Analysis of Electrical Power Usage in Houses Using Smart Electrical Distribution Switch

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ABSTRACT

Various power meters are introduced by electricity company to measure the consumption of power of consumers. Household with many occupants who use these electrical power meters need an automated smart switching system for the household electrical devices to monitor and control the power consumption in order to save power. This paper aims at proposing Smart Distribution Switch which is connected to household electrical devices and it is programed to monitor and control the electric power consumption of devices in households such that any device whose usage is not needed at a time is isolated from the grid in order to save power.A field survey was conducted to collect data randomly from a sample of households in the Sunyani municipality and the issues concern were why individuals in a household wish to have their separate power meters, how individuals use their electrical appliances and how much electric power consumed at the end of the month. The average consumption of each device used was determined, and the results confirmed that more devices used at a greater amount of time corresponded with higher consumption, and hence higher bills. Linear regression was used to analyze the results because it uses the methods of optimization and gradient decent to learn models that have parameters and it is practically used to make prediction of linear functions.

Keywords— *Power meter, consumption, Smart Distribution Switch, microcontroller, EPROM, Electrical, Optimization*

I. Introduction

Electrical Power is very important in our daily life and most of our activities are associated with electricity [1]. If it is not properly used, a great amount of it is wasted annually [2]. It should therefore be managed very well to enhance it judicious use. There has been a great increase in the consumption of electrical power in our homes and residential areas [3]. Most individuals who live in a large family and use the same meter who contribute equal amount of money to buy electric power but consumes different amount of power. The individuals are not able to monitor the consumption of others and their consumption hence there is the need to use smart electrical power meter [4] in order to avoid the inability in monitoring and controlling of the usage of electric power by the consumers. The unmetered electric power and some other factors such as power theft, defective power meters which generate wrong figures or do not read at all, the disconnection from the grid and reconnection to the grid which may lead to voltage leakages, when consumers use electrical power over a period and they fail to pay for itcan cause power losses**,** and these losses represent about several hundreds of Kilo Volts Amperes, however, these losses, the voltage, real and apparent power can be checked using smart electrical meter which sends the power consumption data and some other operational information to the distribution operating center [5]. There are several power meters which have been proposed and designed because the power meter is very important in measuring the amount of electric power consumed by a consumer, however, [6] the function of some of these power meters is limited and hence their application is restricted. Some of these power meters are designed so that data is been sent through Bluetooth or wireless communication to a personal computer and such meters will be difficult to be used at remote areas where telecommunication networks are weak or not available or personal computers are not available.

There are several switches, and in electrical engineering, a switch is an electrical component which can be used to connect or disconnect or divert the flow of electric current in an electrical circuit. A switch can therefore control the amount of electrical power that flow in electrical systems and can also be used to block the flow of electrical power. In this case a switch can be used to control and monitor the flow of electrical power in electrical distribution system. There are smart electrical switches which don't use wireless communication and which can be programmed to control and monitor systems, and for smart distribution, it is very important to get smart switch which will optimize the distribution performance and as distribution grid is becoming very complex, smart switches are needed for controlling and monitoring of electrical power distribution in the household where distribution will not be interrupted and the user can be provided with very vital information about power consumption, and the smart switch can be programmed according to the requirement of the user [7]. There is also a switchgear which is a type of a smart switch and which is made up of components like switches, fuses, and circuit breakers which are combined and can be used to control, protect and isolate an electrical equipment to facilitate continuous and reliable supply of electricity. According to [8], it is very important to have smart distribution systems that can perform efficiently without any interruption and can also provide to users the necessary information about the consumption of power and its quality. That smart distribution system can help power sources to be managed intelligently which can make efficient and reliable distribution of power. However, smart distribution switch will control and monitor devices and individuals' consumption and disconnect the devices which are not to continue consuming power and user from the household grid as soon as their share of contribution is finished. Also in [9], it is clear that for the optimization of the performance of smart distribution, it is very necessary to use smart switch. This will enhance general performance in distribution of power, hence Smart Distribution Switch is proposed to monitor and control individual's consumption of electric power, and it will help the consumer to plan on which electric power appliances to use and how long to use them in order to avoid power wastage. Smart distribution will need smart meters and according to the U.S. Department of Energy's report on smart grid system, it is estimated that about sixty-five million smart meters have been installed by 2015 [10] and also by 2020, it is expected that about 830 million of smart meters would be deployed worldwide [11]. The smart meters are able to accumulate greater amount of data that is able to give enough information to monitor operational systems in almost real time [12].

The proposed smart distribution switch is used to control andmonitor the electric power consumption of electrical devices of individuals in households in both remote and urban areas and can also help to save and manage power in order to avoid power wastage. It also helps consumers to plan well on the appliances to use and how long to use them and help in the prediction of consumption.

This paper is organized as follows: Section 2 talks about the related literature, Section 3 describes the methods and the materials, Section 4 presents the results and discussion and finally the conclusion is in Section 5.

