Internet-Based Electric Meter with Theft Detection, Theft Notification and Consumption Monitoring for Residential Power Lines Using Wireless Network Technology

Maria Criselda B. Loyola, Jhamel B. Bueno, and Roshmeir D. De Leon
Electrical Engineering Department, Malayan Colleges Laguna, Cabuyao City, Philippines
Email: mcbloyola@mcl.edu.ph; {jhamelbueno1996; rxmeir.deleon}@gmail.com

***Abstract*—In support of a proposed bill in the Philippines, the Recoverable System Loss Act, which aims to reduce the system losses cap thus making electricity cheaper, the objective of this project is to help the distribution utility and the consumer in decreasing the incidences of power theft. An electric meter which features theft detection and notification, and an internet-based energy consumption monitoring system were designed to alleviate the problem. Theft detection is achieved through the utilization of microcontrollers and current sensors, while theft notification is achieved through the utilization of LoRaWAN technology. The theft detection module can identify illegal tapping and meter bypassing. A star network of electric meters was implemented to test the LoRaWAN in an energy metering application. The theft detection and notification modules were 100% successful in identifying and transmitting the correct type of theft. The watt-hour measurement of the electric meter exhibited 99.9% accuracy in reference to a commissioned digital electric meter. In coordination with the electric meter, theft notifications and meter data were accessible to both the consumer and distribution utility through an online energy monitoring system: enermon.tech. The LoRaWAN gateway was able to receive theft notifications from an electric meter node as far as 601 m line of sight with an average round trip time of 33.09 milliseconds in the implemented area. This system provides immediate notification of the presence of pilferage for the distribution utility and consumer to address.**

***Index Terms*—electricity pilferage, illegal tapping, LoRaWAN, meter bypassing, non-technical system loss, wireless network**

I. Introduction

One of the major concerns of Meralco, the country's largest private distributor of electricity, is the rising incidences of illegal tampering of electric meters, 'jumpers,' and stealing of electric conductors. These acts of pilferage are serious threats to the safety of the community, because these acts result in fires and electrocution. These are punishable by law under the Republic Act 7832, the "Anti-Electricity, Electric Power Lines, Equipment, and Materials Pilferage Act."

Electric pilferage is accounted for under non-technical system loss. Distribution utilities charge each consumer a certain percentage for system loss. Therefore, even though a consumer does not steal electricity, they are charged higher than what they actually consumed. The distribution utility does not have full responsibility of the incurred costs due to electricity pilferage, which makes them unmotivated perhaps to prioritize addressing the issue. The Recoverable System Loss Act proposed by the chairman of the Senate Committee on Energy aims to reduce the cost of electricity in the Philippines by further reducing the system losses cap from 8.5% to 5% for private distribution utilities and 13% to 10% for electric cooperatives, and the exemption from value-added tax of the system loss charge.

Given the current situation of the Philippines' electrical distribution sector, the objective of this project was to design an electric power meter and an internet-based energy consumption monitoring system. The electric power meter features theft detection for residential power lines, and a theft notification system for both the consumer and distribution utility. This electric power meter may help in improving the way the government and distribution utilities address electricity pilferage in the Philippines. If adapted nationwide, incidences of power theft due to 'jumpers' could be reduced. The electric power meter cannot be tampered, which eliminates the occurrences of theft due to meter tampering. The electric meters were implemented in a LoRaWAN network to wirelessly transmit watt-hour data and theft notifications, which were displayed on the energy consumption monitoring website.

II. Related Literature

A. Electricty Pilferage and System Loss in the Philippines

According to a study [1], electric energy is frequently stolen by the lower and middle class who are motivated by the desire to save money. The same study

Manuscript received October 5, 2018; revised April 10, 2019; accepted May 6, 2019.
Corresponding author: Maria Criselda B. Loyola (email: mcbloyola @mcl.edu.ph).

doi: 10.18178/ijeetc.8.5.238-246

categorized the issues of electric power theft to safety, economy and society. Power theft is a safety issue, because it can cause electrocution and fires.

Electricity theft is responsible for economic problems in the electric utility due to revenue loss caused by unpaid electricity of the consumers. The thieves have a tendency to consume more energy, resulting to power quality problems. An increase in power demand to values greater than the transformer-rated power can result to different quality deviations like transformer overload, voltage unbalance and steady-state voltage drop on system buses [2].

System loss charges represent the cost of electricity lost in the distribution system from the receiving point of private distribution utilities and electric cooperatives to the consumer's metering point as defined by Recoverable System Loss Act of 2016. System loss can be classified into 'technical losses or 'non-technical losses.' Technical losses refer to the losses due to power dissipation that occur in electrical system components in transmission and distribution. Non- technical losses cannot be directly taken into account, because they are losses that are due to electricity pilferage and administration errors [3].

As stated in the R.A. 7832, system loss is charged to the consumer, despite it being unconsumed power. The law allows private distribution utilities and rural cooperatives to collect the costs of these losses through the system loss. The Chairman of the Senate Energy Committee Filed Senate Bill 1188 or the Recoverable System Loss Act in attempt to lower the cost of electricity. This bill seeks to lower the current cap of system loss charges as mandated by the R.A. 7832 from 8.5% to 5% for private distribution utilities and 13% to 10% for electrical cooperatives. The bill also proposes the exclusion of non-technical system losses in the system loss charge that is passed on to the consumers. Meralco currently stands with 6.5% system loss charge, which is lower than the prescribed cap.

