. A large number of research has focused on improving the capabilities and design of smart electrical meters, which are primary to modern energy systems [7][8]. Many research papers have proposed many evaluation methods to assess the performance of smart electrical meters[9][10]. These papers examine and evaluate important factors such as data accuracy, reliability, compatibility, and integration with the larger smart grid network. The main outcomes from these appraisals have played an important role in developing effective demand-side management plans, which are vital for grid stability and efficient energy utilization, particularly in the electrical grids which integrate sources of renewable energy. Fault detection and system reliability have also been key areas of research. Smart meters with real-time monitoring capabilities can find issues such as short circuits and power failures, reducing downtime and enabling rapid response [11]. In addition, IoT-enabled smart meters provide both operators and users with valuable insights into energy usage patterns, potential cost reductions and supporting proactive energy management. The most recent papers have also concentrated on IoT-based energy monitoring solutions to improve transparency in billing processes and energy consumption. Systems using microcontrollers like the ESP32 gather real-time data from smart meters and send updates through platforms such as WhatsApp and Telegram, assisting users in managing and tracking their energy consumption. Another paper on secure data aggregation for smart meters has evaluated cloud-edge collaboration models like improve privacy and system efficiency [12][13]. Recent research papers in the implementation of IoT-based electrical power meters have been explored and evaluated in various studies, aiming to enhance energy management and monitoring. For example, a smart meter system for smart cities is developed that uses the Message Queuing Telemetry Transport (MQTT) protocol to transmit data on current , voltage, energy, and power consumption to a centralized database, enabling efficient monitoring and billing processes[14]. Also, an electric power meter based on the ZigBee wireless sensor network was designed by employing the XBee-PRO OEM RF Module for wireless communication. This design facilitates remote reading of power consumption, minimizing human error and reducing the need for manual meter readings[15]. In another project, An IoT-based electricity metering system was developed that integrates IoT technologies and embedded systems to allow electricity departments to read meter readings remotely. The system includes features such as fire detection and provides online monitoring or power tripping in case of overvoltage or to help consumers manage their energy usage in an effective way [16]. Moreover, the smart meter allows for automatic and manual control of electrical loads via a web application, providing efficient energy use[17].

Finally , the main aim of smart electrical meters in energy-saving has been achieved . Tools like real-time estimation models are used to monitor consumption patterns that promote sustainability and resilience in response to global energy challenges. This research underscores the significance of smart meters in the future of smart electrical meters.

3. METHODOLOGY OF THE PROPOSED METER (MATERIALS & METHODS)

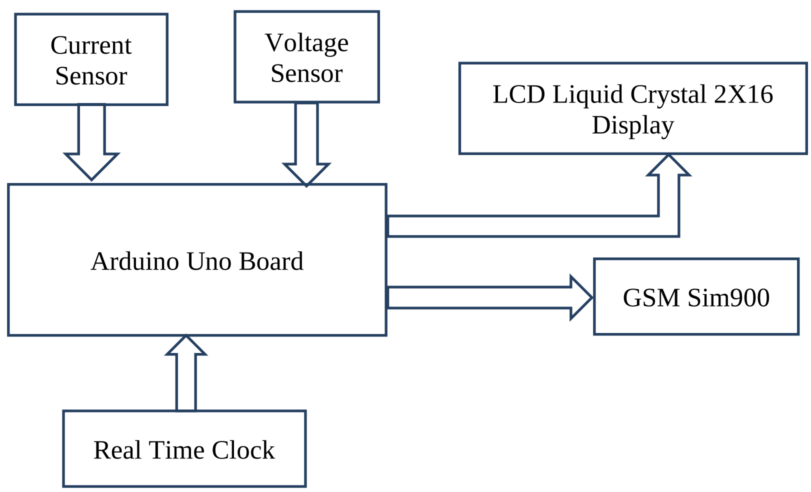

Figure 1. Block Diagram of the proposed Meter Circuit

3.1. Measurement Circuit

To calculate the consumed electrical power we have designed a digital electrical power meter alternative to using the classical electromechanical power meter. The circuit design consists of several components namely: Arduino UNO board (ATmega328P), CT sensor SCT-013-000, 9V AC-AC voltage Adapter, DS3231 Real Time Clock, GSM Sim900, LCD liquid crystal 2X16 display, Number of resistors and capacitors for voltage step down. The computer connected to a Microcontroller via USB cable and Current transformers (CTs) sensors is used to measure alternating current to the electricity consumption of a building. CT works as a split core type for wiring connections to prevent any high voltage electrical work needed. For building monitoring, primary and secondary winding which used via the opening in the CT. Whether primary indicates to the live or neutral wire (not both) coming into the building while the secondary winding is made of many turns of fine wire housed within the transformer the alternating current flowing in the primary produces a magnetic field in the core.

$$I_{secondary} = CT \text{ turns Ratio} \times I_{primary} \quad (1)$$

$$CT \text{ turns Ratio} = \text{Turns}_{primary} / \text{Turns}_{secondary} \quad (2)$$

The number of secondary turns at the CT below is 2000.