II. RELATED LITERATURE REVIEW

These scholars [13] aimed at how single phase energy meter is designed and implemented which can also be monitored remotely by the use of Short-Message Service(SMS)**.** Some discrete components or devices and a metering chip (ADE7755) were used to design the energy meter. The Short-Message Service (SMS) with the meter was set up with the help of Neoway M590 Global System/Standard Mobile Communication (GSM) module. The GSM receives commands from mobile phone for communication. Nonetheless, this meter has to be connected to a switch before connecting to the home appliances.[14] designed a digital energy meter where he used Advanced Virtual RISC (AVR) microcontroller to transmit the data measured by wireless means to a computer. The circuit designed was implemented or put into effect on PCB, that is Printed Circuit Board. Microsoft visual studio C# was used to write a program to monitor the received. An 8-bit Advance Virtual RISC (AVR) low power microcontroller was used, however, smart distribution switch will control and monitor devices and individuals' consumption and disconnect the devices which are not to continue consuming power and therefore manage and save power. Again, [15] focused at developing a management system which was prototype to manage prepaidelectrical power meter based on RFID. The work was done by using wireless gateway, digital meter, microcontroller, and Radio Frequency Identification (RFID) reader to design the proposed prepaid electrical meter and the designed circuit is connected to a computer, where Radio Frequency Identification (RFID) reader is used to read the information on the credit card. The RFID reader reads the information on the ID card and this information is sent to the server to check if it is authentic and later the client receives the information. It is obvious that in the areas where there is no telecommunication network or the telecommunication system is not working well, it will be difficult to implement such system. Furthermore, [16] developed a system of energy meter which used wireless communication with a circuit in which the power can be on or off. The system is used to measure electrical energy bills and the information about energy consumption is sent to the consumer. The dead line information about the payment of the bill is also sent to the consumer and if the consumer refuses to pay the bill, the power supply is disconnected. Though it is a very good technology, however, it implementation will be difficult at an area where the wireless and telecommunication technology is not available. In addition, [17] presented a work on the prepaid electricity meter which alerts the consumer on the usage of energy consumption, however, this proposed energy meter use a Radio Frequency Identification (RFID), personal computer and a wireless gateway in it operation. In an area where wireless and RFID technology is not available, or not reliable, it will be difficult to implement this system. More so, [18] gave a presentation on the effectiveness of feedback on energy consumption using wireless communication, [19] designed an Electricity Power Detection Theft using wireless prepaid Meter which was used to detect the stealing of electrical power, and [20] designed the Building of a prototype wireless prepaid Electricity Metering that was used to determine the amount to be consumed at a time. All these power meters use wireless technology and they help consumers to plan and use energy wisely. Besides, wireless communications are used in many smart grid applications which can be used to collect meter data [21], however, certain environments remain a challenge when it comes to wireless solutions [22]. It is a fact that areas where telecommunication infrastructure are not available will surely have wireless communication issues and therefore it will be difficult implementing wireless metering system and even where it is available it is subject to interference.

III. MATERIALS AND METHOD

A field survey was conducted on several credit or post-paid meters and prepaid meters used by different consumers for a period of twelve months in the Sunyani Municipality to collect data on the electrical consumption of consumers. The meters were read monthly by the meter reader and the researcher where the previous and present readings were noted, and again the researcher selected two tenants and recorded hourly and daily consumption of the appliances; radio,11W bulb, Television, Fridge, Iron and Heater. This was to compare the hourly, daily and the monthly consumptions. The electrical power meters recorded consumption in Kilowatt hour (KWh) and are connected across a 240V with 60Hz transmission line, and a current of 15A to 60A can flow through it without breaking it.

The issues concern were why individuals in a household wish to have their separate power meters, how individuals use their electrical appliances and how much power consumed at the end of the month. Linear regression was used to analyzed the results which confirmed that higher bills corresponded to higher consumption.

The control of the circuit is done with the used of the PIC16F877A microcontroller chip made by Microchip Technology with a data memory of 16-bit which can be programed easily using C/C++ compilers [23], LCD display Max232 is the screen which displays the power used and 20MHz crystal clock which shows the smallest interval of time to accomplish any instruction by the microcontroller. The proposed Smart Electrical Distribution Switch (SEDS) is connected to the power meter and which has multiple phases of connection to the occupants of a house and to the various appliances for the control of power consumption. The amount of power consumed based on the consumption rate will be recoded and stored on EPROM of the microcontroller which is programed and run in MikroC compiler. The microcontroller is used in an embedded system and need no operational or external digital parts to function as a complete computer and it is used to accumulate or gather the real power information. Smart distribution switches are devices acting as an interface between the utility-controlled smart meters and the home area network. These devices control and take care of the data exchange between smart meters, utility or service providers and power consumption in-house objects. They also manage the information for several homes, a multi utility controller, also known as gateway of energy, manage and control the exchange of data for a particular home. The smart distribution switch is operating as a Data concentrated unit (DCU) that manages the data input from the occupant in the house and also allows saving and better management of power. Each network connected to an apartment will be managed and monitored by the DCU through a console based application written on the microcontroller. It coordinates the activities between the users and the meter [24]

Both hardware and software are implemented at desired stages. The microcontroller is programed to monitor the usage of power and also provide a set of control commands for isolation of devices that should not consume power. The programming language employed to run the microcontroller is MikroC compiler. The MikroC compiler generates code for the PIC microprocessor. The proposed model block diagram is shown in figure 1 and the circuit diagram is also shown in figure 2.

