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Design and evaluation of an IoT-based energy meter/power limiter to improve the management of low-voltage electrical subscribers - a case study of SNEL Likasi - DRC

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Abstract: **Subscriber management in a low voltage distribution network is nowadays becoming a complex task which requires accurate data collection as well as rapid and pragmatic actions. The use of traditional methods putting human and all his imperfections at the center for billing, control and other interventions has therefore become obsolete, making this way of working an ineffective method. A modern way to solve this problem and improve subscriber management is to replace human with modern technological means facilitating easy and transparent communication between subscribers and the company and vice versa. This is why we propose in this paper an IoT-based energy meter for efficient data collection and easy (remote) management of subscribers. The proposed system uses a microcontroller, sensors, an OLED display, a relay module, a GSM module and web technologies including HTML, CSS, JavaScript, MySQL and PHP to produce two artifacts, a smart meter and a web application. The evaluation of the results showed that the system is able to help to improving the management of SNEL low voltage subscribers.**

Keywords: **electrical energy, energy meter, electrical grid, low-voltage subscriber, IoT, SNEL, web app, power limiter.**

I. INTRODUCTION

Energy metering is an important task in the management of electrical subscribers in the energy distribution. It requires care, accuracy and transparency in handling data. It mainly allows the energy provider to produce electricity bills and charge subscribers based on their energy consumption on a regular basis. It is usually based on an energy meter often placed in the house of customers so that both the subscriber and the energy provider can access information of energy consumption. Since the advent of the integration of the internet of things (IoT) in energy metering, this operation has positively changed the way of managing electrical energy and subscribers in an electrical grid [1]. This novel technology allows devices to communicate and exchange data between them via internet. It has the capability to solve many problems in different areas and improve the efficiency, accuracy and economic benefit of a system [2]. Similarly, the successful integration of IoT in the energy metering system can lead to energy wastage reduction, meter reading facilitation and remote control, more accuracy in meter reading, fault detection, less operation cost and the removal of possible corruption related to meter reading [3], [4].

Despite all the opportunities that offers the integration of the IoT in the energy metering nowadays, the National Company of Electricity (SNEL) of the Democratic Republic of Congo (DRC) has not yet implemented this technology in the management of electricity customers. Actually, the company uses two different methods of energy metering supported by electromagnetic and electronic type of energy meter, which offer no possibility of be-directional communication between the company and the energy meter installed in the houses of customers in order to read and control energy meter remotely from a single control room. Thus, the company still produces electricity bills based on meter reading performed by operators who go house to house to read the energy meter for customers who have energy meter. The same principle is also applied for the bills distribution and the payment control. In addition to this, some customers do not have energy meter for billing electricity, so they are billed for energy consumption on an inaccurate basis. Such practices can be prone to mismanagement of electricity subscribers, which can lead to corruption, energy waste and theft, high management costs and huge loss of money, time consuming, errors, etc. We therefore introduced this study to assess to what extent an energy meter/ power limiter based on IoT could help the national company SNEL to improve the management of its energy and electricity subscribers since this question has not yet been addressed.

The purpose of this study is to analyze current problems in the management of electrical subscribers and propose a system made up with a smart energy meter and a web application in order to solve these problems and help the company improve the management of its customers. To fulfill this, specific objectives of the study are: (1) primary investigation through observation, questionnaire, and interview on the subscriber management system to highlight current problems, and define our system requirements according to that; (2) Design and develop an energy meter and a web application (IoT-based energy meter) using the Arduino platform and web technology including HTML, CSS, JavaScript, PHP and MySQL; (3) evaluate the system through different use criteria to determine how well it fulfill the requirement and how useful it can be in the management of electrical subscribers of the SNEL.

II. LITERATURE SURVEY

According to [5], the smart energy meter has advantages over traditional energy meters by integrating features such as load-side management, data recording and alarms, accuracy and two-way communication with facilities.

On the other hand, research [6] addresses two questions regarding smart energy metering: (1) «What factors influence the acceptance and use of smart meters in organizations? »; (2) «What are the benefits of smart meter technology for organizations? » The results of this research show that there are no conclusive studies on the issue of acceptance, however, the use of smart meters in some countries such as Germany is mandatory for a given category of consumers. However, due to the need for accurate information and value-added services, organizations are still seeking a compromise between legally binding support on a national scale and technical support to solve the problem of information gap in electrical grid that do not have a smart energy meter.

