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MODELING AND SIMULATION OF POST-PAID ENERGY METER FOR MULTIPLE COMMERCIAL USERS

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Abstract

The increasing demand for electricity and the need for efficient energy management have led to the development of advanced energy metering systems. Traditional post-paid energy metering systems often suffer from limitations such as inaccurate billing and lack of real-time monitoring, resulting in disputes and revenue losses. This research work aims at design and simulation of a post-paid energy meter for multiple commercial users. To address these challenges associated with the traditional post-paid energy meter, this study designed a post-paid energy meter that can accurately measure and display energy consumption among multiple commercial users. The meter uses a voltage and current sensing circuit to measure the energy consumption of each user, and a microcontroller to process the data and display the results. The system is designed to enhance transparency by providing each user with detailed consumption data, reducing disputes over energy bills. The system was simulated using Proteus 6.0 professional circuit design suite and the Arduino IDE. The results show that the designed system achieved 99.62% effectiveness and 100% accuracy in measuring and distributing energy consumption among the five facilities, enabling each facility to determine its energy consumption and bill.

Keywords: Post-paid energy meter, multiple commercial users, energy consumption, billing, revenue protection.

Introduction

Post-paid energy metering involves the tracking of energy consumption by the consumers, and charge them periodically (e.g. monthly), which they pay after consumption. This approach is commonly used in residential and commercial settings, where customers receive a bill for their energy usage at the end of each billing cycle, allowing them to manage their energy expenses based on their actual usage.
Energy metering systems have been widely used all over the world for measuring and billing electricity consumption in various sectors, including commercial and residential areas, where accurate and efficient energy management is crucial for both utilities and consumers. The traditional post-paid energy metering system has been the most used method for billing electricity consumption (Gopinath et al., 2013), allowing customers to consume energy and then pay for it after the fact. However, this system has several limitations, including inaccurate billing due to human error or tampering, energy theft through meter manipulation or bypassing, and lack of real-time monitoring, which can lead to delayed responses to energy usage issues and increased costs for utilities and consumers alike (David, 2018).
In recent years, there has been a growing trend towards the use of advanced metering infrastructure (AMI) and smart metering systems (Arooka et al., 2010). These systems offer several benefits, including real-time monitoring of energy consumption, automated meter reading, and improved billing accuracy (Yeboah & Darko, 2019). However, the adoption of these systems has been

slow, particularly in developing countries, due to various challenges, including high upfront costs, technical complexities, and regulatory barriers (Kumar et al., 2017).

In the context of multiple commercial users, the traditional post-paid energy metering system often relies on manual meter reading and billing processes, which can lead to errors and inaccuracies (Gopinath et al., 2013). Moreover, the lack of transparency in energy consumption and billing can lead to disputes and mistrust among users (David, 2018).

This research work comes from the fact that Electricity in Nigeria is mostly used with no form of accurately calculating the actual consumption of the users; this led to estimated billing and the payment of what is called a “flat rate” which turns out to be always higher or lower than what a customer owes the power utility company. Electric meter or energy meter measures the total power consumed over a time interval. Power utility companies use electric meters installed at customers' premises for billing and monitoring purposes. They are typically calibrated in billing units, the most common one being the kilowatt-hour (kW-hr). They are usually read once each billing period (Schweppe et al., 2013).

However, despite the benefits of traditional metering systems, challenges persist, particularly in developing countries (Kumar et al., 2017; David, 2018). One key issue is the lack of efficient metering systems for multiple commercial users. The importance of accurate energy measurement and billing has been widely recognized (Depuru et al., 2011; Jamil et al., 2018; Nguyen et al., 2018). Advanced metering infrastructure (AMI) has also been identified as a key enabler of smart grid systems, allowing for real-time monitoring and control of energy consumption (Gungor et al., 2011; Lu et al., 2018; Meng et al., 2016). This research aims to address this gap by developing a robust energy metering model, building on previous work (Han et al., 2017; Saha et al., 2018; Li et al., 2019; Yeboah & Darko, 2019).

This research stems from the need to reduce the cost of using multiple energy meters or multiple commercial users and/or using a single meter for multiple users which has always been a problem, to improve energy metering accuracy and efficiency for multiple commercial users, develop a comprehensive modelling and simulation framework for energy metering, investigate the impact of real-time energy usage data on energy metering accuracy, contribute to the development of sustainable energy management practices to mitigate revenue losses.

While existing research focuses on residential or single-user commercial energy metering, there is a lack of comprehensive studies addressing the unique challenges of multi-user commercial environments. This research aims to bridge this gap by developing a robust energy metering model capable of accurately allocating energy consumption and billing among multiple commercial users.