On the other hand, An AC voltage measurement is needed to calculate real power, apparent power. The measurement is used to convert AC to AC power adaptor and can be saved which does not require high voltage work. The adapter transformer provides high voltage isolation. While DS3231 is a low -cost and accurate and real-time clock (RTC) device. The device contains a battery input, and it maintains accurate timekeeping when main power to the device is interrupted. RTC maintains date and time information and can be modified automatically.

Besides, GSM/GPRS Quad-band cell phones are used for communication, SMSs, and internet access. The module is like a big package (0.94 inches x 0.94 inches x 0.12 inches) with L-shaped and can be called in four sides and managed via AMR926EJ-S processor for communication purposes.

Also of receiving the circuit commands. And An LCD screen is very commonly used in various devices and circuits to display special & even custom characters due to economical; easily programmable.

3.2 Real Power Calculations

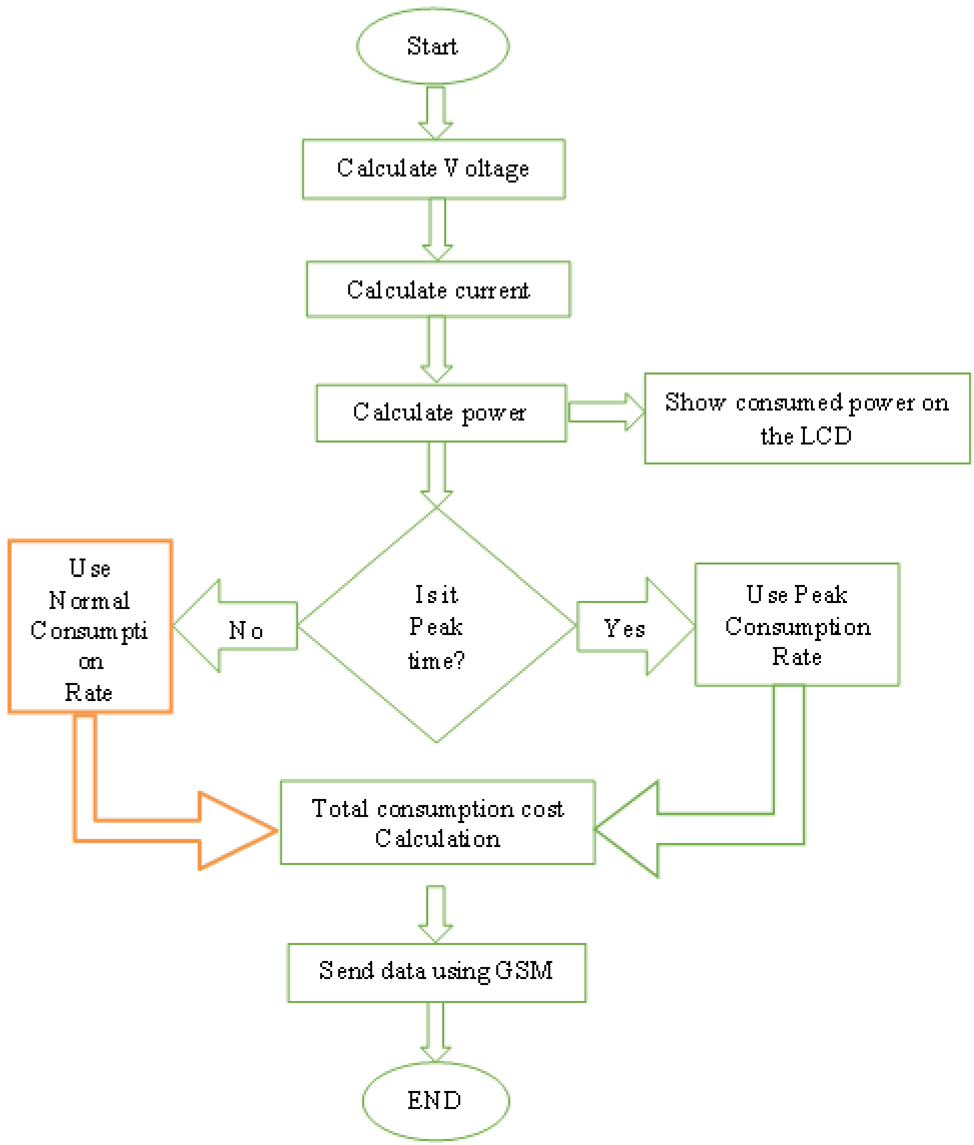

Figure 2. Flowchart of the Real Power Calculation Scenario

3.2.1 MAIN CURRENT POWER CALCULATION

CT sensor connects to an Arduino to meet input requirements of the Arduino analog inputs. Two main parts are used to achieve the balance between positive voltage between 0V and the ADC reference voltage which are CT sensor and burden resistor and biasing voltage divider (R1 & R2). Several steps can be taken to convert the current signal. These Steps can illustrate via measure The YHDC SCT-013-000 CT by choosing the current range you want which has a current range of 0 to 100 A, multiplying by √2 to Convert maximum RMS current to peak-current see Eq. (3).

