Application of IOT to control and monitor the utilization and consumption rate of electricity using a digital prepaid meter prediction

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Abstract:

This work focus on solving problem on electricity billing system that brought about customer dissatisfaction as well as financial and energy losses for utility companies. The application of IoT technology which comprises of hardware and software components. Hardware components include a three-phase electric meter, ESP8266, and relay, working in tandem to facilitate connectivity, with remote control, and real-time monitoring while Software components encompass a user interface, Arduino IDE for programming and interfacing, and an Android application for mobile access. The integration of these elements creates an innovative solution for efficient energy management, providing users with enhanced control and visibility into their consumption patterns within the framework of a smart prepaid meter system.

KEYWORDS

IOT, Control, electricity, prepaid meter, prediction

1.0 INTRODUCTION

The 21st century has witnessed a remarkable transformation in the way we generate, distribute, and consume electricity. As we stand on the precipice of a new era in energy management, the integration of cutting-edge technology into our power infrastructure has become imperative. The Internet of Things (IoT) has emerged as a pivotal force in revolutionizing the electricity sector, offering a transformative approach to control and monitor the utilization and consumption of electricity. IoT is the abbreviation of the Internet of Things. IoT was first invented by Kevin Ashton in 1999. The use of IoT is connecting various physical devices to the internet. IOT is the network of physical objects like devices, vehicles, buildings, and other items embedded with electronics, software, sensors and network connectivity. This enables these objects to collect and exchange data. If they do not pay the bill, then power is disconnected from server. The steps in energy management are monitoring, controlling, conserving energy, and evaluating energy use in a building or company, taking into account several parameters such as cost, environmental impact, availability, and so on Horinv. S (2017). The primary objective of energy management is to develop approaches that decrease energy usage, expenses, and environmental, impact, while still maintaining the comfort level of individuals using building or room.

The amount of energy consumption by domestic, commercial and industrial user can be measured using energy meter. The smart meter make it easier to manage energy as more people become energy consumers. All the data monitoring is done through a web based portal provided with a dedicated internet connection. The system has to be constructed in such a way that the power consumption is analysed properly. Presently the system adopted human involvement which leads to the time consumption also, it has always been a necessity that a particular individual or person from the energy department should visit the consumer house and note down the readings and therefore errors can get introduced. To alleviate stress, intelligent energy has been implemented. The conventional approach to electricity distribution and monitoring has been predominantly centralized and rigid. Electricity generation and distribution systems have operated with limited real-time data, making it challenging to optimize supply, detect faults, and adapt to the ever-changing energy landscape. Furthermore, as the global demand for electricity continues to surge, it becomes imperative to find innovative solutions to manage energy resources more efficiently.

IoT, a paradigm that connects everyday objects to the internet, has paved the way for an interconnected and data-rich ecosystem that empowers us to monitor, analyze, and control devices and systems remotely. In the context of electricity management, the integration of IoT into smart meters is redefining the way we consume and manage electrical power. By seamlessly connecting devices and sensors within a smart grid, smart meters allow for real-time data collection and analysis, enabling utility companies, consumers, and governments to make informed decisions about energy consumption. The significance of this transformation cannot be overstated. IoT-enabled smart meters offer numerous benefits, including improved energy efficiency, reduced operational costs, enhanced grid reliability, and the potential to reduce carbon emissions. These meters empower consumers with the ability to monitor and control their energy usage, leading to reduced bills and a more environmentally conscious approach to electricity consumption. At the same time, utility companies gain valuable insights into power distribution, enabling them to optimize their resources and provide better services. This symbiotic relationship between consumers and utility providers creates a win-win situation for all stakeholders.

This paper delves into the fascinating world of IoT-enabled smart meters and their application in the management of electrical resources. This article portrays a resolution for decreasing the need for human intervention in energy administration for both residential, commercial and industrial consumers.

In this work, the application of the Internet of Things (IoT) takes center stage, offering an innovative approach to control and monitor the utilization and consumption of energy within a smart prepaid meter system. The integration of a three-phase smart meter, ESP8266, and relay technology forms the foundation of this cutting-edge initiative. By leveraging IoT principles, this project aims to enhance the efficiency and intelligence of energy management. The utilization of a three-phase smart meter ensures accurate measurement across multiple phases, while the ESP8266 serves as a crucial component for seamless connectivity and data exchange. The incorporation of relay technology further extends the system's capabilities, enabling remote control and real-time monitoring. This project represents a significant advancement in the realm of smart prepaid meters, showcasing the potential of IoT to revolutionize energy consumption control and management.

