Design and Implementation of A Transformer Monitoring System for Batelec II

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ABSTRACT

The Batangas II Electric Cooperative, Inc. (BATELEC II) owns and operates about 6,997 distribution transformers, which are being maintained yearly per area by checking their operating voltage and current. During periodic maintenance, the utility company checks the transformers for any damage or a capacity upgrade based on the load growth in that particular area. The company finds it difficult to measure peak load in a particular area since it requires personnel to monitor and measure power during peak hours (7pm to 9pm): moreover, limited equipment such as the load logger, which costs millions of pesos is also a concern. With this, the utility company resorts to transformer oversizing to prevent such overloading. This study on the design and implementation of a transformer monitoring system for BATELEC II is a system that uses voltage and current sensor to measure transformer parameters and sends those data wirelessly using Zigbee communication. Furthermore, the system accurately measures the data and sends the data to the server in the form of a graphical user interface that monitors the voltage, current and power as well as the status, whether normal, under voltage, overvoltage, overload or outage. It has a database that records hourly data of the current of each transformer. The system costs around 10,000 pesos per unit and could further be lower on mass production.

KEYWORDS: Transformer, Monitoring System, My SQL Community Server, XBee Module, Arduino Microcontroller

1. INTRODUCTION

Transformers are vital components in an electrical system. Two types of transformers are utilized in the generation, transmission, and distribution of electrical power: the distribution transformer and the power transformer. Power transformers are used for the transmission of heavy load at voltages greater than 33kV and with 100% efficiency. It is also physically larger in size compared to distribution transformers. This type of transformer is used in generating stations and transmission substations. Distribution transformers, on the other hand, are used for the distribution of electrical energy at voltages of less than 33kV for industrial purposes, and 440-220V for domestic purposes, such as residential and commercial applications. Failure of transformers poses a big problem for the consumers, as they may not be able to perform their tasks effectively because of the absence of electricity.

The Batangas II Electric Cooperative, Inc. (BATELEC II) is one of the two (2) electric cooperatives that distribute electricity to Batangas Province with its principal office at Antipolo del Norte, Lipa City. BATELEC II owns and operates about 6,997 distribution transformers. Those transformers are maintained yearly per area by checking its operating voltage and current. During periodic maintenance, the utility company checks the transformers for maintenance and determines if a transformer needs a capacity upgrade based on the load growth in that particular area. [1] However, the company has experienced a number of issues and concerns relative to the maintenance of their transformers.

Figure 1 shows the common problems encountered by BATELEC II from 2009 to 2015. A total of 87% of the common problems encountered were found in outage, leakage and sparking of transformers.

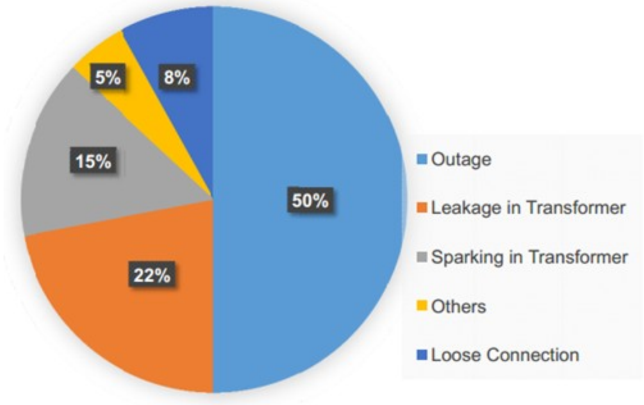

Figure 1. Common Problems Encountered by BATELEC II (2009 – 2015)

Notifying the utility company about the complaints regarding transformer failures is done either through phone calls or by going to their offices personally. Such action leads to longer downtime in identifying the cause of the failure and repairing the transformer. Typical response time includes the travel period and searching for the cause of the fault. The response time of the utility company in the problems encountered in transformer is around three to six hours.