In addition, [2], [3] and [4] proposed in their research an IoT-based energy meter composed of elements of the Arduino platform (Esp8266, Arduino uno, Arduino mega, GSM module, etc.) and a web application for remote interaction with the energy meter. The main purpose of their research is to continuously inform energy consumers about their energy consumption and bill amount via an online web page and SMS alerts.

Furthermore, [8] attempts to ensure power quality and consumer management through IoT-based smart meters. This research found that IoT-based energy meter can help solve the problem of voltage drops that can damage household appliances and equipment by monitoring demand and managing customer load in real time.

All the papers reviewed above are conclusive in one or two research questions they address, among others data recording, remote communication between consumers and their energy meter, advantage of smart energy meter based on IoT, load management and consumer monitoring in a distribution grid, etc. However, they do not address the question of subscriber management and the issue of distribution grid stakeholders. Therefore, our paper tries to solve all these problems by proposing an IoT based energy meter capable of remotely managing subscribers (connection, isolation), ensuring accurate billing and requiring the subscriber to respect the subscribed power by defining a power ceiling not to be exceeded.

III. METHODS /APPROACH

This research was a development type research. For this, our research approach was based on the design science research cycles, which are relevance cycle, design cycle and rigor cycle as shown in **Error! Reference source not found.** [9]. The relevance cycle in our research consisted of data collection and problem highlight in the current management of electrical subscribers of the SNEL through questionnaire and interview in order to define our system requirements. The design cycle consisted of designing our proposed system (IoT-based energy meter) and evaluated it based on the data collected in the relevance cycle. As for the rigor cycle, it consisted of using a base of existing knowledge to the research project to ensure its innovation by discussing different solution through a critical literature review.

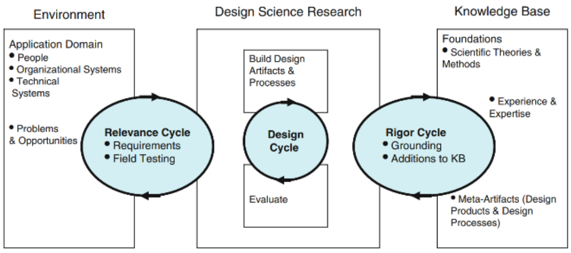

Figure 1: Design science research cycles

3.1 Data collection

For the data collection, we conducted a primary investigation from both sides, the subscriber side and the company side. On the subscriber side, we have conducted the investigation to be aware of what subscribers face as problems in the current management through the technic of questionnaire, which has benefited of 200 random participants from the LIKASI town. We used for this Google Form as tool to create the questionnaire paper and we shared it via social media in order reach people from different places. On the company side, we used the data we collected from subscriber to formulate relevant questions with which we conducted the interview with a company agent. The relevance of the question in the interview was determined by an average calculation of the frequency with which a problem was reported in the questionnaire survey. After collecting the data, we used a statistical approach to analyze it and draw down the system requirement.

3.2 System design

To meet properly the problem that encounter the SNEL in the management of its subscriber in the town of Likasi DRC, we propose here a system based on two main components which are: (1) a connected energy meter based on IoT (myMETER) capable of sending data to a remote server; (2) a web application based on WEB technology for interacting remotely with the energy meter. The connected energy meter should be installed at the customer’s side and the web application accessible from the company’s office.

3.2.1 myMETER design

The energy meter is the component responsible for controlling and measuring all the necessary parameters needed to determine the energy consumption of a subscriber. It is made up with voltage sensor, current sensor, relay module, display and microcontroller as illustrated Figure 2.

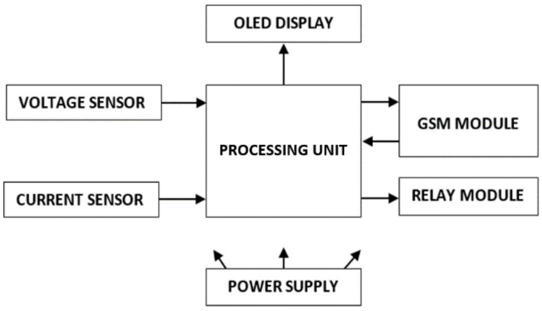

Figure 2: Energy meter circuit diagram

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a. Processing unit

We made use of the Arduino Uno board for the process unit of our system [10].

b. Voltage sensor

For measuring voltage, we made use of the ZMPT101B voltage sensor given in Figure 3. This voltage sensor measures AC voltages at the input in a range of 0 to 240V and gives at its output a voltage in the range of 0 to 5V DC image of the input voltage.

Figure 3: View of ZMPT101B AC voltage sensor

c. Current sensor

For current measuring we chose the ASC712 20A current sensor shown in the Figure 4 [12].

