

Minimizing Household Electricity Theft in Nigeria Using GSM Based Prepaid Meter

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ABSTRACT: Many households indulge in different forms of electricity theft and illegal tampering of electric metering devices. These lead to distribution system faults and overload as well as loss of revenue by the distribution companies, this paper envisages the utilization of the global system for mobile communication (GSM) into the prepaid energy meter for increased generation of revenue in developing countries like Nigeria. The proposed meter is set to carry a unique identification number such as the consumer's phone number which may be encrypted into the memory of the microcontroller. Electricity theft is being detected as the GSM module sends message to the distribution company. Revenue generated can be increased through the use of the proposed meter as unaccountability by utility workers and billing irregularities are eliminated. The results obtained from the simulation shows that immediately an illegal load is connected to the utility system either within the residential meter jurisdiction or otherwise stated, the GSM module alerts the utility company no matter how small the illegal load is.

Keywords -/ Electricity theft, GSM networks, Prepaid meter, Short message service and Revenue generation.

I. INTRODUCTION

Meters in the past and today in a few countries, were electromechanical devices with poor accuracy and lack of configurability. The present billing system is minimally able to detect power theft and even when it does that it is at the month. The distribution company is unable to keep track of the changing maximum demand for the domestic consumer while the consumer is faced with problems like receiving due bills for bills paid for and also poor reliability of electricity supply and quality [1]. Prior to the introduction of prepaid meter, various methods were proposed to detect electricity theft which includes: inspection of suspicious load profile, though the method was good certain drawbacks accruing to this method are the requirement of large manpower and huge labour, this failed due to dishonesty of the service workers. A huge amount of money is lost due to theft, in some countries; the government has to provide subsidies to the power sector to maintain a reasonable price of electricity [2]. The major problem facing the electricity industry in many developing countries is poor revenue generation. This arises from illegal consumption of electricity via mostly meter tampering and bypassing as well as direct connection to the low voltage distribution lines. In order to solve all the problems of the traditional meter reading, the consumer load should be tracked on a regular basis as this will help ensure accurate billing, keep track of the maximum demand and detect theft.

The prepaid meter enables the distribution companies to collect electricity bills from the consumers prior to its consumption. This meter is not only limited to automated meter reading but is also attributed with recharging ability and exchanging information with the power sector pertaining the details of the consumers' consumption [3]. This paper is aimed at creating a design that will regulate the listed problem as well as increase revenue collection via payment by SMS. It shows the embedded features combination of the hardware and software to implement the desired goals. In smart meters provide an opportunity to better monitor and control household energy consumption by both consumers and utility without persons visiting each house.

The design and implementation of a Bluetooth-based energy meter where several meters are in close proximity, communicated wirelessly with a Master PC was presented in [4]. Distance coverage is the major limitation for this kind of system because the Bluetooth technology works effectively at close range. [5] In their paper, proposed the use of Automatic Meter Reading (AMR) using wireless networks. Certain AMRs utilized

the internet for data transmission. Moreover, the design and implementation of an SMS-based control for monitoring the complex applications where the SMS is used for status reporting such as the occurrence of power failure.

Many issues involving billing systems for electricity board usage were considered in [6]. This paper discussed the remote control of home appliances with in-built security scheme when the user is away. Maheswari and Sivakumar [7], developed an energy efficient and low cost solution for street lighting system using Global System for Mobile Communication (GSM) and General Packet Radio Service (GPRS). The experimental set-up allowed the operator to turn off the lights when not required, regulate the voltage supplied to the street-lights and prepared daily reports on glowing hours. A prepaid energy meter like-mobile phone was proposed in [3]. It contained a prepaid card analogous to mobile SIM card. This card communicates with the power company using mobile communication infrastructure. If the card is out of balance, the consumer load is disconnected from the utility supply by the contactor. The distribution company can recharge the prepaid card remotely through mobile communication based on customer requests.

II. ELECTRICITY THEFT MECHANISMS

2.1. Different Types of Illegal Electricity Theft

Electricity thefts may occur in different forms. From available literature and practical daily reports in Nigeria [8] – [12], the common ways include bypassing (illegal tapping of electricity from the feeder), meter tampering (by grounding the neutral wire as it does not measure readings) and physical methods to evade payment of bills. The basic method of stealing electricity is a direct wire-connection to a main power route passing a shop or a house so that electricity can flow to the consumer without crossing the electric meter installed by a government agency which is responsible for providing electrical services to customer. There are different types of theft done all over the world. Huge amount of power theft are done by tapping from line or bypassing the meter, According to a study 80% of the total theft detected all over the world is from residential buildings and 20% from commercial and industrial premises [8].

(A) *Meter Tampering*: Customers tamper the meter by grounding the neutral wire, this causes the meter to assume an incomplete circuit and it does measure the meter reading.

(B) *Meter bypass*: The input terminal and output terminal of the energy meter has been shorted by a wire. This act prevents energy from been registered in the meter [9].

(C) *Illegal terminal taps of overhead lines on the low tension side of the transformer*: Primarily, electricity theft affects the power sector as a whole, tapping of the low tension side of the transformer result in overloading which causes tripping and can lead to blackout.

