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Automated Regulation Of Electricity Consumption Using Load Classification With Iot-Based Monitoring (ARECLCIM).

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ABSTRACT
The Automated Regulation of Electricity Consumption Using Load Classification With IoT-Based Monitoring, is designed to tackle the excessive use or wastage of insufficient available electricity. The design is carried outwith theMatlab/Simulink software and also simulated with it to achieve the desired result. A two-bedroom flat building is considered in this work and the loads of the building were classified into Primary, Secondary, and Tertiary Loads. The Primary Loads are to run continuously as well as the Tertiary load which is programmed to run between 6pm to 6am,the Secondary Loads are conditioned to be triggered off once a certain threshold of energy consumption is reached to enable prolonged use of the Primary and Tertiary Loads. This is to maintain a certain limit of energy consumption within a period say the month and avoid conspicuous billing of the utility companies for those on the direct connection of supply or running out of units from metered customers thereby rendering the household in abrupt darkness. As aimed, when simulated at a 24-hour run time the total consumption unit was 33.2908 units. With a progressive increase in the simulation time, the total consumption of the loads progressively attends to 80 units of energy which triggers the isolation of the secondary load while the primary and tertiary loads function optimally within the targetedlimit of 100unitsof consumption for the said period. The monitoring of the consumption of this system is achieved remotely through ThingSpeakwith an hourly analysis of the consumption.
Key-words: Regulation, Electricity Consumption, Thingspeak, Microcontroller (Matlab Function Block)

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I. Introduction

Development of countries beckons on power/electricity as seen in technologies, businesses, and the livelihood of a city in general. However, due to the demand in electricity and the intricacies of its production down to the end users has made it more crucial for it not to be bastardized in usage therefore giving rise to a sort of accountability. The insufficient generation of electricity and the rising rate of need especially in developing countries like Nigeria made it more imperative for a regulated and controlled use of the available supply. In Nigeria currently with different bands of Bands in tariff – Band (A, B, C, D, and E) with the band A at N209 per unit of energy, a spike from N72.67 has become a concern to the populace. Therefore, the rate at which the energy is used is now of essence.

This design tends to limit consumption within the user's affordability. the design monitors the rate of consumption and isolates a certain section for sustenance of supply within the facility. Records are kept daily via internet based. With the records of consumption one can always calculate his estimated billing more precisely.

II. Reviewed Works and Gap

In the course of reduction in energy consumption, [8] presented a Home Energy Management system (HEMS) scheduling analysis. The scheduling plan avoids the electricity wastages which arise majorly due to residents' negligence on appliance control. The energy consumption was evaluated using Fixed Pricing (FP) data, scheduling plan developed using Microsoft.net framework with C++, whereas the front end showing the scheduled operating periods for the appliances was developed using Telerik UI framework for Windows. This is in similitude of the [4] design in HVAC systems.[3], discussed the comparison of Arduino and other controllers, and the application of Wi-Fi modems to introduce a Smart concept. With the use of a Wi-Fi modem, the consumer can monitor his consumed reading and can set the threshold value through a webpage. This system as proposed can disconnect the power supply of the house when needed via the web. In like manner [5] aimed to develop a Smart control module that can be used to schedule the operation of electrical appliances as well as control and monitor power usage at the outlet location aided with IOT-gadget.[6], deigned an interface method to accomplish residential remote load scheduling and control through a novel algorithm realized with LabVIEW. [1], presented a customizable GUI and an inexpensive embedded system with internet connectivity for monitoring and controlling several devices and home appliances remotely, using android-based smartphone application or computer-based application.The GUI is designed and created for the Android phone on Android Studio while the PC segment is designed using PHP and JAVASCRIPT.