Figure 4: View of ASC712 current sensor

This sensor measures the intensity of the current by using the current-to-voltage conversion technique with a direct relationship between the measured current and the output signal. It can measure a current up to 20A with a maximum current consumption of 11 mA and a sensitivity of 100 mV/A.

d. GSM module

In order to enable our meter to communicate remotely with the rest of the system (server and web app) through internet, we made use of the SIM900A GSM/GPRS shield given in figure [13]. SIM900A shield is a GSM modem that uses mobile network service for making or receiving phone calls, sending or receiving SMS, connecting to internet through GPRS, TCP/IP, HTTP, and more.

e. Relay module

The relay module is responsible of establishing or cutting the current flowing in the circuit.

f. OLED display

The OLED display was used to display electrical parameter of the energy meter including input voltage, current and energy consumption. The Figure 5 gives a view of an OLED display.

Figure 5: View of Arduino OLED display

The operating algorithm of the energy meter is given in Figure 6.

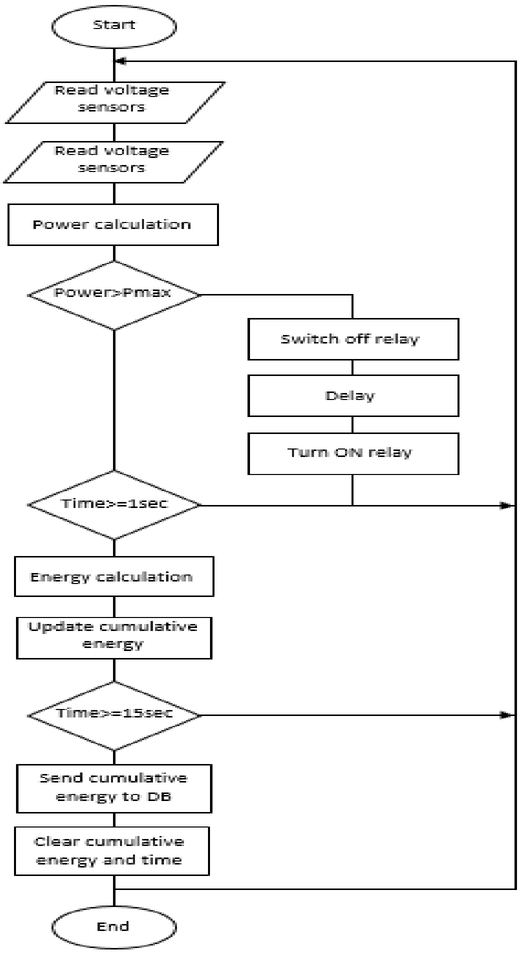

Figure 6: Operating algorithm of energy meter for sending information to the server

3.2.2 mySNEL app design

The web application is the component from which users can interact with the system. It offers a user interface mainly designed in HTML, CSS and JavaScript; and interacts with the database on the middleware using PHP and MySQL on the backend user. The user interface offers to the user of the app the ability to manage the entire system. The user can manage the energy meter in the system, the subscribers, monitor the status of the energy meter including remote activation and deactivation, etc. The user interface also allows the generation of the bills and the SMS broadcasting to subscriber, which can contain the amount of the bill and other information. The web app we designed has fivee main pages as described on Figure 7 below.

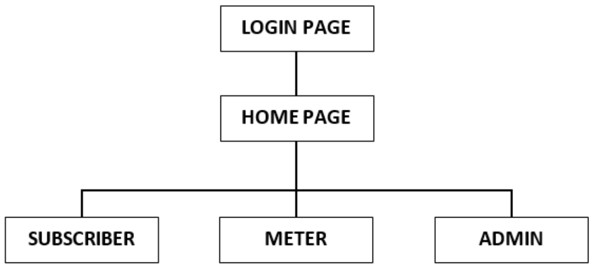

Figure 7: Web app pages map

3.2.3 Global system architecture

The global system architecture is given in Figure 8 below:

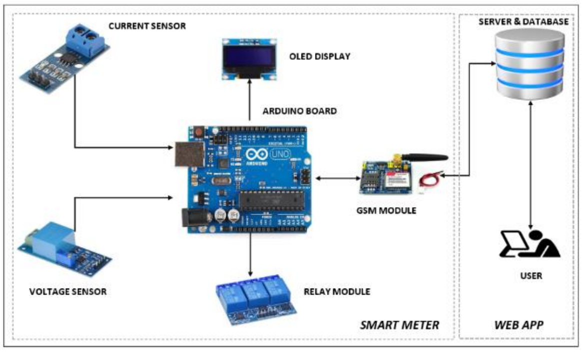

Figure 8: Global system architecture

IV. RESULTS & DISCUSSION

The realization of the connected meter based on IoT is given in Figure 9.