B. Previous Works on the Detection and Notification of Electric Power Theft

A study [3] proposed the use of a current monitoring system to detect power theft in low-tension transmission lines. It proposed that power theft can be detected when an imbalance of currents is detected between poles. Current between poles is assumed to be balanced under no-load conditions. The presence of load causes a change in current between poles. This method utilizes a current transformer for measuring currents, a signal conditioner circuit for converting the currents to voltage, and microcontroller for analyzing measured values. Installing the system in-between poles enables easier identification of the location of power theft. A similar system was proposed by [4] which utilizes an energy meter, PIC microcontroller, and GSM technology. The energy meter used in this study consisted of a current transformer, IR sensor and a magnetic reed switch. This was used to detect the presence of energy theft. GSM technology was utilized to notify the end-user of the presence of theft. Reference [4] stated that the use of GSM technology provided more advantages for wireless transmission, as compared with previous methods.

A study in press conducted by Loyola *et al.* [5] utilized microcontrollers, Zigbee and GSM technology to detect power theft and notify the consumer. The study was able to detect theft in the form of illegal jumpers and meter bypassing, and was successful in notifying the end-user and the distribution utility via SMS.

Using GSM, however, limits the way of notifying the consumer and the distribution utility through Short Message Service (SMS) only. A comparative study by Khare *et al.* [6] stated that GSM modules offers a limited data service. Using this type of communication system limits the scalability of the power theft detection and notification system, because it is impractical to install several GSM units to accommodate the data traffic in a large-scale application.

In a study proposed by Tariq *et al.* [7], wireless sensor networks were used to detect and report the presence of illegal tapping. Their study used a Resistive Temperature Sensor (RTS) node to obtain the real-time measurement of the line resistance of circuit branches to detect the presence of illegal tapping. An increase in the line resistance is a result of an increase in the load that is due to illegal users [7]. Data gathered by the sensor nodes were transmitted through motes linked together to form a network. The network formed by the motes connected to each electric meter will increase the range of transmission.

The integration of ZigBee-based wireless sensor networks in the smart grid was proposed in [8]. Their system can measure the consumer's power consumption, store the data in real-time and display the time of use values. The same study used ZigBee to collect and broadcast data and upload it to the consumer's personal computer. The smart meter system includes a scheduling mechanism that allows the consumer to set the time of usage of the electricity. Their smart meter system allows the consumer to have control over their energy consumption in accordance to the smart grid concept. Wireless sensor networks have a wide range of applications in creating a manageable, reliable and flexible smart grid [8]. This study applied the concept of wireless sensor networks in a residential area for the purpose of smart metering and energy consumption monitoring. The communication protocols the study used require multiple sensor nodes in the home and a personal computer as its server.

Another similar study that used wireless sensor networks was conducted in [9]. They stated that wireless sensor networks have the advantage of better accuracy, lower power consumption, improved area coverage and minimal human intervention. Deployment of multiple sensors can retrieve more accurate data compared to a single sensor.

A study conducted by Wixted *et al.* [10] compared the performances of data transmission methods of wireless sensor networks. Their study claimed that cabling, Bluetooth, WiFi, and Zigbee were only suitable

for short-range applications in the span of meters up to a hundred meters. Long Range (LoRa) technology is suitable for applications that require wide network coverage. The use of LoRaWAN technology and multiple gateways increased network coverage and was able to reach into problematic areas.

Low Power Wide Area Networking (LPWAN) technology is the combination of low data rate and long range communication. LoRaWAN currently displays its increasing popularity for being one of the most successful technologies under LPWAN. It was defined that LoRaWAN employs LoRa as its physical layer. Its range could reach up to 15 km in sub-ruban areas and 2 to 5 km in urban areas. LoRaWAN networks were commonly deployed as star networks [11].

Limitations of LoRaWAN technology was identified in [11] analytic study of LPWAN technologies. The objective of the study was to provide a more realistic understanding of the capabilities and appropriate applications of LoRaWAN technology. The researchers concluded that there were several factors to consider for the appropriateness of employing LoRaWAN in a certain application. These were the number of end-devices, the distance of the end-devices to the gateway, the spreading factor, and the number of channels of the gateway. The study also identified that LoRaWAN is not guaranteed to be successful in real time monitoring and industrial automation applications, where response time is a critical consideration. For metering applications, the study concluded that it is appropriate on a case-to-case basis. The study commended LoRaWAN technology for its success in smart lighting, smart parking, and smart waste collection. In the case of smart city applications, the number of messages sent per day was limited and latency was not a major issue. LoRaWAN's key features of wide coverage area and connectivity of a great number of devices were utilized in this application.

For large-scale consumers, the use of LoRaWAN technology is more applicable to GSM technology. Low power wide area networking enables a wide area network coverage with minimal human interaction for energy consumption monitoring and theft detection and notification. On the other hand, Zigbee technology can also be considered for its data transmission, but its range is limited as compared to LoRaWAN.

C. Energy Consumption Monitoring

Beside power theft detection and notification, Islam *et al.* [12] developed a smart metering system that can reliably and accurately monitor power consumption of the end-user. This study addressed the issues of inaccurate meter reading due to human error and power theft. It utilized the GSM technology, Arduino microcontroller and network-based technologies to create this system. Their system allows the consumer to monitor his/her power consumption and billing information through a database. It also allows the distribution utility to remotely obtain this information through the transmission of data through a GSM modem installed at both ends, consumer and server. This type of system addresses the system loss that is due to inaccurate meter readings and meter tampering.