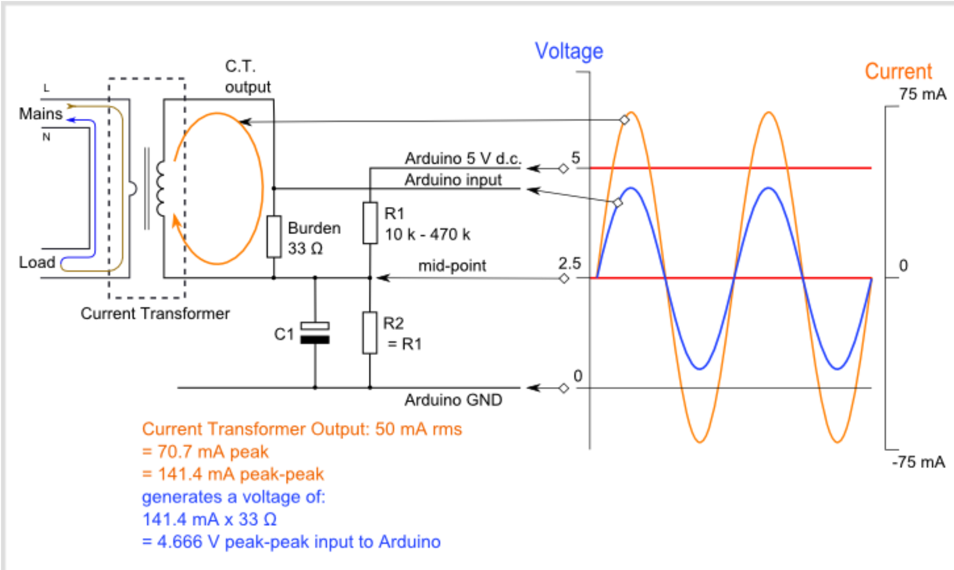

Figure 3. Circuit Diagram for the CT sensor and Arduino

Primary peak-current = RMS current × √2 = 100 A × 1.414 = 141.4A (3)

And, to give the peak-current in the secondary coil by dividing the peak-current by the number of turns in the CT. The YHDC SCT-013-000 CT has 2000 turns, so the secondary peak current can be calculated by

Secondary peak-current = Primary peak-current / no. of turns (4)
= 141.4 A / 2000 = 0.0707A.

In addition, to maximize measurement resolution, the voltage across the burden resistor at peak current should be equal to one-half of the Arduino analog reference voltage (AREF / 2) by.

Ideal burden resistance = (AREF/2) / Secondary peak-current (5)
= 2.5 V / 0.0707 A = 35.4 Ω
35.4Ω is not common resistor value. The nearest value of 35.4 is 33 Ω.

3.2.2 VOLTAGE CALCULATION

The output signal from the AC voltage adapter is a near-sinusoidal waveform. If we have a 9V (RMS) power adapter the positive voltage peak be 12.7V, the negative peak -12.7V.
Two steps are performed to convert the output of the adapter to a waveform (< 5V for positive peak and >0V for negative peak). A voltage divider is used to scale down the waveform via connected across the adapter's terminals and using a voltage source across Arduino's power supply.

For an AC-AC adapter with a 9V RMS output, a resistor combination of 10k for R1 and 100k for R2 would be suitable
Peak_voltage_output = R1 / (R1 + R2) x Peak_Voltage_Input (6)
10k / (10k + 100k) x 12.7V = 1.15V
The voltage bias provided by R3 and R4 should be half of the Arduino supply voltage.
Power calculation equations:
P(kw)=((0.707 *pf*I(A)V(v))/1000)*(1/12) (7)
For the Iraqi national electrical network the power factor is almost constant at (0.8).
Here's the circuit diagram and the voltage waveforms:

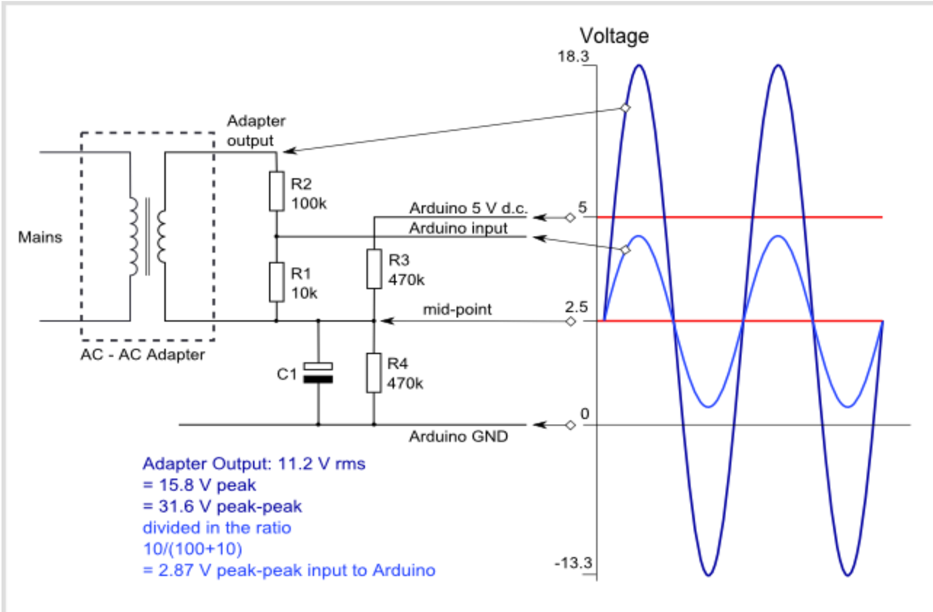

Figure 4. Voltage Transformer and Step-down Resistors with I /P Wave Forms

3.2.3 VOLTAGE EQUATIONS

RMS values both voltage and counts. Thus the number seen by the microcontroller is:
Counts = (input pin voltage ÷ 3.3) × 1024 (8)
Where:
Input pin voltage = adapter output voltage ÷ 11
And:
adapter output voltage = mains voltage × transformer ratio
voltage constant = 230 × 11 ÷ (9 × 1.20) = 234..26 (9)
(234.62/5)=46.924 which means each 46.924 volt in real life equal to 1v in Arduino input.