(D) *Illegal tapping to bare wires or underground cables*: This is the most used method for theft of power. 80% of total power theft all over the world is done by direct tapping from line. The consumer taps into a direct power line from a point ahead of the energy. This energy source is unmeasured in its consumption and procured with or without switches.

(E) *Unpaid bills*: Non-payment of bills by individuals, government institutions and untouchable VIPs results in utility running at a loss and a must continually increase in electricity charges.

(F) *Billing irregularities*: This incorporates the inaccurate meter reading taken by bribed servicemen and intentional fixing of the bill by office staffs in exchange of illicit payments from the consumers.

2.2. Causes of Electricity Theft

All energy distribution companies operate with some accepted degree of losses. This is no different from the scenario of Nigeria. The losses incurred are subdivided into two namely; Technical losses and Non-technical losses.

(A) *Technical losses*: These are naturally occurring losses and consist mainly of power dissipation in electrical system components such as transmission lines, power transformers, measurement systems, etc. They are caused by the physical properties of the components of power systems [9]. *Non-technical losses*: These refer to those losses that are independent of technical losses in the power system. The most prominent forms of non-technical losses in Nigeria are electricity theft and non-payment of bills. It can also be viewed as undetected load [10]

Theft is a serious crime, it creates short fall, increase of load, decrease of frequency, which is not acceptable, causing load shedding and increase of tariff on the legal consumers [11]. Some may argue that the distribution companies providing services give; over-voltage, poor service and make excess money thus, some theft will not affect its operations and profitability. Nigeria's power system is an illustration of a worst-case situation prior to its privatization in 2013. The distribution companies have not upgraded their systems to meet

the technological trends in advanced countries. In certain cities, however, the post-paid energy meters are gradually being replaced with the prepaid meters, the issue of constant electricity continually plague the country as this has not been achieved prior to its privatization in the last ten months.

Some localized catalyzing factors influencing electricity theft in Nigeria include lack of accountability in electricity market system, political protection of employees involved in corruption, influential customers who do not pay their bills, absence of effective laws to abate electricity related crimes and inadequate and ineffective enforcement of existing weak laws and generally negative attitude of electricity customers. Electricity pilferage has its root in corruption and bad governance. Customers attitude contribute a great deal to revenue losses. These attitudes range from their ill-conceived feelings that electricity should be a welfare commodity and therefore legitimate to steal from the state, to the generalization that the state is not incurring losses. They do not have the fore-knowledge that the money realized from the payment of bills are re-instated into the power sector for its improvement and development.

2.3. Existing Ways of Tackling Electricity Theft

The first step in electricity theft reduction is to become knowledgeable about the theft problem. Unless the nature and extent of power theft is known in great details, any attempts to deal effectively with the problem are prone to fragmented and limited action that has little over-all success [12]. Corruption is one of the difficult problem areas for electricity organizations because power theft occurs with the connivance of employees of the power sector. Employees should hence, be paid adequately so that the issue of bribe collection will not be their last resort. Power companies are combating theft through the use of smart meters and sophisticated software that continuously records consumption and send the data back to them. One advantage of using the smart meter is that it eliminates contact between the consumers and the power provider's employees thus preventing the issue of bribery [13].

The already existing methods which may be utilized in tackling electricity theft in some countries where practiced include proper enforcement of electricity regulatory laws, periodic and impromptu checks of consumer homes, electronic tampering detection meter and use of prepaid meter. The limitations of using the smart meters is that: consumers feel it discloses privacy of their homes which is not ethically true and that it interferes with radio frequency and create problems in radio transmission profile [14]. Periodic checks are not 100% efficient due to its laborious and sluggish nature. Adopting this kind of method in electricity theft reduction will delay accurate and effective reading of the meters in remote areas that are non-accessible. Moreover, as result of the ever-increasing rate of corruption (such as greed and bribes) in the Nigeria, the proper enforcement of laws would take a drastically longer time than stipulated. In the past, committees that were set-up see it as an avenue to amass wealth rather than strictly punish defaulters thus all these reasons have hindered the growth of our power sector.

2.4 Merits of Proposed Methodology

The proposed methodology has the following advantages over the existing schemes, which are outlined hereunder.

- (A) In the Existing Meters, manual billing is often restricted and delayed by bad weather condition in other cases the printed billing may even get lost whereas the proposed meter, prevents house to house visitation in order to issue bills as it requires consumers to pay for the consumption before its usage.
- (B) The need for the disconnection of power supply before is no longer taken care of by the electrical workers because the proposed meter automatically disconnects it when the consumers units have been used up.
- (C) In using the prepaid, the consumer pays for the units needs. It also manages the customer's consumption as it provides credit control and facilitates affordability [15].
- (D) GSM application in system monitoring: Nowadays, GSM modules are used to transmit the meter reading from one end to the other. The main aim of this work is to use the GSM network alongside the prepaid meter in reducing theft and losses. It is also used in remote monitoring and records the energy meter reading. This also can be used to disconnect the power supply to the house in case of non-payment of electricity bills. The GSM modem with SIM card is required for each energy meter which aids continuous reading. In case of tampering, it immediately sends signal to the central server of the utilities. Another advantage of the GSM is that it enables the utility engineers efficiently plan for network expansion while delivering a higher quality of supply [16], [17].
- (E) Mobile Phone Based Recharging: In this work

Prepaid Energy meter may be recharged from a remote location by using a mobile phone. The user transfers the amount to the service provider bank account and the service provider makes a call to the system, and recharges by entering digits from its key pad. The recharging can be done from any mobile set but the system access code must be put in to the system to log into the energy meter. The energy meter sends a pulse to the microcontroller indicating a unit is consumed.

