DESIGN AND IMPLEMENTATION OF ANTI-THEFT DISTRIBUTION TRANSFORMER MONITORING SYSTEM FOR RURAL AFRICA

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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 parameters of the transformer [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 is responsible for the transmission and reception of the parameters to/ from the GSM modem while the embedded system and the public GSM network is linked together by the GSM module.

Keywords: Distribution Transformer, monitoring system, power utility company, GSM network, Server.

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 dissipation of power 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., 2017). 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 tampering of energy meters, unlawful connections like hookups, bypass, inconsistent billing, and unresolved bills are the most common forms of electricity theft (Bigyan et al., 2016). Accordingly, non technical losses majorly consist of electrical power theft which comprises of illegal connections, billing errors, meter tampering amongts others (Saeed *et al*., 2020). The challenge therefore in most developing countries is the possibility of power distribution with fewer technical and non-technical losses (Uhunmwagho, 2014). 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*., 2015).

Evidently, technical losses can be easily detected and controlled comparatively, and information about total load and total energy are used for its computation. Conversely, non-technical losses occur are largely due to immoral activities by humans.

Related Works

Current Electricity supply situation in Nigeria

Currently, electricity supply in Nigeria can be described as follows:

1. Inadequate preventive and scheduled maintenance of the facilities of power distribution companies (DISCOs) in Nigeria resulting in huge energy losses.
2. Recurrent system collapse resulting from the use of old-fashioned and heavily overloaded
   Equipment.
3. Insufficient cooperation between urban planning officials 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. Vandalization of distribution equipment.

Electricity Theft Methods

Electricity power theft from overhead lines, transformers, cables and meters occur in one or more of the underlisted ways:

1. Illegal access to energy meters and damage of seals.

2. Theft occurring through the damage and removal of meter wires.
3. Illegal connections to the low voltage side of the transformer.
5. Billing irregularities.
6. Unpaid bills by electricity consumers.

Methods of Preventing Energy Theft

Work done in academia and industries have proffered diverse solutions to address electrical power theft (Saikiran and Hariharan, 2014). Work done in Shokoya and Raji, (2020), showed that electrical power theft can be reduced through an improved commitment to provide adequate power and effective management through deregulation, and efficient price control. Also, work done by Murrill et al., (2023), 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 power theft combative measures achieved by injecting a narrow band power line carrier signal into the distribution power line along the power frequency signal (230V, 50Hz).

2., Power theft detection achieved through the use of power line communication (Swaminathan *et al.,* 2014).

3., Power theft detection through the use of fuzzy logic to compare between the total load supplied by the distribution transformer and the total load consumption of the consumer (Omijeh *et al*., 2012). Work done in Omijeh *et al*., (2012), proposed an intelligent power theft detection system (IPTDS) that detects power usage variation through the use of a tree connection system of energy meters which allows illegal connections to be detected.

Authors in Dike *et al*., (2015), Nabil *et al.,* (2013), Prasad and Kiran, (2014) proposed the use of remote energy meter monitoring system to detect customer behaviour around meters to allow for trackability, and report irregularities to utility companies who often respond to power theft by discontinuing the supply to connected loads.

Authors in Rengarajan and Logonathan, (2012), developed a power theft prevention system that compares the total supplied power by the distribution transformer with the total energy comsumption. The authors deployed the use of fuzzy logic controller to moderately decrease the supply voltage in response to the error detection obtained from the comparism and eventually terminate the supply. Authors in Himadri *et al*., (2010), presented a theft detection system for both analogue and digital energy meters. To detect theft in digital energy meters, the authors adopted the use of a current sensing transformer for life and neutral. In contrast, to detect energy theft in analogue meters, the authors employed the use of a light dependent resistor, a light emitting diode, a shaded aluminium disc, and a microcontroller to perform voltage comparism and measurement.

Illegal tampering of power from distribution transformers is at its peak, hence, to reduce energy theft, GSM based energy meter 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. Detection, without human interface, electrical power theft.
2. To send short messaging service (SMS) to power utility companies when power theft is
   Detected
3. Cut off power when the temperature exceeds 60^0 C.

Material and Method

The proposed model is of great use when compared to the manual monitoring system. For manual monitoring system, it is quite impossible to monitor the rise in ambient temperature, rise in oil temperature, and the load current on a regularly basis. The GSM based system can, however, provide a real-time surveillance of the distribution transformer, and responds to any abnormality by terminating supply to the load thereby preventing any failure (Kiran and Ramchandra, 2016). 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 company when illegal connection or vandalization 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. 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. Figure 1 shows the block diagram of the GSM based energy meter.