Figure 9: View of the connected meter

This meter measures the voltage (U) and the current (I) then calculates the electrical power (P) by the formula:

$P=U*I$ (1)

After calculating the electrical power, it calculates the electrical energy (ε) after a given time (t) by the formula:

$\varepsilon=P*t$ (2)

Then sends the result to the web application.

One of the pages of the web app is given in the Figure 10. The web app can allow the company to connect/isolate subscriber, create/edit and delete subscriber, managing meters as well as users.

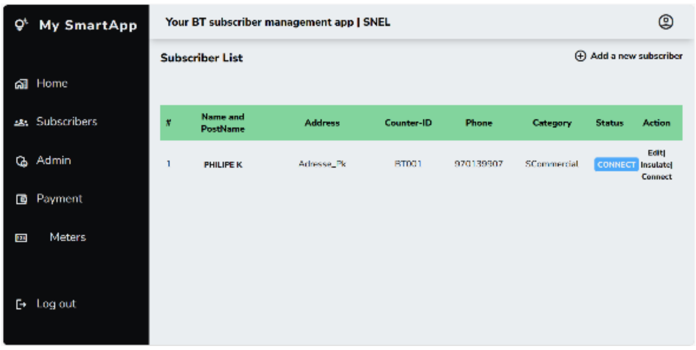

Figure 10: view of the subscriber management page of the Web App

The result from the questionnaire revealed two main activities that lead to the major problems faced by subscribers. These activities are: (1) flat rate energy billing; (2) bill payment control. For the energy billing, about 90% of subscribers have no energy meter as shown in Figure 11.

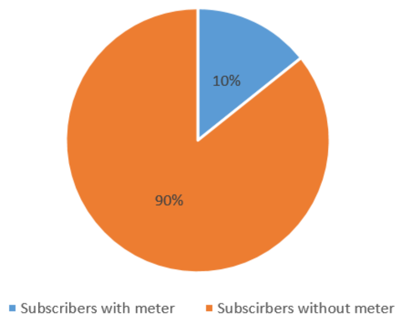

Figure 11: Statistics of subscribers with energy meters

They all are billed based on the rapport of the production department. This practice leads to poor management of subscriber billing. It considers that all subscribers of a given area consume the same energy quantity leading to the same amount of monthly bill although in reality their consumption are different; some consume more than others. Thereby, some subscribers pay a lower amount than they should while others pay more than their consumption.

As for the bill payment control, the Figure 12 shows that around 30% of subscribers surveyed face money extortion from the company agents even though they have already paid their bill. This is due to the lack of an easily accessible database of subscriber payment information.

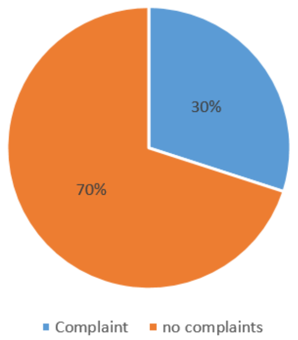

Figure 12: Statistics of complaints on money extortion during invoice checks

Money extortion usually occurs when the subscriber loses the already paid bill. However, some subscribers in this situation still manage not to give money thanks to the influence peddling they have.

From the company side, the interview conducted highlighted three main problems on different activities of the company: (1) difficulties in accessing home of subscribers for bill distribution, control and subscriber isolation in case of bill no-payment; (2) the respect of energy consumption regarding the power subscribed by the subscriber; (3) the SNEL has no means of ensuring that the agents sent to the field do their work properly (no reliable feedback). With this, an agent sent to the field to isolate subscribers not in good standing with bill payment for example can easily be corrupted and not isolate the subscriber.

V. CONCLUSION

In view of the complaints and observations made within SNEL company, it seems clear that this grid needs to improve its method of managing subscribers. This can be achieved thanks to the energy meter that we have proposed in this paper as it is capable of eliminating human intervention which is at the very heart of the problem of good management. However, the proposed system is limited by the fact that it must necessarily have at least one user (human) for management of the system. The latter can always be the subject of corruption or the author of extortion of money from subscribers. The improvement

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that our system brings apart from an adequate collection of data is the reduction of potential actors of mismanagement to a very small number (only the users of the application).

The future researcher can therefore think about solving the management problem at the user level of the proposed system and/or adding a customer area for monitoring consumption, remote payment, frequently asked questions and experience sharing to further improve management and service.

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