III. SYSTEM DESIGN

The design of the project consists of the hardware design and software design. A Computer Aided Instruction (CAI) was first used to create a circuit model of the design before it was built and the software was implemented.

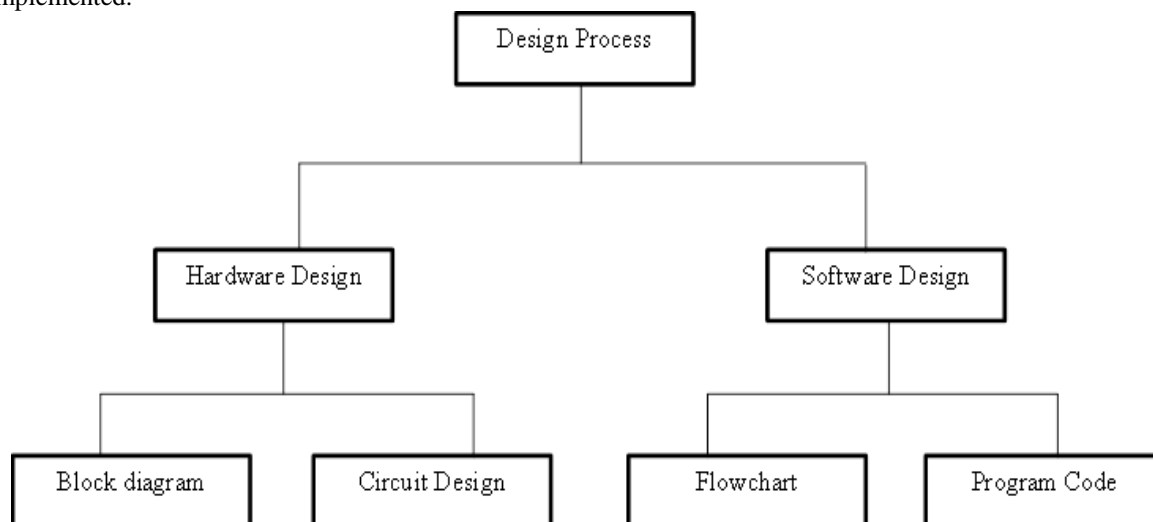


Figure 1: Design process for the GSM-based prepaid meter

3.1. Composition of Hardware

The hardware comprises of the following electronic components.

(A) GSM modules (SIM 300): It is used specifically for the purpose of sending messages although various tasks can be performed with it. For the purpose of this project the GSM module used is the SIM 300. It also helps in long duration communication.

(B) Microcontroller: This is a chip which contains a processor, having a non-volatile programming memory called a flash or ROM (Read Only Memory) and also a volatile memory for input and output called RAM (Random Access Memory). The brand used is an AT89C52, a high performance, and low power CMOS (Complimentary Metal-Oxide Semiconductor) family controller. The programs are encoded in the microcontroller. Its functions include:

(i) Transmission of the consumption amount to the GSM module.

(ii) Taking the pulses from the energy meter and incrementing the unit.

This depends upon the calculation and stores in memory.

(C) EEPROM: This is known as Electrically Erasable Programmable Read Only Memory. It is a type of non-volatile memory used in computers and other electronic devices to store small amounts of data that must be saved when power is removed. It can be programmed and erased in circuit by applying specially programming signals. It does not require a power source to maintain its data. It is limited to applications that require infrequent reprogramming sessions. The code name of the EEPROM used is AT-24C02C.

(D) Buzzer: This is the sound output; it produces alarm or sound when an illegal load is added to the meter.

(E) Liquid crystal controller (LCD): This is a thin flat panel device made up of the LCD driver and the glass; it is used for displaying information such as text, images and moving pictures. Also, the pulse count, unit price and meter reading are displayed. It is an electronically-modulated optical device made up of several pixels filled with liquid crystals and arrayed in front of a light source (backlight) or reflector to produce images or text either in monochrome or colour. Its advantages include its lightweight construction, portability and low power consumption which makes it more feasible for battery powered electronic equipment. The kind used is the LM016L, 16*2 LCD which means it has 2 line displays with each line having 16 characters. It has 14 pins and is powered from a 5V dc supply.

(E) Pull-up resistor: This is added in the circuit because it helps to send the appropriate signal to the LCD. It is also used because the port O of the microcontroller is below 0.6V which is quite low.

(F) The power supply: Every electronic circuit needs appropriate power supply for its operation. Basically microcontrollers, energy meters, LCD and relays operate on + or -5V supply. For this reason a 5V power supply is used.

(G) Crystal oscillator: The AT89C52 microcontroller has on-chip crystal oscillator, but requires an external crystal oscillator to run it. It is often times connected to inputs pin 18 and pin 19 that is, XTAL1 and XTAL2 respectively. It creates a frequency used to keep track of time, to provide a stable clock signal for digital integrated circuits.

(H) Opto-isolator: Also known as an opto-coupler is a device containing an infrared LED and a matching phototransistor, mounted close together within a light-excluding package.