3.2.4 CURRENT EQUATIONS

Voltage is measured relative to the processor supply voltage. Which is used as the reference (in this case 3.3 V) and scaled so that the reference voltage would give the maximum count of (2) ^10 = 1024.
So after calculating the values of current and voltage we can sub them in main power equation:

P (Kw) = ((0.707 *pf*I (A) V (v))/1000)*(1/12). (10)

So after calculating the real power and dividing it by 12 to take read each 5 minutes with a cumulative 12 reads
To get the real power in (kwh) then multiply it with the consumption time cost that we are getting from RTC and showing the read on the LCD display then send the accumulative cost each 15-day using the GSM Sim 900.

4. MOTIVATION

From the recent annual report via the International Energy Agency (IEA) for 2019 In Iraq, although significant additions to the generation energy have been made recently and with available capacity expanding by 8 gigawatts (GW) (or 90%) between 2012 and 2018 [1]. However, this has not been matched by improvements in the condition of the power grid or reductions in losses (technical and non-technical). Several challenges such as Iraq damage wrought by ISIS war against and constrained budgets that lead to not producing enough electricity to satisfy demand. Besides, Iraq's population is growing at a rate of over 1 million per year. Hence, electricity demand is set to double, reaching about 150 terawatt hours

(TWh) (17.5 gigawatts [GW] average throughout the year). Thus, Iraq faces a profound need to develop its domestic energy infrastructure, in particular in the electricity sector to avoid these issues.
As alongside the after-mentioned issues and challenges concerning in Section Introduction, there are some of the factors that give rise to distribution losses (technical losses), but not all of them. Technical matters such as corona discharges, arcing and the skin effect. These issues such as:

Components of the Electrical Network

To better understand the challenges of energy distribution in Iraq and the factors affecting efficiency, it is essential to examine the key components of the electrical network, including circuits, meters, and transformers. These elements play a significant role in technical losses and impact overall power delivery.

1. Circuits (Underground Cables and Overhead Lines)

Electricity is distributed and transmitted through overhead lines and underground cables, which consist of conductive metals such as aluminum or copper. These metals exhibit electrical resistance, which leads to energy dissipation in the form of heat[18]. This phenomenon results in conduction losses, which have become more significant during peak demand periods due to increased current flow in the meta=ls[19]. Also, many factors like corona discharge, the skin, and arcing effect further contribute to inefficiencies in power transmission[20]. The losses that occur in the electrical circuits are classified as variable losses, as they depend on the load and can constitute up to two-thirds of total technical losses in the system.

2. Meters

Electricity meters are designed and used to measure consumer power usage, however; they also introduce minor power consumption. The cumulative effect across millions of meters results in 2% to 3% of total technical losses although each meter draws only a small amount of electricity [21]. In addition, outdated and inaccurate metering systems contribute to non-technical losses and billing discrepancies, further exacerbating inefficiencies in energy distribution. The integration of smart meters can help and minimize these losses by providing real-time monitoring, automated energy management, and accurate billing.

3. Transformers

Transformers play a crucial role in stepping up or stepping down voltage levels for efficient energy transmission. However, they introduce core and copper losses, which remain relatively constant regardless of the load. These are classified as fixed losses and account for approximately one-third of total technical losses. Transformer efficiency depends on factors such as design, maintenance, and load balancing, with poorly maintained or overloaded transformers leading to excessive energy dissipation.
By understanding these components and their contribution to losses in the electrical grid, it becomes evident that addressing inefficiencies requires a comprehensive approach. Implementing modern solutions, such as high-efficiency conductors, advanced metering infrastructure (AMI), and optimized transformer designs, can significantly reduce energy wastage and improve the overall performance of Iraq's power system.

5. RESULTS AND DISCUSSIONS

Electricity rates the price of electricity amounts or quantities of energy that is consumed within a specified time without depending on the type of load and sometimes referred to theoretically can be calculated by knowing the generation, transmission, and distribution costs, and taking into consideration the operational, capital and fixed costs. In some countries electricity rates typically vary for residential (household), commercial (business), agricultural and industrial customers. We can see this variation in the United State of America (from as electricity tariff or the price of electricity. State to state) and in some countries in the European Union and some other countries like turkey for example. Various recent works [8][9][11] have explored improvements in real-time monitoring, , IoT-based smart metering solutions, and data accuracy. These studies show enhancements in data aggregation, cloud-edge collaboration for efficient power management , and predictive analytics. Smart meters have improved in reliability and error minimization by integrating such methodologies. To ensure the reliability of our smart power meter, calibration was performed using a standard reference meter under controlled conditions. The designed meter was tested and verified at various current and voltage levels to evaluate and measure its precision across many operational ranges. The calibration process involved various test runs where measured energy consumption was compared and evaluated against a high-precision reference meter. Our

