EXPENSE CAPPING ENERGY CONSUMPTION SYSTEM WITH AUTO - DISCONNECTION

Gladdy Christie H. Compasan and Clark Darwin M. Gozon
College of Engineering and Architecture, University of Science and Technology of Southern Philippines, Cagayan de Oro City, 900 Philippines
For correspondence; Tel. + (63) 926-196-2806, *gladdychristie.compasan@ustp.edu.ph
clarkdarwin.gozon@ustp.edu.ph

ABSTRACT: *The contemporary era is characterized by a significant dependence on electrical energy, underscoring the urgent need for global energy conservation. Given the limitations of renewable resources and the detrimental impacts of non-renewable sources on the environment, challenges loom over the energy landscape. Globally, electricity consumption has doubled over the years. In the Philippines, this increase is driven by residential and industrial sectors. In response, distribution companies like MERALCO have introduced innovative solutions like Kuryente Load (KLoad) to promote energy savings. This paper presents a novel approach, the Development of Expense Capping Meter-Based System with Auto-Disconnection. The system 's capability covers: (a) monitoring of real-time energy consumption; (b) accurate clamp meter-level readings; and (c) an auto-disconnection mechanism when customer's energy expense exceeds the budgeted consumption. The study's scope covers device creation and an administrator's page for energy data management.*

Keywords: Expense Capping, Renewable Energy, Energy Consumption System, ANOVA

1. INTRODUCTION

The contemporary era is marked by an unprecedented reliance on electrical energy, rendering its conservation a critical global concern. With the insufficiency of renewable resources and the detrimental environmental effects of non-renewable resources, such as increased carbon footprint and climate change risks, the energy landscape is fraught with challenges [1]. Despite these alarming issues, the global consumption of electrical energy has surged, with countries like China, the United States, and India leading the way [2].

In the Philippines, the rapid escalation in electrical consumption is particularly noticeable, doubling from 36.85 TWh in 2000 to 74.15 TWh in 2017. This increase is largely attributed to the residential and industrial sectors, which together account for over half of the country's electricity consumption [3]. In response, distribution companies like Manila Electric Company (MERALCO) have introduced innovative solutions such as Kuryente Load (KLoad), a prepaid electricity service that has enabled customers to save about 20% on energy consumption [4].

This paper introduces the Development of Expense Capping Meter-Based System with Auto-Disconnection, a novel approach aimed at assisting distribution companies in mitigating economic losses due to delinquent customers. The system preserves the post-paid billing system while offering real-time updates on energy consumption and providing expense limits tailored to the customer's budget.

The primary objective of this research is to develop a customer expense capping meter-based system that can provide reliable current reading, read current as accurately as a clamp meter, and communicate disconnection based on the current reading once the expense limit has been reached. The significance of this study lies in its potential to offer a fast, reliable, and convenient system for monitoring monthly energy consumption, benefiting distribution companies, and customers, in general [2, 3].

This innovative system not only furnishes dependable real-time current readings but also rivals the precision of traditional clamp meters in accuracy. Furthermore, its capacity to communicate automatic disconnection when consumption reaches preset expense limits holds profound implications for energy conservation and cost efficiency. This trifecta of capabilities—reliable readings, clamp meter-level accuracy, and automated disconnection—presents a transformative solution for both consumers and distribution companies.

The scope of this study is confined to the creation of a device and an administrator's page for distribution companies to monitor and store data on energy consumption, allowing customers to set consumption limits and receive notifications. The system's functionality, limitations, and the context of its development at the University of Science and Technology of Southern Philippines are further detailed in the subsequent sections.

2. Related Studies

Some studies and research undertakings have been done to investigate the need for such improvement. A study on reliable and economically feasible automatic meter reading system using power line distribution network introduces an electrically-controlled power relay switch to restrict customers' power consumption through remote control, integrated into the automatic meter reading system. The relay switch interrupts current flow when consumption exceeds a set maximum level, as determined by a sensor and logic circuit. A reset switch circuit reinstates power [5].

