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Smart Energy Management in Pakistan: Advanced Prepaid Meters with PLC Modems and Wireless Technology for Theft Detection

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Abstract
In the face of rising electricity theft and inefficient energy management in developing countries like Pakistan, the implementation of advanced metering systems has become crucial. This research explores the integration of prepaid energy meters with Power Line Communication (PLC) modems and wireless technology to enhance energy management and detect theft in Pakistan's power sector. Prepaid Energy Meter with theft detection based on PLC modem and wireless network will boost the management of cash flow in energy expenditure, minimize bill trouble for customers and minimize the employment of manpower to take meter readings. This paper describes the architecture of this device that is capable of tracking the energy used every day, so theft is not likely. This system allow users to use electricity within their home when the user's prepaid account includes a certain prepaid package. It can also calculate the total energy used in Kilo-Watt-Hour readings per day and per month, and the remaining sum of

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prepaid units. This system will make users pay for the electricity before it is consumed. Units are purchased using GSM technology and deducted according to energy consumption. Once the prepaid unit are larger than or exceed a convinced amount later than utilize, a message sent to remind the customer about the status of their connection will be sent by the device via mobile phone. The findings indicate that the combination of prepaid energy metering, PLC modems, and wireless technology can significantly reduce energy theft, improve billing accuracy, and optimize overall energy distribution, making it a promising solution for modernizing Pakistan's power sector.
Keywords: Prepaid Energy Meters, PLC Modems, Wireless Technology, Advanced Metering Infrastructure.

Introduction

Energy management in developing countries, particularly in Pakistan, has long been a challenge due to inefficient infrastructure, outdated systems, and the rising issue of electricity theft. Pakistan, like many other countries, has been grappling with the significant problem of energy loss through both technical and non-technical means [1]. Among the most prevalent forms of energy loss is electricity theft, which not only causes substantial financial losses but also puts immense strain on the national power grid, resulting in frequent load shedding, increased operational costs, and an overall reduction in power supply reliability. This issue has worsened over the years, as traditional energy metering and billing systems continue to fall short in detecting unauthorized usage and ensuring accurate billing. In addition to electricity theft, the existing metering systems in Pakistan are often characterized by manual readings, unreliable data collection, and delayed billing cycles. These shortcomings not only hinder effective energy distribution but also affect the financial sustainability of power utilities, as inaccurate readings and fraud reduce the revenue generated from electricity sales [2]. Furthermore, power utilities are often unable to effectively monitor energy consumption patterns in real-time, which limits their ability to optimize grid operations, detect abnormalities, and take proactive measures to reduce losses. In this context, the need for an advanced, reliable, and efficient energy management system has never been greater. One promising solution is the implementation of smart energy metering systems, specifically prepaid meters, which offer several advantages over traditional postpaid systems [3]. Prepaid metering allows consumers to pay for electricity before it is consumed, providing a more equitable way of managing energy costs while minimizing the chances of disputes related to billing. Additionally, prepaid meters can be equipped with technologies that facilitate remote monitoring, real-time data transmission, and theft detection, further enhancing their effectiveness [4]. This research proposes the integration of prepaid energy meters with Power Line Communication (PLC) modems and wireless technology as an innovative solution for addressing energy theft and inefficient energy management in Pakistan. The PLC modem facilitates communication over existing power lines, enabling real-time monitoring of electricity consumption and efficient data transfer between the energy provider and consumers. Wireless technology, particularly GSM-based communication, further enhances the system by allowing users to receive notifications regarding their remaining balance and energy usage, and providing a seamless platform for transaction management. By combining these technologies, the system not only

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addresses the issue of energy theft through advanced detection methods but also offers practical benefits such as reduced manpower requirements for manual meter readings, improved accuracy in billing, and enhanced consumer control over energy consumption. The proposed system also provides real-time alerts, allowing consumers to stay informed about their energy usage and avoid disconnection due to insufficient prepaid units [5].

This paper aims to design and evaluate the effectiveness of this integrated prepaid metering system in Pakistan's energy sector. The research will focus on examining the architecture of the system, its capabilities in tracking energy usage, detecting theft, and enabling efficient billing processes. Furthermore, it will assess the potential impact of this system on improving overall energy distribution, reducing operational costs, and enhancing cash flow management for energy utilities [6]. The study will also explore the challenges and limitations of deploying such a system in Pakistan, considering the country's unique infrastructural, socioeconomic, and technological landscape. The integration of prepaid meters with PLC and wireless technology presents an exciting opportunity to modernize Pakistan's power sector, reduce losses, and provide more reliable and accurate energy distribution. By examining this innovative solution, this research aims to contribute valuable insights into the future of energy management, both in Pakistan and in other developing countries facing similar challenges.

