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ORIGINAL RESEARCH

Design and implementation of anti-theft distribution transformer monitoring system for rural Africa

Frank Onaifo[1] | Alexander Okandeji*[2] | Peter Alao[1] | Stephen Ojo[1] | Oladimeji Okunfolarin[1]

[1]Department of Elect/Elect Engineering, Olabisi Onabanjo University Ago-Iwoye, Ogun State, Nigeria

[2]Department of Electrical/Electronic Engineering, University of Lagos, Akoka, Lagos State, Nigeria

Correspondence

Email: aokandeji@unilag.edu.ng

Present Address

Dept. of Electrical and Electronic Engineering, University of Lagos, Lagos, Nigeria

Abstract

This paper designs a 15KVA three-phase distribution transformer incorporated with a three-phase smart meter for automatic monitoring against theft and vandalism. The monitoring system is designed to send short message services (SMS) to the power utility company when there are abnormalities in the transformer parameters [such as overload, temperature rise, load current, oil level, and voltage variation]. The monitoring unit consist of an embedded system which houses the Arduino Microcontroller, global system for mobile communication (GSM) modem SIM900 for sending SMS, load current sensors which determines the load connected to the transformer, and Bypass current sensors which checks for illegal connection to the transformer. The Arduino Microcontroller/embedded system is connected through a relay to the distribution transformer while the SIM900/GSM module is connected to the Microcontroller/embedded system, relay and optocoupler. The optocoupler isolates the high voltage side of the circuit from the low voltage side. The embedded module process, transmit and receive the parameters to/ from the GSM modem while the GSM module is the link between the embedded system and the public GSM network. The utility provider is expected to have a personal computer (PC)-based -server located at the utility control center basically to collect data from the transformer. This paper presents an alternative method of protecting transformer electrical installations using electronic means compared to the conventional cases of using patrol vehicles by the power utility service provider.

KEYWORDS:

Distribution Transformer, monitoring system, power utility company, GSM network, Server

1 | INTRODUCTION

Electricity generation, transmission, and distribution in general, consist of technical and non-technical losses. Technical losses in particular occur only during electrical generation while technical and non-technical losses can occur during transmission and distribution of electricity. Technical losses are due to power dissipation in transmission lines and transformers, leaking and loss of power, overloading of lines. In contrast, non-technical losses are power losses due to diversion through theft Pranali et al.[1]. The services of a distribution transformer can be prolonged if fault conditions are detected on time. This can usually be done using the Supervisory Control and Data Acquisition (SCADA) system, which is quite expensive. A cheaper alternative of control can also be achieved from the consumer end to complement the control from the generation end. However, observing issues related to distribution transformers through the use of an expansive SCADA system is an expensive suggestion.

Through any means necessary, electricity theft reduction is thus an important issue as it guarantees regular supply for consumers which invariably guarantees financial stability of the utility companies. It is worth noting that meter tampering, stealing, illegal connections like hookups, bypass, billing irregularities, and unpaid bills are the most common forms of electricity theft Bigyan et al.[2]. Accordingly, non technical losses majorly consist of electrical power theft which comprises of illegal connections, billing errors, meter tampering amongts others Nagi et al.[3], Pabla[4]. The challenge therefore in most developing countries is the possibility of power distribution with fewer technical and non-technical losses Chinwuko et al.[5]. Due to the high demand of electricity, there is a need for excellent operation of power system installations to ensure efficient supply. Consequently, together with proper maintenance of generation, transmission, and distribution of power, efficient demand and supply of electricity requires prompt alert of faults arising from technical losses and power theft associated with non-technical losses in the generation, transmission, and distribution sub-systems Thangalakshmi et al.[6].

Evidently, technical losses can be detected and easily controlled to some extent, and they are computed with information about total load and total energy bill. On the other hand, non-technical losses occur due to some immoral activities. Power Theft is a non-ignorable crime which negatively affects the economy of a nation Pranali et al.[1].