A study in [13] stated that an energy monitoring and control system is essential to maximize energy savings and to significantly reduce cost. It proposed real time energy consumption monitoring system with the remote control of switches in a residential or corporate environment. The project proposed in [13] utilized the Wi-Fi networks for their communication protocol, because it is affordable, readily available, and transmission to different modules is secure. The data collected from the different points of their system are compiled in a MySQL database. It was successful in creating a system that allows smart management of energy consumption and reducing energy costs. In addition, these types of sustainable management systems are beneficial to the environment.

In a study by Son [14], a smart meter was used in monitoring the power consumption of selected appliances inside a house in Korea. It was emphasized that energy consumption monitoring was the first step in reducing the electricity cost of a house. The energy consumption module developed in [14] estimated the energy consumption of different appliances based on the data gathered and stored by the smart meter.

Before, electric meters were used solely for the purpose of electric billings and are ignored by the consumer, because only the representative from the distribution utility knows how to interpret the data displayed. Even though digital meters and smart meters are now available in the market, some areas have their meters placed on an elevated, centralized location. They cannot monitor their consumption proportional to their budget.

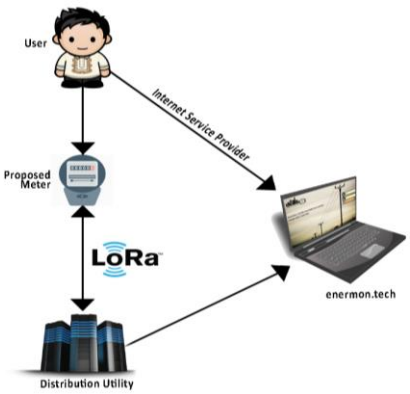

Fig. 1. Conceptual framework of electric meter with theft detection, theft notification and energy consumption monitoring using LoRaWAN technology.

III. METHODOLOGY

The entire system of this project consists of the electric meter and the energy consumption monitor. The electric meter features a theft detection and notification system, aside from measuring and displaying the power consumption of the household.

Fig. 1 shows that the consumer has access to the electric meter and the energy consumption monitor via

the internet. Electric meter data and theft notifications were transmitted to the distribution utility via LoRaWAN technology. The distribution utility owns the server of the database where meter data are collated. A user account and admin account in the energy consumption monitor are provided for the consumer and distribution utility respectively.

A. Energy Consumption Monitoring

The electric meter is the main component of the system. The electric meter features a theft detection and notification function. The electric meter measures the energy consumption of the consumer and transmits the data collected to the distribution utility.

The theft detection module compares the current measured before the meter (I_{CT}) and the current measured by the meter (I_{PA}). If both current readings have values that do not exceed the threshold, there will be no succeeding action taken, because theft is not present. If there is a disparity in the current readings that exceeds the 9% threshold, theft is assumed to be present. Theft was classified as either 'illegal tapping' or 'meter bypassing' depending on the value of the current.

A voltage divider circuit and a burden resistor were used to interface the current transformer to the analog input of the Arduino. Fig. 2 shows the schematic diagram of the voltage divider circuit for interfacing the current transformer to the Arduino Mega 2560.

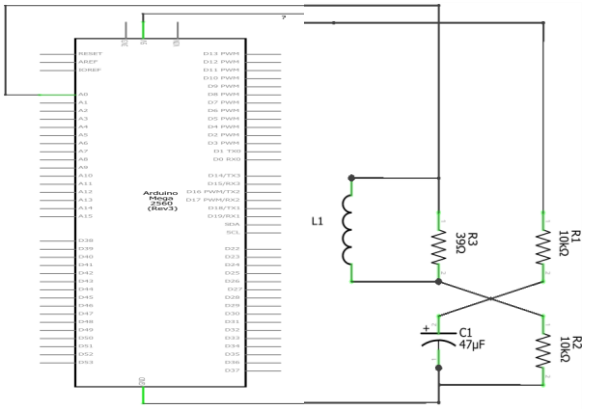

Fig. 2. Schematic diagram of voltage divider circuit for interfacing a current transformer to an Arduino.

The notification alert is sent through the LoRaWAN transceiver to be received by the distribution utility. A warning notification is displayed on the electric meter to alert the consumer of the theft. The LoRaWAN transceiver used is a Microchip LoRaWAN RN2483 assembled breakout board, which operates on 868-MHz.

Due to constraints in the number of Arduino Mega 2560's Pulse Width Modulation pins and a conflict with the library of the TFT display, another microcontroller was used to control the LoRa transceiver. An Arduino Nano communicates with the Arduino Mega 2560 as its slave. I2C communication was implemented to transfer the watt-hour data and theft status readings of the Arduino Mega 2560 to the Arduino Nano. An Arduino Nano was chosen for its compact design and minimal number of pins were required for its connections.

The energy consumption monitoring system displays the data collected from the electric meter. The consumer can access this database given a unique user ID and a password that corresponds to their electric meter. Their electronic bill can also be viewed through the database. The distribution utility controls a server account, which receives the consumption data of all the consumers and notifications of power theft incidents. The languages used for the user interface and event listening were a combination of JavaScript, Cascading Style Sheets (CSS), and Hypertext Markup Language (HTML). On the server side of the system, PHP was used as the scripting language, and MySQL was used to construct the database.