Problem Statement

Electricity theft and inefficient energy management remain significant challenges in developing countries like Pakistan, where a considerable portion of the power supply is lost to unauthorized consumption. Traditional energy metering systems in Pakistan are often outdated, prone to errors, and vulnerable to manipulation, which leads to financial losses for power utilities and inaccuracies in billing for consumers [7]. The Energy Meter System has many limitations. There are:

- There is consistently an opportunity of theft and defilement.
- Meter perusing and other related undertakings like bill instalment are performed by an enormous number of staff for example huge number of workers are required [8].
- Consumer needs to remain in line for a considerable length of time for charge installment.
- There is consistently an opportunity of human blunder while taking the manual meter perusing [9].
- There is no check and parity and confirmation strategy of meter perusing.
- Consumer isn't update of his use.
- Increase labour for meter perusing in corresponding with increment of new lodging.
- Time and work devouring.
- Need to pay further activities for detachments and reconnections when there have overdue debts.

Research Objective

The primary objective of this research is to explore the integration of prepaid energy metering systems with Power Line Communication (PLC) modems and wireless technology to address the challenges of energy theft and inefficient

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energy management in Pakistan's power sector. The specific objectives of this study are:

- To build a Prepayment (prepaid) Energy Meter with theft detection to monitor sum of power deliver base solely on the prepaid meter number, So there is no chance of theft and corruption.
- To give the framework which can lessen the expense and loads to set up the framework utilizing the proposed vitality arrangement [10].
- To design a payment system which solve the problems manually and also reduces the manpower.
- To apply to get the concept of "*First Pay First Serve*".
- To save time using an energy meter by only reload prepaid.

Methodology

This part will explain the overall framework in the board's effort, remembering the underlying progress made for this undertaking, which selects the title, the study phase which takes the route to the report being drawn up. Once the title of the endeavour is given, the early organization is to choose the objective of this adventure critical improvement. This task is done to decide on the most proficient method on the way to utilize to produce a prepaid vitality meter with theft detection based on PLC modem and wireless system for handling of electricity.

Project Development

This branch is clarified quickly concerning the advancement of task beginning the earliest starting point until it's finished [11]. Choosing the proper programming is fundamental to guarantee the improvement procedure is finished in the assigned time period. So as to help the fast advancement of Prepaid vitality Meter framework, the improvement devices are necessary to contain the highlights of inherent grammar and rationale featuring. The subtleties of the segments utilized in this task will be clarified in the accompanying area. The venture began by various arranging and actualized in a Gantt diagram [12]. It is significant that the job is done as needs be to the timetable. Move was made to ensure the venture runs easily. The nuances of the sections used in this assignment will be explained in the going with region. The endeavor started by different masterminding and completed in a Gantt graph [13]. It is critical that the activity is done as necessities be to the plan. Move was made to guarantee the endeavor runs without any problem.

Flow Charts

In view of the flowchart shown in Figure 1, the Prepaid vitality Meter System's course of action co-ordinates successively. It is beginning to gather information on the vitality framework and the Prepaid framework to determine how the capacities of the mechanism are. By then the features of the Prepaid vitality framework are understood. First, the enhancement method which can be used in the Prepaid Energy Meter is interpreted and explained [14]. Continue to do machine programming and interfaces in the wake of researching the results. Test the bumble mess and pick the delayed consequence of the prepayment essentialness meter structure. The figure of flow charts of prepaid meter shown in below in Figure 1.

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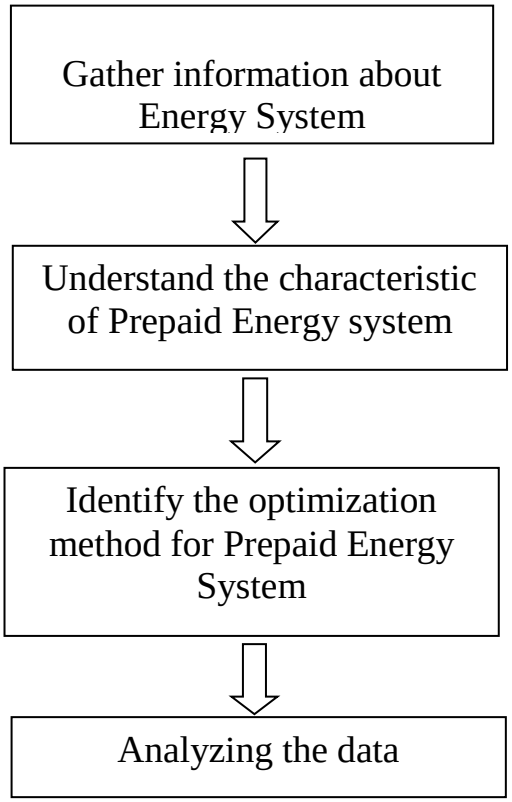

Figure 1: Flow Chart of Prepaid Energy System [15].

In light of the Planning Chart in Figure 2, the Prepaid Energy Meter System are begun by doing an exploration and audit the related hypotheses. Plan the idea of the framework structure. In the wake of coming out with the difficult appraisal in regards to the framework, need to include information obtaining and dissect. Subsequent to ensuring the perfect outcome that will be assessed, the fuel frameworks are prepared to plan and actualize. It is required for testing, yet in the event that have the blunder, the framework need to do some adjustment. In conclusion, set up the documentation for the framework.