The [7], proposed a system that supports active energy efficiency methods to support an energy-efficient culture. The method used to carry out this research is research and development. This research produced a prototype of an electrical power control and monitoring system that has a smart panel based on a Raspberry PI 3 and PZEM-004t power energy meter. A developed system [2] of an integration of both hardware and software. The software is used to monitor power usage and the consumption of household appliances and control systems through overcurrent relays and notification of any mismatches. The developed system consists of Arduino UNO, a Wi-Fi module (ESP8266), a relay, a low current sensor breakout (ACS712), and a liquid crystal display (LCD). This is very much similar to [9].

[10] implemented the construction of a laboratory setup at the Smart Grids Test Lab (SGTL) to test and validate the control techniques of HEMs to advance Home Energy Management Systems (HEMS) technology and optimize household energy management. The Power Hardware in the Loop (PHIL) simulation is integrated with the multi-timescale co-simulation framework since the design makes use of the idea of real-time simulation. This creates an enablement for complete and multilayered examination of HEMS control abilities in trending scenarios. The configured laboratory incorporated a series of interconnected devices ranging from AC and DC power sources to variable loads, a solar PV emulator, a Battery Energy Storage System (BESS) emulator, a Digital Real-Time Simulator (DRTS), and a supervisory controller module. [11] impacted greatly on the dimension of HVAC systems which are the very highly significant energy consumers in facility buildings. The HVAC consumes over 60% of total energy usage within a facility as the case may be. The research as shown enhanced energy efficiency and convenience at the point of implementation, intentionally targeting cooling and heating equipment in the facility or building. To enhance an optimal energy performance, the research work deployed a model predictive control system employing the use of artificial neural networks (ANN). The approach incorporated improved technologies, adding field-programmable gate arrays (FPGAs) and communication modules and protocols such as message queueing telemetry transport (MQTT), to improve a scalable expansion and adaptability as required.

As proposed by [12], [16] demonstrated in their paper detailing a smart adaptable system with a unique technique for effective distribution and control of HEMs use of energy. The system employs cutting-edge Internet-of-Things (IoT), AI, and machine learning technology along with a sensor grid to distribute energy in the house in a preferred adaptable way. Efficiency was raised and unnecessary energy use was decreased with the suggested method. It preserved a more sustainable and safety-conscious style of living. The necessary speed was generated by the used sensor. Furthermore [13] explores also the transformative potential of integrating the Internet of Things (IoT) devices into home technologies transforming them into a smart home. This according to the paper began with the examination of specific devices such as intelligent thermostats, smart lighting devices, etc

As the ability of homeowners to control and maintain their consumption is being greatly improved by the recent development in home automation. The lighting and shutter control are the main topics of this study by [14], which is key for energy conservation and creating a desired enabling environment. The Blynk program was designed to enable a smooth control depending on user preferences, environmental circumstances, and energy efficiency.

According to [15], smart metering is of the essence in reducing energy use in both residential and commercial buildings. The Deep Belief Neural Network (DBN) technique was introduced in a novelty way, including the latest advancements in intelligent sensors and Internet-of-things technology. It provides a method for examining data collected from the Internet of Things (IoT) connected smart devices and data technologies that promise intelligent home applications. The energy consumption pattern is implemented using the suggested Deep Belief Neural Network

III. Methodology

3.0 Data Collection

The data pertinent to this study such as voltage, current, and threshold values of the primary, secondary, and tertiary appliances are obtained from random values within a given upper and lower limit. This can also in practical instances be gotten from the supply source. The system is designed to function within a specified period, not to exceed a certain unit for instance 100 units of energy as a targeted reference in this work.

3.2 Methods

This scheme is introduced to categorize the available loads in the building into primary, secondary, and tertiary loads and distribute them accordingly to visualize the power consumption pattern in the building and incorporate automatic control overload.

3.3 The Design

The design of this system stems from considering a two-bedroom flat apartment that is fully equipped with appliances that an average home should have which are Televisions, Refrigerators, pressing iron, laptops, phones, Electric fans, a water heater, a water pump, an Electric cooker, security lights, and of course lighting points and sockets.