The distribution utility receives the data transmitted from the electric meters of the consumers through a gateway. The gateway forwards the data transmissions from the electric meter to a backend system, which is hosted by the things network. Data collated in the things network is then retrieved by an Application Programming Interface (API) for utilization of the energy consumption monitoring system.

The IMST iC880A LoRaWAN concentrator board features long range coverage, high robustness, immunity against interference, and supports multiple channels and spreading factors in parallel. It requires a Linux host to run its software. The Linux host used was a Raspberry Pi 2 Model B.

B. Prototyping Assembly, Data Flow, Control Logic, and Network Topology

Fig. 3 shows the physical assembly of the components used in the consumer end device. The components of the electric meter were connected as shown on the schematic diagram. The electric meter's power source was tapped onto the load side of the electric meter, which is also 230 VAC. The 230 VAC was rectified and reduced to a 12 VDC output by an AC–DC converter. To provide an appropriate DC voltage level for the microcontrollers and LCD display, a DC filter was used to reduce the 12 VDC to a 5 VDC supply.

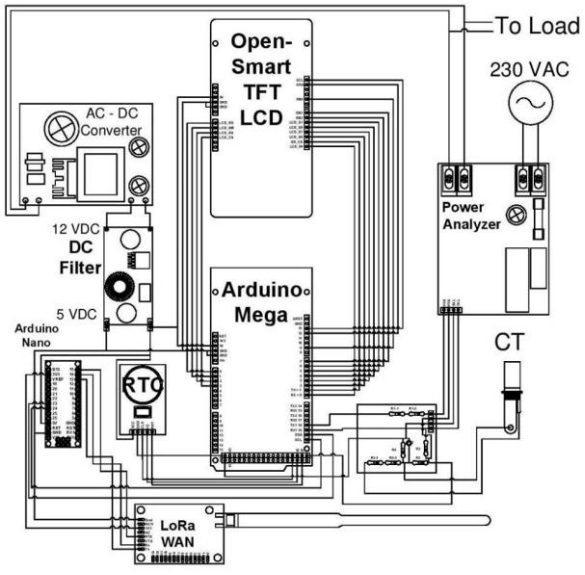

Fig. 3. Schematic diagram of electric meter.

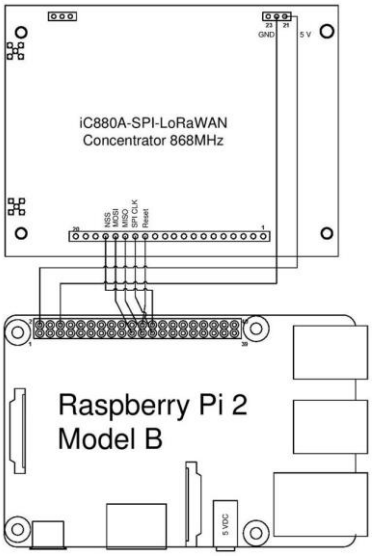

Fig. 4. Schematic diagram of LoRaWAN gateway.

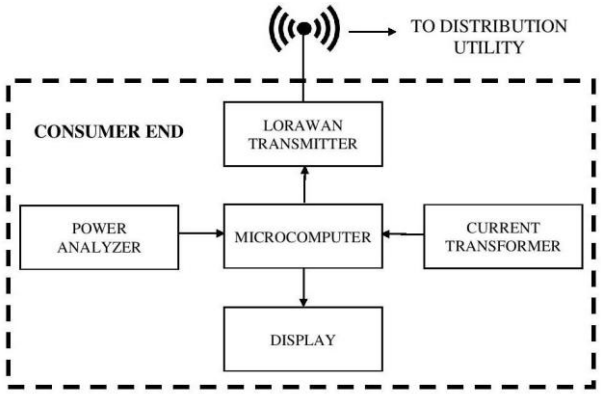

Fig. 5. Block diagram of the system's data flow at Consumer E.

Fig. 4 shows the assembly of the distribution utility end device. The gateway components, as previously discussed, are connected as shown on the schematic diagram. The gateway is powered through the Micro USB port of the Raspberry Pi. The gateway requires an input voltage and current of 5 V and 2 A respectively. An external 868-MHz antenna is attached to the concentrator board through a pigtail cable.

Fig. 5 shows the data flow of the consumer end devices. The microcontroller receives and analyzes data from the power analyzer and the current transformer. The data obtained is shown on the display and transmitted via the LoRaWAN transmitter.

This project uses the star network topology as shown in Fig. 6. Each meter is considered as a node and is represented by the circles on Fig. 6. Several nodes are connected to the gateway represented by the larger circle, which is the central point of the nodes. The gateway uploads the data to the internet then a server, which is considered the bus represented by the rectangle.

This network topology was chosen because several star networks can be implemented consisting of electric meters and a gateway over a certain area. This type of network topology can be used in the large scale application of this system. Data is centralized at the server of the distribution utility.