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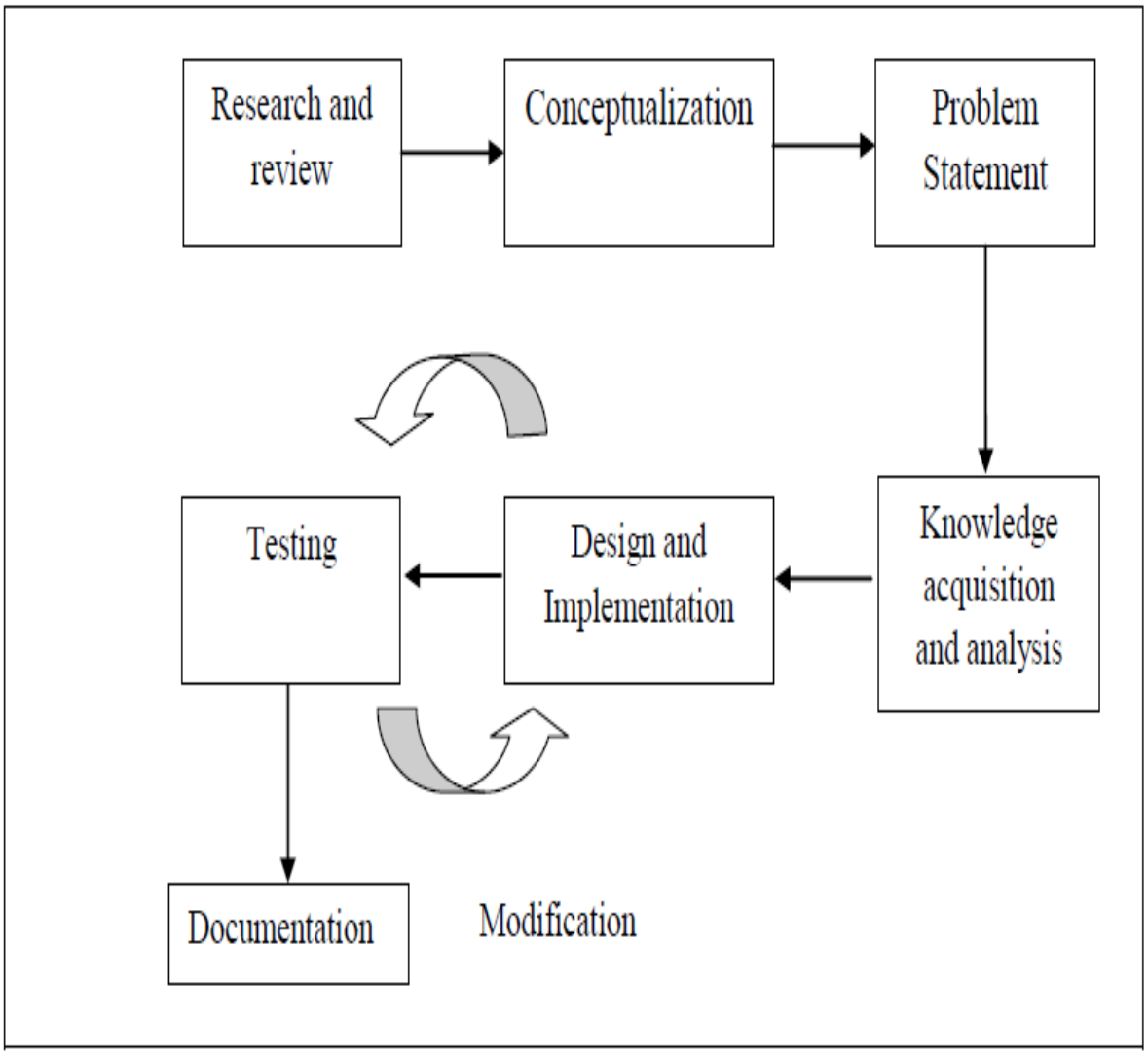

Figure 2: Planning Chart in the Prepaid Energy Meter [16].

Results and Simulation

In this section we will discuss about the results of our project. The project Prepaid (prepayment) Energy Meter with theft detection based on PLC modem and wireless system has been implemented successfully. This framework (system) can be embraced generally in light of its ease and furthermore on the grounds that it stops income spillage to the effectively troubled power sheets on account of power burglary

For Power Supply

Step #01 Selection of voltage regulator

We select **LM7805** voltage regulator IC
Rating

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Input voltage range = 7V-35V
Output voltage range = 4.8V-5.2V
Current rating = 1A

Step #02 Selection of Transformer

Minimum input to our selected IC is 7V so we need a Transformer to step down the main AC to this value.But on secondary side of Transformer there is a rectifier of diode bridge and its voltage drope across of it is 1.4V
V secondary = 7V+1.4V
V secondary = 8.4V

Step #03 Selection of Diode

The selected diode must have current rating more than the load current (**i.e 500mA**).
So we select **1N4007** diode because it has the current rating of 1A more then our desire.