results indicated an average deviation of 3.61%, which falls within the acceptable industry tolerance of ±5% for smart metering systems[10]. To improve accuracy, our system incorporates periodic self-calibration routines that adjust for environmental factors such as power quality variations and temperature fluctuations. While reducing drift errors commonly observed in conventional meters, this ensures consistent performance over time. Our smart power meter provides several advantages, particularly in accuracy and data management compared to traditional electromechanical meters. Conventional analog meters rely on mechanical components, which are prone to tear and wear, leading to higher error margins of 5–10% over time. Moreover, legacy digital meters lack automated tariff adjustments and real-time monitoring, making them inefficient in load balancing. Modern smart metering solutions, like those used in European Union and the United States, have integrated real-time data transmission via ZigBee or Wi-Fi networks, reducing human error in manual readings. However, many existing systems still suffer with reliability and cost-effectiveness in regions with unstable network infrastructure. Our approach, which employs GSM-based data transmission, ensures reliable connectivity in rural and urban areas alike. Additionally, the implementation of dynamic pricing strategies encourages demand-side management, reducing peak-hour congestion more effectively than static tariff models.
In summary, our smart power meter demonstrates competitive accuracy, improved cost management, and enhanced fraud prevention through real-time monitoring, GSM integration, and adaptive tariff structures. These features position it as a viable solution for modernizing Iraq's electrical metering system while addressing existing limitations in conventional and semi-smart meters.

5.1 PEAK TIME CALCULATION

Najaf city was taken as a case study in this research. We can modify the results to all regions in Iraq so we have communicated with the ministry of electricity in Najaf city to get the consumption database of Najaf city then we processed the data to get the peak consumption hours and the normal consumption hours over the year to classify the cost into two types: 1) Peak time consumption cost (which was higher cost than normal hour's usage), and 2) Normal time consumption cost. This process will make the consumers avoid using unnecessary devices in the peak hours to help in achieving load balance on the day's hours. From data we collect, we plot those Figures that represent the electricity consumption in some days for specific feeders during summer and winter for year 2014 because it's the only data that available to the research use so as to specify the peak time and the normal usage time which suppose-to have two different electricity rates.

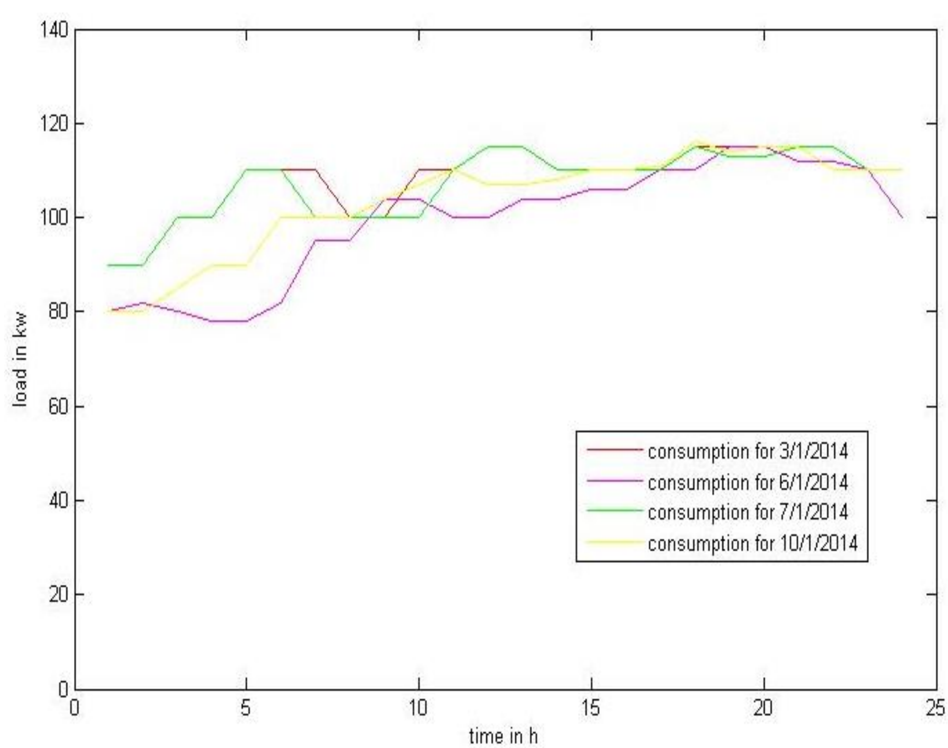

Figure 5. Electricity Consumption for four days in feeder Alemaraa District in Najaf

From Figure 5, we found that the peak load time for winter is started from (12am) to (9 pm) for a residential feeder