3.2.1 Primary Load

The primary load includes the lightbulbs, laptops, printers, etc. as depicted in Fig 3.1 below. The figure indicates the number of items available thereby representing the all gadgets physically in use. The power rating of the appliance are also indicated with which the simulation runs.

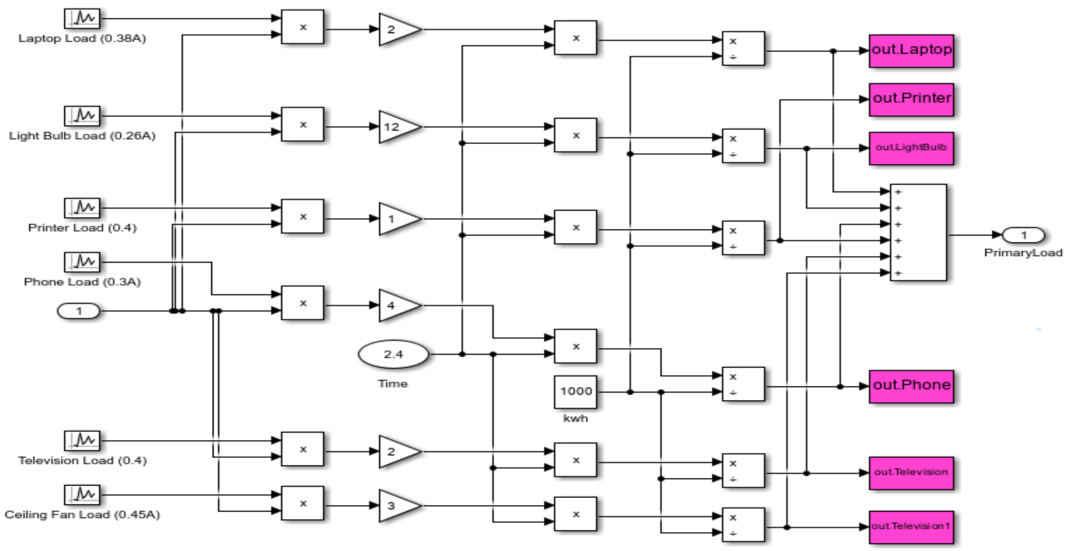

Fig. 3.1 Primary Energy Consumption Simulink Block Configuration

3.2.1 Secondary Load

In similitude of the to the primary load domain configuration of appliances, the secondary load class is also assembled. The sum of the consumption by the secondary load is viewed with the display unit block.

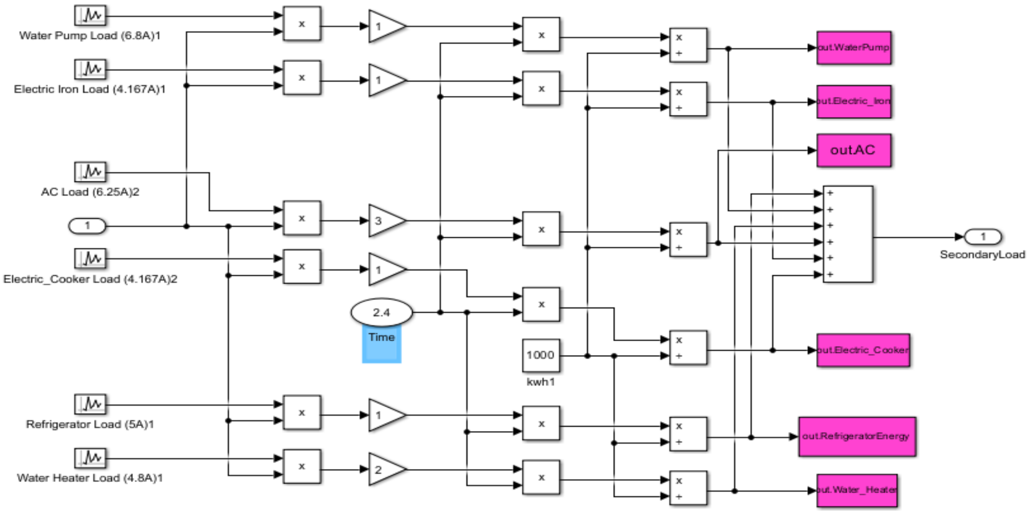

Fig. 3.2 Secondary Energy Consumption Simulink Block Configuration

3.2.3 Tertiary Load

In the scheme, we limited the tertiary consumption to the security light, as seen in Fig. 3.3. This class can also be extended to any other device that falls within its time use.

