Distribution Transformer Parameter's Monitoring System Using Internet of Things

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ABSTRACT--Transformer is an important and expensive device used by electricity industries for efficient distribution of power supply therefore adequate care needs to be taken to ensure distribution of uninterrupted power to consumers at all times in order to reduce the energy downtime of the transformer to the lowest minimal. When fault occurs in a distribution network, transformers are often patrolled in order to detect the particular transformer at fault and this contributes to increase in the energy downtime. With the current setup, it will be near impossible for the staff on duty to effectively monitor the entire transformer parameters since he cannot be physically present at all times. This proposed work aims at monitoring the parameters of distribution transformers by sending data at a given time interval stating the condition of the distribution transformer to ensure early detection of the faults in a transformer and prompt response to faults. The parameters monitored are voltage and current levels of the transformer using voltage sensor and current sensor respectively. These sensors were used to monitor the transformer's health so as to ensure quick detection of faults. The sensors output were fed to the microcontroller and processed. The microcontroller computes the connected load power from the sensed voltage and current. The retrieved data was processed which was further logged and displayed on the online platform which makes the system very efficient and the data accessible from any part of the world. The sensors were simulated and their model equations formulated. Their graph were also plotted which describe the dynamics of the system.

Keywords: Transformers monitoring, Current level, Voltage level, Transformer parameters, Data, Online platform, Model equations.

1. INTRODUCTION

Electricity is an important facet of national development and source of energy. It is required at every aspect of human life. Its requirement for basic developmental services includes provision of food, industrial activities; provision of pipe borne water, health care, conducive abode, telecommunications and quality education among others [1]. In our present world today, electricity is the most widely used and desirable form of energy. One important observable trend is that the increase in country's population results to the increase in electricity demand [2]. The starting point for a power system is to have sufficient supply to meet the present demand plus a spare or redundant capacity to ride through system shocks which are inevitable. This in simple terms means that generation capacity must at all time be greater than the estimated demand. This can only be achieved by having accurate and up-to-date data to carry out robust planning of the power system. In Nigeria power systems, distribution transformers are electrical equipments that distribute power to the low-voltage users directly. Their operational condition under rated condition, which guarantees their long life, is an important component of the entire distribution power system. There can be no significant development of infrastructure and economy without this as the energy consumption of a nation is directly proportional to its economic relevance in today's world. Overloading and ineffective cooling are the major causes of distribution transformers failure resulting in unexpected loss of supply to a large number of customers [3]. This eventually affects the systems reliability. Since it is very costly to repair or replace a single transformer, it also has its impact on the economy of the country. Therefore, a distribution transformer real-time monitoring system should be in place to monitor the operating parameters and report same to a monitoring centre in real-time. The parameters can provide useful information about the health of transformers which will help the utility to optimally use their transformers and keep the asset in operation for a longer period.

Electric power transformers are the link between the generators of a power system and the transmission lines and between lines of different voltage levels [4]. Electric power transformers are robust and efficient electric equipment that play a fundamental role in supplying electric energy at adequate voltage levels to consumers. Nevertheless, power transformers undergo changes in their reliability and operational lifetime over the years. This is mainly due to the heavy loading of the equipment, driven by the need to achieve increased profits and the related reluctance to invest in new facilities by the power companies in a competitive market environment [5]. In the prevailing circumstances in the world where economy is progressively unstable, monitoring system and innovative solutions are necessary to address the power supply problem [6].

2. Review of Related Works

Several kinds of system developments and works have been done around the area of distribution transformer parameters monitoring. Journal papers and textbooks of related works were reviewed and the discussion of the papers was carried out as follows:

[7] Theophilus, et al proposed a microcontroller-based room temperature monitoring system; which focused only on temperature monitoring of the distribution transformer. This has so many limitations because other parameters like voltage, current and oil level were not monitored.

[8] proposed the application of GSM technology to monitor faults and quick isolation in order to improve the efficiency and reliability of the power systems but was limited to Voltage and current profile observation, winding and oil temperature, vibrations and humidity monitoring.

[9] designed a system that which allows the values of the parameters to be sent to monitoring node through GPRS. If any emergency condition occurs, message will be sent to the corresponding engineer through GSM and similarly on webpage. But GPRS base system has drawbacks: Can have high latency especially in text messaging, Expensive to add terminal above four and transit delay of data, etc.

[10] designed a Microcontroller-based Electric Power Distribution Automation system which continuously monitors the transformer parameters such as load current, voltage, oil level and ambient temperature with the help of sensors. These values are displayed continuously on the LCD display and it is recorded in the system memory. If any abnormalities occurs in the transformer then an alert message with the parameter values are sent to the monitoring centre along with the location by means of GSM and GPS which are integrated with the Arduino board. The drawback of this system is that GSM based transformer monitoring system is not cost effective considering the number of transformer to be monitored.