Monitoring systems are used to prevent this situation. Checking of voltage and current measurements ensures that there is enough power given by each transformer to consumers. It also gives the utility company an early detection of possible faults due to overloading, under/over voltage or under/ over current, and can forecast a good depiction of load growth for future expansion. In addition, it helps the utility company improve its response time for repairs, and have a better schedule for preventive maintenance.

A study regarding a low cost distribution transformer monitoring system by Kolyanga et al. in Uganda provides a similar study that uses SMS feature to transfer the transformer data to the central station. [2] Other studies include the Advanced Distribution Transformer Monitoring System by Wornpuen et al. in Thailand, which uses the combination of radio frequency and GSM to send the data to the central unit. [3] Remote Condition Monitoring System for Distribution Transformer by Nelson et al. details the use of the internet to provide the health index of the transformer. [4]

Objectives of the Study

This study aimed to design and implement a transformer monitoring system which will measure the voltage, current, and power at the load side in a time-based function. Specifically it aimed to achieve the following: (i) develop a data acquisition device that will establish the important parameters of the transformer and the use Zigbee communication in transmitting data to the server for monitoring; (ii) develop the software application and database system (DBS) to store the information received from the data acquisition device; and (iii) test the system for functionality and reliability.

The prospered transformers monitoring system may lessen the burden of looking for the transformer to troubleshoot and forecast the possible maintenance, thus reducing the possible complaints of consumers as well.

2. MATERIALS AND METHODS

The design and implementation of the transformer monitoring system was divided in to two main parts mainly:

- Hardware system design and implementation
- Software system design and implementation

Hardware System Design and Implementation

Figure 2 shows the block diagram of the proposed hardware design. The hardware of the system is the data acquisition devices that collects the data coming from the transducers, converts it into useful information and sends it to the server and other data

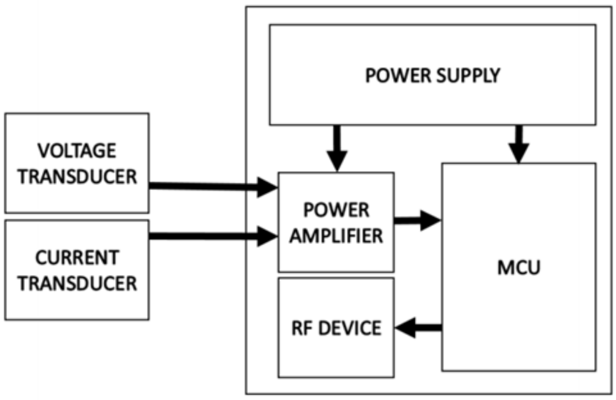

Figure 2. Block diagram of the hardware

The data acquisition hardware was built on a microcontroller system interfaced with an instrument transformer or transducers for measuring voltage and current. It is also connected to a long-range RF transmitter to send and receive data from other transformers.

System Architecture

Figure 3 shows the system architecture of the transformer monitoring system. The system is composed of three data acquisition devices and the server that monitors the activity of the three transformers.