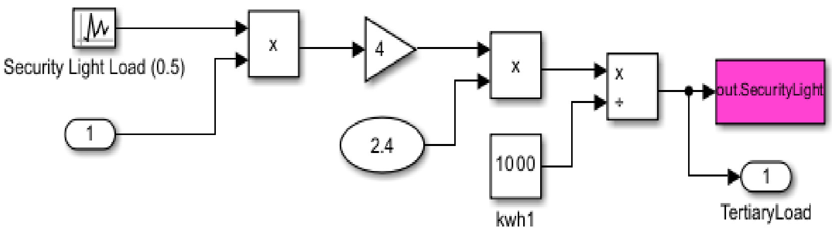

Fig. 3.3 Tertiary Energy Consumption Simulink Block Configuration

3.4 THE ARECLCIM

The system receives supply or power from the utility line with which it gets energized and thus activates all functions, it distributes three different outputs which connect to the Primary, Secondary, and Tertiary outlets. The supply could pass through the installed utility meter (Prepaid or Postpaid) or a direct line. The system has been set to recognize a targeted value of 100 units of energy as a targeted limit for the month and thence a set threshold for isolation of the secondary loads at 80 units. As simulated with Matlab/Simulink. The trail of consumption as used by the different classes is been monitored and shown by the display blocks. The system controls the tertiary load by tripping and reclosing its circuit at 12-hour intervalsof usage. When the total consumption of the system gets to 80 kwh, it isolates the secondary loads which is the major or heavy consumers of the energy. The primary and tertiary loads function normally as they are more needed in the building.

The current sensors read the consumption of the different classes of load and transmit the same figure to the cloud-based IoT devices (ThingSpeak) through the mechanism of the Raspberry Pi, Microcontroller etc. which is hereby represented with the Matlab function where the control algorithm is written as depicted in figure 3.4 below.