[11] proposed the design and implementation of a mobile license system used to monitor the load currents, overvoltage, voltage oil and oil temperature. The on-line monitoring system integrates Global Service Mobile (GSM) Modem, with single chip. The drawback of this system is that GSM based transformer monitoring system is not cost effective considering the number of transformer to be monitored.

The proposed work, distribution transformer parameters monitoring system using internet of things will have many advantages over the previous works because it will monitor parameters like: oil and winding temperature, current and voltage profile of the transformer, Fault location, GPS location and the flexibility of accessing these monitored parameters remotely.

3. Methodology and System Design

Prototyping method was adopted for the design of this work. The model system is expected to monitor and retrieve parameters from a distribution transformer in order to detect transformer faults timely, prevent transformer breakdown and minimize trouble shooting by patrolling all the distribution transformers in a locality just to detect the faulty transformer. The online distribution transformer system to be developed is expected to possess features that will monitor the voltage and current level of the distribution transformer. A central controller would be used to coordinate the entire operation of the system and send these data to online through a dedicated wireless internet. The sensed data can be monitored from the online platform from any part of the world. The materials used were aurdino board, Wi-Fi Shield, PT100 temperature sensor, current sensor, ATMEGA328 microcontroller, amplifier, distribution transformer, Matlab etc. The block diagram of the entire system is shown in figure 1.

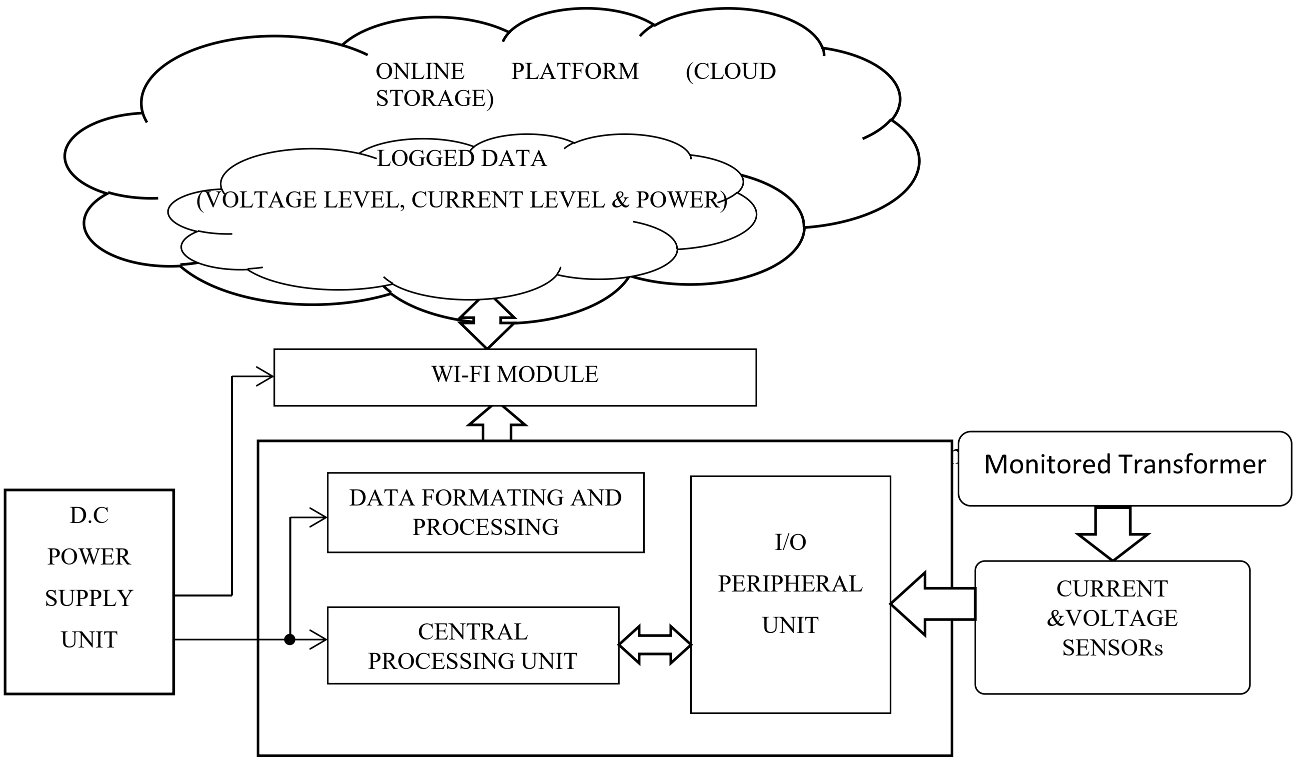

Figure 1: Block diagram of entire system

a. Transformer Voltage Sensing Unit

This unit measures the voltage across the transformer by using voltage transformation and rectification technique, the voltage from the distribution transformer is transformed from 220V to 12V using stepped down transformer as computed using equation (1):

$$\frac{V_2}{V_1} = \frac{n_2}{n_1} \qquad (1)$$

$$V_2 = \frac{V_1 \times n_2}{n_1}$$

Where:

$V_1 -$ $Primary\ winding\ of\ the\ distribution\ transform$

$V_2 -$ $Secondary\ winding\ of\ the\ distribution\ transfor$

$n_2 -$ $Number\ of\ turns\ for\ secondary\ winding\ of\ the$

$n_1 -$ $Number\ of\ turns\ for\ primary\ winding\ of\ the\ distribution\ tra$

$V_1 = 220V, V_2 = 12V$

$$Turn\ ratio = \frac{n_2}{n_1} \qquad (2)$$

$$\frac{n_2}{n_1} = \frac{V_2}{V_1} = \frac{12}{220} = 0.0545$$

The stepped down voltage is rectified using full wave bridge rectifier and filtered using electrolytic capacitor, the filtered signal is further stepped down using voltage divider theorem (VDT) in equation (3):

$$V_o = \frac{R_3}{R_2+R_3} \times V_i \qquad (3)$$

Where :

V_0 – Output voltage from the voltage divider circuit

V_i – input voltage to the voltage divider

R_2 – Resistance of the resistor at the voltage divider circuit

R_3 – resistance of the resistor at the voltage divider circuit

$V_i = V_2$

Substituting for Vi in equation (4):

$$V_o = \frac{R_3 \times n_2 \times V_1}{n_1 \times (R_2 + R_3)} \qquad (4)$$

$$Since, \frac{n_2}{n_1} = 0.0545$$

$$V_o = \frac{R_3 \times 0.0545 \times V_1}{(R_2 + R_3)} \qquad (5)$$

Distribution voltage for commercial use in Nigeria ranges from 260V ~ 450V. Therefore, simulation is carried out from 0V ~ 450V. The sensor is designed to read maximum of 450V which corresponds to 4.9V. The maximum input voltage to the microcontroller is 5.0V, the R_2 and R_3 is determined when V_1 (the input A.C voltage) is 450V and V_o (the input d.c voltage to the microcontroller) is 4.9V with a tolerance of ±0.1V.

For maximum voltage input, V_o = 4.9V @ V_1 = 450V, from equation (5)

$$\frac{V_o}{V_1} = \frac{R_3 \times 0.0545}{R_2 + R_3} = \frac{4.9}{450} = 0.0109$$

$$\frac{R_3}{R_2+R_3} = \frac{0.0109}{0.0545} = 0.2$$

$$R_3 = 0.2R_2 + 0.2R_3$$

$$R_2 = \frac{0.8}{0.2} R_3 = 4R_3$$

(6) From equation 6, If R_3 = 1KΩ, R_2 = 4KΩ as shown in the voltage divider Circuit of figure 2.

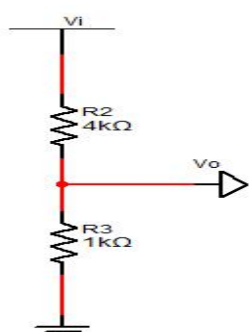

Figure 2: diagram of the voltage divider Circuit

$$V_o = \frac{R_3 \times 0.0545 \times V_1}{R_2 + R_3} = \frac{0.0545 \times V_1}{5} = 0.0109V_1 \qquad (7)$$

The digital value equivalent read out from the microcontroller is also computed using equation (8)

$$digital\ value = \frac{Input\ Voltage}{Reference\ Voltage} \times 1023 = \frac{V_o}{V_{ref}} \times 1023 \qquad (8)$$

$$digital\ value = \frac{V_o}{5} \times 1023 = V_o \times 204.6 \qquad (9)$$

Where,

V_o - Input voltage which varies from (0 ~ 4.9) V corresponding to input voltage that varies from (0 ~ 450) V

Vref - The reference voltage = 5V,

The analog to digital conversion (ADC) resolution is 10 bit, $2^{10} - 1 = 1023$.

From equation (8),

$$V_o = 0.0109 \times V_1$$

Substitute V_o in equation (9)

$$digital\ value = 2.2301 \times V_1 \qquad (10)$$

$$V_1 = \frac{digital\ value}{2.2301} = 0.4484 \times digital\ value$$

$$V_1 = 0.4484 \times digital\ value \qquad (11)$$

Equation (11), V_1 is the voltage for the distribution transformer which was programmed into the microcontroller for voltage sensing and it was also simulated using a prototype with digital value ranging from (0 ~ 1023). The circuit diagram for the voltage sensing unit is shown in figure 3.