(I) Bridge rectifier: It is made up of four diodes and it is used in converting the 12V AC to 12V DC.

(J) Voltage regulator: The specification of the voltage regulator is the 7805, whose function is to maintain the voltage level to 5V in the power supply unit.

3.2. Working Operation

The electric meter is used for energy measurement. It is a single phase meter interfaced to a microcontroller via ADC (Analog Digital Converter). The ADC is used because the signal coming from the meter is analog whereas that needed by the microcontroller is a digital signal; thus, the ADC helps to achieve this signal conversion. Also, both the load and meter are connected to the ADC. The 220V from the mains which is the meter is converted to a 5V dc for use in the microcontroller using an opto-coupler (also known as an optical isolator, which is a component that transfers electrical signals between two isolated circuits by using light and it also prevents high voltage from affecting the system receiving the signal).

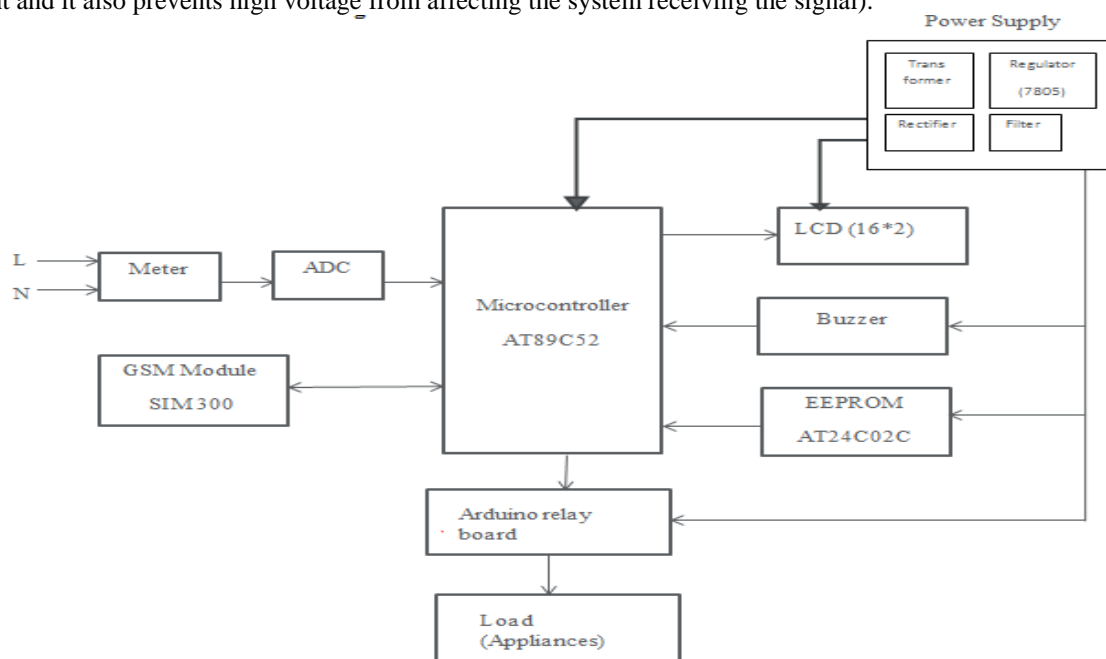


Figure 2: General block diagram

The purpose of the microcontroller is to send display data to the LCD and control the various functions of the meter. The microcontroller also continually checks for balance stored in the EEPROM, and if balance in credit is low, it sends a message to the consumer through the GSM module. Depending on the result, the microcontroller will activate the buzzer if the credit is low and the controller triggers the relay if the credit goes very low. An EEPROM is used to store various calibration parameters of the meter such as the recharge made and also stores the meter's data during a power-down. The GSM module provides the wireless connection and SMS-based facility for the design. Lastly, Power connection and disconnection is implemented using a relay which is a switching device, it is also used to activate the load. The more the load added, the faster the recharge that is used up.

The coding emphasizes the fact that it reduces human labour but increases the efficiency in calculation

of bills used for electricity.