Step #04 Selection of Capacitor

We know that

$$\mathbf{Xc} = \frac{1}{2\pi fc}$$

$$c = \frac{1}{2\pi fXc} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{1}$$

According to OHM Law
V=IR

$$R = \frac{V}{I} \qquad \mathbf{So,} \qquad Xc = \frac{V0}{I0}$$

By putting Xc in Equ 1

$$c = \frac{1}{2\pi f(\frac{V0}{I0})}$$

$$c = \frac{I0}{2\pi fV0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2}$$

Where
Io = Load Current
Vo = Load Voltage
So,

Io = 500mA **Vo = 5V** **f = 50HZ**

By putting values in equ 2

$$c = \frac{500\times10^{-3}}{2\times\pi\times50\times5} \quad \rightarrow \quad C = 3.1847 \times 10^{-4}\, F \cong 4.7 \times 10^{-4} F$$

This value of capacitor is near to the value so we select **470uF** capacitor for filtration.

Step #05 Selection of LED and Resistor across LED

We select LED of rating:

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VF = 2.1V, IF =20mA

We know that at secondary side of transformer is 9V and voltage drop across rectifier diode bridge is 1.4V So,

$$V = 9 - 1.4V = 7.6V$$

In parallel connection voltage is same So, 7.6V at LED.
LED according to data sheet operate on 2.1V So,

$$VR = 12 - 2.1$$
$$VR = 9.9V$$

According to OHMS Law

$$V = IR \qquad R = \frac{V}{I}$$

VR=9.9V, IF=20mA

$$R = \frac{V_R}{I} = \frac{9.9V}{20\times10^{-3}} = 500ohm \cong 680ohm$$

So,we select 680ohm resistor across LED

For Potential Transformer

Potential transformer here we use is 220v to 12v
Voltage on primary side = V1 = 220V
Voltage on secondary side = V2 = 12V
Turn ratio of transformer:

$$\frac{NP}{NS} = \frac{VP}{VS}$$

$$\frac{NP}{NS} = \frac{220V}{12} = \frac{19}{1}$$

$$NP : NS = 19 : 1$$

Turn Ratio = 19 : 1

For Divider Circuit

In voltage divider rule we kept one resistor 1kΩ value constant and other resistor value we can change according to our own desire.

$$R1 = 1k\Omega \qquad Let \quad R2 = 1k\Omega$$

So we know that

$$V1 = \frac{R1}{R1+R2}\times VT \quad \rightarrow \quad V1 = \left(\frac{1k}{1k+1k}\right)\times 12 \quad \rightarrow \quad V1 = 6v$$

$$V2 = \frac{R2}{R1+R2\times VT} \quad \rightarrow \quad V2 = \frac{1K}{1K+1K}\times 12 \quad \rightarrow \quad V2 = 6V$$

Now let **R2 = 3kΩ**

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$$V1 = \frac{R1}{R1+R2} \times VT \quad \rightarrow \quad V1 = \frac{1K}{1K+3K} \times 12 \quad \rightarrow \quad V1 = 3V$$

Now

$$V2 = \frac{R2}{R1+R2} \times VT \quad \rightarrow \quad V2 = \frac{3K}{1K+3K} \times 12 \quad \rightarrow \quad V2 = 9V$$

So we select

R1 = 1kΩ
R2 = 3kΩ

Resistance For Second LED

We select LED of rating:

VF = 3.1V, IF =30mA

We provide 12v So, Vs = 12V

$$VR = 12 - 3.1$$
$$VR = 8.9V$$

According to OHMS Law

$$V = IR \qquad R = \frac{V}{I}$$

VR=8.9V, IF=30mA

$$R = \frac{V_R}{I} = \frac{8.9V}{30\times10^{-3}} = 296ohm \cong 300ohm$$

So,we select 300ohm resistor across LED

For Base Resistance of Transistor

From transistor data sheet IC = 200mA

We know that

$$I_c = \beta I_B$$

Assume

$$\beta = 100$$

$$I_B = \frac{I_C}{\beta} \quad \rightarrow \quad I_B = \frac{200\times10^{-3}}{100}$$

$$I_B = 2 \times 10^{-3} \quad \rightarrow \quad I_B = 2mA$$

We know that

$$R_B = \frac{V_{BB}-V_{BE}}{I_E}$$

$$here \quad V_{BB} = 5V, \quad V_{BE} = 0.7V, \quad I_B = 2mA$$

Put the values in above formula

$$R_B = \frac{5V-0.7V}{2\times10^{-3}} \quad \rightarrow \quad R_B = \frac{4.3}{2\times10^{-3}} \quad \rightarrow R_B = 2.1K\Omega$$

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$$R_B = 2.1K\Omega \approx 2.2K\Omega$$

The value of resistance is 2.1k which is near to 2.2k So, we select 2.2k resistor across transistor base. The framework (system) switches the force gracefully ON just if the balance in the framework is more prominent than or equivalent to 1 Rs. The framework ascertains the measure of intensity devoured by the heap associated and deducts the in this way from the parity sum [16]. The system sends alerts to the user as shown in Figure 3 when:
1. The framework (system) balance is Rs. 5 to remind the client to revive.
2. When balance is zero (0) inform that power is cut off.
3. System recharged by the user.