MATERIALS AND METHODS

This project involves a hardware-centric approach with the utilization of IoT for controlling and monitoring energy consumption in a smart prepaid meter. The key hardware components include a three-phase smart meter, ESP8266, and relay. These components likely work in tandem to establish connectivity, enable control, and provide real-time monitoring capabilities.

The software system incorporates a user interface for interaction, likely facilitating user control and visualization of energy-related data. The Arduino IDE is employed for programming and interfacing with the hardware components, ensuring seamless communication and functionality. Additionally, an Android application is used, presumably to enhance user accessibility and provide a mobile platform for monitoring and controlling the smart prepaid meter system. The combination of these hardware and software components forms a comprehensive solution for efficient energy management in the context of a smart prepaid meter.

ARCHITECTURE MODEL

In the application of IoT for controlling and monitoring electricity consumption using smart meters it involves combination of hardware and software components. The software component is encompassed within Arduino IDE using c language. Arduino is the main controller which connects energy meter, GSM module and other sensors so as to communicate with each other. Arduino can only work after the designed program is uploaded into it. Hardware components such as Energy meter Nodemcu microcontroller, Energy Meter with optocoupler for connecting with processor, appliances connected through relays, WiFi module, Switching Device etc., are used in the system. The Arduino Integrated Development Environment (IDE) is a cross platform application (for Windows, macOS, Linux) that is written in functions from C and C++. It is used to write and upload all the programs to Arduino compatible boards, but also, with the help of 3rd party cores, other vendor development board. WampServer refers to a software stack for the Microsoft Windows operating system, created by Romain Bourdon and consisting of the Apache web server, Open SSL for SSL support, MySQL database and PHP programming language.

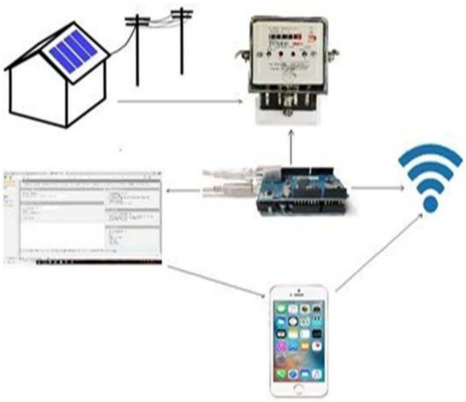

Fig.1: Architecture Model

COMPONENT OF THE WORK

The materials or components used in the application of IoT to control and monitor utilization and consumption of energy in a smart prepaid meter are classified into hardware and software component.

HARDWARE COMPONENT

Hardware component used in this system are electric meter, wifi module ESP8266, relay

ENERGY METER (THREE PHASE)

An electricity meter or energy meter is a device that measures the amount of electric energy consumed by a residence, a business, or an electrically powered device. Electricity meters operate by continuously measuring the instantaneous voltage (volts) and current (amperes) to give energy used (in joules, kilowatt-hours etc.). Meters for smaller services (such as small residential customers) can be connected directly in-line between source and customer. For larger loads, more than about 200 ampere of load, current transformers are used, so that the meter can be located other than in line with the service conductors. The meters fall into two basic categories, electromechanical and electronic. The main method of communication between energy meter and the android application. The reading information from the energy meter in real time is uploaded to a central database via IOT.

Fig. 2: Electric Meter

WIFI MODULE ESP8266

The ESP 8266 Wi-Fi module is a lowcost component with which manufacturers are making wirelessly networkable microcontroller module. ESP 8266 WiFi module is a system-on-a-chip with capabilities for 2.4GHz range. It employs a 32bit RISC CPU running at 80 MHz. It is based on the TCP/IP (Transfer control protocol) [3]. It is the most important component in the system as it performs the IOT operation. It has 64 kb boot ROM, 64 kb instruction RAM, 96 kb data

RAM

Wi-Fi unit performs IOT operation by sending energy meter data to webpage which can be accessed through IP address. The TX, RX pins are connected to the 7 and 8 pins of the Arduino microcontroller.