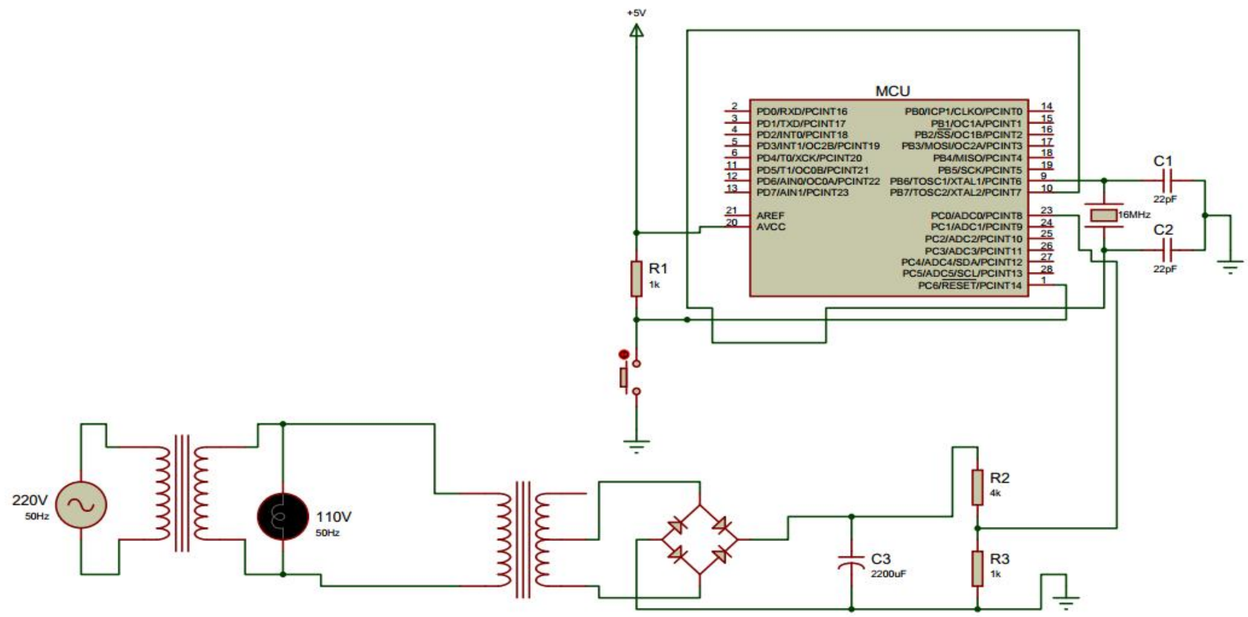

Figure 3: Circuit diagram for voltage sensing unit

b. Transformer Current Sensing Unit (ACS712)

This unit measures the current flowing through the distribution transformer and sends the equivalent current value to the analog input of the microcontroller. ACS712 sensor was chosen for sensing current because it provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems. The device package allows for easy implementation. The current sensor has two terminal input pins and three terminal output pins. The two terminal input pins are connected in series to the load on the distribution transformer. The output pins VCC and GND pins are connected to +5V and ground power supply respectively while the OUT is the analog output from the sensor which varies with respect to the load or current flowing through the distribution transformer. The OUT pin is connected to pin 24 of the microcontroller where the current value is computed based on the datasheet from the manufacturer the current – digital readout is as shown in equation (12):

$$I = (517.0 - d1) \times 0.0741. \qquad (12)$$

Where d_I– Digital Equivalent value for Current

I – Current value (A).

The maximum current rating for the current sensor is 30A from the datasheet. The maximum power rating for the distribution transformer that the developed system can operate on, based on the selected current sensor was also calculated using equation (13):

$$P_d,max = I_s,max \times V_d \qquad (13)$$

Where:

P_d,max – Maximum power rating for the distribution transformer (VA)

V_d – Voltage rating of the distribution transformer (V) = 220V

I_s,max – Maximum current rating for the current sensor (A) = 30A

Therefore;

$P_d,max = 30 \times 220 = 6600VA = 6.6KVA$

Also, the power load on the distribution transformer is shown in equation

$P_L = I_S \times V_d \times \cos \Theta$

Where,

P_L – Power rating for the connected load

$\cos \Theta$ – Power factor = 0.8

I_s – Current flowing through the current sensor

Furthermore, the maximum power load (P_L,max) that can be on the 6.6KVA distribution transformer is as stated in equation (14):

$$P_{L,max} = P_{d,max} \times \cos \Theta \quad (14)$$

$$P_{L,max} = 6.6 \times 30 \times \cos \Theta = 5.28KW$$

However, the current flowing through the load was simulated using the built prototype which also corresponds with its equivalent simulation result from MATLAB ranging from (0 ~ 30A) and the power consumed was calculated using equation $P_L = I_S \times V_d \times \cos \Theta$. The circuit diagram for the current sensing unit is shown in figure 4.