Another study about Wireless Home Automation Using IoT employs IoT for home automation, utilizing Arduino Uno and ESP8266 boards to control devices like lights, fans, and sensors. The ESP8266 board acts as a Wi-Fi access point, enabling remote device control via a mobile app. A relay module facilitates circuit connections [6].

In the concept of profiling and prediction, a study entitled Profiling, Prediction, and Capping of Power Consumption in Consolidated Environments utilizes energy consumption profiles to set consumption limits for budgeting. Two budget types are identified: average budget to capture long-term consumption and sustained budget to accommodate current draw restrictions. Accurate predictions are achieved within error margins [7].

3. CONCEPTUAL AND THEORETICAL FRAMEWORK

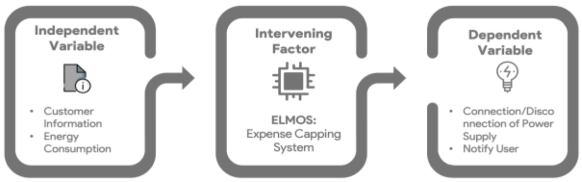


Figure 1. Input, Process, Output

This study is underpinned by the conceptual framework depicted in Figure 1, focusing on the monitoring of customer energy consumption. The framework facilitates customers in setting monthly consumption limits and empowers distribution companies to automatically disconnect the power supply upon reaching 100% of the predetermined limit.

4. METHODOLOGY

Research Design

The research design employed in this study is quantitative, examining the relationship between customer energy consumption (independent variable), the expense-capping system (intervening variable), and the connection or disconnection of the power supply and system response time (dependent variables). The control variable in this study was the voltage used by the customer, standardized at a rating of 230 V.

Design and Construction of Expense-Capping Energy Consumption System with Auto-Disconnection Materials

The construction of the system required materials such as given in table 1:

Table 1. Materials and Quanity

Item	Quantity
1. NodeMCU 1.0v	1
2. USB micro-B cable	1
3. 1-channel relay module	1
4. 12V power supply	1
5. ACS712 current sensor module	1
6. Resistors	-
7. Capacitors	-
8. Printed circuit board	-
9. Soldering iron	-
10. Jumper wires	-

System Design

The system design for automated, digital, and real-time energy consumption monitoring and disconnection of power supply is illustrated in Figure 2.

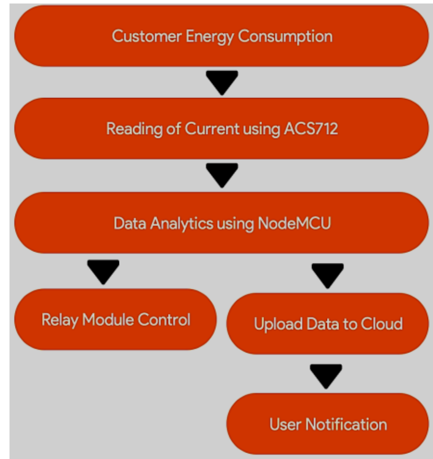


Figure 2. System Design

Circuit Design

The circuit diagram, as shown in Figure 3, encompasses the microcontroller, relay module, and current sensor ACS712.