RELAY

The main usage of the Relay was seen in the history for transmitting and receiving the information, that was called as Morse code where the input signals used to be either 1 or 0, these change in signals were mechanically noted in terms of ON and OFF of a light bulb or a beep sound, it means those pulses of 1s and 0s are converted as mechanical ON and OFF using electromagnets. Later this was improved and used in various applications. Let's see how this electromagnet acts as a switch and why it is named as RELAY.

The main operation of this device is to make or break contact with the help of a signal without any human involvement in order to switch it ON or OFF. It is mainly used to control a high-powered circuit using a low power signal. Generally, a DC signal is used to control circuit which is driven by high voltage like controlling AC home appliances with DC signals from microcontrollers.

SOFTWARE COMPONENT

USER INTERFACE

This is aspect where control and physical monitoring takes place. This is a website protocol that operates via web server. The IOT application was incorporated to allow a user to control and monitor the energy meter from anywhere in the world once there is an internet connection. The energy units used by the external or applied load which was calculated by the microcontroller that was sent to the cloud server and stored, all these operations are always performed by the user interface aspect.

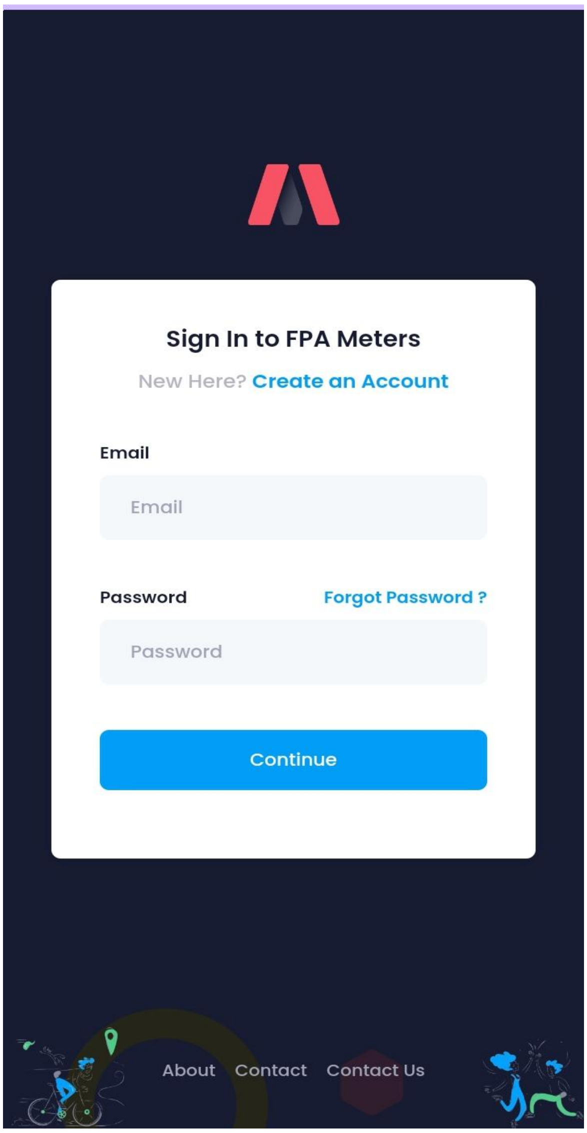

Fig. 3: User interface

THE MICROCONTROLLER (ARDUINO IDE).
The software application used in the development of this smart energy control system is microcontroller Xtensa LX7 dual-core. It is programed using C language with Arduino IDE software. It is a development environment that employs a user interface for adding and editing in the Arduino coding language. This program was used to program the monitoring, recharge and control aspects of the system. The Arduino micro controller which uses ATMEGA328 is programmed using C language with Arduino IDE software. It's a development environment that simply uses a user interface for adding and editing in the Arduino coding language. The Arduino programing initiate the gyroscope and accelerometer function and capture the data's coming from the MPU.4.