This research work is important because it offers solution to multi-facility bill splitting. This means in an institution with multiple commercial shops this research work found a way to split the bill according to the consumption of the different shops. Before now, the tradition was to have an estimated bill for each commercial user. Therefore, there is a need for a more accurate and efficient energy metering system that can provide real-time monitoring of energy consumption and transparent billing for multiple commercial users.

This journal aims to model and simulate a meter that can administer electricity to five commercial users at once while keeping a record of the total energy consumed as well as everyone’s precise consumption quota. This will be achieved through the following objectives, to: Model an alternating current (AC) voltmeter circuit and AC Ammeter circuit, Simulate the entire Post-paid electricity meter for multiple commercial users, Determine the energy consumed by the commercial users and split this energy into the individual shops according to their consumption rate and lastly validate the performance of the post-paid energy meter with the existing ones.

The scope includes the determination of energy consumption patterns and modeling, energy metering system design and evaluation, and real-time energy usage data integration. The Post-paid electricity meter will be modelled for five commercial users. The prototype presented in this thesis handles five facilities running on 220V AC with a maximum safe load of 5 KVA.

Materials and Methods

Materials

The materials used in this work include:

Arduino nano microcontroller; ACS712 current sensor;Proteus 6.0 professional circuit design suite;

Arduino IDE; Resistors; Transformer; Diodes; Capacitors; Voltage regulator

Model of the systems

Figure 1 shows the 5V power supply designed for the energy meter. A center tap 12-0-12V, 500 mA transformer is used in this design such that part of the 12V of the secondary goes to a voltage regulator to power the controller and the display. The other 12V is used in designing the circuit for measuring the AC voltage. Both circuits share a common ground at the center tap. Sharing common ground is necessary for the voltmeter circuit that will be connected to the controller's analog channel. After rectification by D1 and D2, the ripple laden voltage is passed to a capacitor for filtering. The following calculations were made when selecting the filtering capacitor C_1.

The capacitance of the filtering capacitor C_1 is calculated using the equation (1).

$$Y = \frac{1}{4\sqrt{3}fRC} \quad (1)$$

Where Y is the ripple factor, f is the frequency of AC (50 Hz), R is resistance calculated, and C is the capacitance of the filtering capacitor C_1- to be calculated

The ripple factor, Y, is obtained using equation (2) and the calculated value is 0.06928.

$$Y = \frac{V_{AC\_RMS}}{V_{DC}} \quad (2)$$

R is obtained using equation (3) as 33.94 Ω

$$R = \frac{V}{I} \quad (3)$$

Therefore, substituting the values of *R*, *Y* and *F* into equation (1) and making C subject of formula

We obtained the capacitance C as $1228\,\mu f$. Therefore, a standard capacitance of 1000 µf was used as depicted in Figure 1.

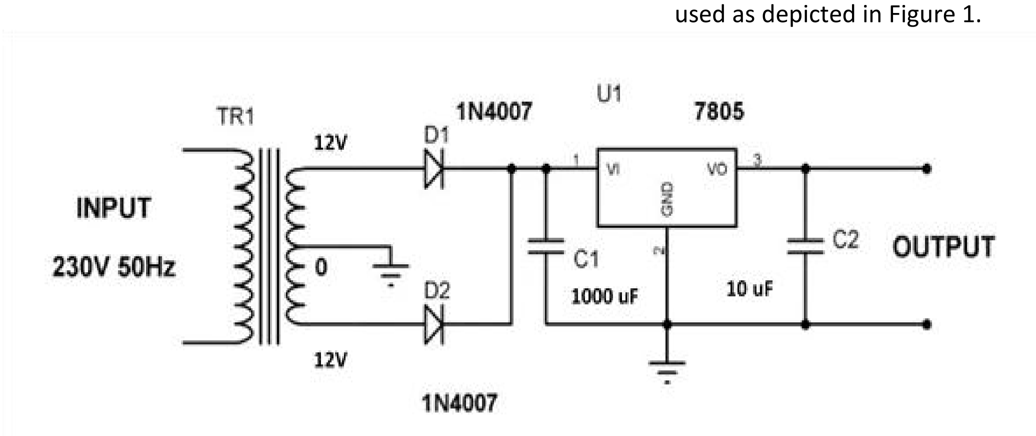

Figure 1: Power supply design

The capacitor C2 is selected according to datasheet of lm7805 voltage regulator. According to datasheet a capacitor between 1 µf and 10 µf can be placed at the output (Texas Instrument, 2009).