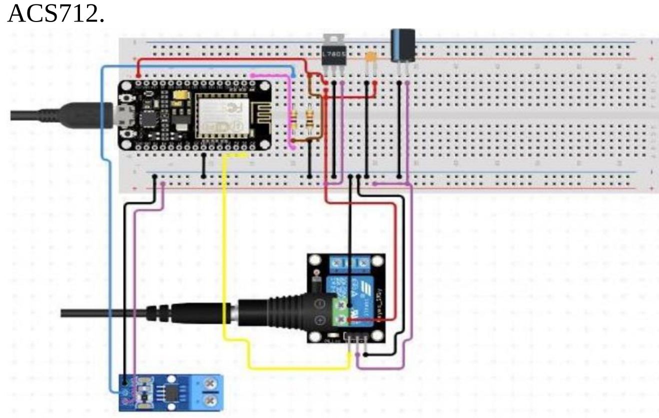


Figure 3. ACS712

Construction of Hardware

The construction process involved a step-by-step assembly of the device. The components, including NodeMCU 1.0V, relay module, ACS712, resistors, capacitors, and L7805, were systematically placed and connected on the breadboard. The connections were made following a specific sequence, ensuring proper alignment and connectivity between the ground pins, power pins, resistors, capacitors, and the nodeMCU 1.0V. The final step involved connecting the nodeMCU 1.0V to the computer using a micro USB cable and uploading the necessary codes.

Evaluation of the Working Prototype Data Gathering Instruments

To assess the efficiency and accuracy of the device and system, various instruments were employed for data gathering:

Personal Computer. The personal computer, equipped with the Arduino IDE program, facilitated the uploading of codes and programming of the current sensor module ACS712 with NodeMCU 1V as the microcontroller. It served as the display for the current reading of the current sensor ACS712.

Clamp Meter. The clamp meter functioned as a verification tool, comparing its current reading to that of the current sensor ACS712. This comparison ensured the accuracy of the current reading by the sensor.

Stopwatch. The stopwatch measured the response time of the communication between the device and the system, assessing the speed of the relay module's disconnection after receiving the signal from the cloud and the system's notification speed upon reaching 80%, 95%, and 100% of energy [8] .

Testing. Systematic testing was employed as the technique for data gathering and analysis. Conducted over the entire duration of the device's operation, the testing involved five trials using a 650W load for sampling. The current reflected on the computer monitor, as read by the current sensor, was compared to the clamp meter's reading, with current measured in amperes (A).

Research Locale. The study required a robust internet connection and was conducted at University of Science and Technology of Southern Philippines and spanned the first semester of A.Y. 2018-2019, concluding in December 2018.

Statistical Treatment. The statistical analysis utilized a one-way analysis of variance (one-way ANOVA) to interpret the collected data. This statistical technique identified significant differences between two variables, specifically comparing the current readings of the sensor and ammeter to test the device's accuracy [9] [10].

5. RESULTS AND DISCUSSION

Expense-Capping Energy Consumption System

The proponents of this study were successful in developing an expense-capping energy consumption system with auto-disconnection. The system consists of the hardware, cloud, and user interface. The hardware consists of the NodeMCU, current sensor, and relay module.

The current sensor measures the current passing through the line it is connected to. It sends a signal to the NodeMCU containing the current data through the A0 pin. The NodeMCU interprets this data through the computations in the Current Sensing code uploaded in it. It calculates the current using the sent data and delivers it to the cloud.

The cloud uses the delivered data to determine the energy consumed by the user. It accumulates the energy consumed throughout the usage and compares it with the desired expense cap as declared in the user interface [11]. The cloud will return three possible values to the NodeMCU: 'SUCCESS', 'HALT', and 'PROCEED'.

A **'SUCCESS'** response indicates that the system may start to collect current data and continue to collect current data.

A **'HALT'** response indicates that the total energy consumed has already reached the expense cap desired by the user. It signals the relay module to break the connection of the line.

A **'PROCEED'** response indicates that the system may collect current information. It signals the relay module to reconnect the line.