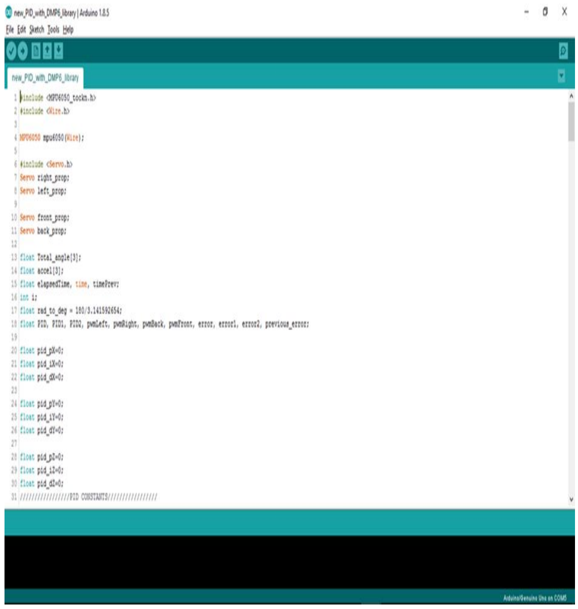
Fig. 4: Arduino IDE

ANDROID STUDIO
Android Studio is the official integrated development environment (IDE) used for Google's Android operating system, built on JetBrains' IntelliJ IDEA software and designed specifically for Android development. It is available for download on Windows, macOS and Linux based operating systems. It is a replacement for the Eclipse Android Development Tools (ADT) for native Android application development.

ANDROID APPLICATION
A smart phone is used as an interface for controlling and monitoring the prepaid meter. An android application was developed using Android studio. The choice of Android phone is made because Android phones are incorporated with internet-based facilities. It is easy to program an application that can easily send data wirelessly to the prepaid meter. This is where the user can check for the current unit, recharge and control the meter status.

Fig. 5: Andriod application

DESIGN THEORY AND CALCULATION

The following are the theoretical calculations considered for the smart system design. Before proceeding to the calculations, first we have to keep in mind the pulse rate of the smart prepaid meter. There are two pulse rates of smart prepaid meters, first is 400 imp/kwh and second is 800 imp/kwh. So here we are using 400 imp/kwh pulse rate smart prepaid meter. At first, we need to calculate the pulse for 25,531 watt, which means how many times Pulse LED will blink in a minute, for the load of 25,531 watt.

$$Pulse = \frac{(Pulse\ rate \times watt \times time)}{1000 \times 400}$$

So pulse for 25,531 watt load audit in 60 seconds, with smart prepaid meter of 400 imp/kwh pulse rate can be calculated as below:

$$Pulse = \frac{400 \times 25{,}531 \times 60}{1000 \times 400}$$

$$Pulse = \frac{612{,}744{,}000}{400{,}000}$$

$$Pulse = 1531.9\ pulse\ per\ minute$$

Therefore, we need to calculate the Power Factor of a single pulse, that is, how much electricity will be consumed in one pulse?

$$PF = \frac{Watt}{(hour \times pulse)}$$

$$PF = \frac{25{,}531}{60 \times 1531.9}$$

$$PF = 0.2778\ watt\ in\ a\ single\ pulse$$

$$Units = \frac{PF \times Total}{1000}$$

$$Total\ pulses\ in\ an\ hour\ is\ around\ 6 \times 60 = 360$$

$$Units = \frac{0.2778 \times 360}{1000}$$

$$Units = 0.100008\ per\ hour$$

If a 25,531 watt is used for a day, then it will consume

$$Units = 25.531 \times 24$$

$$Units = 612.744\ Units$$

Assuming unit rate of 75 Naira per unit at a particular region, then 612.744 Units at 75 Naira per unit is given as: $75 \times 612.744 =$ 45,959 Naira.

WORKING PRINCIPLE

When we power up the system then it reads and checks the available balance with the predefined value and take action according to them, like if available balance is greater than the amount set then Arduino turns ON the electricity of home or office by using relay. And if balance is less than the amount set then Arduino sends a notification to user phone regarding low balance alert and requesting to recharge soon. And if balance is less than amount set then Arduino turns OFF the electricity connection of home and sends a notification to users phone for Light Cut alert and requesting to recharge soon. Energy meter monitoring is completely done by Android application. Through android application users are able to control, recharge and monitoring the system in any location.