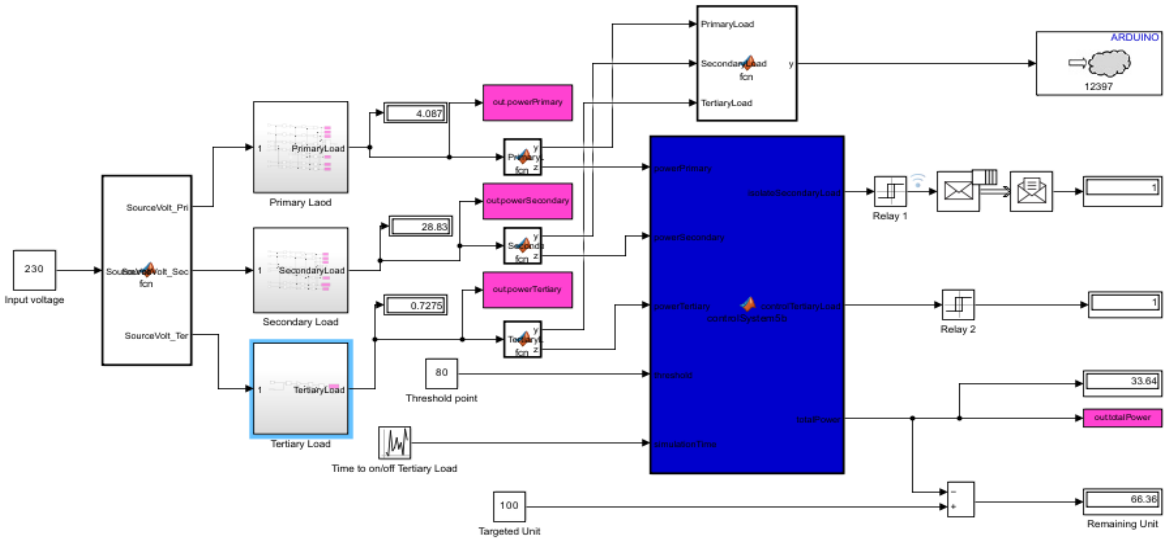

Fig.3.4The ARECLCIM System Design

The Current sensors pick the readings and through the raspberry pi

i. Energy Monitoring

The system continuously monitors the energy consumed in the building. This includes tracking the power usage of different electrical loads such as lighting points, electronics, air conditioning (AC) systems, water heaters, and other appliances.

ii. Load Isolation

At certain predefined conditions, the system isolates the secondary loads, which typically include heavy consumers of energy such as the AC circuit and water heater. By isolating the secondary load components which consumes greater portion of the energy, the system now allows the primary load components, such as lighting points and sockets for electronics to remain active.

iii. Tertiary Load Control

The system is programmed to control the tertiary load, which in this Dissertation is the security light, based on specific time intervals. For example, the security light may be scheduled to turn on at 6 PM and turn off at 6 AM.

iv. User Information

This system keeps track of the energy consumption, collates the total energy expended hourly, and displays it on the display unit provided as seen in the circuit diagram represented in Figure 3.5. The same information is communicated to the cloud-based internet-of-things for record-keeping, evaluations, analysis, etc. as will be discussed later.

Upon implementing the secondary load isolation, the system informs the user on the action to be carried out through the message route (SMS). This allows the user to be aware of the action and make necessary adjustments or arrangementsfor what the next step of action.

An hourly total consumption rate sample is harnessed by the sequence viewer as seen in the appendix.

Overall, the system aims to optimize energy usage in the building by efficiently managing the operation of different loads. It provides users with information about their energy consumption and implements control strategies to minimize unnecessary power usage while ensuring essential services remain operational.

3.5.0 Monitoring Energy Consumption

The system monitors the energy combined by measuring the power consumed by each load. The power consumed by a load can be calculated as the product of the voltage across the load and the current flowing through it. It is mathematically expressed as follows:

$$P_{load} = V_{load} \times I_{load} \quad (3.1)$$

The total power consumption of the building is the sum of the power consumed by all loads, expressed mathematically as follows:

$$P_{total} = \sum_{i=1}^{N} P_{load_i} \quad (3.2)$$

Where,

P_{load} = Individual loads such as the primary load, secondary load, and tertiary loads.

Primary loads P_p, Secondary loads P_s and the Tertiary P_t loads. Equation (3.2) is expressed as;

$$P_{total} = P_p + P_s + P_t \quad (3.3)$$

$P_{total} = VI_p + VI_s + VI_t$

$P_{total} = V[I_p + I_s + I_t]$ (3.4)

The energy consumption (KWH) is expressed as follows:

$E_{total} = P_{total} \times t$ (3.5)

Where

V = Voltage from a supply (V)

I_p =The current of the primary load (A)

I_s =The current of the secondary load (A)

I_t =The current of the tertiary load (A)

t = Time (hrs)

3.5.1 Load Isolation Process

Load isolation occurs when the total power consumption exceeds a certain threshold. In the steady, the decision to isolate the secondary loads is based on comparing the total power consumption with a given threshold. It is mathematically expressed as follows;

$$I_{SL} = \begin{cases} \text{true} & P_s > P_t \\ \text{false} & \text{otherwise} \end{cases} \quad (3.6)$$

The secondary loads are air conditioners, water heaters, etc.

Where I_{SL} = Isolate secondary loads

3.5.2 Tertiary load control

The tertiary loads such as the security light are controlled based on the time, for example, it turns on at 6 pm and turns off at 6 am. It is mathematically expressed as follows:

$$CTL = \begin{cases} \text{true} & 6pm \le t \le 6am \\ \text{false} & \text{otherwise} \end{cases} \quad (3.7)$$

Where;

CTL = control tertiary load,

t = time

3.5.3 User information and load Tripping

The user information and load tripping system is an automated control system that informs the user about energy consumption and load tripping.