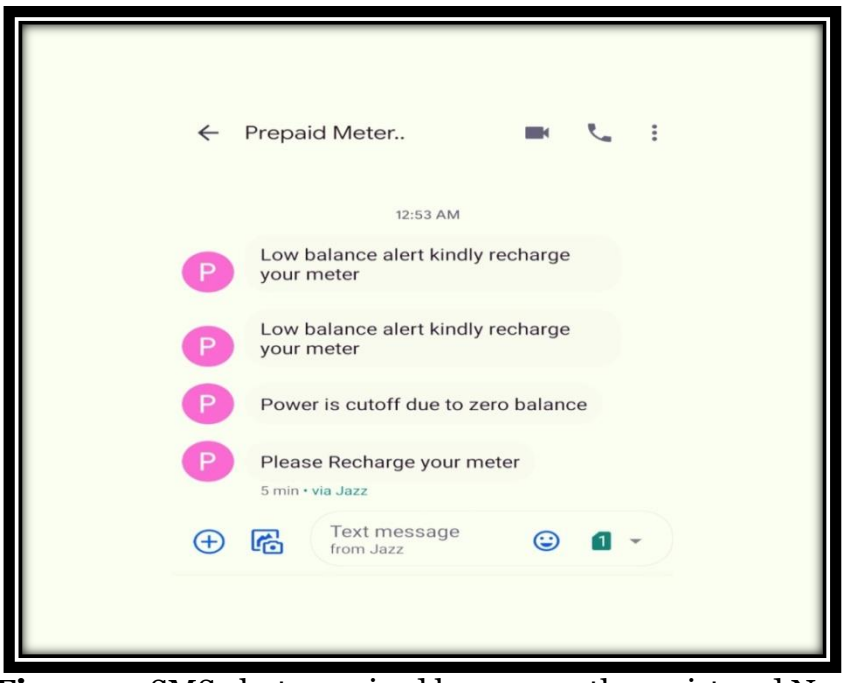

Figure 3: SMS alerts received by user on the registered Number

The client can energize the framework (system) just by sending a SMS to the framework (#-revives the framework for Rs 10).The framework gets the message through the GSM module. After the message is gotten it is decoded by the Arduino dependent on the code and revives the framework and sends alarm to client that energize of Rs 10 is done as appeared in Figure 4 (considering # is sent by the client) and switches back the force ON by setting off the transfer.

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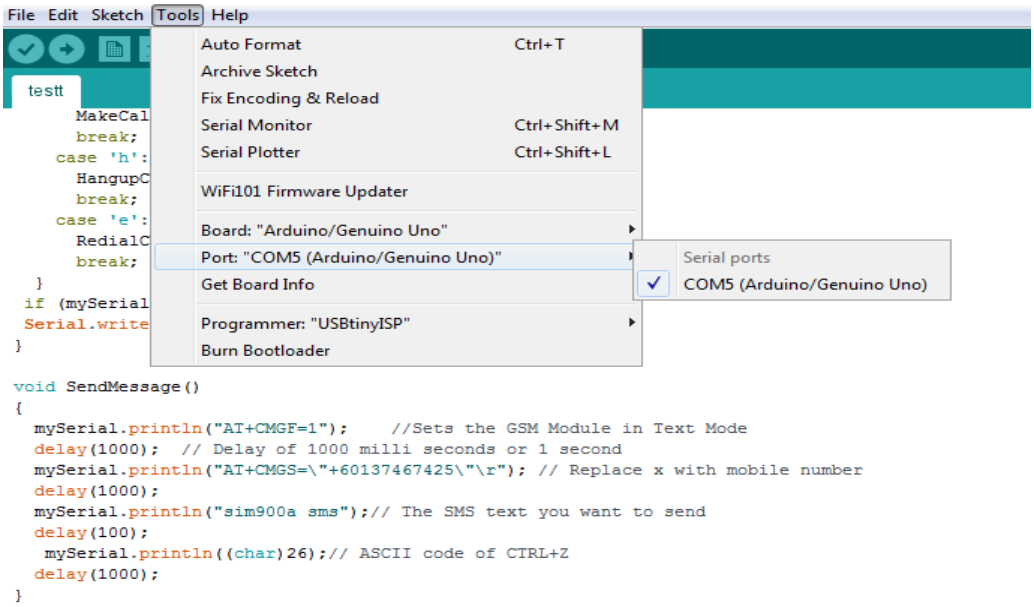

Figure 4: Arduino Serial Monitor showing SMS Rx and Tx

The framework is made carefully designed by offering a straightforward instrument where the framework turns OFF the force gracefully by setting off the hand-off at whatever point the power meter defensive packaging is lifted or somebody attempts to constrain it open [17]. This has been done with the goal that the act of controlling the readings of the meter by the clients to utilize power liberated from cost or at a much diminished expense is checked. The framework insinuate the power board at whatever point a client attempts to use power much after the parity in his/her record tumbles to zero by utilizing a flow sensor which detects the power owing through the heap end of the meter significantly after the force flexibly is killed after the equalization has gotten zero. This holds unapproved use of power under control by distinguishing robbery of power at the family unit level as appeared in Figure 5.