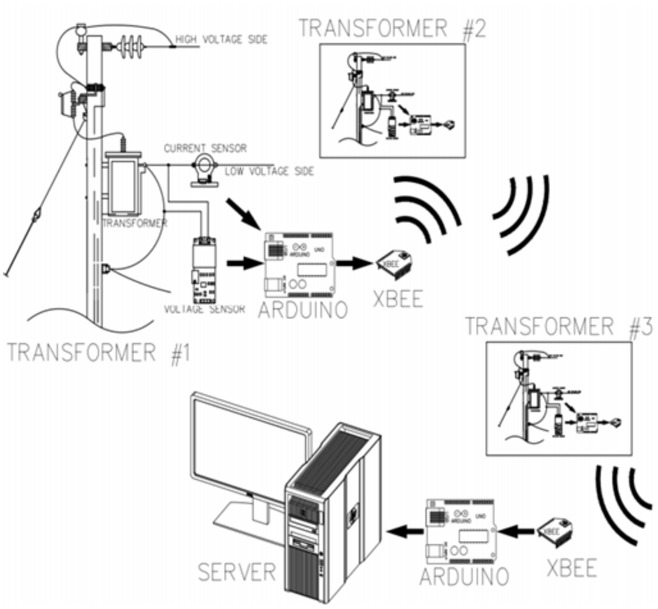

Figure 3. System Architecture

The data acquisition device, composed of sensors, transducers and microcontroller, will acquire data on voltage and current from the distribution transformer. Those data are transmitted using wireless signal such as Zigbee which is connected in line topology to have a continuous reliability of data that will be passed to the server. The interface displays the parameters such as voltage, current and power, and monitors the condition such as overvoltage, overcurrent and power outage.

Hardware Circuit Design

Figure 4 shows the schematic diagram of the hardware.

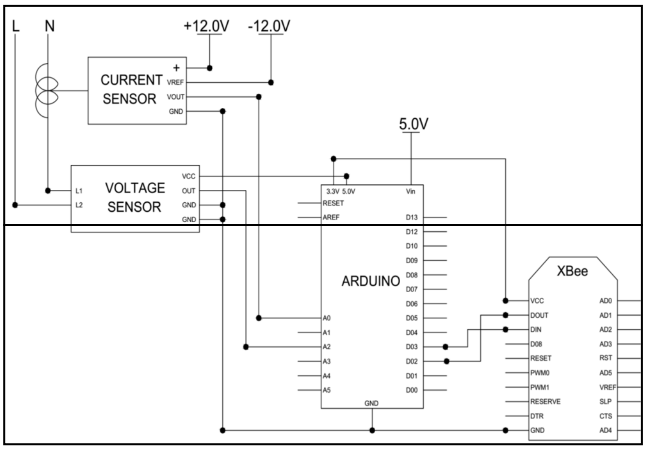

Figure 4. Schematic Diagram of the Hardware

The voltage sensor is connected to the mains of the transformer to measure the voltage. The current sensor is clamped at one of the lines of the transformer. The power supply used has multiple voltage ranges of 5 to 12 volts and used to power the Arduino. The voltage sensor is powered by the 5 V pin of the Arduino. The need for a +12V and -12V supply is for the operational amplifier of the current transformer. All outputs of the sensors are connected to the analog pins A0 and A2 of the Arduino. The Arduino microcontroller is responsible for acquiring the data from the sensors and for sending those data to other data acquisition devices through Zigbee communication. The XBee module is responsible for the Zigbee communication of the device. The supply for the XBee module comes from the 3.3V of the Arduino. The Tx (DOUT) and Rx (DIN) of the XBee are connected to pins 2, and 3, respectively. The use of software serial in the Arduino programming is essential since the serial transmission is done in pins 2 and 3. All of the devices have a common ground.

Hardware Components and Layout

- *Microcontroller*. Arduino was selected to acquire the voltage and current values from the sensors used the project. [5]
- *Voltage sensor*. ZMPTB101B [6] voltage transformer, was used to measure the voltage of the transformer. It uses the concept of a step down transformer to reduce the voltage to a desirable voltage that is acceptable to the Arduino microcontroller.
- *Current sensor*. YHDC HST21 current transformer [7] was selected to measure the current by using the concept of Rogowski coil where the pulsed current in a conductor develops a magnetic field

and the interaction of this magnetic field and the Rogowski coil local to the field gives rise to an induced voltage within the coil which is proportional to the rate of change of the current being measured. [8]

- *Zigbee*. Xbee S3 900HP module was used to provide long range up to 2 km line of sight. [9]
- *Power supply*. ATX power supply was selected to provide ranges of voltage from 5 – 12V DC.

Figure 5 shows the physical layout of the hardware. It is composed of the Arduino with Xbee module, ZMPTB101B voltage transformer, YHDC HST21 current transformer, and the power supply.