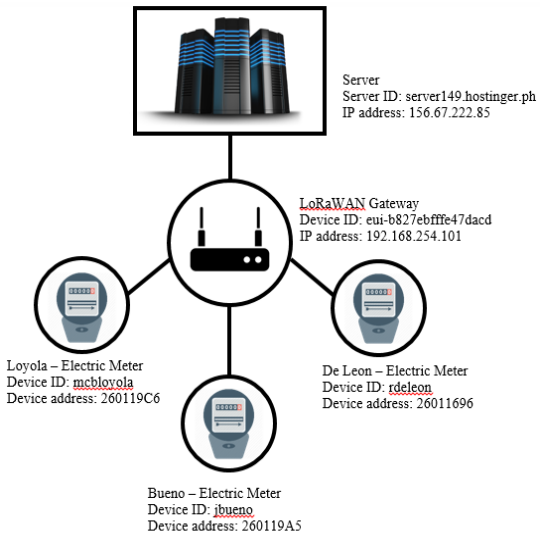

Fig. 6. Network topology of the system

C. *Prototyping Assembly, Data Flow, Control Logic, and Network Topology*

Initial to the assembly of the meter, the current-sensing devices were tested for their accuracy. A digital ammeter was used as reference. The current readings of the power analyzer and current transformer were compared to those from the digital ammeter. Fifteen current readings each were obtained for varying loads. The load was supplied by a constant 220 VAC source. The values of the resistive loads used were 1200-Ω, 600-Ω, 300-Ω, and 100-Ω. Current readings for each load set were interpreted by performing the two-tailed t-test for each current-sensing device. The two-tailed t-test was chosen as the method of data treatment because of the possibility that the output of the current-sensing device may be higher or lower than the reference value and it is appropriate for 30 samples or less. Fifteen samples from each current-sensing device for each load were taken. Each t-test employed 28 degrees of freedom and 99.9% confidence level. The t-test was calculated through the data analysis feature of MS Excel.

To test the accuracy of the watt-hour measurement of the electric meter, a commissioned digital meter was used as a reference. The total wattage of the load used was 999 W, which consisted of an LED light bulb, electric fan, and a hair dryer. The load was constantly supplied from a 230-VAC source. Measurements were taken after 30 minutes.

The LoRaWAN devices were interconnected through the open-source, decentralized network platform, The Things Network. Network connectivity was established by obtaining gateway traffic in The Things Network. The nodes transmitted packets to the gateway simultaneously. The distances of the nodes from the gateway were 69 m, 422 m, and 601 m.

To analyze the reliability of the LoRaWAN transceiver, the round trip time was recorded. The round trip time (RTT) of the system is expressed as the length of time a packet sent by a source plus the time it took for the data to be acknowledge by the receiving end.

Packet capturing was done through Wireshark Network Analyzer. Twenty trials were taken with each lasting for 100 seconds. Within the capture period of 100 seconds, no theft was simulated in the first 30 seconds. Theft was simulated in the next 30 seconds, and no theft in the last 40 seconds. The capture filter was set to the LoRaWAN gateway's IP address. The node placed in the farthest distance from the LoRaWAN gateway was used to obtain the average round-trip time of the network. The activity of the gateway was analyzed and graphed through the software.

The average round-trip time of the 20 trials was computed and its confidence interval. The confidence interval, CI, was calculated using (1), where $\bar{X}$ is the mean, σ is the standard deviation and n is the number of trials. The confidence level used to get the confidence interval was 95%.

$$\text{CI} = \bar{X} \pm 1.96\sigma / \sqrt{n} \quad (1)$$

The kilowatt-hour readings of the electric meter and commissioned digital meter were compared through the two-tailed t-test similar to the testing of accuracy of the current-sensing devices. Thirty samples were taken for the test. For the t-test, 58 degrees of freedom and a confidence level of 99.9% were used.

IV. Results and Discussion

A. Accuracy of Current-Sensing Devices

The current readings of the digital multimeter (DMM), Current Transformer (CT) and power analyzer (PA) for a 1,200-Ω load at a constant 220 VAC source are shown in Table I.

TABLE I. CURRENT READINGS OF THE DIGITAL MULTIMETER, POWER ANALYZER AND CURRENT TRANSFORMER FOR A 1200-Ω LOAD

Trial number	DMM reading (in ampere)	PA reading (in ampere)	CT reading (in ampere)
1	0.185	0.18	0.18
2	0.185	0.18	0.18
3	0.185	0.17	0.18
4	0.185	0.19	0.19
5	0.185	0.18	0.17
6	0.185	0.17	0.18
7	0.185	0.18	0.18
8	0.185	0.19	0.18
9	0.185	0.18	0.18
10	0.185	0.19	0.19
11	0.185	0.18	0.18
12	0.185	0.18	0.18
13	0.185	0.19	0.18
14	0.185	0.18	0.19
15	0.185	0.18	0.17

Table II shows the computed values for the two-tailed t-test for the current values of the power analyzer. The calculated t-value for the two-tailed is less than the t critical value at 99.9% confidence level as shown on Table II. It can be concluded that the current readings of the power analyzer is 99.9% as accurate as the digital multimeter for a 1200-Ω load.

TABLE II. TWO-TAILED T-TEST RESULTS OF CURRENT READINGS OF THE CURRENT TRANSFORMER FOR A 1200-Ω LOAD

Parameter	Variable 1	Variable 2
Mean	0.185	0.181333333
Variance	8.25399E-34	4.09524E-05
Observations	15	15
Pooled Variance	2.04762E-05	
Hypothesized Mean Difference	0	
Df	28	
t Stat	2.219103108	
P(T<=t) one-tail	0.017378173	
t Critical one-tail	3.408155178	
P(T<=t) two-tail	0.034756346	
t Critical two-tail	3.673906401	

B. Accuracy of the Designed Electric Meter

The designed electric meter's watt-hour measurement was tested for its accuracy by comparing its readings with a commissioned digital meter. Table III shows the kilowatt-hour readings of both the electric meter and commissioned digital meter for a constant time of 30 minutes. The watt-hour readings of the designed meter were divided by 1000 to match the displayed kilowatt-hour measurement of the commissioned electric meter.