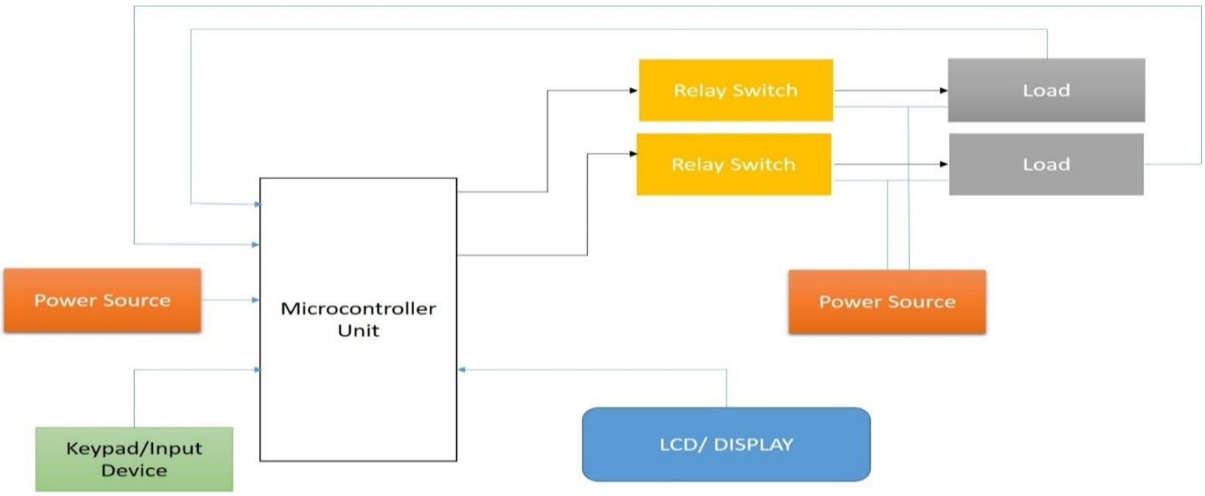

Figure 1 Proposed model block diagram.