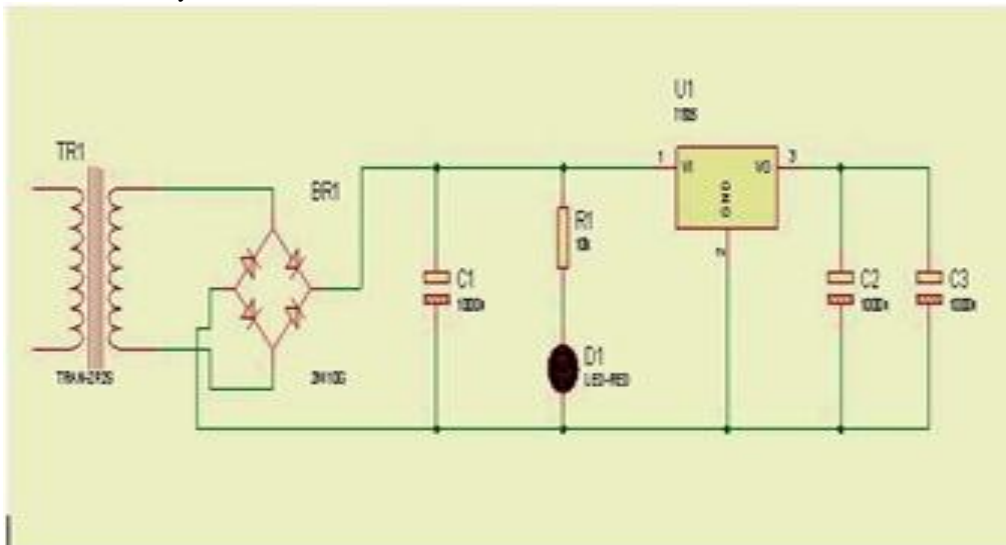


Figure 3: The power supply unit showing the components embedded in it

Circuit connection: Transformer with a voltage rating of 12V is used, 7805 regulator, LED, rectifier, capacitors and resistor. The 230V, 50Hz ac signal is fed to the primary of the transformer as input and the secondary of the transformer is fed for DC output to the bridge rectifier. The regulator is fed from the output of the diode and the resistor through the capacitor for input purpose. The output of the regulator is then fed to the other capacitor which filters ripple.

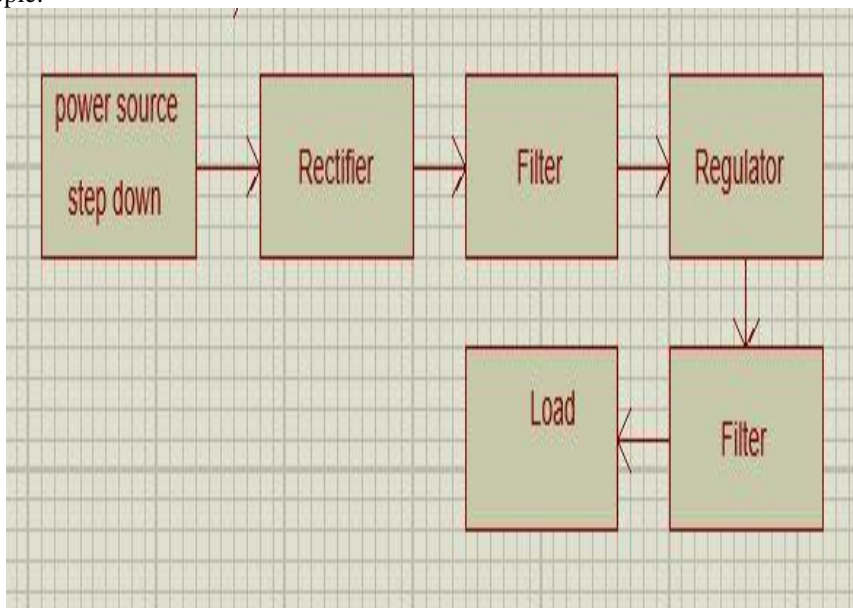


Figure 4: Block diagram of the power supply unit

Circuit Explanation: The power supply configuration consists of the transformer having a voltage rating of 12V DC, which is the power source. It is responsible for stepping down this voltage to about 5V used in the microcontroller. The transformer is thus interconnected to the bridge rectifier circuit which converts the AC input power into DC output power. During the positive half-cycle of supply, two series connected pair diodes of the four diodes conducts that is, it allows the flow of current while the other two do not. During the negative half-cycle the two diodes which did not conduct initially, conducts in this cycle whereas the other two do not conduct here.

This rectifier is suited for high voltage application because the peak inverse voltage during the period

of non-conduction is equal to the peak voltage. The capacitor performs the duty of filtering ripples that is, disturbances and it blocks DC current/voltage. The light emitting diode (LED) blinks at a faster rate if the load consumption increases while it blinks at a slower rate at less load consumption thus, it is used for physical detection. Moreover, the 7805 voltage regulator maintains the voltage level of the circuit at a rating of 5V to prevent burning of the circuit during high voltage and damage during the occurrence of an open circuit.