2 | RELATED WORKS

2.1 | Current Electricity supply situation in Nigeria

1. Inadequate preventive and routine maintenance of the facilities of power distribution companies (DISCOs) in Nigeria resulting in huge energy losses.
2. Frequent breakdowns, arising from the use of outdated and heavily overloaded equipment.
3. Poor coordination between town planning authorities and energy distribution companies.
4. Insufficient generation due to operational/technical problems.
5. Poor and insufficient funding of the power utility company.
6. Inefficient billing and revenue collection system by distribution companies.
7. High indebtedness to DISCOs by consumers.
8. Vandalizing of distribution equipment.

2.2 | Electricity Theft Methods

There are various types of electricity power theft in meters, cables, transformers, and overhead lines some of which are listed below:

1. Illegal tampering of meters and seals.
2. By-passing the Energy meters.

3. Damaging or removing meter wires.

4. Illegal connections to overhead lines on the star side of the transformer.

5. Billing irregularities made by meter readers.

6. Other unpaid bills by consumers.

2.3 | Methods of Preventing Energy Theft

Work done in academia and industries have proffered several solutions to address electrical power theft Saikiran and Hariharan [7]. Empirical analysis carried out by Subair and Oke [8] showed that electrical power theft can be reduced through an improved commitment to the provision of adequate power and proper management through privatization, government price regulation, and consumer. Also, work done recommended the use of prepaid and smart meters which are able to capture the exact power usage of customers. Several research works have been carried out to combat power theft. Examples include:

1. Preventive measures like injection of a narrow band power line carrier signal into the distribution power line along the power frequency signal (230V, 50Hz) can be applied.

2. Detection of power theft can also be done using power line communication Swaminathan et al. [9]

3. Comparison between the total load supplied by the distribution transformer and the total load used by the consumer, and the error signal is used to identify the power theft using fuzzy logic Omijeh et al. [10]. Work done in Omijeh et al. [10] proposed a model for intelligent power theft detection system (IPTDS) which assumes a tree connection system of meters at various levels whereby power usage variations can be monitored and illegal loads detected and reported to the utility companies. Dike et al. [11], Saravanan et al. [12], Nabil et al. [13], and Prasad and Kiran [14], proposed remote monitoring of meter readings and customer behavior around the meter to track and report abnormalities to utility companies with the possibility of terminating the supply to connected loads, as a means of detecting and preventing theft. In contrast, Rengarajan and Loganathan [15] presented a theft prevention system by comparing the total power supplied by the distribution transformer and the total load used by the consumers. They employed the use of fuzzy logic controller to gradually reduce the supply voltage and eventually cut off supply with respect to error detection between supplied and consumed energy. On the other hand, Himadri et al. [16] presented a meter tampering theft detection system for both analogue and digital energy meters.

Work done by Himadri et al. [16] uses current sensing transformers for both the life and neutral lines to detect pilferages in digital meters. Using a light emitting diode (LED), a light dependent resistor (LDR), and a partially shaded aluminum disc as well as microcontrollers for voltage comparison and measurement, work done by Himadri et al. [16] were able to detect tampering in the analogue meters. Illegal tampering of power from distribution transformer is at its peak, hence, to reduce this theft an energy meter (GSM based) which serves as a theft detector to detect illegal tampering of power is proposed. GSM based energy detector can also be used to send information signal to the distribution authority when tampering of power is detected in the distribution transformer. In contrast to existing results, this research work considered the design of a three phase GSM based smart distribution transformer. Specifically, the objectives of this research work are listed below: The GSM based smart distribution transformer should be able to:

1. To detect an electrical power theft without human interface.

2. To send short messaging service (SMS) to power utility companies when power theft is detected.

3. Cut off power when the temperature exceeds 600 C.

3 | MATERIAL AND METHOD

Electrical power transformer is a static device which transforms electrical energy from one circuit to another without any direct electrical connection, and with the help of mutual induction between two windings. On the other hand, an energy meter is a device that measures the amount of electric energy consumed by an electrically powered device.