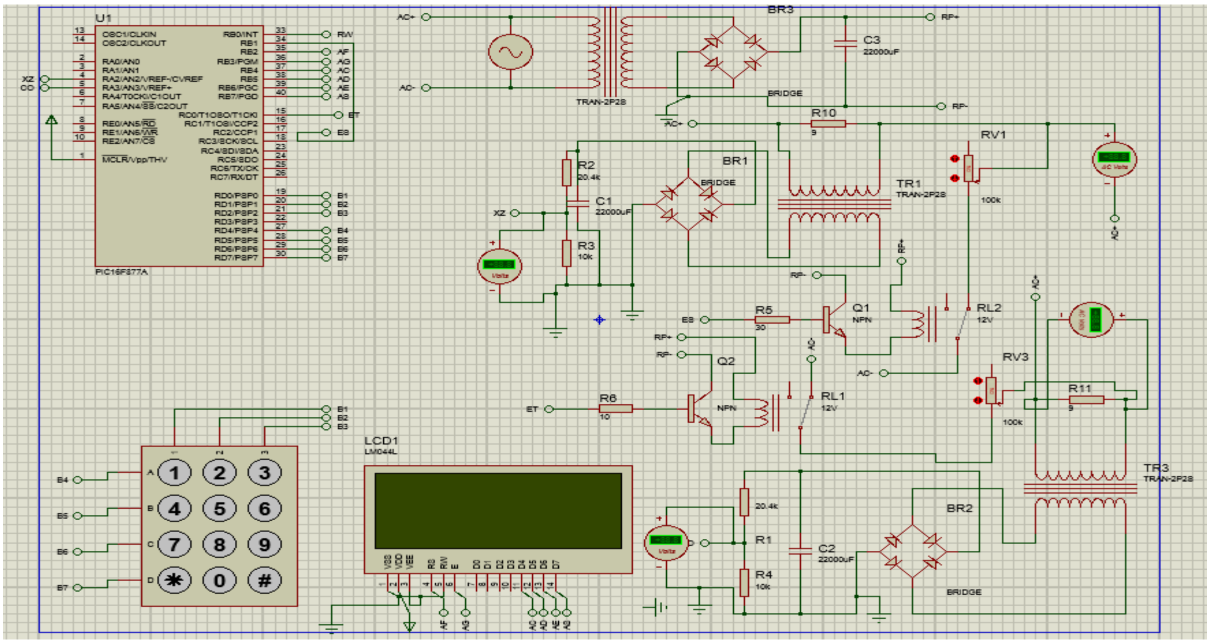

Figure 2 circuit diagram of proposed model

The main work is demonstrated in the embedded control system. The system is mounted between the main switch and the loads of the individual consumers. Here the system monitors all individual loads connected through the main switch, and upon reading the power consumption at all instances, the consumption can be quantified to take further decisions. The average power as well as the power factor are calculated and hence the active or the average power can be calculated as:
$P = V_{rms}I_{rms}Cos$□, where P is the active or average power, V_{rms} , is the root-mean-square-voltage, I_{rms}, is the root-mean-square-current, and Cos□ is the power factor, where □ is the phase angle which is the measure of how much the applied voltage leads or lags the current in the alternating current (AC) circuit. Hence the energy delivered to the load in a given period of time is given as:
Energy = power x time, which is measured in Kwh.
The main embedded control system is partitioned into five sections: These are
Sensor: The sensor consists of a series resistor in the consumer live cable and a step down transformer across it which constantly measures the voltage of the output based on the current drawn by the consumer. With the help of other electronic circuits like rectifiers and operational amplifiers, the value is cut down to a manageable value that can easily be processed by the control unit.
ADC: The signal to be process at all point is in the form of analogue signal which needs to be converted to a digital signal before it can be processed by the control unit. The ADC is an analogue to digital converter which converts the output from the sensor to digital value to be delivered to the control unit.
Control Unit: The control unit serves as the brain of the whole unit. It consists of a microcontroller and its associated components which deal with the real computations of values and purposely for decision making. With any value exceeding threshold value key on it through the key pad and values stored in the EPROM, it issues commands for the buffer circuit to be activated for further actions to be taken. This can be done to either connect or disconnect individual consumer circuits.
Buffer: The buffer circuit links the control unit and the relay driver circuit. It consists of a group of transistor circuits which are activated to cause current to flow for the groups of relays to make the connections and disconnections of the hot cable wires.
Relay Driver: The relay driver is a group of relays connecting different consumer circuits. They are energized and de-energized based on the decision taken by the control unit through the buffer circuit. They are the only section which interacts directly with the consumer hot wire.
The final product is to be achieved through software implementation (simulation) using MATLAB programming environment.

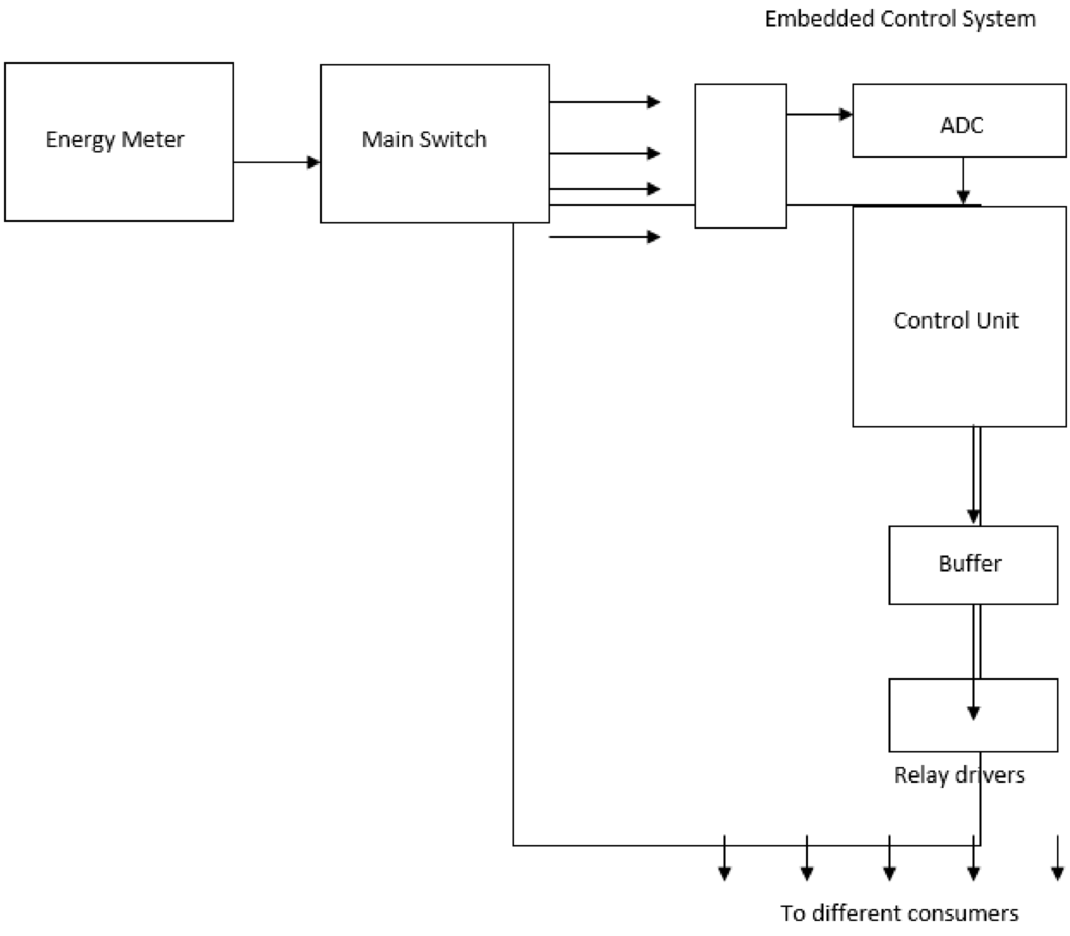

Figure 3. Embedded control system

IV. RESULTS AND DISCUSSION

The table 2.0 is a data used to test the simulation of the Smart Electrical Distribution Switchandthe figure 5 shows a cross-section of multiple power meters installed on a wall of a household in a section of the Sunyani Metropolitan Assembly.

In testing the proposed system, two lines L1 Units and L2 Units showing on the Lead Crystal Display (LCD) of the proposed system, representing two consumers were initialized to 00.0kwh each before connecting load to it. Figure 4(a) shows the initialized figures. Each line was then connected to the same load leading to the same consumption of 2.2kwh and that is shown in figure 4(b). More loads were added to each line, but much more load was added to L2 and it recorded higher consumption than L1. This is shown in figure 4(c).