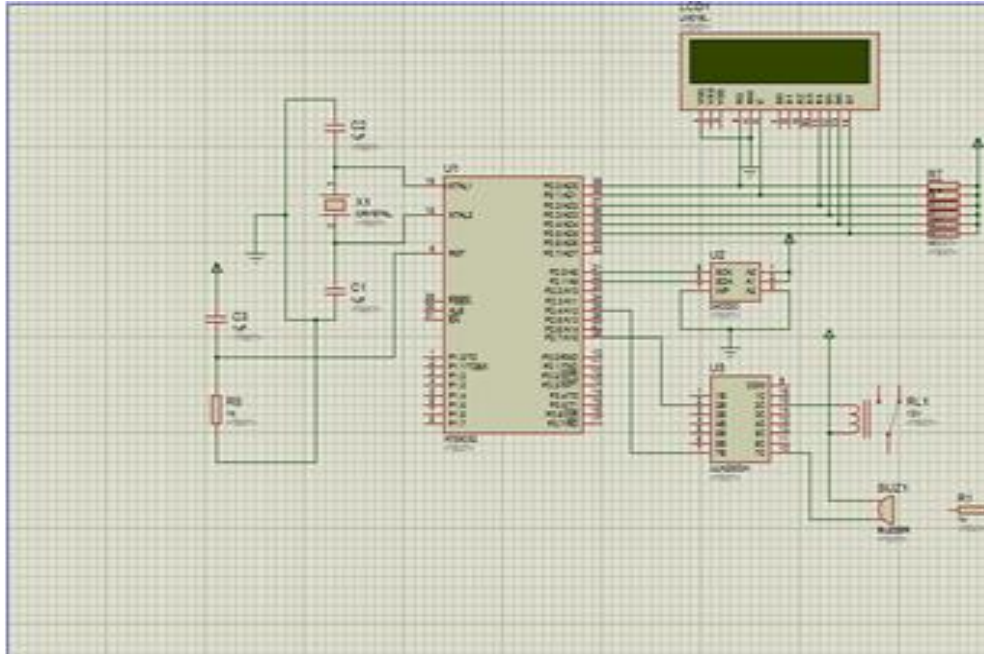


Figure 5: Design schematic diagram

3.3. Mathematical Model of the System

The instantaneous power loss, $P_{loss}(t)$ in a transmission

(A) $P_{loss}(t) = P_{source}(t) - P_{load}(t)$ (1)

Where $P_{source}(t)$ is the instantaneous power that the source injects into the transmission line and $P_{load}(t)$ is the instantaneous power consumed by the load at the other end of the transmission line.

Thus the energy loss, E_{loss} , is given by:

(B) $E_{loss} = \int_a^b P_{loss}(t) dt$ (2)

Where a and b are respectively the starting point and ending point of the time interval being evaluated. It must be noted that a fairly accurate description of $P_{loss}(t)$ as a function of time

(C). Total energy losses = Energy supplied – Bills paid (3)

Total losses = NTL + TL
Where NTL = Non-Technical Losses
TL = Technical Losses

(D). Computation Load meters (4)

$X = a + b + c$
Where X = Sum of load meters
a, b, c are 3 different load meters

(E). Residential Meter = Sum of Load meter * illegal Load (5)

Where Y = Residential ISM d = illegal loads which are d1 and d2
d1 is the illegal load within the Residential ISM and d2 is that outside the Residential ISM.

3.4. Programming Language and Simulation Software Utilized

The Programming languages used:

(A) Assembly language which is the hex code

(B) .M-IDE (Microcontroller Integrated Development Environment) used for the code compilation

The implementation flowcharts are as shown in Figures 6 and 7. People always tamper their meter, when the total unit loaded into the meter is exhausted, the algorithm shown in Figure 6 would apply. The steps involved in actualizing this are:

Number of load meter as a, b and c

2. Calculate a, b and c as sum of Load meter given as X

3. Illegal load = 1.01 and above but not less than 1 (d1 and d2)

4. No illegal load d1 and d2 = 1

5. Calculate $X*d1$ or $d2$ or $X*d1$ and $d2$ as Y

6. Equate $Z = X$

7. Verify if $Z < Y$

If Yes, display illegal load detected and send SMS alert to utility company

If No, return to number 2 or loop number 2

8. End

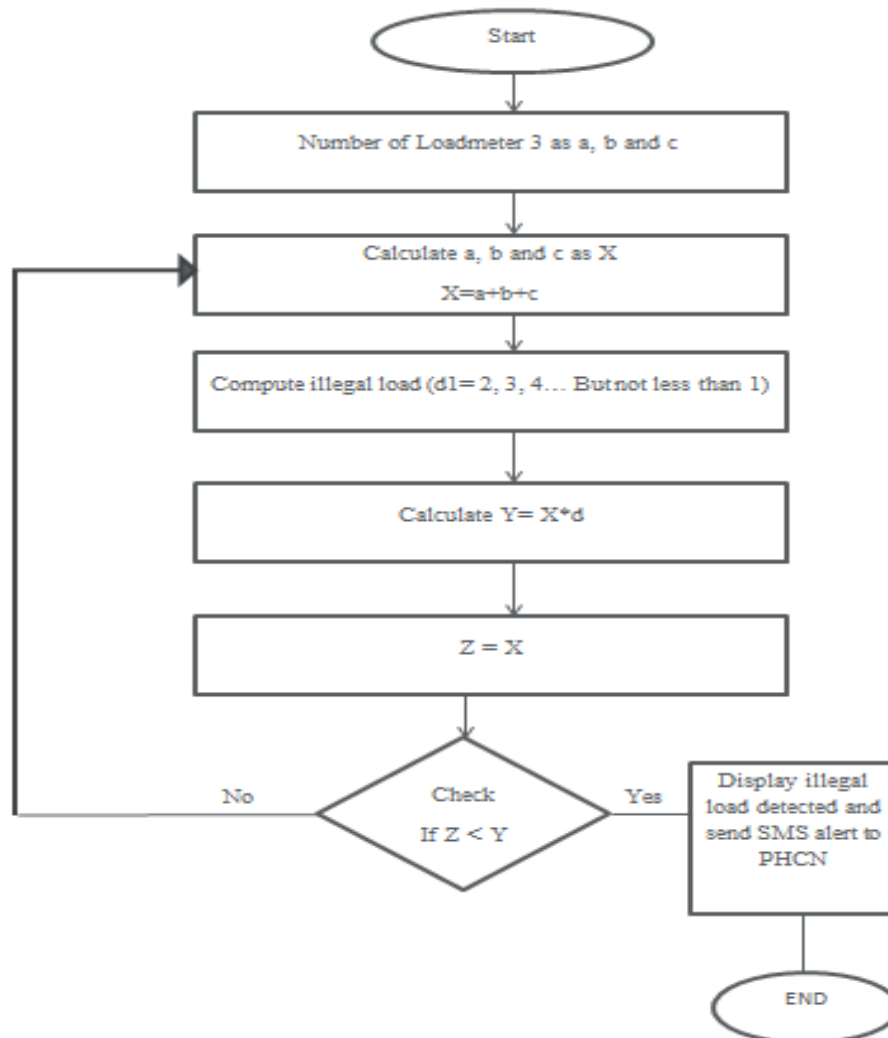


Figure 6: Flow chart for the integrated fingerprint attendance

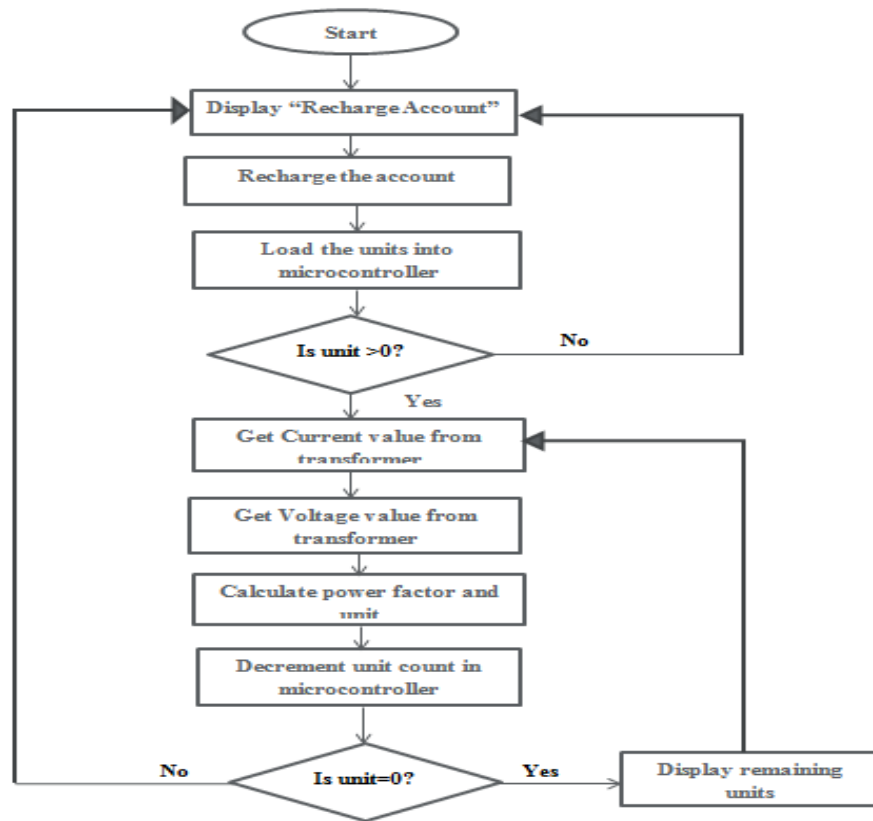


Figure 7: Flow chart for account recharge

Residential ISM: Its function is similar to that of the main ISM except that it is a concentrator for smaller coverage region. It is recommended to be installed inside the house as shown in Fig. 8