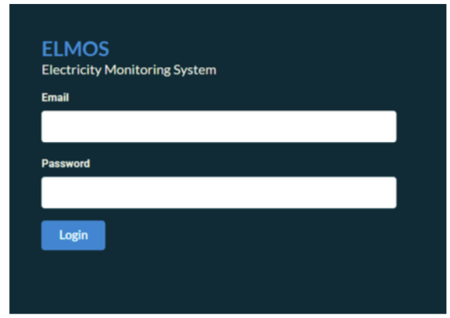


Figure 4. User Interface Log-In Window

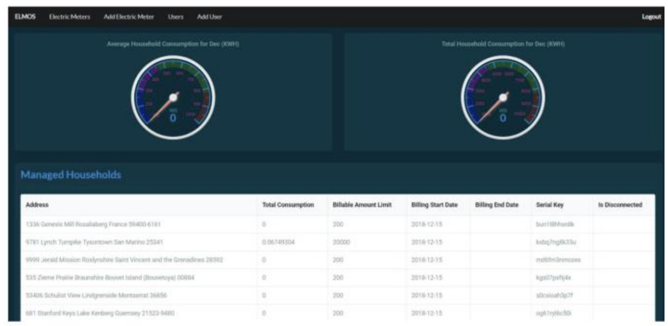
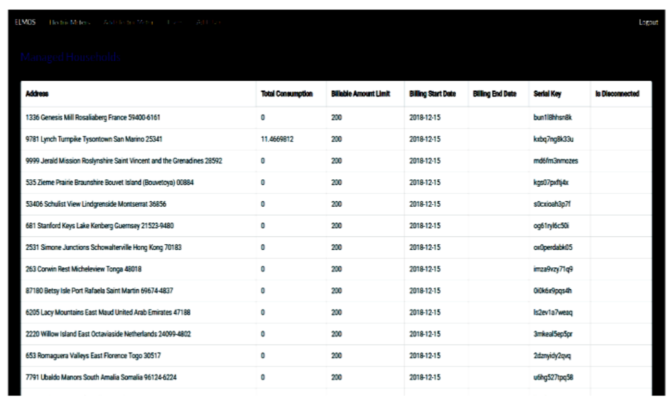


Figure 5 Main Window of the User Interface

The Electric Meters tab, as shown in Figure 6, exhibits a more detailed view of the Managed Households. It shows the address of the electric meter, its total consumption, expense cap, billing start and end date, serial key, and status. Each household is clickable and shows the personal details of the chosen meter as shown in Figure 7. It is in this window where the user can update the expense cap initially desired.



Address	Total Consumption	Billable Amount Limit	Billing Start Date	Billing End Date	Serial Key	Is Disconnected
1336 Genesis Mill Rosaliaberg France 59400-6161	0	200	2018-12-15		bun1l8hhsn8k	
9781 Lynch Turnpike Tysontown San Marino 25341	11.4669812	200	2018-12-15		kxbq7ng8k33u	
9999 Jerald Mission Roslynshire Saint Vincent and the Grenadines 28592	0	200	2018-12-15		md6fm3nmozes	
535 Zieme Prairie Braunshire Bouvet Island (Bouvetoya) 00884	0	200	2018-12-15		kgs07pxftj4x	
53406 Schulist View Lindgrenside Montserrat 36856	0	200	2018-12-15		s0cxioah3p7f	
681 Stanford Keys Lake Kenberg Guernsey 21523-9480	0	200	2018-12-15		og61ryl6c50i	
2531 Simone Junctions Schowalterville Hong Kong 70183	0	200	2018-12-15		cx0perdabk05	
263 Corwin Rest Micheleview Tonga 48018	0	200	2018-12-15		imza9vzy71q9	
87180 Betsy Isle Port Rafaela Saint Martin 69674-4837	0	200	2018-12-15		0i0k6x9pqs4h	
6205 Lacy Mountains East Maud United Arab Emirates 47188	0	200	2018-12-15		ls2ev1a7weaq	
2220 Willow Island East Octaviaside Netherlands 24099-4802	0	200	2018-12-15		3mkeal5ep5pr	
653 Romaguera Valleys East Florence Togo 30517	0	200	2018-12-15		2dznyidy2qvq	
7791 Ubaldo Manors South Amalia Somalia 96124-6224	0	200	2018-12-15		u6hg527tpq58	

Figure 6 Electric Meters Tab of the User Interface

Figure 7. Detailed Information of a Household Meter with Ability to Add Load.