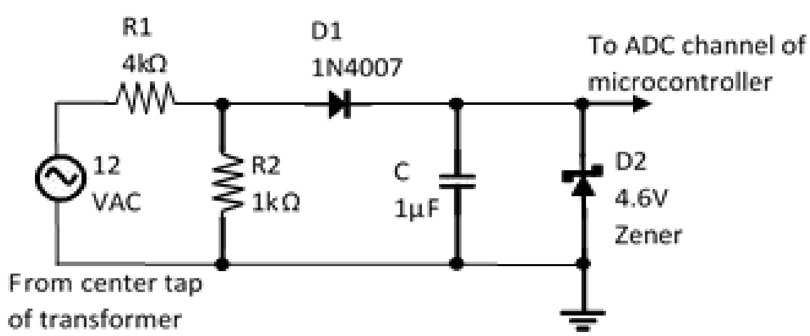

Figure 2: Design of AC voltage sensing circuit

Figure 2 shows the design of the AC voltage sensing circuit. The 12V AC output from the transformer is converted to DC and then reduced to a safe voltage using a voltage divider circuit. This ensures the microcontroller's digital converter (ADC) channel doesn't receive more than 2.5V, even when the input voltage is 220V. A 4.6V zener diode is also used to protect the ADC channel from voltages above 5V, preventing damage and inaccurate readings.

Based on all these considerations, the selection of R1 and R2 is done as follows:

From ohms law, V = IR (4)

Where V is voltage = 12VAC

I is current and R is equivalent resistance

R = R1 + R2 (5)

Therefore, current flowing through the circuit will be

$$I = \frac{V}{R1+R2} \quad (6)$$

$But\ Voltage\ drop\ across\ R2, V = IR = I\ x\ R2 = 2.5V$

Therefore, from the equation (6) the values of R1 and R2 is calculated in term of ratio as

$$\frac{\mathrm{R1}}{\mathrm{R2}} = \frac{3.8}{1}$$

Therefore, the ratio of R1 to R2 is approximately 4 to 1 and so R1 was selected as 4kΩ while R2 was selected as 1kΩ. It is completely safe to select 4kΩ especially when resistor tolerance is considered. Also, the transformer used is rated 220V to 12V at both windings in the secondary. If the transformer ratio is designated N, then:

$$\mathrm{N} = \frac{220}{12} = 18.33$$

The ADC channel of the controller used in this design is a 10-bit ADC channel. This means that when 0 to 5V is fed to the ADC channel of controller it will correspond to a value that is between 0 and 2^{10}. This is same as 0 to 1024. That means if y volt is fed to the ADC channel, the value (y/5) x 1024 will be returned as the analog equivalent.

Given all these parameters, the following formula was established and programmed into the controller for calculating the AC voltage:

$$\left[\frac{y}{1024} \times 5\right] \times \frac{R1+R2}{R2} \times N \quad (7)$$

Where y is the analog value of voltage read by controller

R1 is 4kΩ in actual sense it is approximately 3.8kΩ because of resistor tolerance

R2 is 1kΩ

N is transformer turns which is 18.33 as a test, if it is projected to measure 220VAC, this voltage divider circuit becomes 2.5 volts or $\frac{2.5}{5}$ ×1024 = 512 analog equivalent. This means that the controller reads the 220 VAC as 512 and asses this value into the formula (which will be programmed into the controller).So, by substitution, we have: 219,16V which concludes how the controller measures AC voltage in this design. Which by calculation is 99.62% accurate.

Interfacing Current sensor with Microcontroller

The current sensor used in this design is an ACS712 sensor. This sensor can measure up to 30A of both DC and AC current (Allegro Microsystems, n.d.).
The current sensor is interfaced to the controller and programmed to read current. The out pin is connected to the ADC channel of a controller while Vcc and ground pins are connected to 5V and ground respectively.

Simulation of the entire Post-paid electricity meter for multiple commercial users.
Simulation was done using the proteus 6.0 professional circuit design suit. The schematic diagram of the circuit was drawn in the proteus environment while the software was written in the arduino IDE. After compiling the software, it was then linked to proteus for simulation. Figure 3 shows the circuit diagram in the simulation environment.