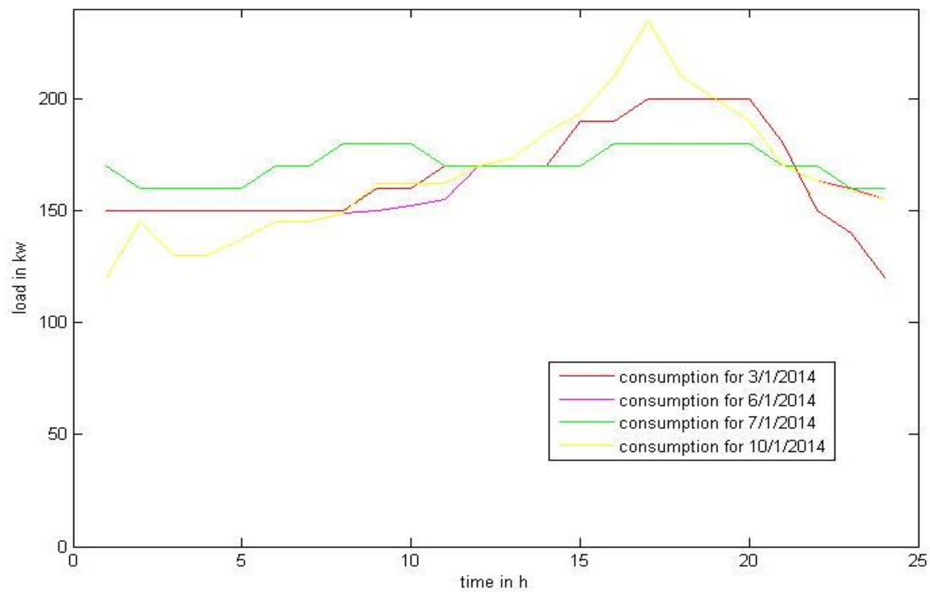

Figure 6. Electricity Consumption for four days in Feeder Markaz-AlBahar District in Najaf

And from Figure 6, we found that the peak load time for winter is started from (8 am) to (6 pm) for agricultural feeder.

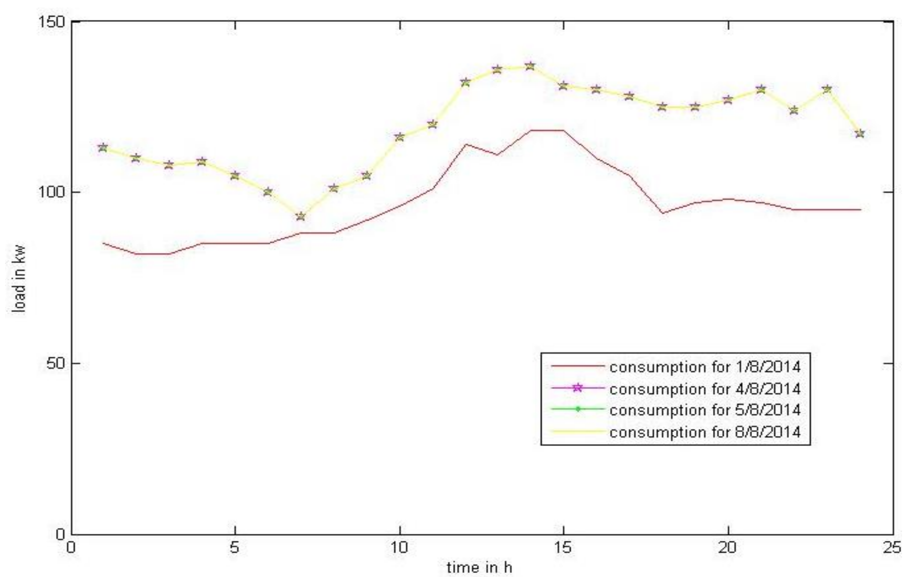

Figure 7. Electricity Consumption for four days in Feeder AlEmaraa District in Najaf

From Figure 7, we found that the peak load time for summer is started from (11 am) to (11 pm) for a residential feeder.

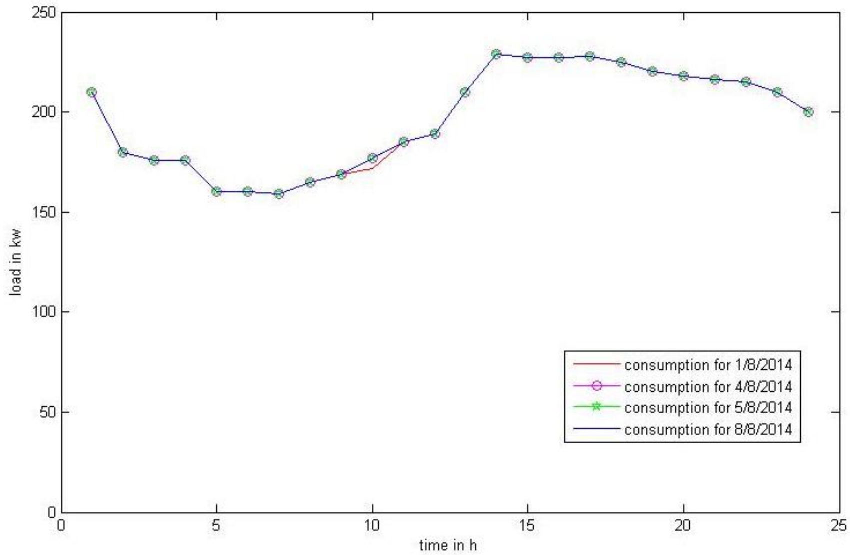

Figure 8. Electricity Consumption for Four Days in Feeder Markaz-AlBahar District in NajafFigaf

And from Figure 8, we found that the peak load time for summer is started from (12 am) to (12 pm) for agricultural feeder. And the rest of daytime is assumed to be normal load time.