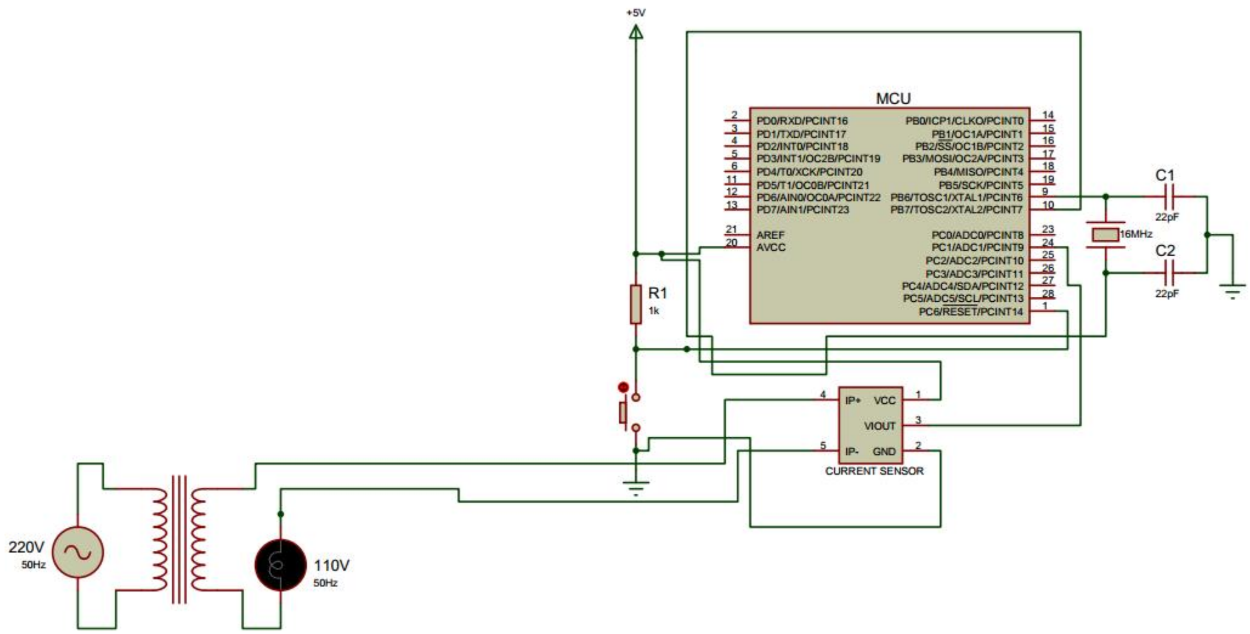

Figure 4: Circuit diagram for current sensing unit

4. System Evaluation and Results Analysis

The system was implemented and tested using the built prototype. The derived model equations from the sensing modules were also simulated using the built prototype and MATLAB respectively in order to validate the results. The graph was plotted to understand the dynamics of the sensors.

The voltage and current sensors were calibrated using standard equipment like Variac and Ammeter respectively to validate the sensed and processed value. Multimeter was also used to monitor the voltage across the transformer and also the current flowing through the transformer, the monitored voltage and current were compared with the voltage and current values displayed by the microcontroller. Table 1 shows the standard voltage levels and their output equivalent from the sensor.

Table 1: Standard voltage levels and their output equivalent from the sensor

S/No	Input Voltage (V)	Output Voltage (V)	Digital Equivalent
1	180	1.962	401.4
2	200	2.18	446
3	220	2.398	490.6
4	240	2.616	535.2
5	260	2.834	579.8