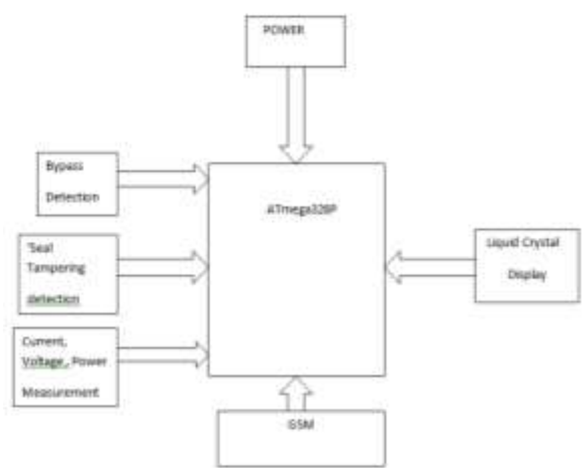

Figure 1: Block Diagram of a GSM based energy meter

System Design

The monitoring unit consist of an embedded system which houses the Arduino Microcontroller, 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. A personal computer (PC)-based - server to store data from the transformer is located at the control center.

Microcontroller programming

The programing is done using C-language and programmed in the Arduino board which houses the microcontroller and other components. The code is shown under Appendix A.

Implementation

For a power robbery event, the presence sensor detects it, and the "POWER THEFT" message is sent to the monitoring team through the GSM module. It is additionally displayed on the LCD screen as shown in Figure 2.

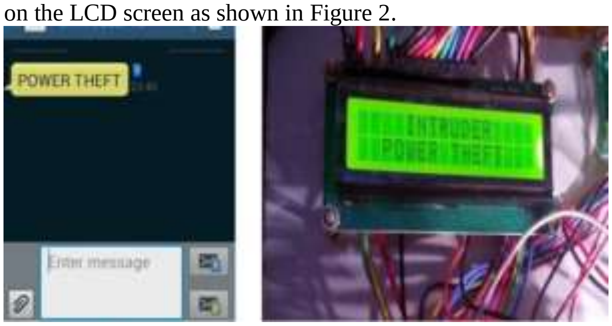

Figure 2: Power Theft Detection

The presence of an intruder activates the IR sensor and the "INTRUDER" message is sent through the GSM module to the maintenance Department. An example of such message as displayed on the LCD screen is shown in Figure 3.

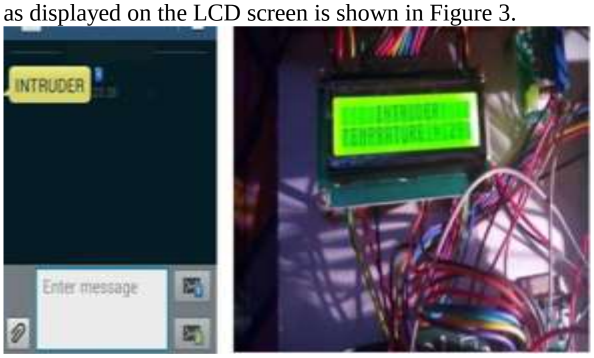

Figure 3: Intruder Found Detection

Also, abnormal temperature of the transformer activates the temperature sensor and the message "TEMPERATURE HIGH" is sent through the GSM module to thee utility company. The temperature value is displayed on LCD screen as shown in Figure 4.

Figure 4: Temperature High Detection

In addition, once the oil-level in the Transformer gets to the minimum level, the oil-level sensor is 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.

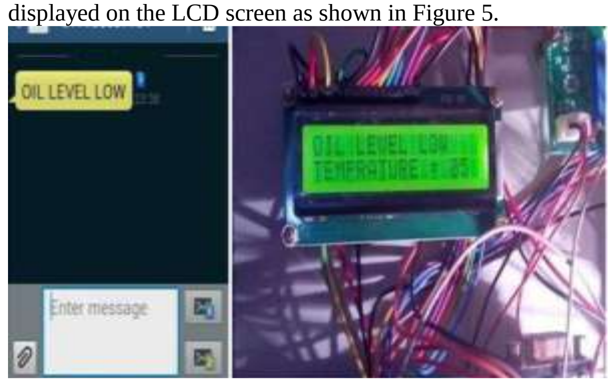

Figure 5: Oil Level Low Detection

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. The distribution transformation model is shown in Figure 6.

Fig 6: Distribution Transformer model using Solid works software

Design Analysis

The power supply design for the proposed system and the AC voltage section is shown in Figure 7 and Figure 8, respectively..

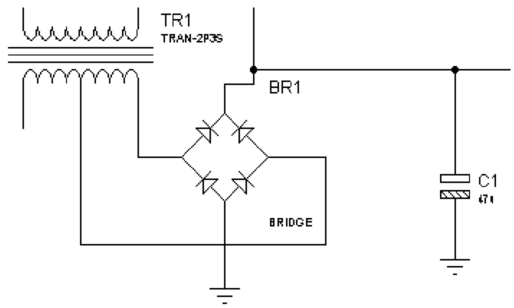

Fig 7: Power Supply Design

Thus, it follows that

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

where $V_{p(in)}$ = Peak rectified full – wave voltage applied to the filter, F = output frequency,

Peak primary voltage, $V_{p(prim)} = \sqrt{2} \text{ X } 220 = 311V$

$V_{p(in)} = V_{p(sec)} - 2 \text{ x } 0.7v = 12 - (2 \text{ x } 0.7)$

$= 12 - 4 = 11.6v$ (For full-wave rectified voltage at the filter input)

Formula for filter capacitor $= \frac{1}{2FRLC} = \frac{1}{2x50x50x47} = 4.3\mu$

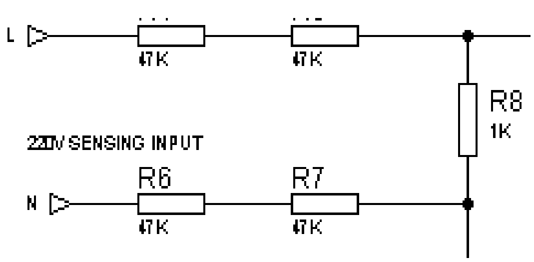

Fig 8: AC Voltage Section

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 (2)

V_{in}= 220V

RT = ?