The GSM based monitoring of distribution transformer is quite useful as compared to the manual operating system. In the case of manual monitoring system, it is not possible to monitor the oil level, rise in oil temperature, rise in ambient temperature, load current regularly. Upon the reception of any abnormality, action can easily be taken immediately to prevent any failure of distribution transformers Kiran and Ramchandra[17].

The method used in this study comprises of the combination of the transformer, Arduino micro-controller, programming logic with embedded system. The system provides a simple way to detect an electrical power theft without human interface by sending SMS to a power utility when illegal connection or vandalism is detected. The transformer is built by coils of copper windings and thereafter connected in Delta and Star. The monitoring system operates such that after initialization, it checks the state of the feeder pillar for blown fuses and display on the LCD screen Theraja and Theraja[18]. The GSM module is activated only after confirmation that the fuses are intact and automatically send SMS to the utility provider showing the state of the transformer Vrushali et al.[19] Figure 1 .

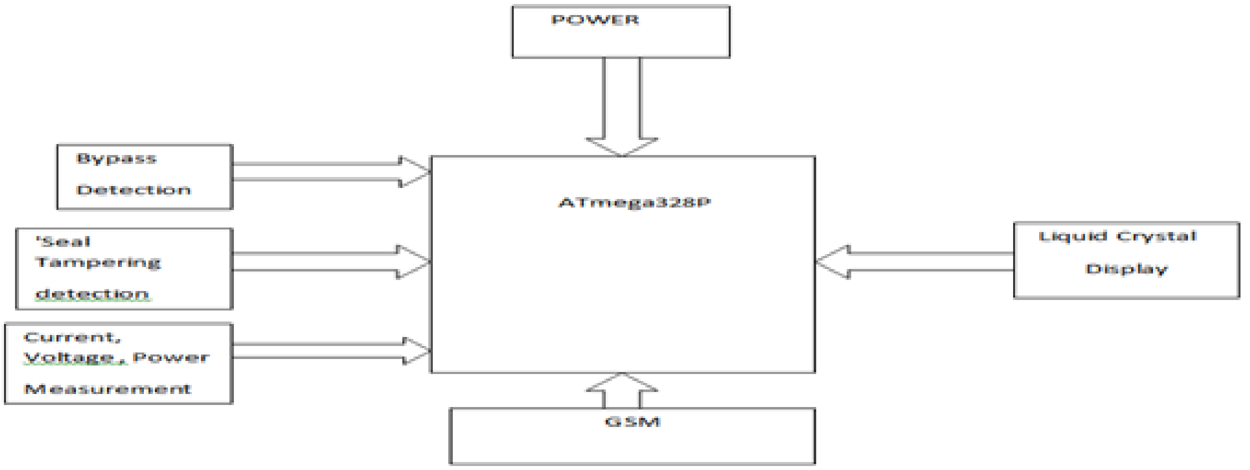

FIGURE 1 Block Diagram of a GSM based energy meter.

3.1 | System Design

The monitoring unit consist of an embedded system which houses the Arduino Microcontroller, global system for mobile communication (GSM) modem SIM900 for sending SMS, load current sensors which determines the load connected to the transformer, and Bypass current sensors which checks for illegal connection to the transformer.

The Arduino Nano, made up of ATmega328P Microcontroller/embedded system, is connected through a relay to the Distribution transformer. The SIM900/GSM module is connected to the Microcontroller/embedded system, relay and optocoupler. The optocoupler isolates the high voltage side of the circuit from the low voltage side. The embedded module process, transmit and receive the parameters to/ from the GSM modem while the GSM module is the link between the embedded system and the public GSM network. As stated earlier, a personal computer (PC)-based -server is located at the utility control center to store data from the transformer. The programing is done using C-language and programmmed in the Arduino board which houses the microcontroller and other components.

3.2 | Implementation

On the off chance that the power robbery happens, the presence sensor detects it, and the "POWER THEFT" message is sent to the watchfulness office through the GSM module. It is additionally displayed on the LCD screen as shown in Figure 2 .