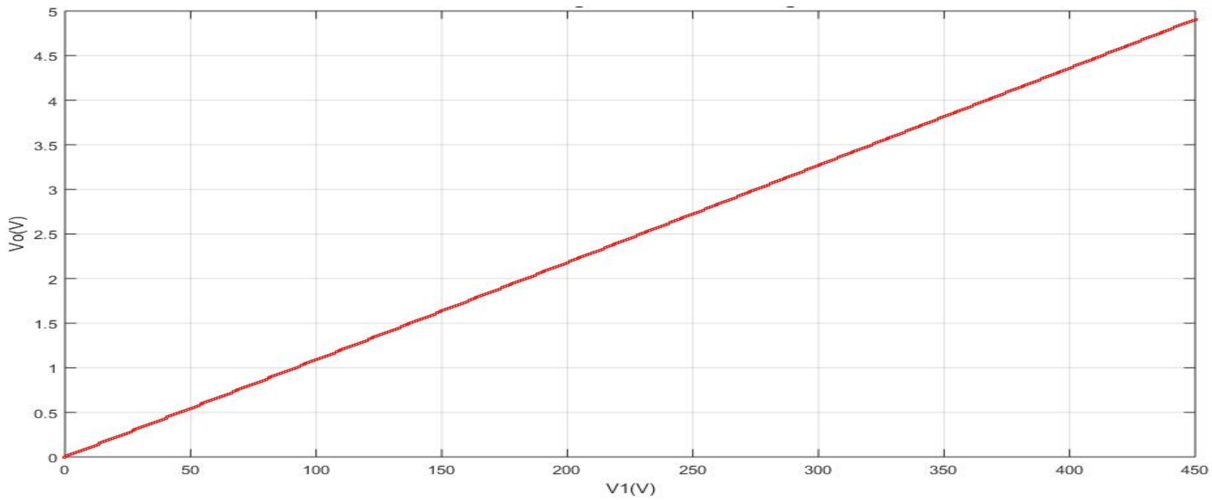

Figure 5: Curve of output voltage against the input voltage

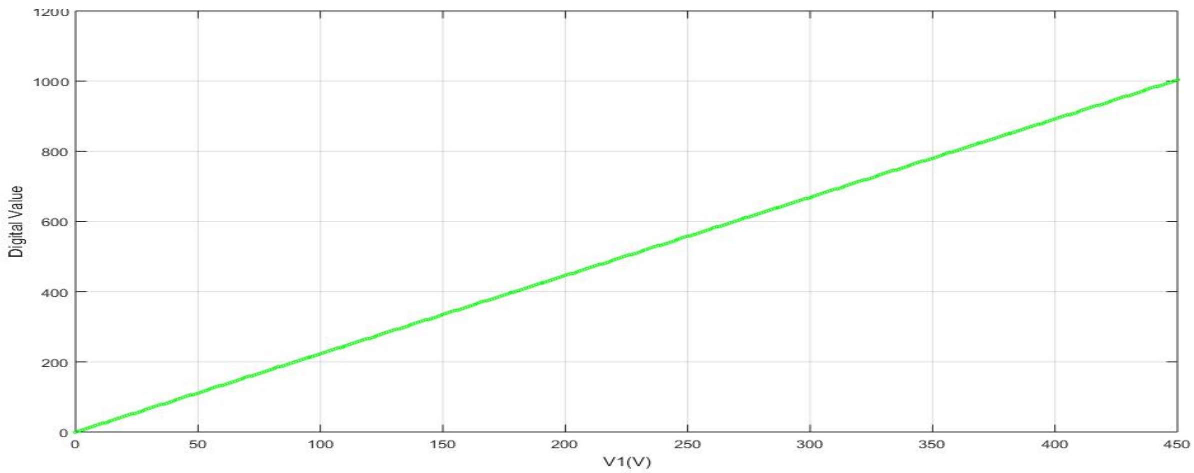

Figure 6: Curve of digital equivalent against the input voltage

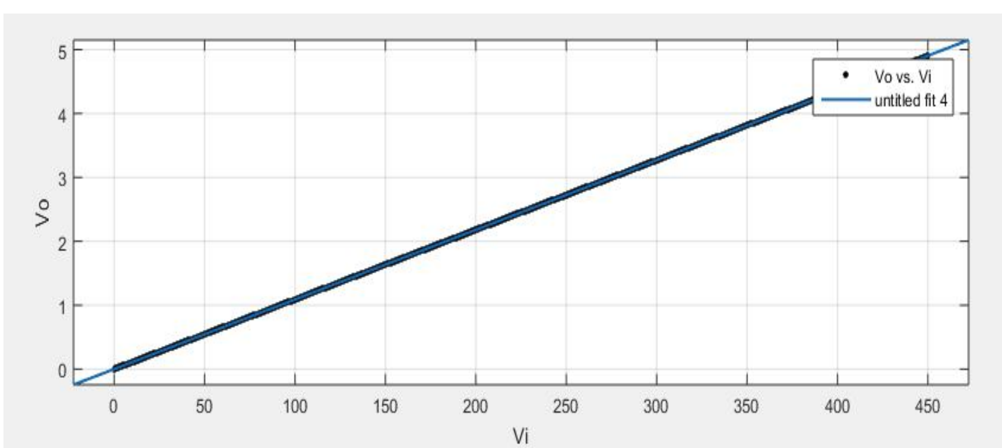

Figure 7: Curve fitting for the output voltage against input voltage

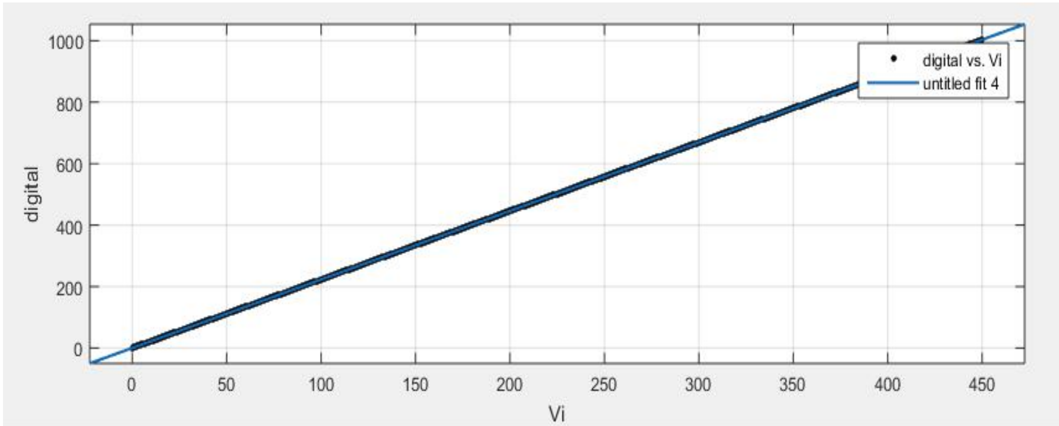

Figure 8: Curve fitting for the digital value against input voltage

Figures 5 to 8 derived from table 1 shows a plot of voltage against the input voltage and the digital equivalent against the input voltage respectively, it can be seen that the curves are linear showing that the system responds positively to the input as desired. Table 2 shows the current levels, power value and their digital equivalent from the current sensor.

Table 2: Current levels and their output equivalent from the sensor

S/No	Current Value (A)	Power Value (W)	Digital Equivalent
1	0	0	517
2	5.039	886.8	449
3	10	1761	382
4	15.04	2647	314
5	20.07	3521	247