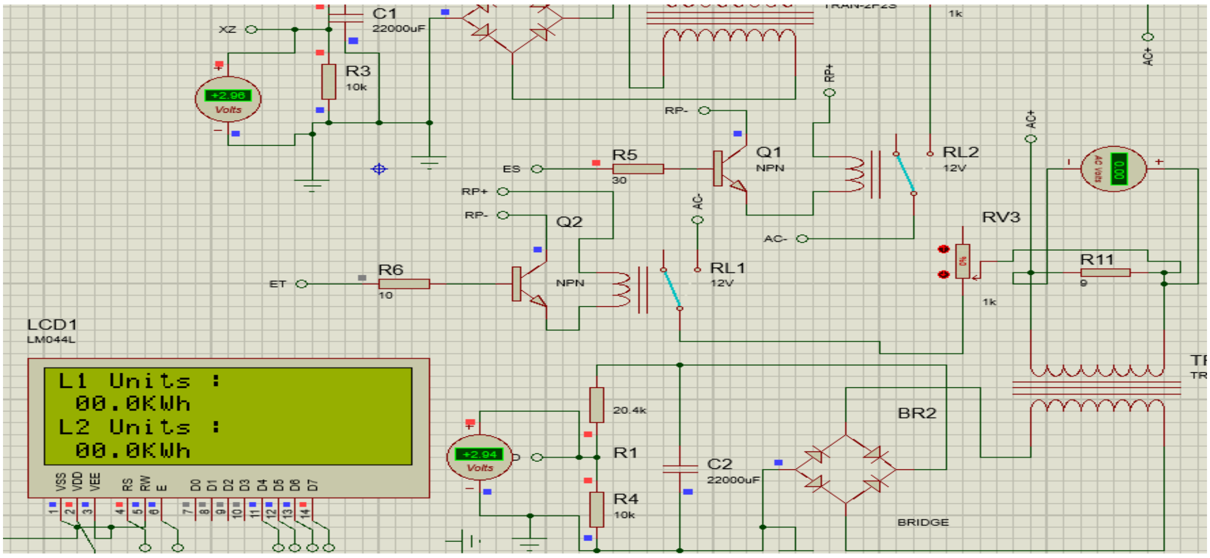

Figure 4(a) showing 00.0khw for L1 and L2

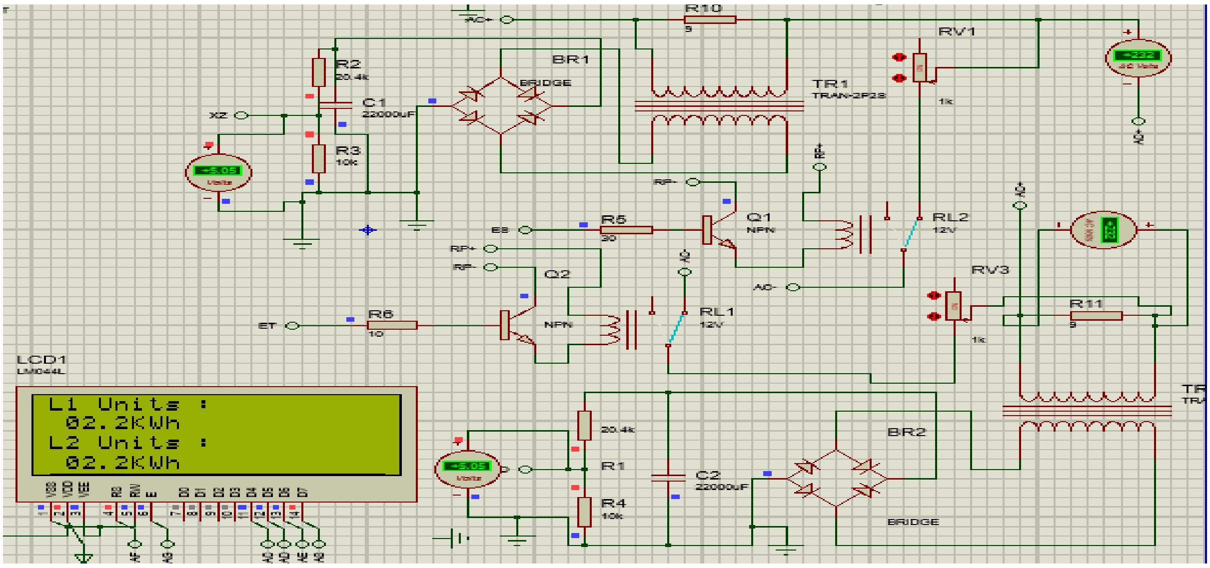

Figure 4b, showing 2.2kwh for L1 and L2

Figure 4(c) showing 09Kwh for L1 and 16Kwh for L2

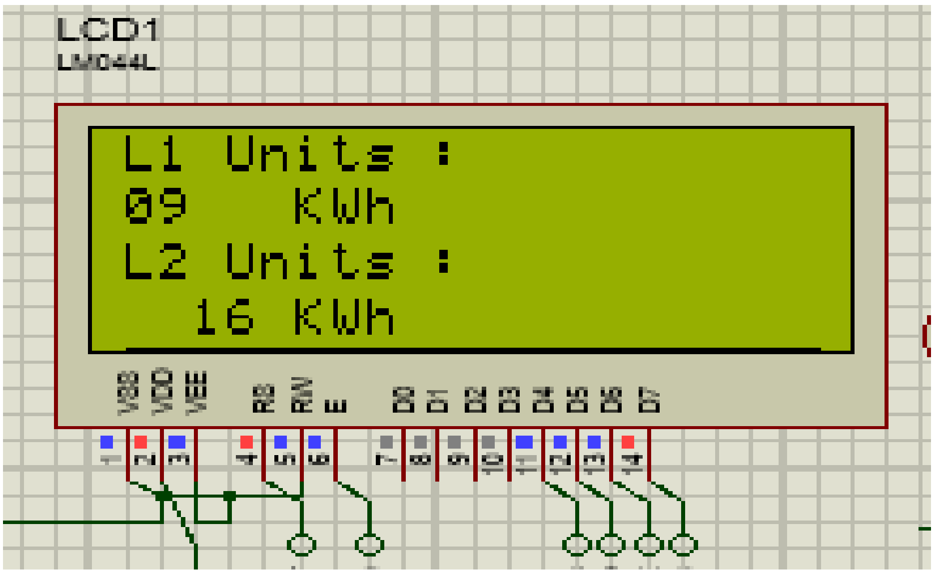

Figure 5a. A postpaid power meter.

Figure 5b shows multiple prepaid power meters on a wall.

The Smart Electrical Distribution Switch proposed also calls for one meter and the amount of power consumed or paid by each contributor is recorded and stored in EPROM of a microcontroller that will reduce each user's power consumption base on the user's consumption rate. It is programed to calculate the electrical power consumed by any device or contributor and it will monitor each contributor's consumption and isolates the user or any appliance from the grid when they are not supposed to consume power and in that case there is saving and better management of power.
The simulated system was loaded up and connected to a device of 2.2kw. As the load absorbed the power supplied, the power reduced until it finally finished. The complete time of consumption of the power was recorded as the simulation time. When the simulated system was loaded up with more power, and maintaining the 2.2kw load, it took more time