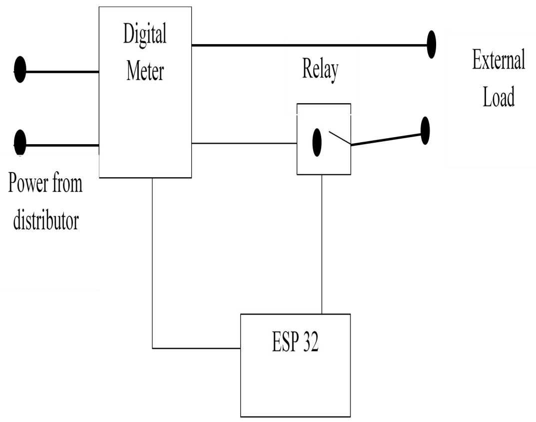

Fig. 6: Circuit diagram

RESULTS AND DISCUSSION

The application of IoT in controlling and monitoring energy consumption in smart prepaid meter has demonstrated significant advancements. Real-time data collection enable IoT technology provides accurate insight into energy utilization patterns.

The table below shows the load audit recorded at Olusegun Obasanjo Innovation Center Federal Polytechnic Ado-Ekiti

Table 1: Estimated power consumed

S/N	Appliances	Quantity	Watt	Total watt	Total kilowatt (kw)
1	Computer	10	61.3	613	0.613
2	A c	10	1625	16250	16.25
3	Bulb	10	40	400	0.4
4	Television	2	420	840	0.84
5	DSTV	2	24	48	0.048
6	Water dispenser	2	525	1050	1.05
7	Ox fan	1	135	135	0.135
8	Refrigerator	1	3250	3250	3.25
9	Photocopier	1	1850	1850	1.85
10	Printer	1	570	570	0.57
11	Ceiling fan	7	75	75	0.525

The total load audited at Olusegun Obasanjo innovation center is 25.531kw.

DISCUSSION

The system was subject to series of test in which all the applied loads such as the Air Conditions, Bulbs, Phone Chargers, Ceiling Fans, Water Dispensers, Televisions and DSTV. Each appliances was off to know their effect on the system when bulb being isolated the data on the table below shows the current unit, deducted unit, and the time in minutes.

WHEN BULB WAS ISOLATED

Table 2: Data recorded when all the bulbs were turn off in ten minutes

S/N	Current unit	Deducted unit	Time(min)
1	84.00	0.0400	1
2	83.96	0.0399	2
3	83.92	0.0499	3
4	83.87	0.0400	4
5	83.83	0.0499	5
6	83.78	0.0400	6
7	83.74	0.0399	7
8	83.70	0.0400	8
9	83.66	0.0399	9
10	83.62	0.0400	10

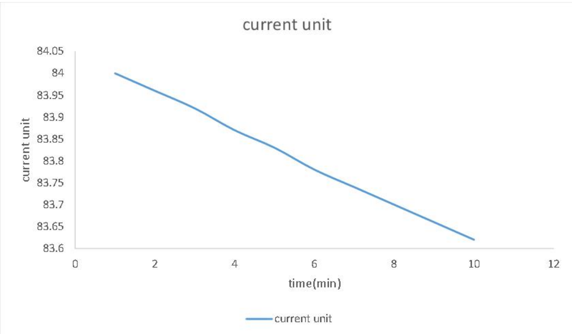

Fig. 7: Graph of Current unit against time

The smart prepaid meter displayed a consistent decrease in the initial unit over time, with fluctuations in the deducted unit due to irregularities. Notably, isolating the bulb from other appliances resulted in a final unit reading lower than the initial unit

WHEN PHONE IS ISOLATED

Table 3: Data recorded when phone charge were turn off in ten minutes

s/n	Current deducted	Deducted unit	Time(min)
1	83.36	0.0400	1
2	83.32	0.0399	2
3	83.28	0.0300	3
4	83.25	0.0300	4
5	83.22	0.0300	5
6	83.19	0.0300	6
7	83.16	0.0300	7
8	83.13	0.0399	8
9	83.09	0.0300	9
10	83.06	0.0300	10

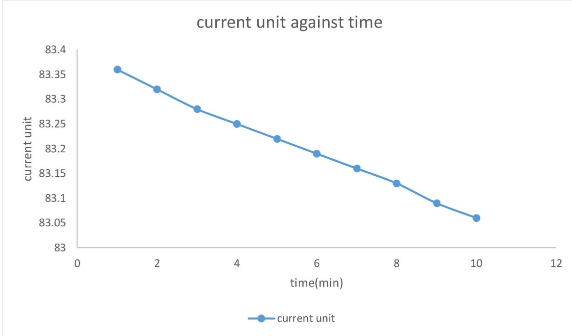

Fig. 8: Data recorded in the user interface when phone chargers were turn off

The recorded observations reveal a discernible trend in the smart prepaid meter's behavior. As time progressed, there was a consistent decline in the initial unit displayed. However, fluctuations in the deducted unit became evident, attributed to irregularities in the system. Notably, when the chargers were isolated from all other appliances, a noteworthy observation surfaced. The final unit reading appeared to be less than the initially recorded unit, indicating impact of isolating the chargers on the meter's readings