TABLE III. COMPARISON OF KILOWATT-HOUR READINGS OF DESIGNED METER IN REFERENCE TO A COMMISSIONED DIGITAL METER

Trial	Elapsed time (in minutes)	Commissioned meter (in kWh)	Designed meter (in kWh)
1	30	0.5	0.5248
2	30	0.5	0.5250
3	30	0.5	0.5245
4	30	0.5	0.5249
5	30	0.5	0.5248
6	30	0.5	0.5245
7	30	0.5	0.5251
8	30	0.5	0.5251
9	30	0.5	0.5285
10	30	0.5	0.5278
11	30	0.5	0.5288
12	30	0.5	0.5289
13	30	0.5	0.5286
14	30	0.5	0.5287
15	30	0.5	0.5290
16	30	0.5	0.5291
17	30	0.5	0.5248
18	30	0.5	0.5243
19	30	0.5	0.5281
20	30	0.5	0.5253
21	30	0.5	0.5239
22	30	0.5	0.5273
23	30	0.5	0.5298
24	30	0.5	0.5264
25	30	0.5	0.5276
26	30	0.5	0.5281
27	30	0.5	0.5286
28	30	0.5	0.5288
29	30	0.5	0.5269
30	30	0.5	0.5279

The results from Table III were analyzed using two tailed independent t-test to identify if there is a statistically significant difference between the kilowatt-hour readings of the commissioned meter and the designed electric meter. Table IV shows the calculated values for the two-tailed t-test. The calculated t-value for

the two-tailed is less than the t critical value at 99.9% confidence level. It can be concluded that there is no statistically significant difference between the kilowatt-hour measurement of the designed meter and commissioned meter. The designed meter is 99.9% as accurate as the commissioned digital meter.

TABLE IV. CALCULATED VALUES FOR THE TWO-TAILED T-TEST OF THE KILOWATT-HOUR READINGS OF THE COMMISSIONED METER AND DESIGNED METER

Parameter	Variable 1	Variable 2
Mean	0.5	0.526863333
Variance	0	3.55757E-06
Observations	30	30
Pooled variance	1.77879E-06	
Hypothesized mean difference	0	
df	58	
t Stat	-78.00878499	
P(T<=t) one-tail	9.88399E-61	
t Critical one-tail	3.236795339	
P(T<=t) two-tail	1.9768E-60	
t Critical two-tail	3.466328795	

C. Energy Consumption Monitoring System

Fig. 7 shows the homepage of the energy consumption monitoring system website. The website is accessible through the link, enermon.tech. The homepage features the log-in page to the energy consumption monitoring system.

Fig. 7. Homepage of enermon.tech

The consumption monitor that can be accessed by the consumer through their user account is shown in Fig. 8. Their energy consumption can be viewed in graphical and tabular form. The graph can be modified depending on the user's preference. Watt-hour consumption can be viewed on a daily, weekly, monthly or date range basis. The user also has the option to display the watt-hour consumption as a bar graph or line graph. The tabular form displays the date and time the measurement was taken, the kilo-watthour consumption for the day, and theft status.

Fig. 8. Consumption monitor page of the enermon.tech user Interface

Fig. 9. Theft notifications page of the enermon.tech user interface

Fig. 10. Assembled LoRaWAN and gateway set-up

On Fig. 9, theft notifications page of the user account is shown. The user is notified of recent theft activity that occurs in their corresponding electric meter. The number of theft incidents and the type of theft is indicated in this page.

D. Network Analysis

Shown in Fig. 10 is the interior of the assembled LoRaWAN gateway and the actual location set-up of the antenna. For increased coverage, a longer, high-gain 868-MHz antenna was used. The gateway was connected to the internet through a LAN connection. Height and location of the LoRaWAN gateway were critical factors to be considered. The LoRaWAN gateway was placed on the fifth story of a building inside the school premises.

The network capture filter was further set to log the conversation between the electric meter and the LoRaWAN gateway. The IP address of the electric meter was '13.95.217.18,' served as the source. The IP address of the gateway was '192.168.254.101' and served as the destination. The round trip time graph was extracted from the filters.

The network was simulated to capture events of electric theft. The average delay in milliseconds was obtained by getting the average roundtrip time for the 20 trials and recorded in Table V. The total average round trip time of the network was 33.092 milliseconds.