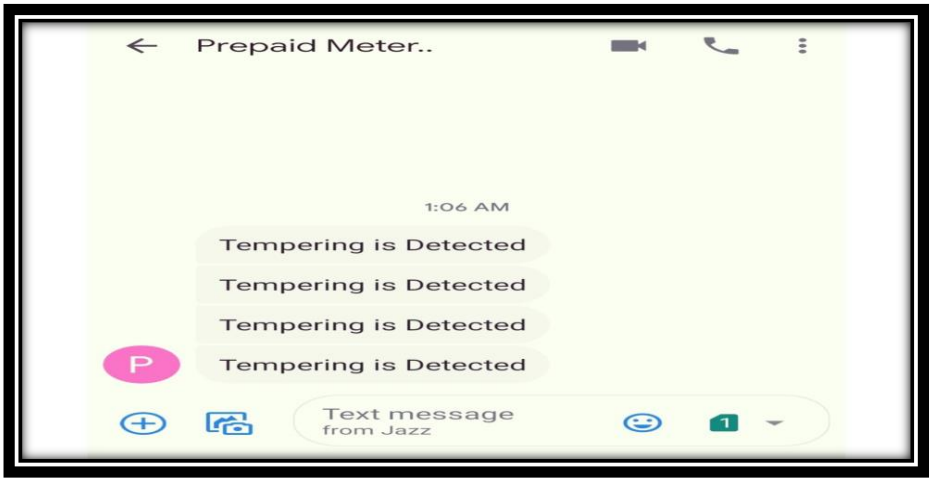

Figure 5: Alerts received when Tampering is detected.

The simulation model and final visulization of this project are shown in figure 6 and 7.

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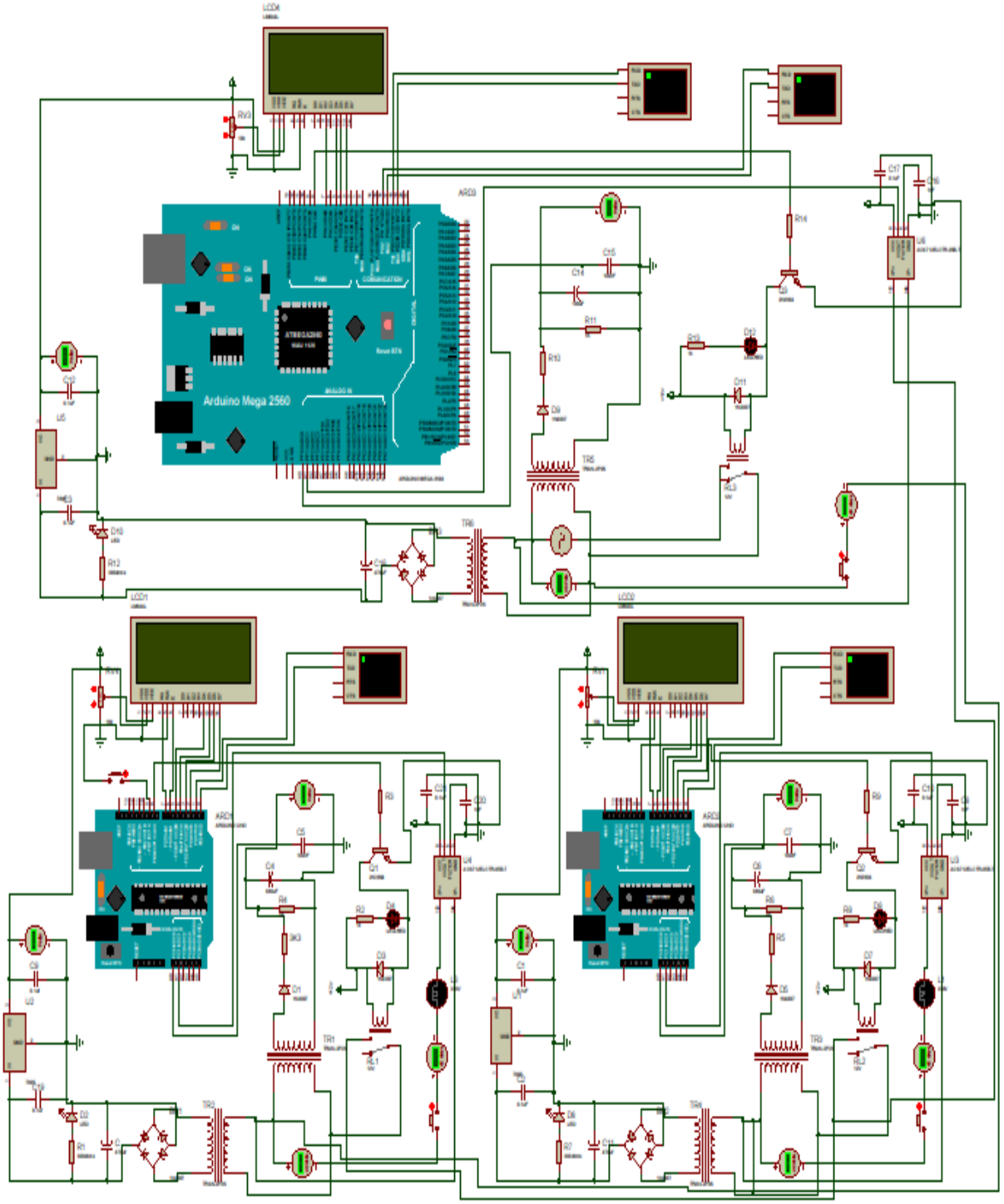