for the power to finish, hence more time to isolate the user from the system. However, it was observed that a little change or fault can cause the setup to record error and therefore there is the need for optimization in the designing and programming.
The table 1.0 represents a sample of the amount of consumption in Kwh and equivalent unit price in cedi (GHS) and table 2.0 illustrates monthly power consumptions, load (Kw) and the simulation time in minutes.

Table 1.0

User/Energy	Energy/GHS	Energy/Kwh
A	5.0	12.2
B	6.0	14.8
C	9.0	22.0
D	7.0	17.1

(Sample of users' consumptions in money, GHS and their equivalent energy in Kwh)

The figures 6a and 6b hypothetically explains the consumptions in the table 1.0. In figure 6a, the end of each continues vertical line from the E/GHS axis shows that a device or a contributor should not continue consuming power, but they continue to consume and waste power because there is no an automated smart switch to isolate the devices from the grid. However, in figure 6b, the automated Smart Electrical Distribution Switch monitor and control the devices power consumption and isolate the devices from the grid and hence saving power.

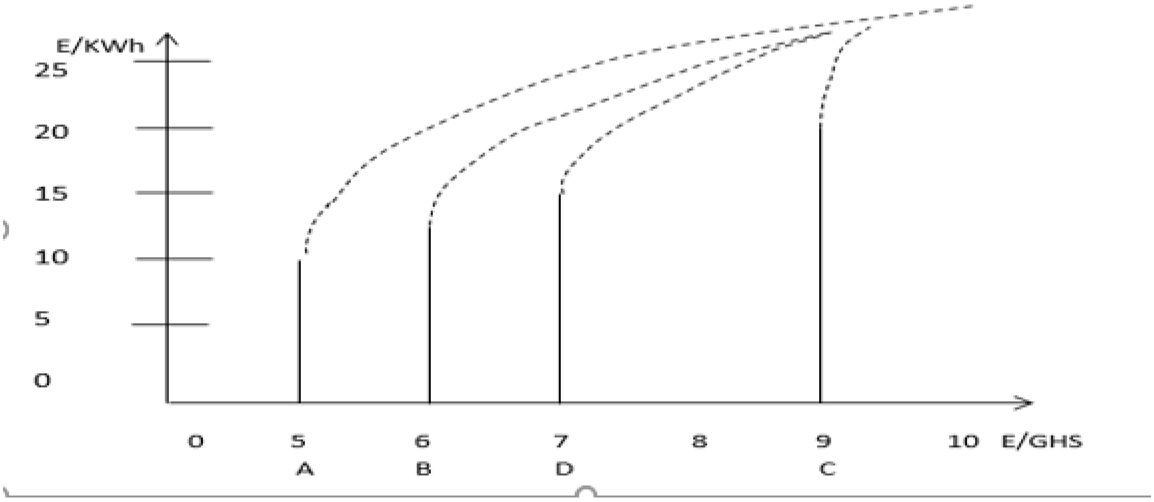

Figure 6a, a graph energy(kwh) against energy(GHS)