3.6 The Internet-of-Things.

The Internet-of-things Monitoring phase of the system incorporates Raspberry Pi, Arduino, Current Sensor, ethernet port, USB etc. Each class of the load is installed with a current sensor represented in this work with the Matlab function block - it senses the consumption and communicates the same to a definite Matlab Function block (Microcontroller). The Microcontroller then communicates the device data such as the device id and the power consumed to the cloud database known as the ThingSpeak through the raspberry pi.

The ThingSpeak analytically keeps track of the power consumption with graphical views to enhance understanding when accessed by the user. The user can always track the consumption of his household remotely and as well can predict his billing for the month.

The figure below shows the architecture of the embedded Internet of Things. The ThingSpeak is preferred here amongst other cloud tools because of it's peculiarity in data analytics.

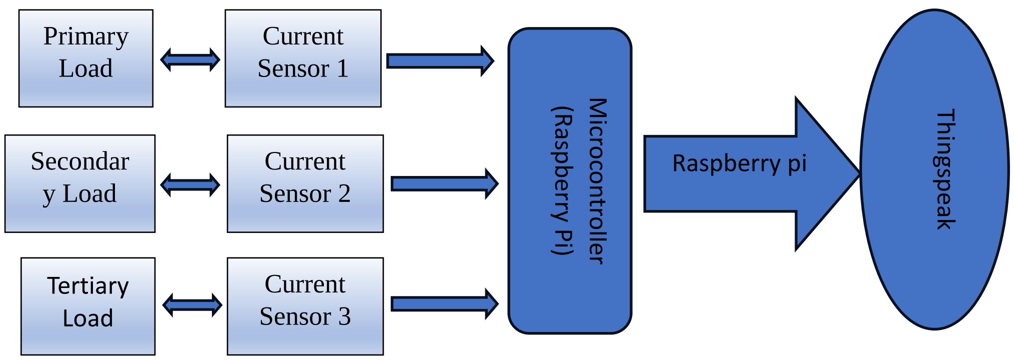

Fig. 3.5 Architecture of the IOT implementation

IV. Simulated Results and Discussion

The results from this study were obtained from the simulation of the automated energy management system in a two-bedroom flat. The results obtained ranged from the energy consumption by the primary loads (i.e. Light bulb, Laptops, Printer, Television, Phone), energy consumption by the secondary loads (i.e. Refrigerator, water pump, electric cooker, air-conditioner, Electric Iron), and energy consumption by the tertiary loads (i.e. security lights) and the total energy consumption per day which is 24hrs.

Note, in the result tables, the figures recorded from the simulation were multiplied by 10 to give a better presentation.

Table 4.0 Result obtained and recommendation

Time (hrs)	Total Energy Consumed by Primary Load Components (kwh)	Total Energy Consumed by Secondary Load Components (kwh)	Energy Consumed by Tertiary Load (kwh)	Total Energy Consumed by all Loads (kwh)
0	0	0	0	0
1	1.577121093	13.04789147	0.307773379	14.93278594
2	3.086383707	25.9767774	0.600354562	29.66351567
3	4.39347929	38.55111666	0.847674467	43.79227042
4	6.275429665	52.1335968	1.223693208	59.63271967
5	8.268931436	65.91170812	1.624686143	75.8053257
6	8.825648457	77.17008498	1.704010848	87.69974428
7	10.21485989	89.88843339	1.969714901	102.0730082
8	12.39202998	103.9886496	2.411827605	118.7925072
9	13.01007839	115.3545852	2.504883223	130.8695469
10	14.94420746	129.0285728	2.892583759	146.865364
11	17.38520415	143.59147	3.393762123	164.3704362
12	17.75838255	154.5279694	3.431996095	175.7183481
13	21.53367983	171.4308713		192.9645512
14	22.94796476	184.1931919		207.1411567
15	23.52453692	195.4863894		219.0109263
16	25.16268723	208.6413097		233.8039969
17	27.06175224	222.2538043		249.3155565
18	28.76322029	235.5197669		264.2829872
19	30.62345909	249.0641708		279.6876299
20	30.92810722	259.8804865		290.8085938
21	32.31694811	272.5981851		304.9151332
22	32.74921458	283.6383092		316.3875237
23	33.62005947	295.4475819		329.0676414
24	37.35423046	312.2783594		349.6325899