Figure 6: Simulation of prepaid meter with theft detection

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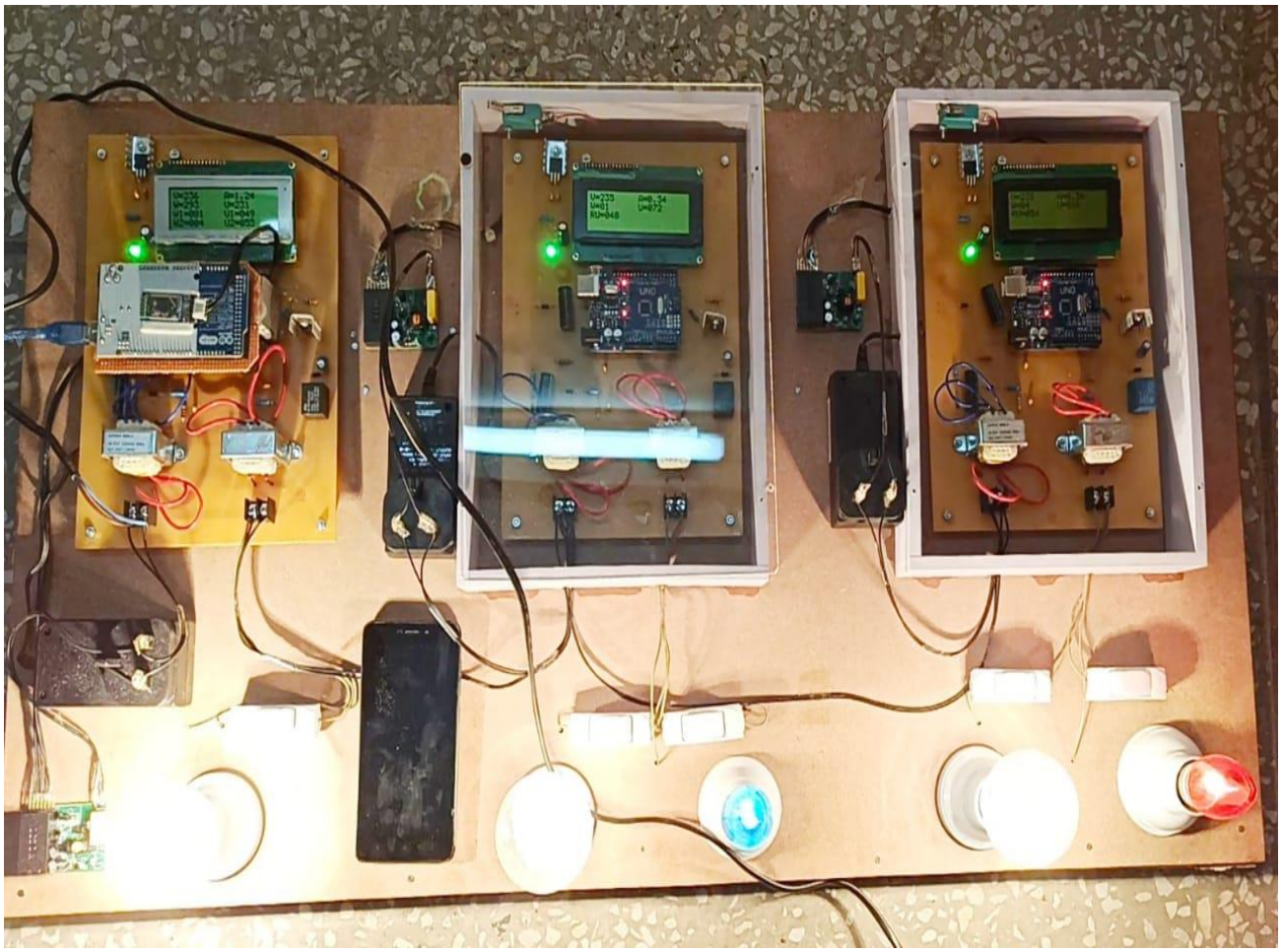