If any intruder is found, the IR sensor gets activated and the “INTRUDER” message is sent through the GSM module to the maintenance Department. Example of such message is displayed on the LCD screen as shown in Figure 3 .

FIGURE 2 Power Theft Detection.

FIGURE 3 Intruder Found Detection.

Figure 3 : Intruder Found Detection Also, if the temperature of the transformer is becoming abnormal, the temperature sensor is activated and the message “TEMPERATURE HIGH” is sent through the GSM module to the maintenance Department. The temperature value is displayed on LCD screen as shown in Figure 4 .

FIGURE 4 Temperature High Detection.

In addition, if the oil-level in the Transformer goes to the minimum level, the oil-level sensor gets activated and the message “OIL LEVEL LOW” is sent through the GSM module to the maintenance Department. The message is also displayed on the LCD screen as shown in Figure 5 .

3.3 | Distribution Transformer System Description

In this design, connection is made in delta and star. From the delta connection, the starting ends of the first coil is connected to the finishing end of the second coil. While in star connection, the finishing end of all three points are connected and referred to as neutral point. The transformer powering the energy-based meter is an alternating current (AC) transformer stepping down 220V to 12V, and it is connected to a 4 diode (full wave rectifier) converting 12V AC to direct current (DC) to power the circuit Figure 6 .

FIGURE 5 Oil Level Low Detection.

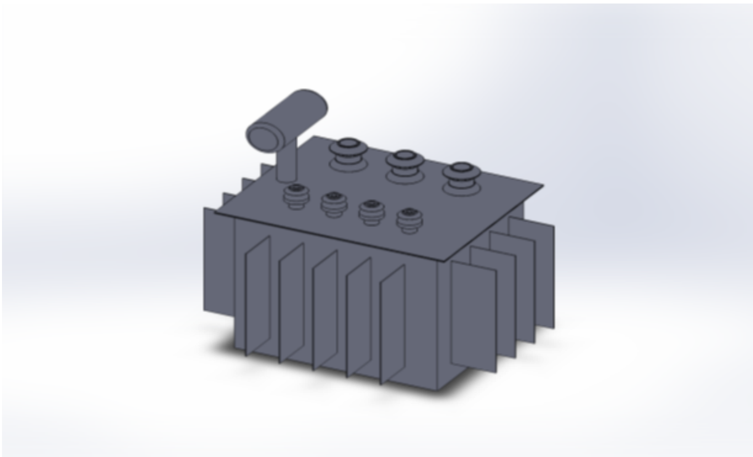

FIGURE 6 Distribution Transformer model using Solid works software.

3.4 | Design Analysis

The power supply design for the proposed system is shown in Figure 7 .

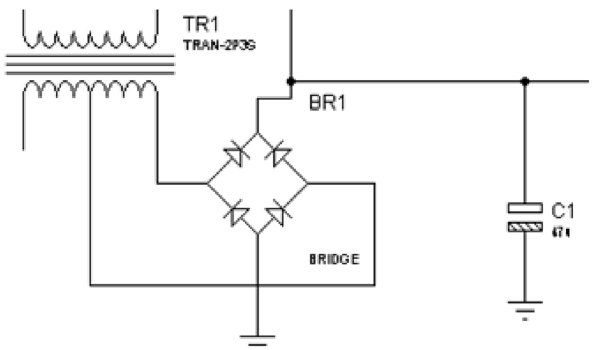

FIGURE 7 Power Supply Design.

Thus, it follows that

$$V_{dc} = V_{p(\text{in})}\left(1 - \frac{1}{2FRLC}\right) \tag{1}$$

where Vp(in) = Peak rectified full – wave voltage applied to the filter, F = output frequency,
Peak primary voltage, V_p(prim) = $\sqrt{2}$ x 220 = 311 V

V_p(in) = V_p(sec) - 2 x 0.7
V = 12 - (2 x 0.7) = 12 - 4 = 11.6 V (For full-wave rectified voltage at the filter input)

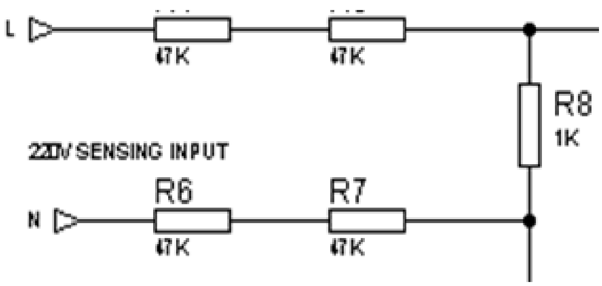

FIGURE 8 AC Voltage Section.