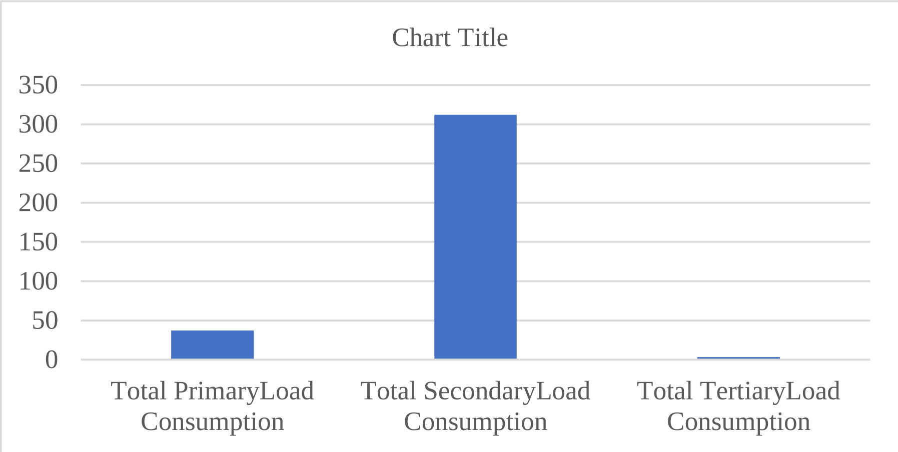

Figure 4.1The different consumption representation

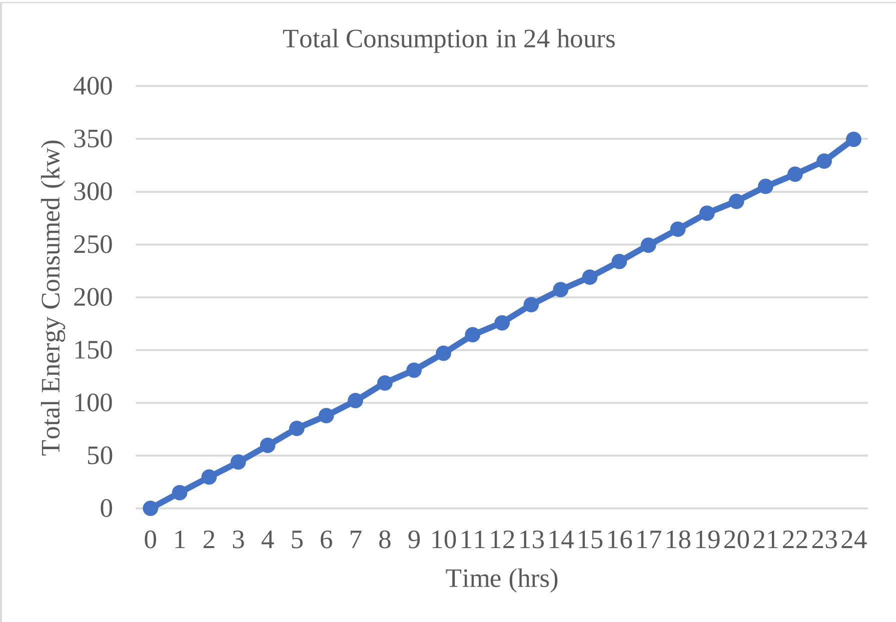

Figure 4.2The Graphical Representation of the Different Consumption

The total energy consumption of all the loads increases as the time of usage increases. From the result above, the total energy consumed is 349.6325899 kwh which is 34.96325899 kwh.