TABLE V. ROUND-TRIP TIME OF EACH TRIAL

Trial	Average RTT (ms)	Trial	Average RTT (ms)
1	31.59	11	4.10
2	28.56	12	28.39
3	28.35	13	28.93
4	28.19	14	20.25
5	40.23	15	29.85
6	29.57	16	28.23
7	28.60	17	28.37
8	71.59	18	28.67
9	65.87	19	28.73
10	55.49	20	28.23

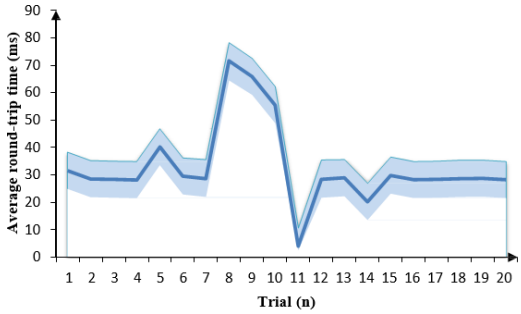

Fig. 11. Average round-trip time graph of the LoRaWAN network

TABLE VI. DISTANCES, DEVICE ADDRESSES, AND DEVICE IDS OF LORAWAN GATEWAY AND END-DEVICES

Distance (m)	Device Address	Device ID
Origin	eui-b827ebfffe47dacd	LoRaWAN - GW
69	260119C6	mcbloyola
422	260119A5	jbueno
601	26011696	rdeleon

With a mean of 0.033092, standard deviation of 0.015175 and n equal to 20, the confidence interval calculated was 0.006652928. Shown in Fig. 11 is the graph of the average round trip time for the 20 trials. The upper and lower limit of the average round trip time was equal to the confidence interval. This shows that the round trip time of the network is stable, because of its low confidence interval with respect to the mean.

Table VI shows the locations of the LoRaWAN gateway and end-devices with their respective devices addresses and device IDs. The network simulation was ran and the gateway traffic and application data stream received on The Things Network were captured.

The gateway traffic received when the three nodes were transmitting data is shown in Fig. 12. The gateway identifies the time, frequency, device address, and payload size of the transmission. The device addresses of the end-devices listed on Table VI are shown to be received by the gateway.

The time, device ID, payload, and decoded payload of the received application data are shown in Fig. 13. The device IDs of the end-devices listed on Table VI are shown to be received in The Things Network application data stream. This showed that the tree network topology was established between the LoRaWAN gateway and three end-devices. Data from the application stream is integrated into the energy consumption monitor website.

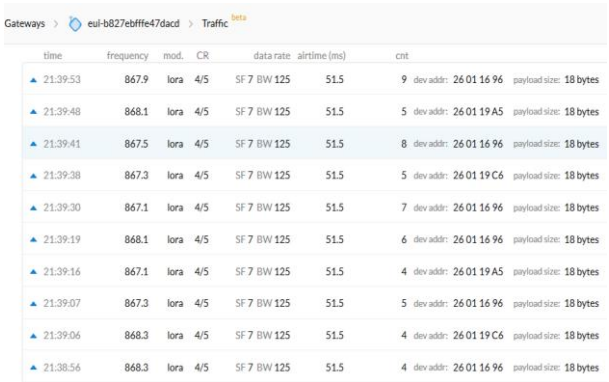

Fig. 12. Gateway traffic via the things network

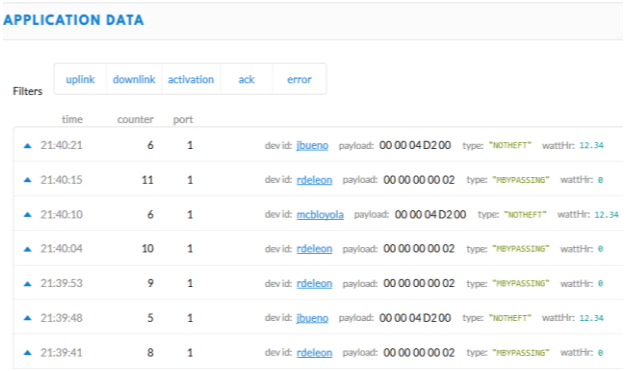

Fig. 13. Application data stream via the things network

V. CONCLUSIONS AND FUTURE WORK

A practical solution to the high cost of electricity in the Philippines has been long overdue. This paper addressed the costs due to non-technical system losses in support of the Recoverable System Loss Act. The objective of the project was to help the distribution utility and consumers in minimizing the incidences of electric pilferage.

The electric meter was 100% successful in detecting two types of electric pilferage: illegal tapping and meter bypassing; and immediately notifying both the consumer and distribution utility of the theft occurrence. The electric meter displays the kilowatt-hour consumption, system voltage, and type of theft detected. Using two-tailed independent t-test, the kilowatt-hour measurement of the electric meter was ensured to be 99.9% accurate.

Wireless transmission of meter data and theft notifications were successfully accomplished through the utilization of LoRaWAN. The LoRaWAN gateway was able to receive packets as far as 601 m line of sight with an average round trip time of 33.09 milliseconds. This showed that theft notifications were received by the distribution utility and consumer relatively fast. The tree network was successfully implemented for three end-devices and a LoRaWAN gateway.

The energy consumption monitor allows the consumer to view their daily, weekly, and monthly energy consumption, as well as a summary of their electric bill and theft notifications. This system also reduces the incidents of inaccurate meter readings due to human error. If adapted nationwide, the system may contribute to the decrease of the cost of electricity and reduction of damages due to electricity pilferage.

The threshold set for illegal tapping can be further examined to become proportional to the load consumed by the household. The impact of the 9% threshold varies per household, therefore setting a threshold proportional to the load consumed by the household will be more appropriate.

ACKNOWLEDGMENT

This work had been supported by Mapúa Institute of Technology at Laguna, Malayan Colleges Laguna, City of Cabuyao, Laguna, Philippines.

REFERENCES

[1] R. Czechowski and A. M. Kosek, "The most frequent energy theft techniques and hazards in present power energy consumption," presented at 2016 Joint Workshop on Cyber-Physical Security and Resilience in Smart Grids, 2016.