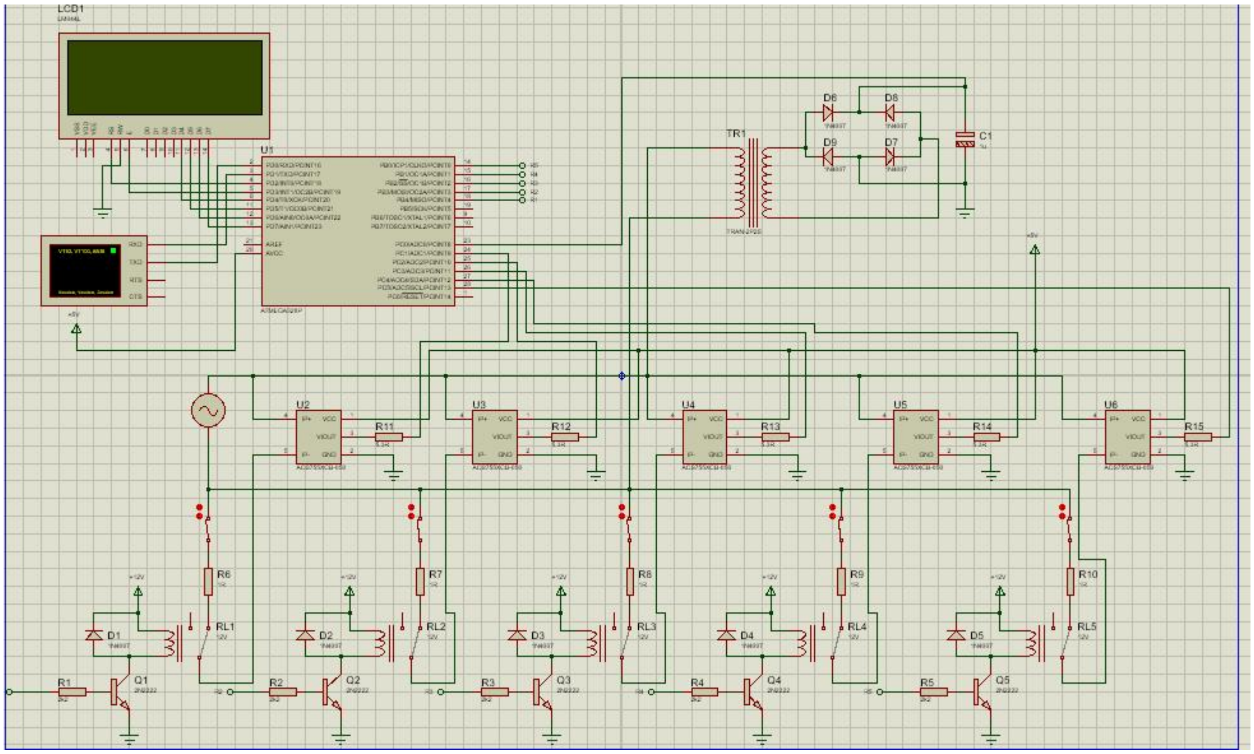

Figure 3: Logic level converter circuit

Determine the energy consumed by the commercial users and split this energy into the individual shops according to their consumption rate.

The microcontroller used in this project is an arduino nano equipped with an ATMEGA328P chip. This controller was the preferred choice for this project because of the relative ease with which it takes to program the controller. This controller, apart from the Atmega328 chip, is also equipped with a CH340 chip that enables serial communication with a computer through a universal serial bus (USB) mini-B cable (Hart, 2009). This eliminates the need to purchase any third-party programmer, and so codes or software written in the C/C++ programming language is burnt directly into the memory of the controller through a USB cable.
Onboard the controller is also 5V and 3.3V regulators. All these components combined make it extremely easy to use the arduino nano microcontroller.
A microcontroller is a miniaturized computer with a central processing unit (CPU), read only memory (ROM), random access memory (RAM) and peripherals like ADC channels. All calculations used in this design, including floating point calculations, are performed by the CPU of this controller.

Validation of the performance of the post-paid energy meter with the existing ones.

The performance of the simulated post-paid meter will be validated by connecting different loads (resistors) across the five outputs of the meter which serve as the shops, the simulated result will then compare with the actual power consumption which can be obtained analytically.

Results and Discussion

Simulation results and discussion

This research work aims at designing a five-facility billing system. Let the consumers of each of the five-facility billing system be regarded as FS1, FS2, FS3, FS4 and FS5. The results are therefore presented based on the following scenarios.

- No load connected on all (five) supply points
- FS2, FS4 and FS5 have loads connected as shown in Table 1 for one second.
- System is switched off and later switched on to check if user's consumption is saved in memory.
- FS2 cut off using switch for two seconds

The above scenarios will be applied to the simulation. Both results will be compared subsequently.