The AC voltage section is shown in Figure 8 . The ADC input of the controller should not exceed 5V and that allows the voltage divider resistor to limit the current to 1.16mA as required by the microcontroller.
from ohms law

$$V = IR \tag{2}$$

V_in = 220 V I = 1.16 mA Total of R4, R5, R6, R7, R8

RT = $\frac{V}{I} = \frac{220}{1.16}$ = 189k Ω

At 220V, the voltage across R8 which is the input to the microcontroller will be at 1.16V, which makes it possible for the controller to measure a voltage 948V in case of overvoltage which induces a system shut down. From equation (2), R8 is calculated as given in (Teraja and Teraja, 2006)

$\frac{V}{R} = \frac{1.16\,\text{V}}{1.116\,\text{V}}\ \frac{inputvoltage}{inputcurrent}$ = 1 kΩ= R8

To calculate the voltage across (R4, R5, R6, R7)

$$V_{\text{IN}} = V_{\text{across}(R4,R5,R6,R7)} + V_{\text{across}(R8)} \tag{3}$$

V_IN(R4, R5, R6, R7)
V_across - V_across(R8)
= 220 V - 1.16 V
= 218.84 V

R_total (R4, R5, R6, R7) = $\frac{218.84v}{1.16mA} = 188.65k\Omega$

Since the same amount of power is required to be dissipated in the four resistors, we set them to the same value by dividing by 4.

$\frac{188.65k\Omega}{4} = 47.16k\Omega$ each

The LCD contrast resistor is shown in Figure 9 . Pin 3 is taken as 0.45V.
Current through R2= current through R1

$I = \frac{0.45\,V}{1\,k\Omega} = 0.45\,mA$

V_R2 + V_R1 = 5 V (input voltage to the controller)

V_R1 = 5 - V_R2 = 5 - 0.45 = 4.54 V

$R\_1 = \frac{V\_R1}{I} = \frac{4.54}{0.45} = 10\,k\Omega$

$\therefore \quad R\_1 = 10\,k\Omega \quad \text{and} \quad R_2 = 1\,k\Omega$

Figure 10 shows the circuit diagram of the energy-based distribution transformer.

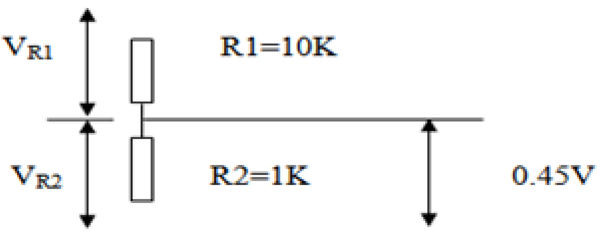

FIGURE 9 LCD Contrast Resistor.

3.5 | Arduino Nano

The Arduino nano has a pin layout that works well with the mini or the basic stamp (TX, RX, ATN, GND on one top, power and ground on the other). This new version 3.0 comes with ATMEGA328 which offer more programming and data memory space. It has two layers which makes it easier to hack and more affordable. Table 1 shows the components of the Arduino nano.

TABLE 1 Components of the Arduino Nano

S/N	Component	Specification
1	Microcontroller	ATmega328P
2	Operating Voltage	5V
3	Input Voltage (recommended)	7–12V
4	Input Voltage (limits)	6–20V
5	Digital I/O Pins	14
6	Analog Input Pins	8
7	DC Current per I/O Pin	40mA
8	Flash Memory	32KB
9	SRAM	2KB
10	EEPROM	1KB
11	Clock Speed	16MHz
12	Dimensions	0.70" × 1.70"

3.6 | Results

After the construction of the units and module, testing was carried out on each of them. Hence, it was ensured that the units and module were in proper working conditions and were connected in the circuit as required. There are two major types of testing for distribution transformer.