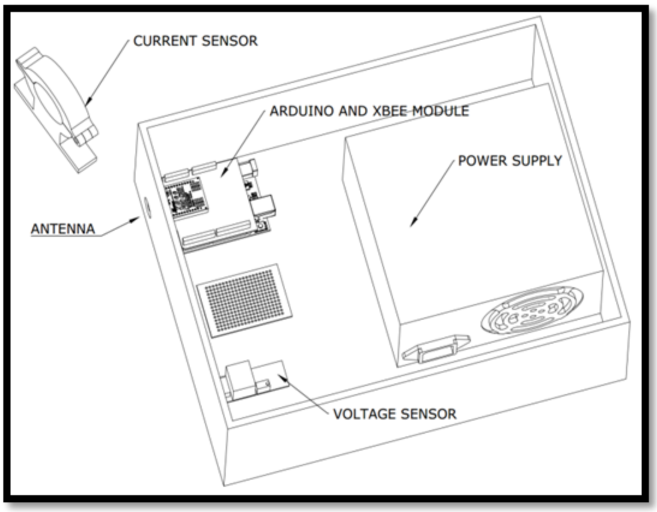

Figure 5. Physical Layout of the Hardware

The size of the enclosure is 235 mm x 300 mm x 115 mm. It houses the power supply of the Arduino and the voltage sensor. The current sensor is connected to one terminal of the transformer to measure the current. Extended cables are used to connect the voltage as well as the power of the whole system.

XBEE and Arduino Configuration

The XBee module must be configured to ensure the connectivity of each device going to the server. The configuration was done using the XCTU software by Digi. The configuration that needed to be changed in every Xbee was the baud rate of the transmission speed, the type of behavior of the module, whether it is an end device, router or coordinator, the destination address or the serial high of the module.

Figure 6 shows the block diagram of wireless configuration.

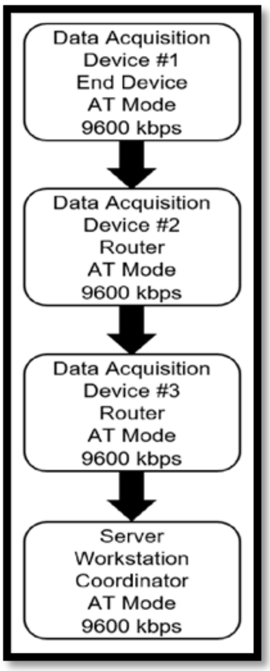

Figure 6. Xbee Configuration Block Diagram

The first device serves as the end device since it will only transmit data to other data acquisition devices. The router configuration serves as a bridge or repeater of receiving data as well as sending other transformer data down to the coordinator where the server work-station is located.

The Arduino microcontroller is programmed using the Arduino Integrated Development Environment (IDE). Each data acquisition device has its own program depending on the role of each device.

Figure 7 shows the general flowchart of the Arduino microcontroller.