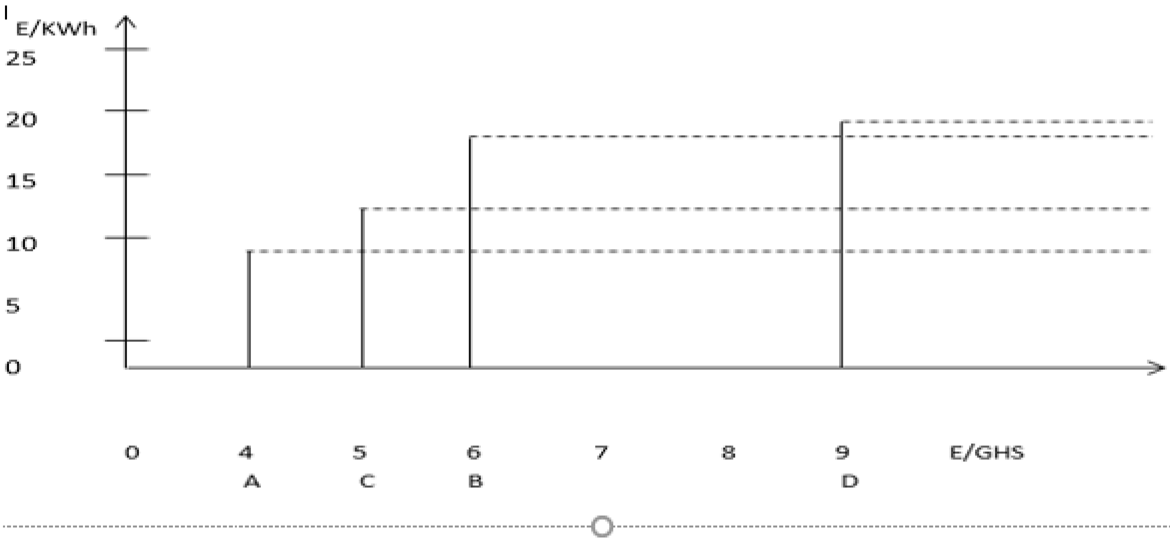

Figure 6b, a graph of energy(kwh) against energy(GHS)

Table 2

MONTH	ENERGY (KWH)	LOAD (KW)	SIMULATION TIME/MINUTE
1	9.70	2.2	1.94
2	14.5	2.2	2.90
3	17.0	2.2	3.40
4	19.4	2.2	3.88
5	9.00	2.2	1.80
6	10.0	2.2	2.21
7	15.0	2.2	2.26
8	16.0	2.2	2.39
9	14.5	2.2	3.90
10	19.3	2.2	3.86
11	19.0	2.2	3.38

(Users energy, load used and simulating time)

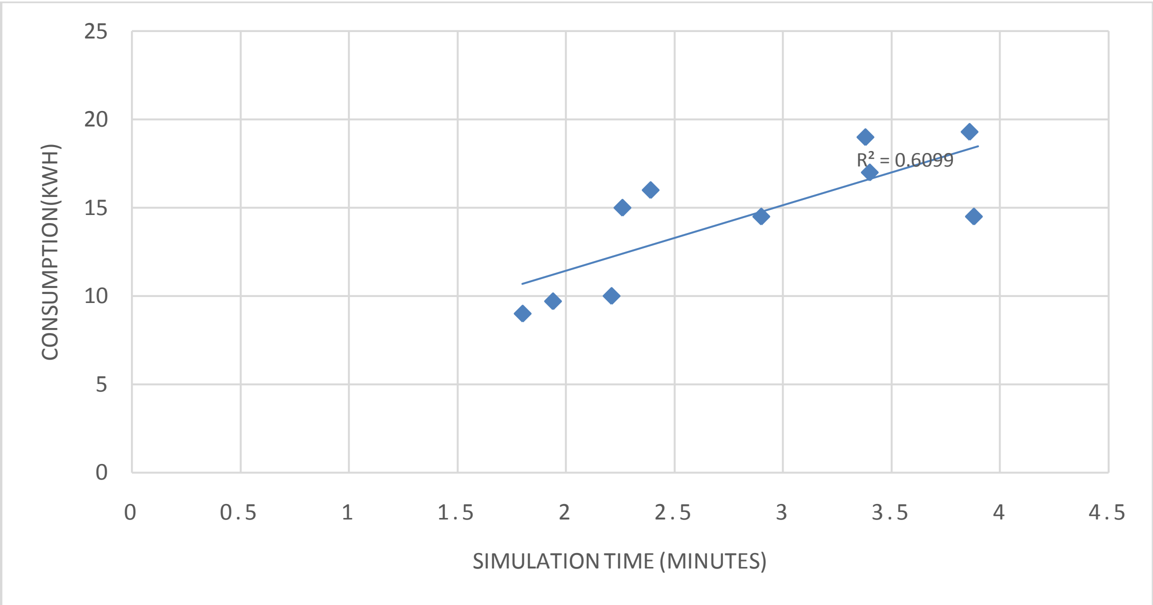

Figure 7. A graph of power consumption (KWh) against Simulation time (minutes)

From the graph illustrated in figure 7, the model is linear and the time is dependent on how long the appliances are used, therefore when the appliances are used for a longer period, the consumption of power is high. The correlation coefficient (R) was 0.78 and that shows that as the time of usage of appliances and load increase the consumption also increases. The SED is programed to appropriately monitor and control the time of usage of the appliances such that an appliance cannot exceed the period of time allocated to it. The system isolates any appliance from the grid whose time expires, hence controlling the amount of power consumption. The proposed system can be used for both credit and prepaid energy meters.