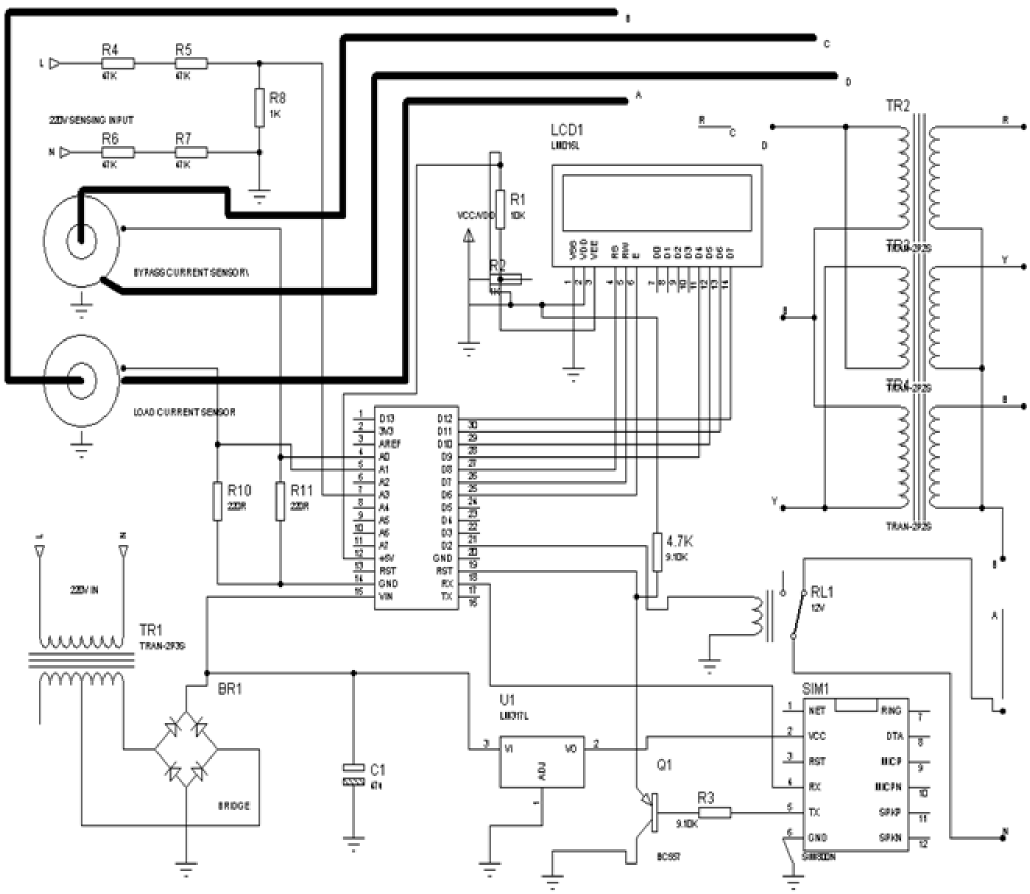

FIGURE 10 Circuit Diagram of an Energy Based Distribution Transformer.

3.6.1 | Continuity test

Continuity test is the checking of electric circuit of current flow. Continuity test is performed by placing a small voltage across the choosing path. Table 2 and Table 3 , respectively, shows the parameters for the continuity test for the primary windings and the secondary windings.

TABLE 2 The continuity test for the primary winding of the transformer.