[2] L. G. Arango, E. Deccache, B. D. Bonatto, H. Arango, P. F. Ribeiro, and P. M. Silveira, "Impact of electricity theft on power quality," in *Proc. 17th Int. Conf. on Harmonics and Quality of Power*, Brazil, 2016, pp. 557-562.

[3] A. A. Chauhan, "Non-technical losses in power system and monitoring of electricity theft over low-tension poles," in *Proc. Second Int. Conf. on Advances in Computing and Communication Engineering*, India, 2015, pp. 280-284.

[4] S. Anusha, M. Madhavi, and R. Hemalatha, "Detection of power theft using GSM," *Int. Journal of Advanced Research Trends in Engineering and Technology*, vol. 1, no. 3, pp. 15-17, 2014.

[5] M. C. B. Loyola, J. J. Apurado, and R. B. Casareno, "Electricity theft detection and notification system using microcontroller, ZigBee and GSM technologies," presented at the 2018 14th Int. Conf. on Computer, Communication and Control Technology, Krabi, Thailand, March 20-22, 2018.

[6] V. Khare, S. Garg, S. Shukla, and P. Sharma, "Comparative study of 1G, 2G, 3G and 4G," *Journal of Engineering, Computers & Applied Sciences*, vol. 2, no. 4, pp. 55-63, April 2013.

[7] M. Tariq and H. V. Poor, "Real time electricity theft detection in microgrids through wireless sensor networks," in *Proc. IEEE SENSORS*, Orlando, FL, 2017.

[8] M. Burunkaya and T. Pars, "A smart meter design and implementation using ZigBee based wireless sensor network in smart grid," in *Proc. 4th Int. Conf. on Electrical and Electronic Engineering*, Turkey, 2017, pp. 158-162.

[9] J. Patil and A. Kulkarni, "Wireless sensor network using flood monitoring," *Int. Journal of Computer Science and Mobile Computing*, vol. 2, no. 3, pp. 297-302, November 2013.

[10] A. J. Wixted, P. Kinnaird, H. Larijani, A. Tait, A. Ahmadinia, and N. Strachan, "Evaluation of LoRa and LoRaWAN for wireless sensor networks," in *Proc. IEEE SENSORS*, Orlando, FL, 2017.

[11] F. Adelantado, X. Vilajosana, P. Tuset-Peiro, B. Martinez, J. Melia-Segui, and T. Watteyne, "Understanding the limits of LoRaWAN," *IEEE Communications Magazine*, vol. 55, no. 9, pp. 34-40, September 2017.

[12] M. S. Islam and M. S. R. Bhuiyan, "Design and implementation of remotely located energy meter monitoring with load control and mobile billing system through GSM," in *Proc. Int. Conf. on Electrical, Computer and Communication Engineering*, Bangladesh, 2017, pp. 158-163.

[13] S. Z. Sanchez, R. M. Fernandez-Canti, J. A. Lazara, I. O. Gomez, and J. A. A. Navarro, "Monitoring and remote control of energy consumption by WiFi networks," in *Proc. IEEE 11th Int. Multi-Conf. on Systems, Signals & Devices*, 2014, pp. 1-5.

[14] S. Y. Son, "Home electricity consumption monitoring enhancement using smart device status information," *Int. Journal of Smart Home*, vol. 9, no. 10, pp. 189-196, 2015.

Maria Criselda B. Loyola received her bachelor's degree in electrical engineering from University of Perpetual Help System Laguna in 2005 and master's degree in the same field from Adamson University, Manila City in 2009. She is currently serving Malayan Colleges Laguna in Cabuyao City, Philippines as the Chair of the Electrical Engineering program. She started her academic career in 2006 as she became part of the faculty of Adamson University and Mapua University before joining Malayan Colleges Laguna in 2010.

Her team's work on the performance of super capacitor as energy storage and power source was accepted as conference paper in Progress in Electronics Engineering, Computer Engineering and Information Technology and was published just recently (2018) in Journal of Telecommunication, Electronic and Computer Engineering. In addition, her work on electricity theft detection, together with another team, was accepted for presentation in International Conference on Computer, Communication and Control Technology last March 2018 and is waiting to be published in the same journal. At present, she is working on another study on energy management system and electricity theft.

Asst. Prof. Loyola is an active member of the Institute of Integrated Electrical Engineers of the Philippines.

Jhamel B. Bueno was born on September 19, 1996. He obtained his Bachelor of Science in Electrical Engineering degree from Malayan Colleges Laguna, Cabuyao City, Philippines in April 2018. In his final study year, he represented the institution in a regional Mathematics quiz bee and his team ranked second, making them qualified for the national level. He used to be a student leader serving the supreme student council of the Mapua Institute of Technology at Laguna for two academic years. He finished his secondary education at Tabaco National High School, Albay under the Engineering and Science Education Program.

Roshmeir D. De Leon was born on November 10, 1995. She attended secondary school in South Mansfield College in Muntinlupa City, Philippines. She graduated with the awards of 1st Honorable Mention, Best in Thesis and Thesis Defense. She first attended De La Salle University-Manila as an Electronics Engineering student in 2012 before transferring to Malayan Colleges Laguna in 2015 under the Electrical Engineering program. She became the president of the Institute of Integrated Electrical Engineers - Malayan Colleges Laguna Student Chapter (IIEE - MCL SC) for the school year 2017-2018. She is also a writer for Malayan Colleges Laguna's official student publication, Kamalayan.