WHEN THE CEILING FAN IS ISOLATED

Table 4: Data recorded when ceiling fans were turn off in ten minutes

s/n	Current unit	Deducted unit	Time(min)
1	82.90	0.03000	1
2	82.87	0.0300	2
3	82.84	0.0400	3
4	82.80	0.0199	4

5	82.78	0.0300	5
6	82.75	0.0300	6
7	82.72	0.0300	7
8	82.68	0.0399	8
9	82.65	0.0200	9
10	82.63	0.0300	10

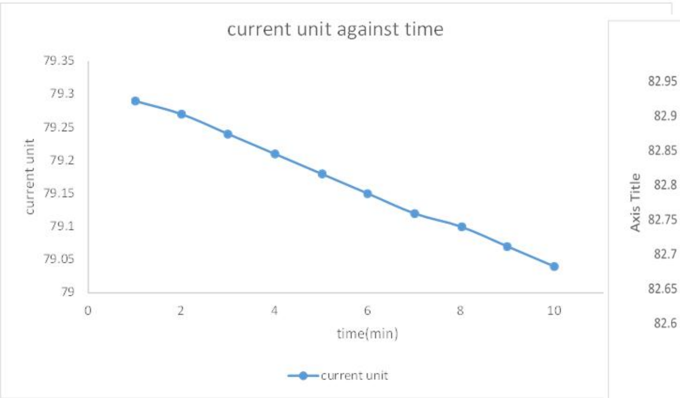

Fig. 9: Graph of current against time when ceiling fans were turn off

Fig. 10: Data recorded in the user interface when ceiling fans were turn off

The smart prepaid meter displayed a consistent decrease in the initial unit over time, with fluctuations in the deducted unit due to irregularities. Notably, isolating the bulb from other appliances resulted in a final unit reading lower than the initial unit.

WHEN WATER DISPENSER IS ISOLATED

Table 5: Data recorded when water dispenser were turn off in ten minutes

s/n	Current unit	Deducted unit	Time(min)
1	82.42	0.0400	1
2	82.38	0.0399	2
3	82.34	0.0499	3
4	82.29	0.0300	4
5	82.26	0.0500	5
6	82.21	0.0499	6
7	82.16	0.0399	7
8	82.12	0.0400	8
9	82.08	0.0399	9
10	82.04	0.0400	10

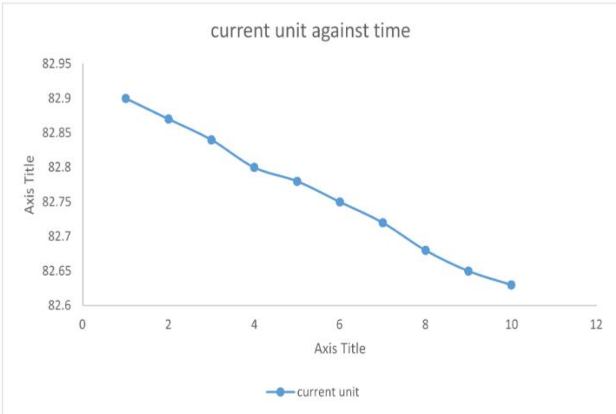

Fig. 11: Graph of current against time when water dispenser were turn off

Fig.12: Data recorded in the user interface

Throughout our observations, a consistent downtrend in the initial unit was discerned on the smart prepaid meter as time advanced. Concurrently, fluctuations in the deducted unit were identified, aligning with the temporal progression and hinting at potential irregularities within the system. An especially noteworthy finding emerged when the Water Dispenser was systematically isolated from all other appliances; the final unit reading revealed itself to be lower than the initially recorded unit This points to a distinct influence on the meter's readings when the Water Dispenser is segregated from the overall electrical load.