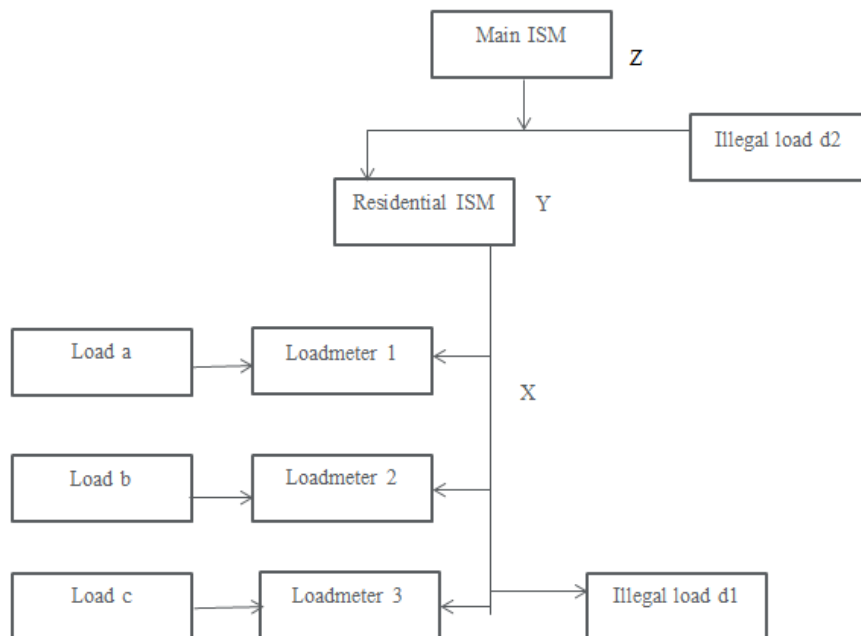


Figure 8: Metered consumption detection method showing illegal load tampering

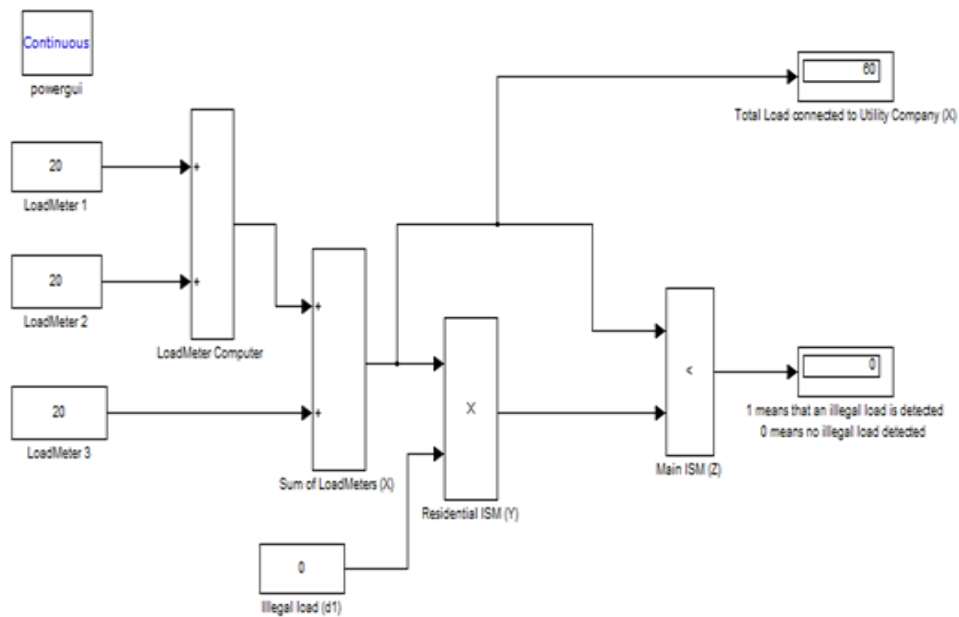


Figure 9: Simulink simulation of the anti-theft metering system.

Load Meter: It's an Intelligent Prepaid Energy Meter (iPEM) which measures the energy consumed by the load connected to it. This measurement is called the metered energy.

Load: This is the true load (metered load) connected to the Load meter. Load a, load b and load c as seen in Fig

Illegal Load: This is the unmetered load. This load enjoys energy consumption from the power utility through bypass (power theft). From Fig.8, Load d1 and load d2 are illegal loads. The illegal connection or bypass is done before the power utility meters. Fig. 8 shows the implementation steps involved detection of illegal loads connected to the meter, while Fig. 9 is resulting Matlab/Simulink model of the power theft metering system with the display and the algorithm and the block diagram is demonstrated using assumed values and the results is shown.

IV. RESULTS AND DISCUSSION

The types of simulation that are performed include:

- Varying the loads connected to the Residential ISM.
- Varying the illegal load connected within the Residential ISM.
- Varying the illegal loads connected within and outside the Residential ISM.
- Varying both the loads connected to the Residential ISM and also the illegal loads connected within and outside the branch ISM.

Table I: Simulation of load meters and illegal loads with ISM(s)

Loadmeter a	Loadmeter b	Loadmeter c	Illegal load within Residential ISM d1	Illegal load outside Residential ISM d2	Sum of Loadmeter X	Residential meter ISM (X*d1*d2) = Y	Main ISM
20	20	20	1	1	60	60*1	60
20	20	20	2	1	60	60*2=120	60
20	20	20	1.5	1	60	60*1.5=90	60
20	20	20	1.25	1	60	60*1.25=75	60
20	20	20	1	1	60	60*1*1=60	60
15	5	10	1	1	30	30*1*1=30	30
15	5	10	1	1.05	30	30*1*1.05	30
25	20	15	1.05	1.75	60	30*1.05*1.75	60
20	20	20	1	2	60	60*2 = 120	60

From Table I, the results of the number of simulations conducted, it can be observed that varying the loads read by the load meters does not affect the Residential ISM reading or the main ISM reading of the loads connected to the utility company. As long as no illegal loads are detected by the Residential ISM or the Main ISM located at the transformer for better performance and monitoring, the GSM module will not alert the utility company for a site investigation. Immediately, an illegal load is connected to the utility system either within the Residential ISM jurisdiction, the illegal load is instantly detected no matter how small the illegal load is.

V. CONCLUSION

The design, simulation and construction of a GSM-based prepaid meter has been achieved. It x-rayed various forms of electricity theft which include unaccountability of servicemen, irregularities of billing leading to a reduction of funds by the utility companies has also been achieved as this work prevents one on one contact between the end user and the workers.

With remote monitoring of the meter reading and sending SMS whenever there is abnormal readings in the customer electricity meter, the developed system may be able to help Utilities reduce the incidences of household electricity theft.

Automation of the customer billing system has been achieved as the meter keeps track of the consumers load on a timely basis. This design, therefore, removes the manual reading of meters with its attached consequences of time consuming system and bill manipulation which reduces revenue generation by utilities while adding higher bills to the consumer.

The work also revolves around the automatic disconnection and connection when the recharge is low or high respectively and extra cost due to reconnection is removed.

Further improvement will be needed in including miniaturized monitoring cameras in the customer meter which will monitor physical activities around the meter in each household to check other illegal acts that were not covered in this work.

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