Table 3

APPLIANCE	PREPAID HOURLY	POSTPAID HOURLY	PREPAID DAILY	POSTPAID DAILY	PREPAID MONTHL	POSTPAID MONTHL
	------------	--------------	------------	--------------	-------------	--------------
RADIO	0.01	0.01	0.12	0.01	3.60	3.60
BULB(11W)	0.01	0.01	0.12	0.12	3.60	3.60
TV	0.02	0.02	0.19	0.19	6.00	6.00
FRIDGE	0.06	0.07	0.54	0.56	18.00	18.00
IRON	0.09	0.09	1.08	0.99	32.40	32.40
HEATER	0.10	0.11	1.20	1.20	36.00	36.00
FAN	0.05	0.05	0.55	0.55	15.00	15.00

Table 3 shows the hourly, daily, and monthly consumption of the various appliances.

The total monthly consumption can be predicted using the expression:

$T_c = (H*D*C)_1 + (H*D*C)_2 + (H*D*C)_3 + \ldots\ldots + (H*D*C)_n$

$T_c = \sum_1^n (H * D * C)$

Where T_c is the total consumption, H is the average number of hours in a day, Dis the number of days in the month, C is the hourly consumption of a device and n is the number of devices used. If the consumption rates per Kwh at varied consumption are known, the total amount of money per month can be estimated.

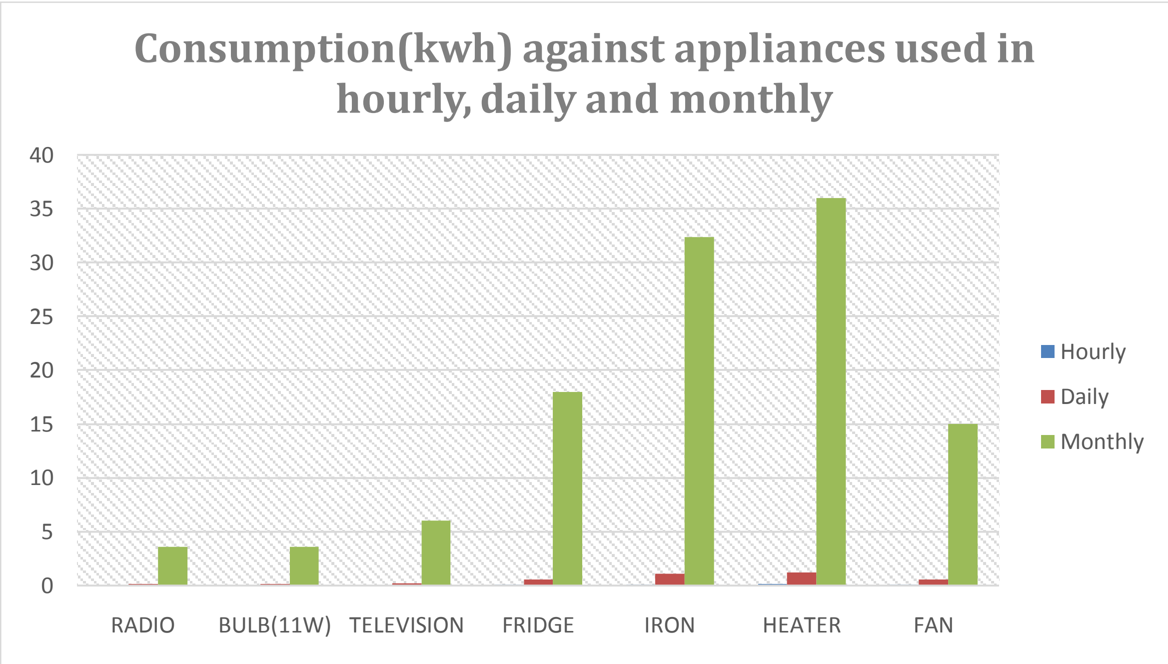

Figure 8, consumption(kwh) of appliances in hourly, daily and monthly.

Figure 8 shows the average consumption in Kilowatt-hour against the various appliances that were used. The water heater consumed higher, followed by the iron, fridge, fan, Television and the radio and bulb. For the water heater and the iron, the consumption for each was so high because these devices have heating coils that consume greater current [25], however, in the case of the Fridge, Television, fan, radio and the bulb their consumptions were moderate. It also shows that it will be difficult to use a short term like hourly or daily to make an accurate prediction of load consumption, however, the hourly and daily consumption of various appliances can be used to predict the monthly consumption.

V. Conclusion

The study is about electrical power usage in households and aims at proposing Smart Distribution Switch for monitoring and controlling the electric power consumption of devices in households and the usage of it helps to preserve power and avoid power wastage by isolating a device that is not in used at any giving time and can also be used in both rural and urban areas. The findings will help to eliminate the difficulties and the limitations that exist in the manual monitoring of power and will also help consumers to plan well on which appliances to use and how long to use them and it helps in the prediction of household power consumption. The right amount of power a consumer decides to use is what is consumed and therefore there is better management of power usage that avoid power wastage. It was observed that a little change or fault can cause the setup to record error and therefore there is the need for optimization in the setup and programming.

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