Table 1: Users load data

S/N	User.	Connected Load (Ω)
1	FS2	10
2	FS4	15
3	FS5	20

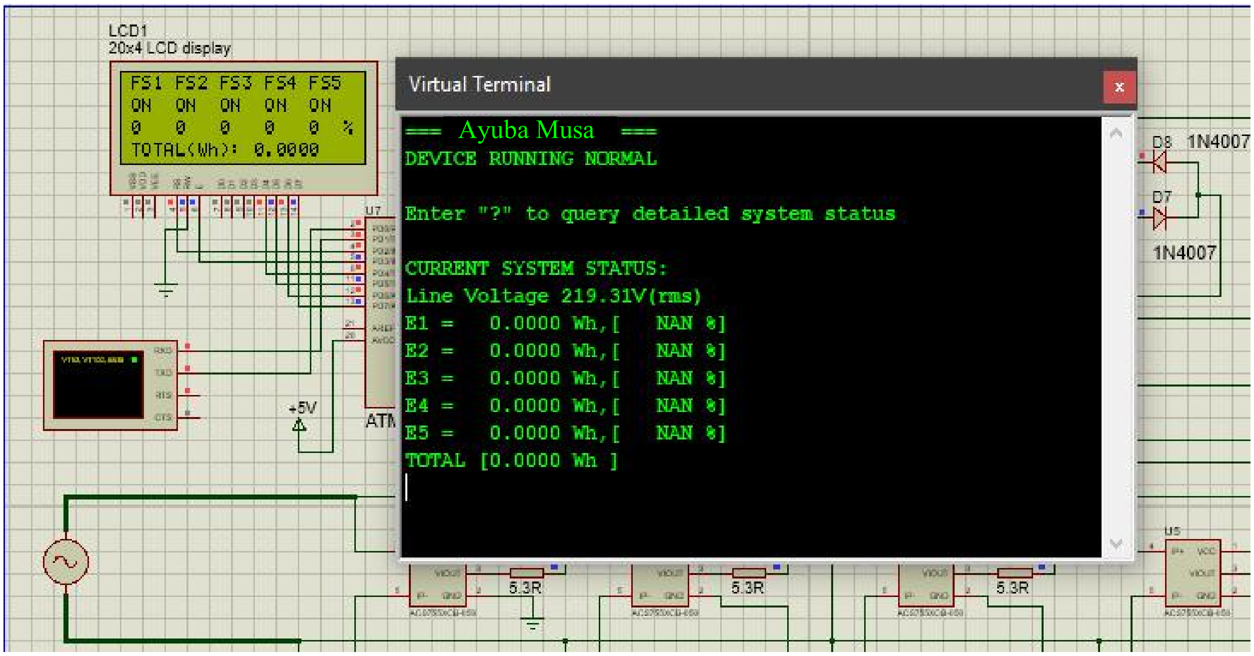

Figure 4: Result when no load is connected

Simulation result when no load is connected to the system

The simulation result when no user engages the system with any form of load is hereby presented in Figure 4.

When no load is connected, none of the facilities draw power, thereby giving a total of 0 Wh consumed and 0 Wh consumed for each of the facility.

Simulation result when F2, F4 and F5 have loads connected as shown in Table 1.

The simulation result when FS2, FS3 and FS5 are engaged as shown in Table 1 is presented in Figure 5. Notice that switches for FS1 and FS3 are open.

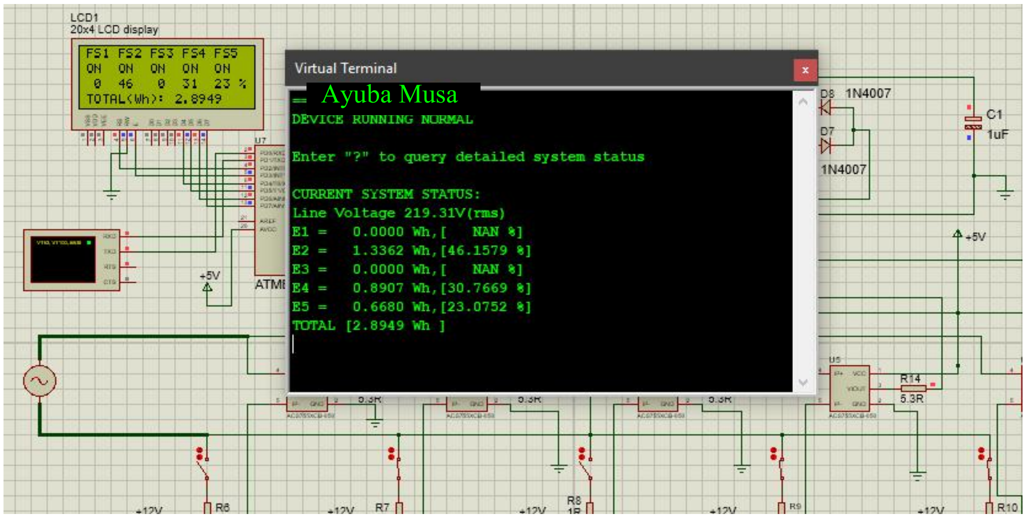

Figure 5: Results when FS2, FS4 and FS5 are engaged

When facilities F2, F4 and F5 are connected, they draw power from the system while the remaining unconnected facilities (F1 and F3 remain at zero). This is illustrated in Figure 5.