Phase	$1^{st} Turn$	$2^{nd} Turn$	$3^{rd} Turn$	End
1	0.16 V	0.20 V	0.24 V	0.29 V
2	0.16 V	0.20 V	0.24 V	0.29 V
3	0.16 V	0.20 V	0.24 V	0.29 V

3.7 | Transformer Result after testing

Input voltage= 415V
Out Put Voltage=100V
AMPRE =35A
Secondary Amps
Red phase = 2Amps
Yellow phase =1.8Amps

TABLE 3 The continuity test of the secondary winding of the transformer.

Phase	$1^{st}Turn$	$2^{nd}Turn$	$3^{rd}Turn$	End
1	0.7 V	0.9 V	0.11 V	0.13 V
2	0.7 V	0.9 V	0.11 V	0.13 V
3	0.7 V	0.9 V	0.11 V	0.13 V

Blue phase = 1Amp

Ratio test : Transformer ratio can be calculated by the number of primary turns to the number of secondary turns. i.e.

Turn Ratio = $\frac{\text{Number of Primary Turns}}{\text{Number of Secondary Turns}} = \frac{1500}{500} = \frac{3}{1}$

Turn ratio = 3:1

Ratio Test for the phases
Phase 1 = 57V
Phase 2 = 60V
Phase 3 = 52V
The complete transformer design is shown in Figure 11 while the complete transformer monitoring system is shown in Figure 12 .

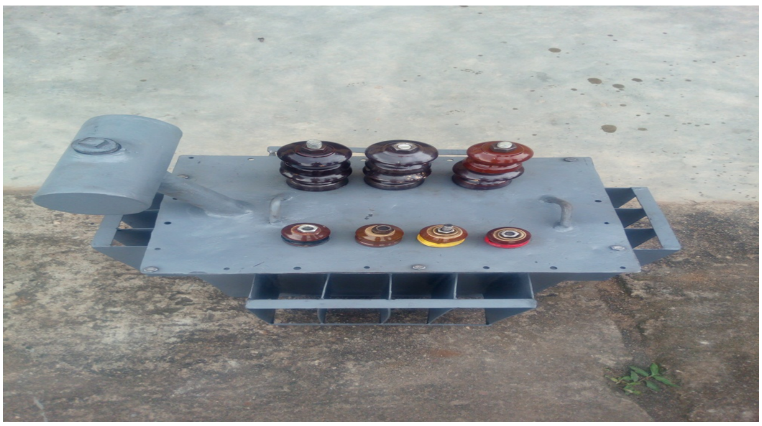

FIGURE 11 Complete transformer.

4 | RESULTS AND DISCUSSION

Normally, the number of turns in the secondary winding is always one third of the primary winding in the distribution transformer and that was why the turn ratio is 3:1. More so, the transformer was tested with 388V as the incoming voltage and the output voltages are 100V, 105V and 92V. 415V been the voltage between two phases normally called (two lives wire either R or Y, Y or B, R or B). The voltage normally supplied to residential houses is 220V to 240V between phase and neutral of the transformer from which the service cable or distributing system is normally delta – star transformer. Delta – star is used to step down high voltage to low voltage. Conversely, in the transmission end, the type of transformer used is star- delta for stepping up low voltage to high voltage.

FIGURE 12 Complete transformer monitoring system.

5 | CONCLUSION

Traditionally, monitoring of distribution transformer has been done manually where the engineer physically visits the transformer based on a scheduled time to check on the oil level, temperature rise, voltage variation, load current and theft detection. The GSM based monitoring of the transformer is of great benefit as compared to the manual monitoring where the monitoring of oil level, ambient temperature rise, load current, voltage variation and theft cannot be monitored always. But with the introduction of the GSM based meter, it is possible to receive the transformer fault information through an SMS remotely to the power utility company to take necessary action before any failure can occur. This new way of monitoring increases the efficiency of the transformer, it brings about a reliable way of operation and increases the lifespan of the transformer.

5.1 | Recommendation

A server module can be added to this design to receive and store the parameters information of the transformer periodically in a database application. The database will be of good source of information on the transformer where the analysis of the stored data helps the utility to monitor the status-quo of the transformer thereby identifying fault before any failure can occur which reduces cost and improves the system reliability.

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CREDIT

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