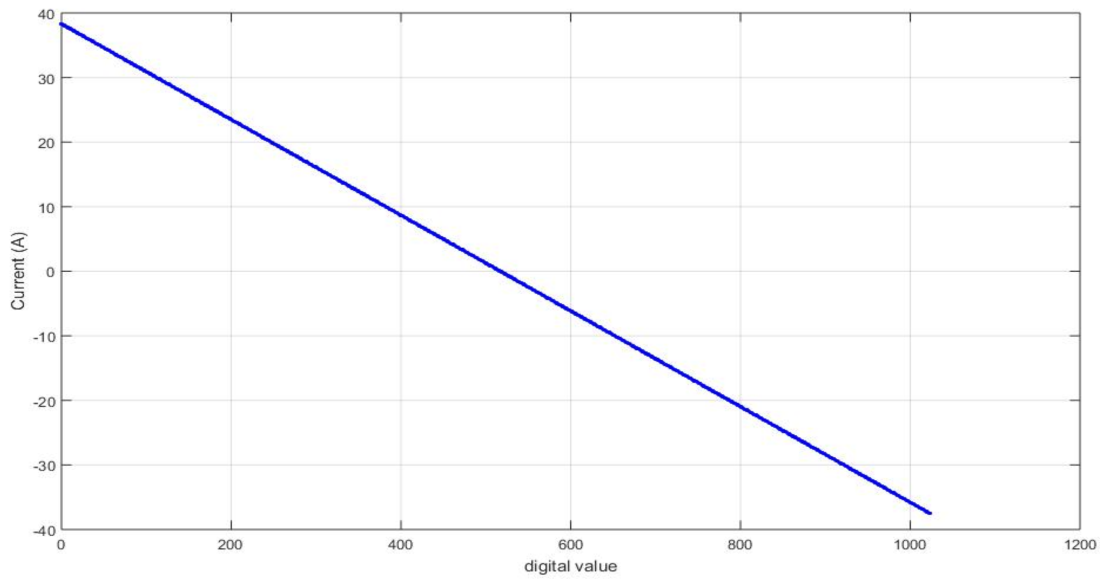

Figure 9: Curve of the current level against the digital value

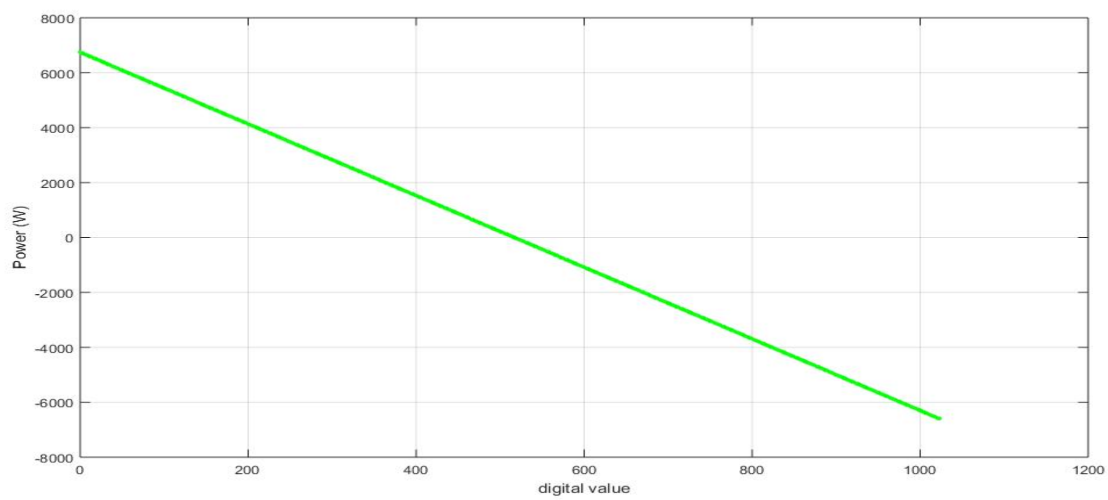

Figure 10: Curve of the power level against the digital value

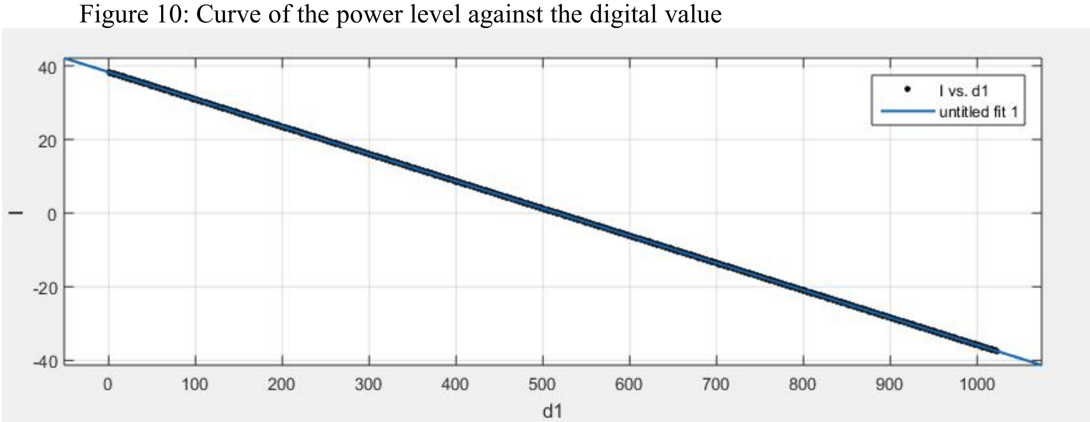

Figure 11: Curve fitting for the current sensor model

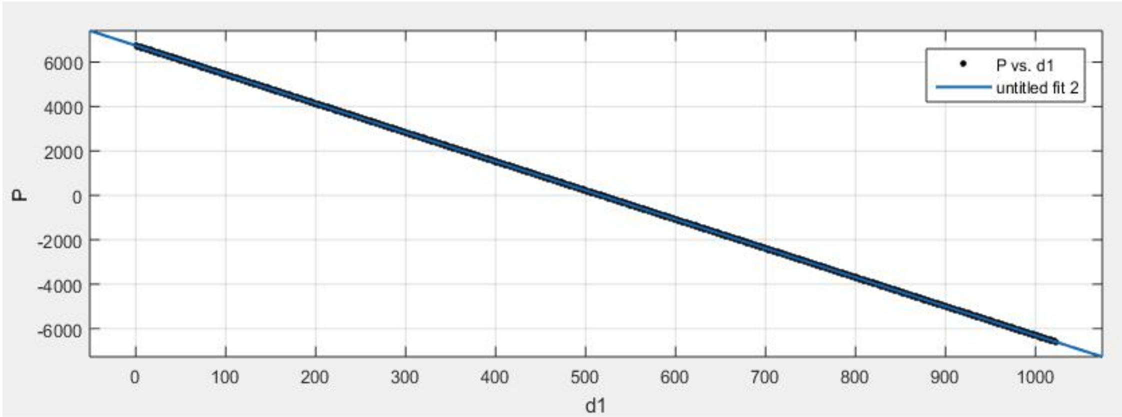

Figure 12: Curve fitting for the power computation

Table 2 shows the current levels, power value and their digital equivalent from the current sensor. Figures 9 to 12 derived from table 2 shows plots of current and power levels against their digital values, current and the curve fitting for power computation against digital equivalent respectively, it can be seen that the curves are linear showing that the system responds positively to the input as desired. Also their slopes are in reverse directions because, their digital equivalents increase with corresponding decrease in current.

5. CONCLUSION

The online distribution transformer parameters monitoring system was developed which possess the feature to monitor the voltage and current level of the distribution transformer. The monitored data were gathered from the voltage and current sensor respectively. The microcontroller coordinates the entire operation of the system and sends these data to online platform through a dedicated wireless internet. The sensed data can be monitored from the online platform from any part of the world, the voltage and current sensors used were tested, calibrated, modeled and simulated to understand their dynamics. The developed system opens possibility to remote sensing which can be implemented to all distribution transformers in order to improve their efficiency by saving maintenance cost, quick fault detection and system forecasting.

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