WHEN AIR CONDITIONING SYSTEM IS ISOLATED

Table 6: Data recorded when Air condition were turn off in ten minutes

s/n	Current unit	Deducted unit	Time(min)
1	79.58	0.0199	1
2	79.56	0.0199	2
3	7954	0.0100	3
4	79.53	0.0100	4
5	79.52	0.0099	5
6	79.51	0.0200	6
7	79.49	0.0099	7
8	79.48	0.0200	8
9	79.46	0.0090	9
10	79.45	0.0100	10

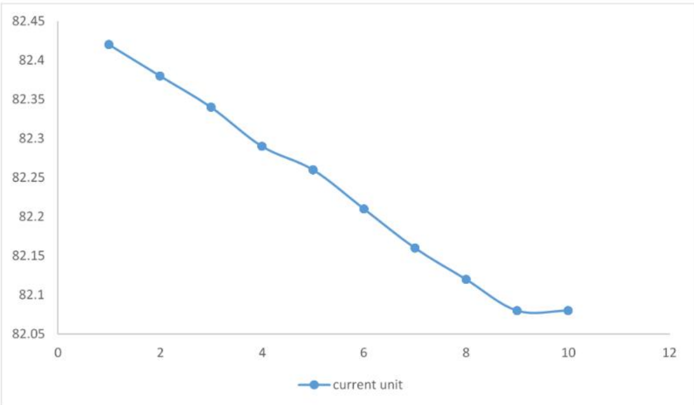

Fig. 13: Graph of current against time when air conditioning system were turn off

Fig. 14: Data recorded in the user interface when Air conditioning system were off

During our observations, a consistent decline in the initial unit was noted on the smart prepaid meter as time progressed. Simultaneously, fluctuations in the deducted unit were observed, correlating with the passage of time and indicating potential irregularities in the system. A noteworthy observation surfaced when the Air Conditioner was isolated from all other appliances; the final unit reading was found to be less than the initially recorded unit. This suggests a distinct impact on the meters reading when the Air Conditioner is isolated from the overall electrical load

WHEN TELEVISION AND DSTV IS ISOLATED

Table 7: Data recorded when television and DSTV were turn off in ten minutes

s/n	Current unit	Deducted unit	Time(min)
1	79.29	0.0200	1
2	79.27	0.0300	2
3	79.24	0.0300	3
4	79.21	0.0299	4
5	79.18	0.0300	5
6	79.15	0.0300	6
7	79.12	0.0200	7
8	79.10	0.0300	8
9	79.07	0.0299	9
10	79.04	0.0300	10

Fig.15: Data recorded in the user interface when television and DSTV were turn off

During our meticulous observations, a persistent decrease in the initial unit became evident on the smart prepaid meter as time unfolded. Simultaneously, variations in the deducted unit were deducted, corresponding with the chronological sequence and suggesting the existence of potential irregularities in the system. A particular noteworthy revelation emerged when the TV/DSTV was methodically isolated from all other appliances; the final unit reading disclosed a reduction compared to the initially recorded unit. This highlights a distinct impact on the meters readings when the TV/DSTV is separated from the overall electrical load.

DISCUSSION

Upon concluding the observations, a notable trend emerged- the Air Conditioner exhibited higher energy consumption. To effectively manage energy usage, it is imperative to establish a designated time during the day for activating the Air Conditioner. This strategic approach aims to regulate and curtail the daily consumption of units, contributing to a more sustainable energy utilization pattern.

CONCLUSION

In conclusion, the implementation of IoT in controlling and monitoring energy utilization and consumption within a smart prepaid meter system, utilizing a three-phase electric meter, ESP8266, relay as hardware components, and a user interface, Arduino IDE, and Android application as software components, represents a significant advancement in energy management technology.

The integration of these components allows for efficient and real-time monitoring, empowering users to have greater control over their energy consumption. The three-phase electric meter ensures accurate measurements, while the ESP8266 and relay facilitate seamless connectivity and remote control capabilities. The user interface, Arduino IDE, and Android application collectively contribute to a comprehensive system that enhances accessibility and usability.

This project not only addresses the challenges associated with traditional meter reading but also introduces a scalable and user-friendly solution. The use of IoT technologies opens avenues for future enhancements and optimizations in energy efficiency.

In summary, the application of IoT in this smart prepaid meter system demonstrates a promising direction for the evolution of energy management, providing users with the tools to make informed decisions, optimize consumption, and contribute to a more sustainable and efficient energy landscape.

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