Simulation result when the system is switched off

When the system is switched off, it is expected that the user's consumption be stored in memory so that when power is restored, the system can resume its metering procedure for all users without losing their previous records. In simulation, loss of power is simulated by clicking the stop button of the simulator. Power restoration is simulated by clicking the play button of the simulator. Figure 6 illustrates this memory retention capability of the system.

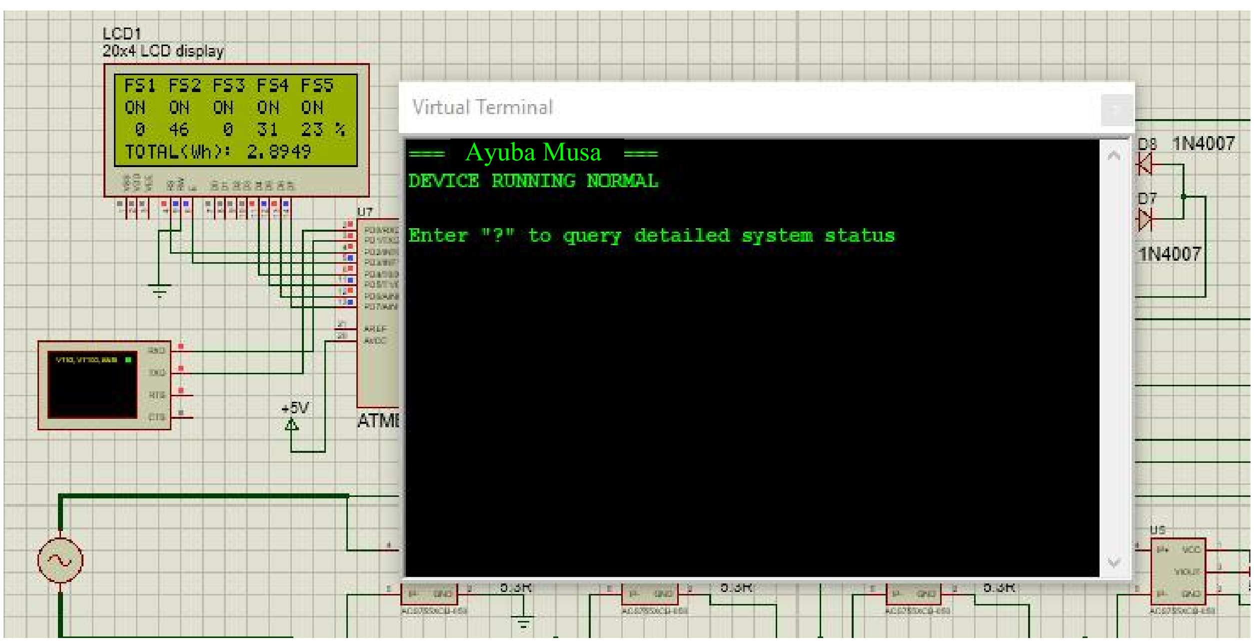

Figure 6: Result showing memory retention

Simulation result when FS2 is cut off for two seconds

The next scenario happens when the user in FS2 is cut off immediately after the results shown in Figure 6. If the disengagement of the user in FS2 is sustained for two seconds, the result in Figure 7 ensues.