An electric meter can be added in the system that is tagged to an existing user through the Add Electric Meter tab. It requires the serial key, address of the household, name of the user, initial expense cap, and the starting billing date. It is shown in Figure 8.

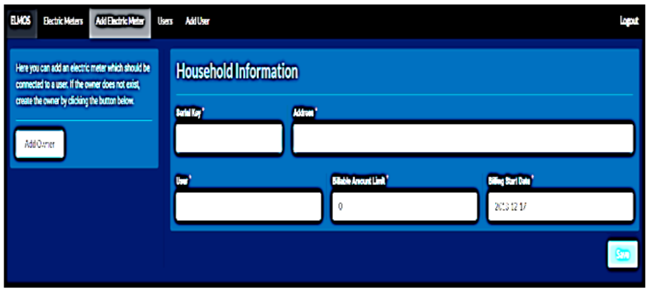


Figure 8. Add Electric Meter Tab of the User Interface

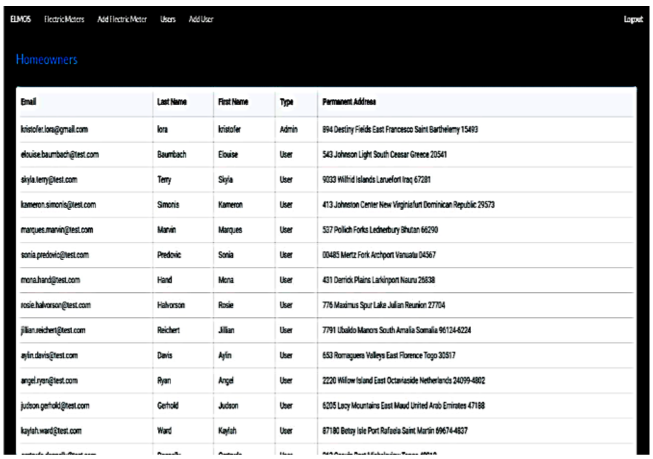


Figure 9. Users Tab of the User Interface

The Add User tab allows the administrator to add another in the system as shown in Figure 10. The full name, contact details, and address of the user is needed to add another user in the system.

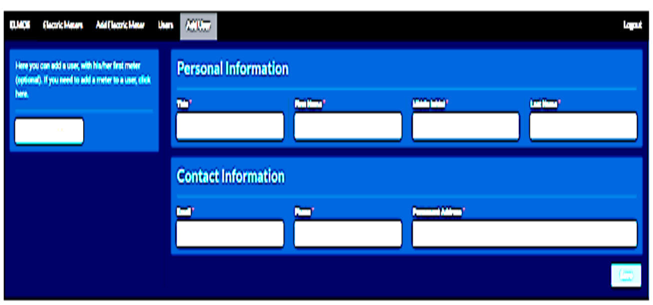


Figure 10. Add User Tab of the User Interface.

Statistical Treatment

The following tables show the different current readings obtained from the current sensor and clamp meter using a load with 650 W rating.

Table 2. Current readings of ACS712 and clamp meter with steam brush-iron as load

Trials	Steam Brush Iron Load Current Reading	
	ACS712	Clamp Meter
1	2	2.83
2	2.87	2.81
3	2.87	2.82
4	2.801	2.82
5	2.835	2.83

Table 2 shows the comparison of the current reading of the current sensor and clamp meter.

Table 3. Current readings of ACS712 and clamp meter with steam brush-iron as load

		N	Correlation	Sig.
Pair 1	ACS712 & ClampMeter	5	-0.561	0.326

Table 3 shows the results of the trials made (N=5) for the experiment and the output presents that the current sensor (ACS712) and the clamp meter are strongly and negatively correlated (r=-0.561, P<0.001).

Table 4. Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ACS712	2.6752	5	0.37853	0.16929
	ClampMeter	2.8220	5	0.00837	0.00374

Table 4 shows that the paired population means are almost equal for ACS712 (μ = 2.6752, SD=0.37853) and Clamp Meter (μ = 2.8220, SD=0.00837). We can see from the standard deviations that the scores in both conditions are similarly dispersed.