I = 1.16mA

Total of R4, R5, R6, R7, R8

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

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 (Theraja and Theraja, 2006).

$$\frac{V}{R} = \frac{1.16V \ input\ voltage}{1.116V \ input\ current} = = 1k\Omega = R8.$$

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

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

V_{across}(R4, R5, R6, R7) = $V_{in} - v_{across}$(R8)

= 220v – 1.16v

V_{across} = 218.84v

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.

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

The LCD contrast resistor is shown in Figure 9. Pin 3 is taken as 0.45V.

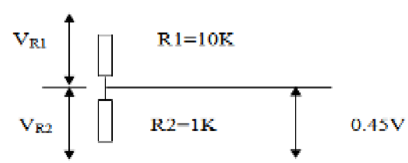

Fig 9: LCD Contrast Resistor

Current through R2 = current through R1

$\mathbf{I} = \frac{\mathbf{0.45v}}{\mathbf{1K\Omega}} = 0.45mA$

$V_{R2} + V_{R1} = 5$ (input of the controller voltage)

$V_{R1} = 5 - V_{R2} = 5 - 0.45 = 4.54V$

$V_{R1} = 4.54V$

$R1 = \frac{VR1}{I} = \frac{4.54}{0.45} = 10K\Omega = R1$

$\therefore$ R1 = 10KΩ R2= 1KΩ

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

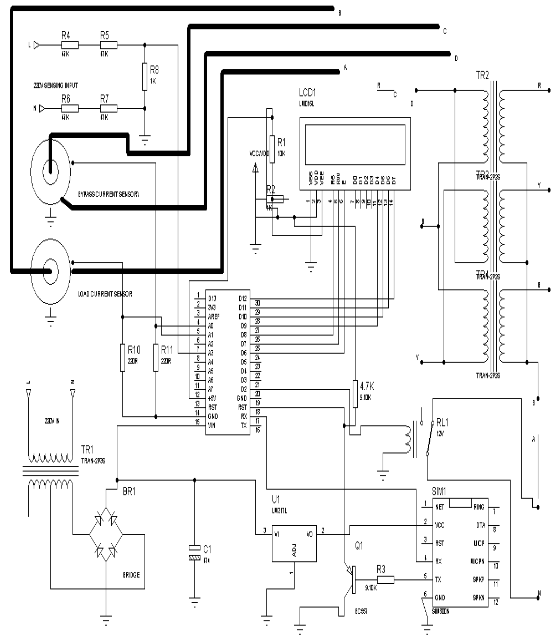

Fig 10: Circuit Diagram of an Energy Based Distribution Transformer

Arduino Nano

The Arduino nano is a microcontroller-based device with digital pins that can be employed for different purpose. It is mainly used for developing and prototyping new applications. Table 1 shows the components of the Arduino nano.

Table 1: Components of the arduinonano

S/N	COMPONENTS	SPECIFICATION
1.	Micro-controller	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.	EElPROM	1KB
11.	Clock Speed	16MHz
12.	Dimensions	0.70” × 1.70”

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.

4.1 Continuity test

Continuity test refers to a quick test to determine if a circuit is open or closed. 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	1st turns	2nd turns	3rd turns	End
1	0.16v	0.20v	0.24v	0.29v
2	0.16v	0.20v	0.24v	0.29v
3	0.16v	0.20v	0.24v	0.29v

Table 3: The continuity test of the secondary winding of the transformer

Phase	1st turns	2nd turns	3rd turns	End
1	0.7v	0.9v	0.11v	0.13
2	0.7v	0.9v	0.11v	0.13v
3	0.7v	0.9v	0.11v	0.13v

Transformer Result after testing

Input voltage= 415V

Out Put Voltage=100V

AMPRE =35A

Secondary Amps

Red phase = 2Amps

Yellow phase =1.8Amps

Blue phase = 1Amp

i. *Ratio test*

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

$$\text{Turn ratio} = \frac{\text{Number of primary tuns}}{\text{Number of secondary turns}} = \frac{1500}{500} = \frac{3}{1}$$

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

Figure 12: Complete transformer monitoring system

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.

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 distribution transformer provides real time surveillance for parameters such as oil level, ambient temperature rise, load current, and voltage variation. The integration of the GSM module to the energy-based meter makes it possible to receive the transformer fault information through SMS which is remotely sent 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.

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