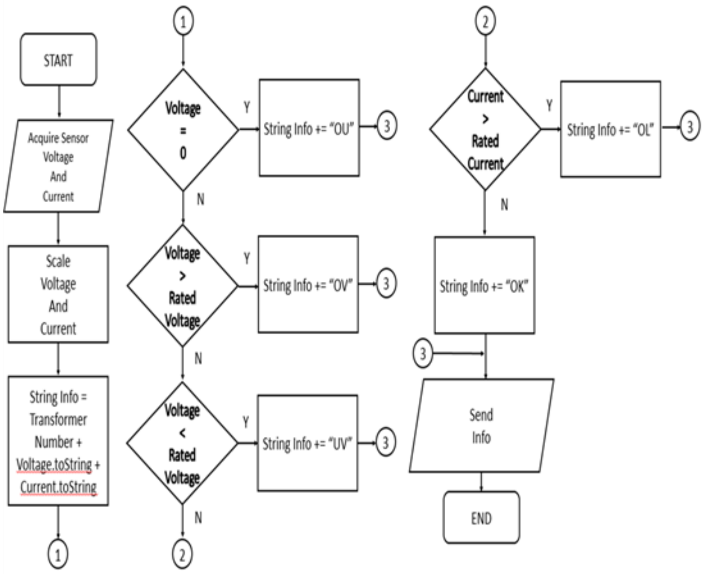

Figure 7. Arduino Program Flowchart

The Arduino acquires values coming from the analog input. It then scales it to its proper measurements and saves it to a variable. The transformer number, voltage and current will then be evaluated to check for the status of the transformer. The status will then be concatenated with the voltage and current parameters and will be sent to another data acquisition device.

Software Design and Implementation

The monitoring system has a user interface in which the transformer parameters are stored in the database. It was built on a graphical user interface to check and monitor the transformer data, load condition, and alarms. The monitoring system uses database to store historical data collected from the data acquisition device. The software has the following features:

a. *Data acquisition and processing*

Through serial communication, the system will gather real-time data of transformer parameter.

b. *Alarm Monitoring*

The software will indicate if an abnormality occurs such as overvoltage, overcurrent, or power outage.

c. *Data archiving*

It stores historical data for easy access.

The graphical user interface of the system was done using Microsoft Visual Basic.

Figure 8 shows the user interface of the transformer monitoring system.

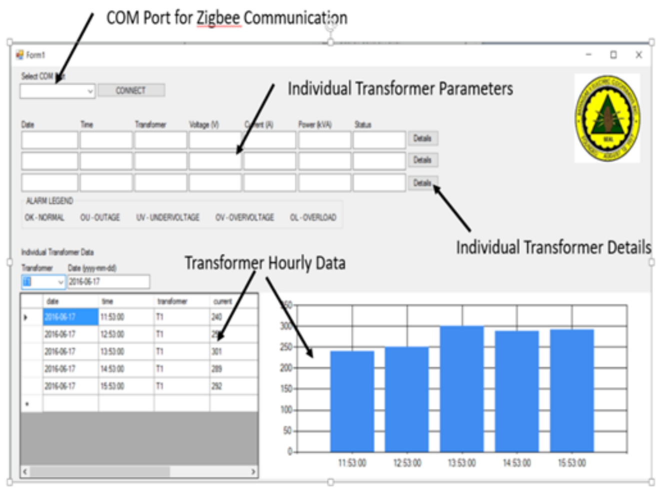

Figure 8. User Interface of the Transformer Monitoring System

The interface is composed of the COM port connection to the Arduino/ XBee module, the individual transformer parameters, details buttons for the detailed specification of each transformer, table for the hourly data of a transformer, and the graph of the hourly current of a single transformer.

Database Design

The database was developed using the MySQL community server linked to the application. The database structure was based on an entity relations model with the different entities linked by relationship. The entities include: (i) parameters entity for storing daily records of the transformer; (ii) information entity for storing the transformer's general information such as operating voltage, phase number, rating, and location; and (iii) daily report entities for recording the daily summary of transformer records.

Testing

The data acquisition device was deployed on the three transformers located within the vicinity of De La Salle Lipa.

Figure 9 shows the test setup of the monitoring device.

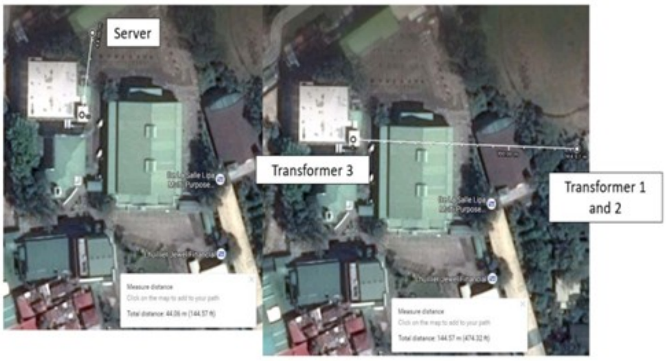

Figure 9. Test Setup

The developers tested the hardware from building obstruction to check the reliability of the connection of each data acquisition device. Since most of the transformers were located near the oval of the institution, the two data acquisition devices were installed there. The third hardware was installed at the transformer near the college library. The longest distance between the two devices was 144.57 m, and the distance between the last data acquisition device and the server was 44.06 m.