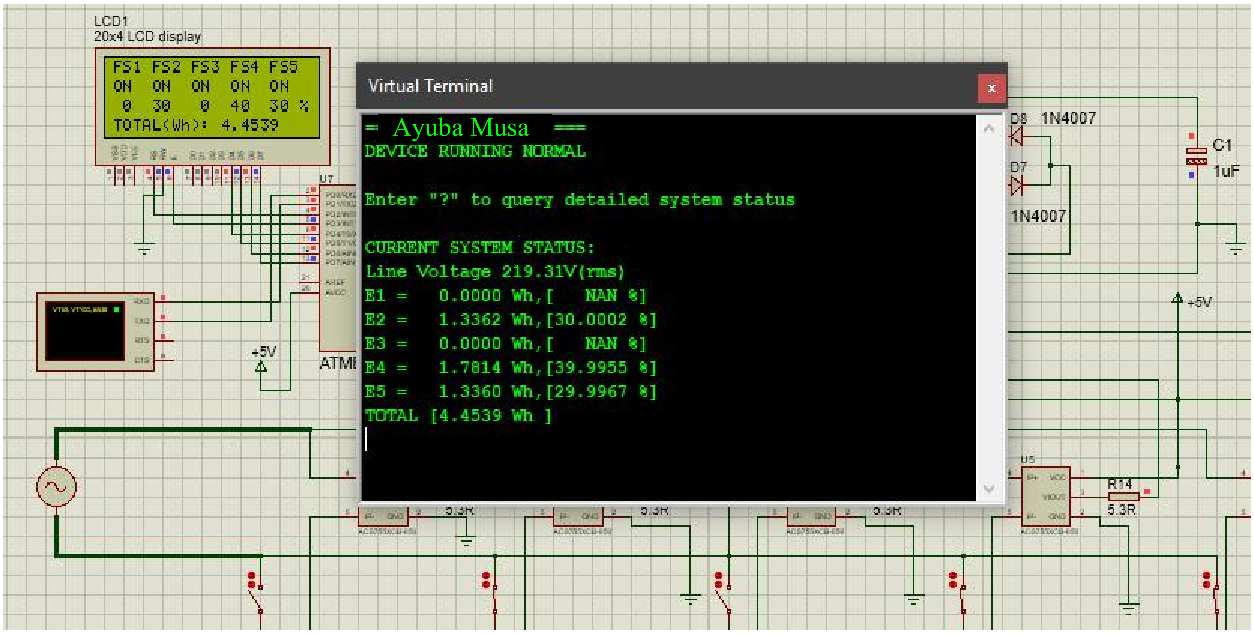

Figure 7: Result when FS2 is disengaged

The results indicated in Figures 4-7 above were validated by comparing the simulated results with analytical calculations using the equation (8) and (9) below: equation (8) was used to find the power consumption while (9) was used to calculate the energy consumption.

$$P = \frac{V^2}{R} \quad (8)$$

Where:

P is the power, measured in watts (*W*)

V is the voltage, measured in volts (*V*)

R is the resistance measured in ohms (*Ω*)

$$E = P * t \quad (9)$$

Where:

E is the energy consumed or produced, typically measured in watt-hours (Wh) or kilowatt-hours (kWh).

P is the power, measured in watts (W) or kilowatts (kW).

t is the time, measured in hours (h).

The test analysis to confirm the consistency of the billing and the accuracy of the results is as follows: For instance, if FS2 is connected to a load of 10 ohms, FS4 is connected to a load of 15 ohms and FS5 is connected to a load of 20 ohms all for an hour as depicted in Table1above, knowing that the line voltage is 219.31V, then their energy consumption will be:

$$Power = \frac{V^2}{r} = \frac{219.31\ x\ 219.31}{10} = 4{,}809.69\ W$$

Where V is AC voltage

R is load resistance

Therefore, FS2 energy consumption in watt hour over a period of one second will be:

$$\text{Energy} = \frac{4809.69}{3600} x\ 1\ seconds = 1.3360\ Wh$$

FS4 energy consumption in watt hour over a period of one second will be:

$$Power = \frac{V^2}{r} = \frac{219.31\ x\ 219.31}{15} = 3{,}206.46\ W$$

Its energy consumption in watt hour over a period of one second will be:

$$\text{Energy} = \frac{3206.46}{3600} x\ 1\ seconds = 0.8906\ Wh$$

FS5 energy consumption in watt hour over a period of one second will be:

$$Power = \frac{V^2}{r} = \frac{219.31\ x\ 219.31}{20} = 2{,}404.84\ W$$

Its energy consumption in watt hour over a period of one second will be:

$$\text{Energy} = \frac{2404.84}{3600} x\ 1\ seconds = 0.6690\ Wh$$

The total energy consumed by FS2, FS4 and FS5 is therefore:

1.3360 + 0.8906 + 0.6690 = 2.8956 Wh of energy

This total energy is shown in Figure 5 which validates the result. Also, if percentages were taken then:

FS2 = $= \frac{1.3360}{2.8956} = 46.13\ \%$

FS4 = $= \frac{0.8906}{2.8956} = 30.75\ \%$

FS5 = $= \frac{0.6690}{2.8956} = 23.10\ \%$

Again, this validates the result presented in figure 5 also.

Figure 6 is merely the result showing the memory retention capability of the system. For instance, if there is a power failure and system switches off, after power restoration, the system retains the consumption of all users.