Recall that all the results were multiplied by 10, so we divide by 10 as well to get the real value. However, to manage energy usage from a supply of 100 units from prepaid or with the intention of not exceeding 100 units of energy in a month for postpaid customers, a threshold was set to 80 units to minimize the total energy consumed in the building. For instance, when the total energy consumed is below 80 units, all the loads in the building will continue to be in use, until when the total energy consumed is equal to or above the threshold (80 units), a message will be sent to the user informing him/her about shutting down of all the secondary loads and then it will shut down the secondary load appliances from getting supply while the primary load appliances and tertiary remains functional.

The hourly documentation of this consumption rate is routed and documented through the cloud (the ThingSpeak) so at any given point the user can log in and view the consumption of his apartment even when he is not around and the children and relatives are.

V. Conclusion

From the successfully simulation of the system, the result shows that the secondary loads consumed much energy and however can be done without

Secondly, the Secondary loads, such as refrigerators, water pumps, electric cookers, and air conditioners, contributed significantly to the overall energy consumption. These loads showed substantial increases during peak usage periods, highlighting their role in elevating energy demand, especially during certain times of the day and certain season. The air conditioner, in particular, was a major contributor to energy consumption, reflecting its intensive use in managing indoor climate.

The tertiary loads, represented by security lights, showed a predictable energy usage pattern aligned with nighttime hours. The security lights were programmed to turn on at dusk and off at dawn, resulting in a clear and consistent energy consumption profile. This pattern underscores the importance of automated controls in managing energy use efficiently.

The implementation of an energy management system with a predefined threshold effectively demonstrated the potential for significant energy savings. By monitoring total energy consumption and shutting down secondary loads when the consumption approached the defined limit, the system ensured that energy usage remained within acceptable bounds without compromising essential household functions. This proactive approach highlights the effectiveness of automated energy management in optimizing energy use and preventing wastage.

VI. Recommendation

Based on the findings of this study, the following recommendations are proposed to enhance energy management in residential buildings:

i. Future research can explore advanced simulation techniques, such as machine learning and artificial intelligence, to predict energy consumption patterns and optimize energy management strategies. These techniques can provide more accurate and dynamic energy management solutions by learning from historical data and adapting to changing consumption patterns.

ii. Further studies can investigate the integration of renewable energy sources, such as solar and wind power, into the energy management system. This integration can provide additional insights into the potential for reducing dependence on conventional power sources and enhancing energy sustainability. Research can focus on optimizing the balance between renewable energy generation and household energy consumption to maximize efficiency and minimize costs.

iii. Research can also focus on analyzing user behavior and its impact on energy consumption patterns. Understanding how users interact with the energy management system and respond to energy-saving measures can provide valuable insights for designing more effective energy management solutions. Studies can explore the psychological and behavioral factors that influence energy usage and identify strategies to encourage more sustainable practices among residents.

iv. Future research can explore the scalability and adaptability of the energy management system to different types of residential buildings and geographic locations. This research can help identify the specific needs and challenges of various residential contexts and develop tailored energy management solutions. Studies can examine the feasibility of implementing similar systems in larger residential complexes, multi-family buildings, and various climate zones.

v. Further studies can quantify the economic and environmental benefits of implementing automated energy management systems in residential buildings. Research can analyze the cost savings from reduced energy consumption, the return on investment for installing energy management systems, and the reduction in greenhouse gas emissions. These findings can provide a stronger business case for adopting energy management systems and encourage wider adoption among homeowners and policymakers.

From the deductions made we can conclude that if this system is implemented, users would need not be scared of not having energy for their preferred points of use.

If eventually integrated into prepaid meters as a function, then the energy meter will become more beneficial to the users as this is the next phase of this system.

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APPENDIX: A1