3. RESULTS AND DISCUSSION

To validate the measurements of the transformer monitoring system, the voltage and current measurement was checked using a clamp ammeter and digital multimeter.

Figure 10 shows the test setup for the digital multimeter and clamp ammeter.

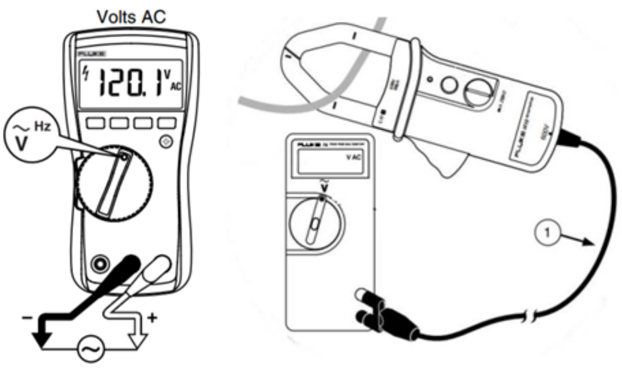

Figure 10. Instrument Setup, Voltmeter and Ammeter

The reading for each transformer was as follows.

Transformer 3: Current = 34.8 A, Voltage = 210 V
Transformer 2: Current = 19 A, Voltage = 225V
Transformer 1: Current = 15 A, Voltage = 224 V

Figure 11 shows the setup of the data acquisition device

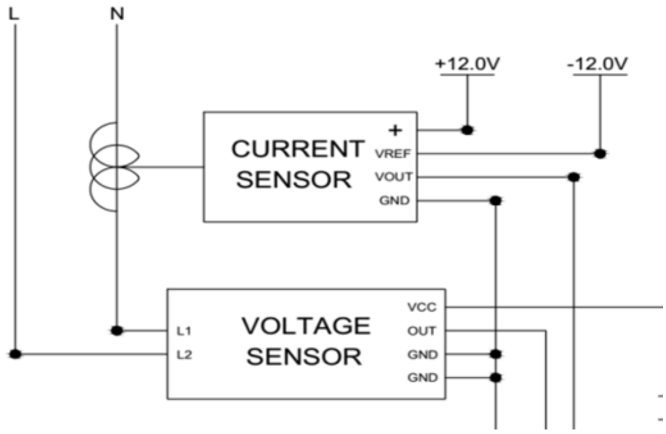

Figure 11. Data Acquisition Setup

The current and voltage sensor acquire the measurements at the transformer. The measurement are displayed at the serial monitor of the Arduino.

Figure 12 shows the serial monitor of all three devices.

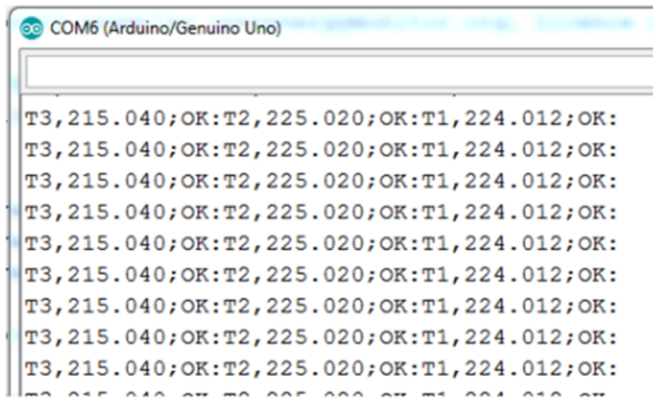

Figure 12. Serial Monitor of the Device

The connectivity was checked given and based on the serial monitor, all data acquisition devices were connected with their respective readings:

Transformer 1 had 224 V and 12 A; Transformer 2 had 225 V and 20 A and Transformer 3 had 215 V and 40 A.