Figure 7 presents the result when FS2 user is cut off from power remotely because of refusal to pay electricity bills. If the cut off happens for a period of two seconds, then FS2 readings stops while the reading of FS4 and FS5 continues for the assumed two seconds. Therefore, if FS4 continues to consume 15 ohms of energy then before FS2 was disengaged it would have consumed:

$$Power_{FS4} = \frac{219.13\ x\ 219.13}{15} = 3201.20\ Watt$$

$$Energy_{FS4} = \frac{3201.20}{3600} = 0.8892\ Wh$$

At this instance, FS2 was disengaged for the next two seconds. Then FS4 energy will grow, in the next two seconds, to:

$Energy_{FS4}$ = 0.8892 + 0.8892 = 1.7748 Wh

If the same procedure is followed, then energy consumed by FS5 will be:

$Energy_{FS5}$ = 0.6680+ 0.6680 = 1.3360 Wh

While energy consumed by FS2 will remain at 1.3360 Wh since it is disengaged.

Therefore:

$Energy_{Total}$ = $Energy_{FS2}$ + $Energy_{FS4}$ + $Energy_{FS5}$ = 1.3360 + 1.7748 + 1.3360 = 4.4468 Wh

And in terms of percentage:

$$Energy_{FS2} = \frac{1.3360}{4.4468} x\ 100 = 30.04\ \%$$

$$Energy_{FS4} = \frac{1.7748}{4.4468} x\ 100 = 39.91\ \%$$

$$Energy_{FS5} = \frac{1.3360}{4.4468} x\ 100 = 30.04\ \%$$

While energies FS1 and FS3 remain 0 % since they were never engaged. Again, this validates the result obtained in Figure 7.

From the results, the system demonstrated 100% accuracy and perfect memory retention capability, retaining user consumption data even after power failure.

This research yielded several key findings: the system accurately measures and allocates energy consumption among multiple facilities in real-time, enabling each facility to track its energy usage and determine its bill, which is a valuable tool for revenue protection. Additionally, the meter provides consumers with detailed insights into their energy consumption patterns, empowering them to make informed decisions about their energy usage. Overall, the system demonstrated its effectiveness in promoting energy efficiency and transparency.

Conclusion

This research successfully developed and validated a pioneering smart metering system that accurately measures and allocates energy consumption across multiple facilities in real-time. The system provides granular energy usage data, facilitating accurate billing, promoting energy efficiency, and empowering consumers to make informed decisions about their energy consumption patterns.

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REFERENCES

Arooka, M., Xiaoqin, Z., Yanping, L., & Luice, A. (2010). Electric meter reading system in rural area. International Journal of Computer and Electrical Engineering, 2(4), 714-718.

David, N. (2018). The effects of energy theft on climate change and its possible prevention using smart meter. Journal of Cleaner Production, 172, 2620-2628.

Depuru, S. S. S. R., Wang, L., & Devabhaktuni, V. (2011). Smart meters for power grid: Challenges, issues, advantages and status. Renewable and Sustainable Energy Reviews, 15(6), 2736-2742.

Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., & Hancke, G. P. (2011). Smart grid technologies: Communication technologies and standards. IEEE Transactions on Industrial Informatics, 7(4), 529-539.

Gopinath, S., Kumar, S., & Kumar, R. (2013). Design and development of advanced electric meter. International Journal of Engineering Research and Applications, 3(4), 1922-1928.

Han, J., Choi, C. S., Park, W. K., Lee, I., & Kim, S. H. (2017). Design and implementation of smart energy meter based on IoT. Journal of Sensors, 2017, 1-9.

Jamil, M., Asghar, F., & Ahmad, N. (2018). Smart energy metering and billing system: A review. Journal of Cleaner Production, 203, 286-302.

Kumar, S., Kumar, R., & Sharma, V. K. (2017). Smart metering for efficient energy management. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 6(3), 157-164.

Li, D., Liu, Y., & Zhang, Y. (2019). Energy efficiency and management in smart grid: A review. Energy Reports, 5, 247-257.

Lu, H., Liu, Y., & Zhang, Y. (2018). Advanced metering infrastructure (AMI) for smart grid: A review. Journal of Network and Computer Applications, 97, 115-126.

Meng, L., Li, W., & Xu, Z. (2016). Wireless communication for smart grid: A review. Journal of Communications, 11(4), 343-353.

Nguyen, T. T., Yoo, H. J., & Kim, H. (2018). Energy management in smart grid: A review. Journal of Cleaner Production, 203, 303-322.

Saha, A. K., Das, S., & Islam, M. S. (2018). Smart energy meter with real-time monitoring and billing system. International Journal of Engineering Research & Technology, 7(3), 1-6.

Schweppe, H., Kupzog, F., and Treytl, A. (2023). Smart grid architecture for advanced metering infrastructure. IEEE Transaction on industrial informatics, 9(3), 1438-1446.

Yeboah, M. A., & Darko, A. (2019). Smart energy metering system for multiple users. International Journal of Innovative Technology and Exploring Engineering, 8(6), 2278-3075.