5.2 PRACTICAL IMPLEMENTATION RESULTS

The designed system was implemented as prototype and tested using real loads as shown in Figure (9, 10) also the GSM module is tested and the readings were received as SMS to mobile phone, in real world this could be replaced with accounts server. The test results are given in Table 1.

Figure 9. Testing of the Manufacturing Meter System via boiler connection

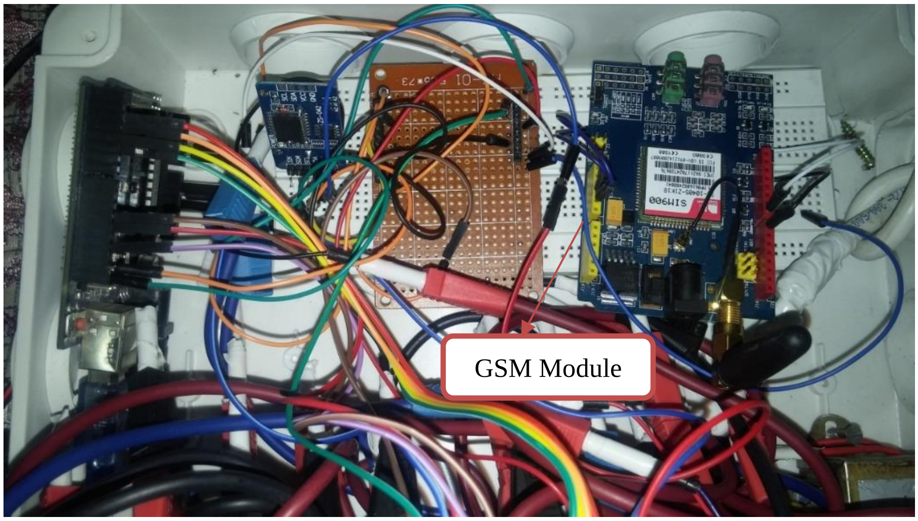

Figure 10. Internal connection of the proposing smart meter system

Below is the Proposed circuit diagram for the Smart system that connected to a proposed power consumption source using a fritzing software (light)

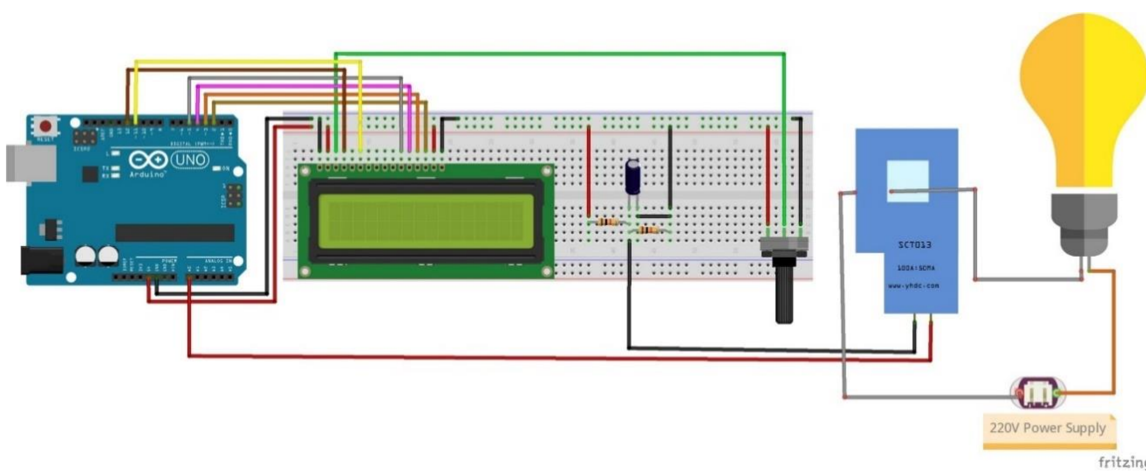

Figure 11. Circuit Diagram for the proposed meter using Fritzing software

Table 1. Scheduling for Multiple Loads Testing of the Proposing System

No	Practical Reading P(W)	Real Reading With Power Meter P(W)	Load Type	Error%
1	53.35	55	Fan wallboard	3
2	248.3	260	Freezer	4.57
3	95.72	100	refrigerator	4.28
4	1987.5	2000	Boiler	0.62
5	2300.52	2400	Electric heater	4.1
6	33.2	35	Lamp(economic)	5.14

From Table 1 it can be noticed that the average error in the readings is 3.61%, this percentage error is due to the use of 33 ohm resistor instead of 35.4 ohm resistor used as burden resistor for CT transformers, Arduino UNO power consumption and connecting wires.