Figure 7: Final visulization of the project

Discussion

We are building Prepaid Energy Meter with theft detection based on PLC modem and wireless system. For this purpose, are depending upon three things: arduino, plc (power line communication) and GSM. Whole system is designed on 12V DC. Basically there is a main meter and several submeters in our system under study. The main meter and sub—meters are interconnected plc. There is gsm system installed in main meter. GSM in controlled by arduino. We are using two arduino kits. One is ardiuno MEGA which is installed on main meter and there are two ardiuno UNO kits which are installed on sub meters. These are interconnected for communication. The advantages of that introduced prepaid meter frameworks are determined as in Figure 8. The prepaid meter records in more detail i.e vitality utilization and other data than that of regular meters. Moreover, prepaid meter gives greater office to the customers and electric power organization, as, to lessen power misfortunes the board, meter understanding cost, quick reaction to the buyer influence request

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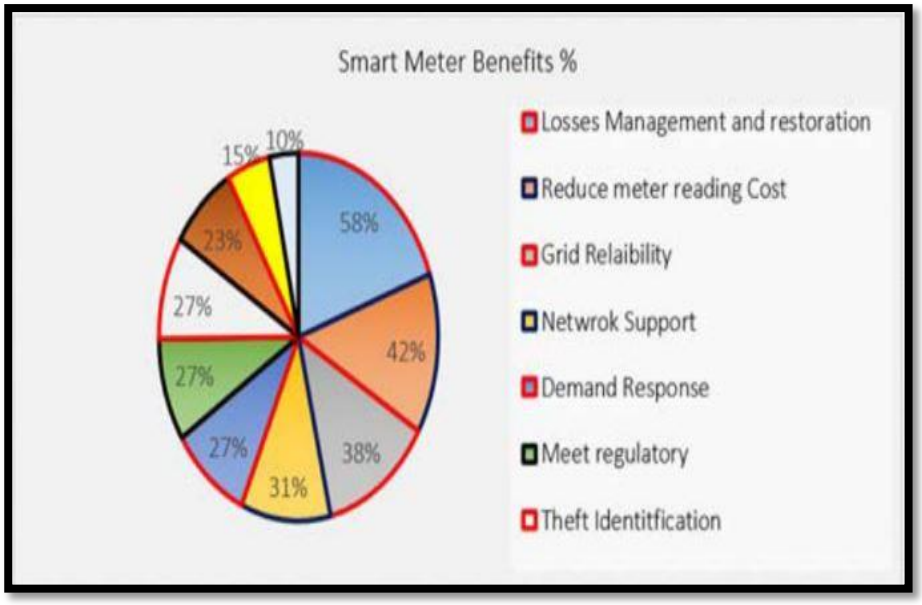

Figure 8: Benefits of Pre-Paid meters

In prepaid meters, the early bills can't be assessed. In these, organization in not ready to recognize the tariff rate as indicated by top interest, and top off and top burden. Additionally supplier can't send the cautions of various vitality units controlled by NEPRA. There are some prepaid cards issues additionally exist. There is no disturbing highlights if any fraud will do any misbehavior. In prepaid meters, it is anything but difficult to forestall the meter perusing.

Future Work

This task can be additionally improved to build the presentation later on. The enhancements should have been incorporated are:

- Show the meter perusing of the vitality use for each apparatus that being utilized at that point.
- 4G, 5G and some other modem can be utilized later on in light of the fact that they can convey data with more speed when contrasted with different modems.
- More hubs can be connected with circulation board for controlling the robbery and over use of the power [18].
- In future we can likewise chip away at the little meters which can help us for observing the burglary and over utilization of power [19].

Conclusion

This research demonstrates that the integration of prepaid energy meters with Power Line Communication (PLC) modems and wireless technology offers a promising solution to address the pervasive issues of energy theft and inefficient energy management in Pakistan's power sector. By enabling real-time monitoring of energy consumption and utilizing GSM-based communication for prepaid billing, the proposed system enhances billing accuracy, reduces the need for manual meter readings, and provides users with better control over their energy usage. Moreover, the theft detection capabilities embedded in the system offer a significant reduction in power loss due to unauthorized consumption,

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ultimately leading to financial savings for utilities and more reliable power distribution. The findings of this study suggest that the implementation of advanced metering systems can optimize energy management, improve cash flow for energy providers, and create a more transparent and equitable energy distribution system. However, challenges such as infrastructural limitations, initial implementation costs, and ensuring widespread adoption in rural areas may hinder the full potential of this solution. Nevertheless, with strategic planning, policy support, and gradual implementation, the integration of prepaid meters with PLC modems and wireless technology could be a transformative step toward modernizing Pakistan's energy sector.

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