Table 1 shows the comparison of measurements of the utility device and the data acquisition device.

Table 1. Measurement Comparison between utility device and Data acquisition device

	Utility Device	Data Acquisition Device	% error
Transformer 1 Voltage	224	224	0.0
Transformer 2 Voltage	225	225	0.0
Transformer 3 Voltage	210	215	2.4
Transformer 1 Current	12	15	25.0
Transformer 2 Current	20	19	-5.0
Transformer 3 Current	40	34.8	-13.0

The percent error for the data acquisition device, it showed that the data acquisition device gave an accurate reading compared to the utility device.

Figure 13 shows the actual running of the transformer monitoring application.

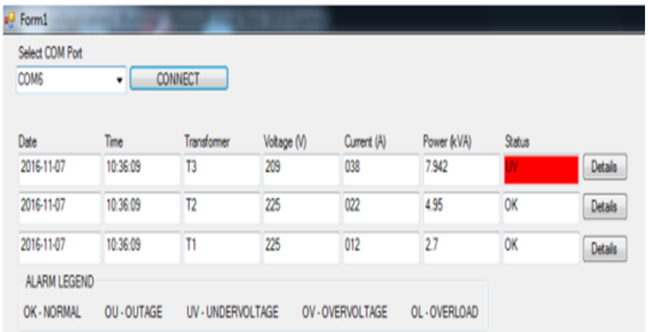

Figure 13. Transformer Load Monitoring Running

Running the application shows the update of each transformer and the status if it is normal, overvoltage, overload, under voltage or outage. It can be seen in Figure 13 that Transformer 3 had an undervoltage status since the voltage dropped below 210 V.

Figure 14 shows the hourly graph of the power consumption of the transformer.

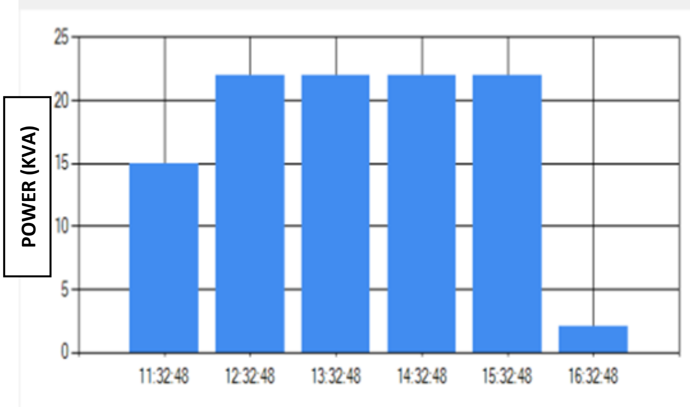

Figure 14. Hourly Data and Graph Monitoring

The system was run and tested for recording of data to the database. In five hours of continuous monitoring, the system gave the hourly current graph of each transformer.

4. CONCLUSIONS

Based on results the following conclusions are drawn: the hardware design meets the needed specifications to measure the parameters and send the data down to the server; the flowchart and codes for the project suit the application to gather the data and store these to the database; and the test is considered a success, since the discrepancies between the values obtained by the data acquisition device versus the voltmeter, and ammeter are minimal.

5. RECOMMENDATIONS

In order to improve the project study, the developers presents the following recommendations: data inside the device must be saved by installing a micro SD to ensure that there will be continuous data even during communication failure. A Global Positioning System may be provided for easy location of the transformer in case of repairs and maintenance. It is also advised to have a smaller form factor by having a smaller power supply to reduce the size and weight of the equipment.

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