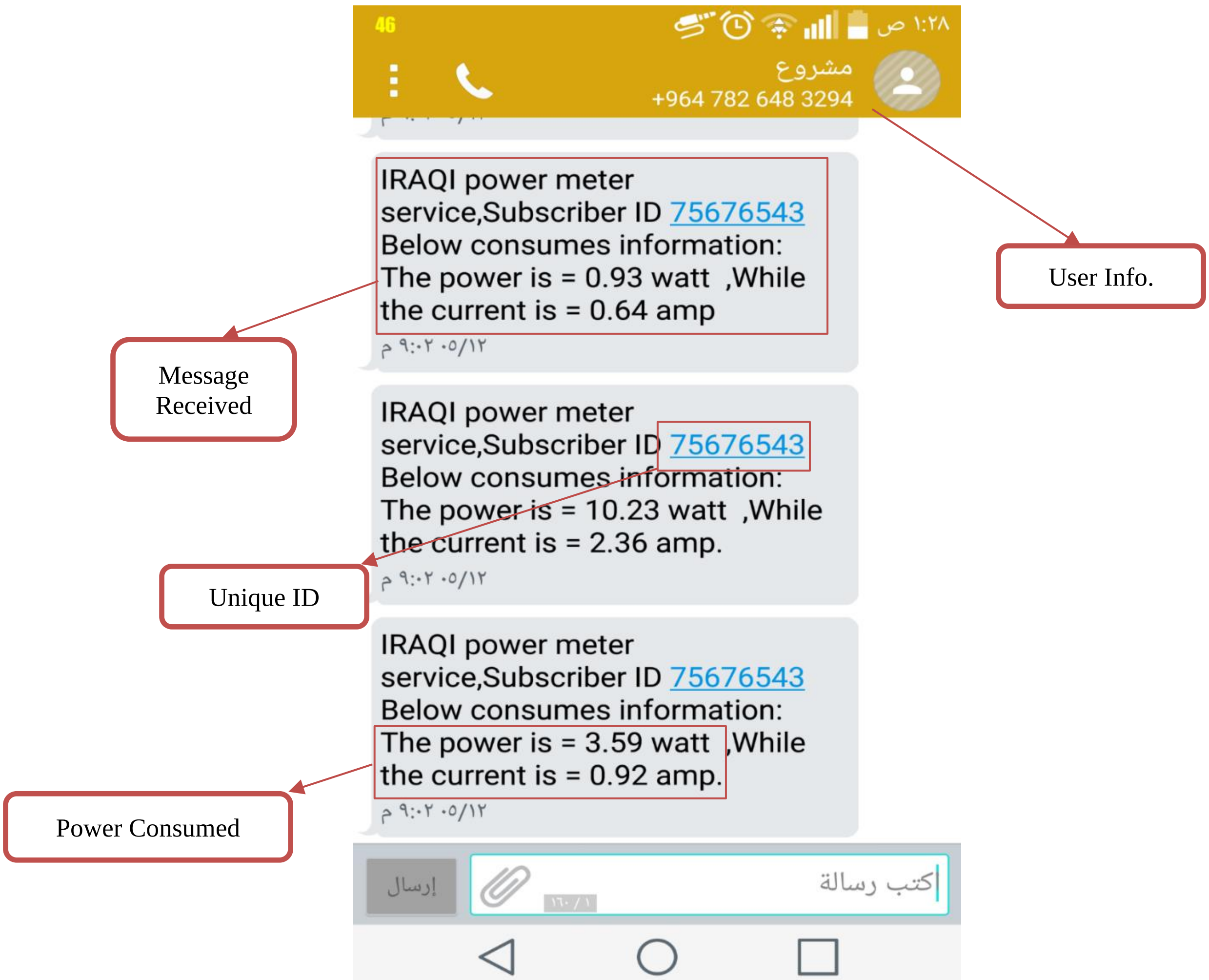

Figure 12. GSM Message Testing via the Proposed System

6. CONCLUSION

The proposed digital smart power meter presents a promising solution to enhance electricity consumption management in Iraq. If adopted by the Ministry of Electricity, the system would provide a cost-effective and automated method for collecting real-time consumption data, enabling more efficient planning and distribution of electrical power. The system's ability to create a live database for each household would significantly aid in improving demand-side management and reducing power outages. However, certain limitations have been identified. The current device has limited internal memory, which can be addressed in future iterations by integrating external SD card storage to accommodate larger datasets. Additionally, the prototype is currently designed for single-phase power measurement; future improvements should focus on adapting the system for three-phase power by incorporating three CT transformers and modifying the software accordingly. Furthermore, for large-scale deployment, connecting the device to a centralized server would facilitate better data aggregation and analysis. During practical testing, the system exhibited an average error rate of 3.61%, primarily due to the use of a 33-ohm burden resistor instead of the optimal 35.4-ohm resistor, as well as power consumption by the Arduino UNO and wiring inconsistencies. Future refinements should address these issues to enhance measurement accuracy.

Overall, the implementation of this smart metering system has the potential to improve the efficiency and reliability of Iraq's electrical grid while reducing costs associated with manual meter readings and fraudulent activities. Further research and development will be necessary to optimize the system for large-scale deployment.

DATA AVAILABILITY STATEMENT

The data used are included in the manuscript

CONFLICT OF INTEREST

The authors declare no conflict of interest in influencing the work in this paper

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