Table 5. Paired Samples Statistics

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ACS712 - ClampMeter	-0.1468	0.38329	0.17141	-0.62271	0.32911	-0.856	4	0.44

Table 5 shows that there is no significant average difference between the current sensor ACS712 and the clamp meter (t_4=-0.856, p=0.001). On average, ACS712 results were 0.1468 amperes lower than the clamp meter results (95% CI [-0.62271, 0.32911]).

4. CONCLUSION AND RECOMMENDATION

To evaluate the device's efficiency and accuracy, a personal computer with Arduino IDE was used for programming and data display, a clamp meter verified the current sensor ACS712's readings, and a stopwatch gauged the system's response time. Systematic testing, involving five trials with a

650W load, compared the computer's current display to the clamp meter's readings. By developing an Expense Capping Meter-Based System with Auto-Disconnection, it offers consumers a vital tool to manage economic losses unmanaged electricity usage of customers. The system's time-effective updates and tailored expense limits facilitate responsible energy use to consumers. This innovative approach not only contributes to sustainable energy practices but also underscores the potential for significant economic savings. The study was conducted in Cagayan de Oro City from the first semester of A.Y. 2018-2019 until December 2018, using one-way ANOVA for data interpretation. Based on the findings, it is recommended to further explore the integration of real-time monitoring with automated disconnection systems in various energy consumption scenarios. Such exploration could lead to more robust and adaptable solutions, enhancing energy conservation efforts and providing distribution companies with more effective tools for managing customer consumption.

6. REFERENCES

[1] Farghali, M., Osman, A.I., Chen, Z. et al. Social, environmental, and economic consequences of integrating renewable energies in the electricity sector: a review. Environ Chem Lett 21, 1381–1418 (2023). https://doi.org/10.1007/s10311-023-01587-1

[2] Phebe Asantewaa Owusu & Samuel Asumadu-Sarkodie | Shashi Dubey (Reviewing Editor) (2016) A review of renewable energy sources, sustainability issues and climate change mitigation, Cogent Engineering, 3:1, DOI: 10.1080/23311916.2016.1167990

[3] Department of Energy. Power Situation Report 2019 available at https://www.doe.gov.ph/sites/default/files/pdf/electric_power/2019-power-situation-report.pdf

[4] Department of Energy available at https://www.doe.gov.ph/press-releases/doe-private-sector-push-prepaid-electricity-service

[5] Moghavvemi, Mahmoud & Tan, S. & Wong, S.. (2005). A reliable and economically feasible automatic meter reading system using power line distribution network. International Journal of Engineering, Transactions B: Applications. 18. 301-318.

[6] Gomathy, C K. (2022). The HOME AUTOMATION USING IOT. Available at https://www.researchgate.net/publication/357748641_The_HOME_AUTOMATION_USING_IOT

[7] Choi, Jeonghwan & Govindan, Sriram & Urgaonkar, Bhuvan & Sivasubramaniam, Anand. (2008). Profiling, Prediction, and Capping of Power Consumption in Consolidated Environments. 1 - 10. 10.1109/MASCOT.2008.4770558.

[8] Easergy P3 User Manual, 2022. Schneider Electric, France available at www.schneider-electric.com

[9] Will Kenton, June, 2023. Available at https://www.investopedia.com/terms/a/anova.asp

[10] Diane Kieman, Natural Resources Biometrics 2014. ISBN 9781942341178, Open SUNY Textbook City, New York. Available at https://knightscholar.geneseo.edu/oer-ost/21/

[11] Katal, A., Dahiya, S. & Choudhury, T. Energy efficiency in cloud computing data centers: a survey on software technologies. Cluster Compute 26, 1845–1875 (2023). https://doi.org/10.1007/s10586-022-03713-0