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Research/Technical Note

Design and Implementation of Gsm Enabled Remote Sensor for Monitoring Power Transformer Operation

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Abstract: Transformer is one of the most vital components of power transmission and distribution infrastructure. In a developing country such as Nigeria, majority of the growing population of the people are still grappling with gross inadequate and epileptic power supply. Only about 4000MW of electricity is available for distribution (by load shedding) due to decay in existing infrastructure. The aim of this work is to apply modern technology to prevent further decay of the equipments particularly the transformer which is very expensive. This article involves the design and implementation of a device to monitor and detect the operating condition of a transformer with emphasis on power distribution transformers. A module embedded Global System for Mobile communication (GSM) enabled device is designed to monitor load currents and temperature, using a micro-controller and sensor. The monitored values are processed and recorded in the system memory which is programmed with some predefined instructions to detect any abnormal working condition of the transformer so that the GSM module can send a Small Message Signal (SMS) to designated mobile telephones containing information about the fault, base on the programmed instructions into the micro-controller. This will help the power distribution company respond swiftly to abnormalities that may lead to catastrophic failures and subsequent system short down. It is a fully automated device capable of reducing the risk of transportation and human errors associated with manual transformer inspection and testing. The device was tested and it responded very well to fulfill the set objectives.

Keywords: Power, Distribution, Transformer, Voltage, Current, Temperature, Monitoring Sensor

1. Introduction

1.1. Background

In order to improve on the reliability of power supply in the existing transmission and distribution network in Nigeria, there is need to device other ways of protecting the transformer, being a very critical component of power infrastructure. The transformer is constructed with inductive materials whose working condition is characterized by continuous dissipation of heat due to high current consumption often times or when there is overload condition. This is why power distribution transformers are usually provided with cooling mechanism for protection against damages caused by excessive heat. When the temperature of the windings under working condition exceeds that of the transformer rating, insulation will deteriorate this may cause the insulator to fail. Prolong thermal heating weakens insulation overtime, and this may result to premature end of the transformer lifespan [10]. This amounts to the suggestion that a comprehensive transformer protection scheme is required, including protection against transformer overload, fault, over-excitation, and protection against internal fault. Transformer suffers the effect of fault, mostly during short circuit condition as explosion causes severe damage. Transformers are very expensive both in maintenance and repairs. Whenever there is a fault on the transformer, power distribution will shut down entirely in the area of coverage by the transformer [21, 23]. In Nigeria presently, distribution transformers are monitored by physical inspection, where the personnel of the electricity distribution company undertake routine check for record keeping or maintenance purpose at certain interval of time. This method of inspection cannot provide adequate information about intermittent overloads and overheating of transformer oil and windings, which are capable of reducing transformer lifespan and result in system breakdown.

1.2. Transformer Failure and Protection

Failures in transformers are caused by many factors which occur during their operation depending on the size and type of the transformer. These factors includes overheating, fluctuations in voltage and current, earth fault and overload [21, 22]. It is necessary to detect these faults at the right time so that appropriate measures can be adopted to forestall breakdown and save cost. A fully automated remote monitoring system is required to gather information on the transformer oil strength with respect to temperature and pressure of the gas bubbles coming out from the oil during chemical decomposition as a result of overheating and/or short circuit in transformer windings [3]. Transformers are manufactured with various means of protection to guarantee safety and reliability in their operation. One major way to protect transformers is the use of relays against earth fault, over current and overload. Examples of such relays protection are bulchholz relay used for earth fault and over current protection and three phase differential relay [23, 24].

2. Literature Review

2.1. Design and Implementation of a Microcontroller Based System for Oil filled Distribution

This research involve the use of PIC16F77A microcontroller to program variations in current values in an oil filled power distribution transformer in conjunction with an ultrasonic sensor whose working principle is the same as thatof radar or sonar [18]. During operation of the sensor, the attributes of a targeted object are detected by the echoes created by the sound waves generated by the object. A piezoelectric material was incorporated in the ultrasonic sensor circuit to convert sound or radio waves both at the sending and receiving ends of the wave. Thus, the piezoelectric material acts like a transducer by transmitting packets of sonic pulses and converting the echo pulses into voltages [1]. The temperature sensor employed in the research is the LM 35 series; it is a precision integrated temperature sensor whose output voltage increases with increase in temperature of objects/material. Other sensors such as voltage and current sensors were also employed to detect changes in operating voltage and current of the transformer under test. MikroC programming language, with a very powerful and efficient compiler known as Mikro C PRO was used to program the operation of the PIC16F77A microcontroller [1, 19, 20]. However, the work is narrowed to the use of LM 35 IC temperature sensor which is not convenient and readily available in the Nigeria market. The PT100RTD series are precision integrated-circuit temperature sensors, whose output voltages are linearly proportional to the Celsius (Centigrade) temperature. The PT100RTD thus has an advantage over other temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The PT100RTD does not require any external calibration or trimming and has low output impedance, linear output, and precise inherent calibration that make interfacing to readout or control circuitry especially easy. As it draws only 60 µA from its supply, it has very low self-heating [4]. Also, there is no provision for alerting the concerned maintenance personnel in the event of an impending danger to the health of the transformer under coverage, as it will help to minimize breakdown and improve reliability of power distribution [9].

2.2. Transformer Wireless Monitoring System Using Arduino/XBEE

In this work, Arduino board coupled with XBEE module, are programmed in such a way as to monitor changes in voltages, currentsand temperatures of a transformer so that measured values can be assessed to determine the working condition of the transformer and avoidpossible breakdown. There was a proof that XBEE modules provide a means of wireless communication system using radio waves over a limited range of detection, and they are used to achieve better energy and temperature monitoring including other remote functions such as monitoring of patients heartbeat as well as blood pressure [5-7]. The report further indicates that when XBEE modules are coupled with Arduino processing board, they provide a better response to the remote control process that is highly reliable and less expensive to purchase [3, 8]. But the work was limited to the programming of Arduino and XBEE modules to process measured values without any feedback. Provision for an information system is needed for the observer to always get first hand information about the operating condition of the transformer under coverage.

2.3. Distribution Transformer Monitoring System Using GSM Technology

In this project, a monitoring system for distribution transformers was designed. Sensors were mounted at strategic points in the body of the transformer to sense weather the operating condition is in line with rated parameters so that any deviation from manufacturers rated values can be sent in the form of a small message signal (SMS) to the power distribution company. This will help in preventing breakdown in the distribution network through enhanced transformer functionality [11, 13-15]. The sensors detect changes in the transformer’s internal characteristics as well as voltages, currents and temperature, which are then relayed to the observer with the aid of an embedded GSM module to alert the operatives so that appropriate steps can be taken in the event of an abnormal health condition. The overall aim is to improve on the reliability of the power distribution to the end users and the safety of the transformer is guaranteed overtime [12-14]. The entire monitoring system comprises of Atmega 32 microcontroller, which was programmed using Bascom-AVR with the transformer name and location imputed in the SMS for easy identification. The project further affirmed that, whenever values of critical parameters are exceeded beyond the rating of a transformer the monitoring system quickly alerts the operatives of the company of an unhealthy condition of a particular transformer in the power line so that appropriate maintenance procedures may be deployed to avoid catastrophic conditions [10, 16, 17]. However, the type of sensor used was not clearly defined as regards the mode of operation in conversion and signal processing. This is because sensors are characterized by low response to input signals due to interference and other limitations. They are therefore prone to failures, and so they cannot provide a reliable and efficient signal at the output.

3. Methodology

The research continued after reviewing some recent articles with step-by-step design of the various units/sections that combines the whole system. Components and units were assembled according to circuit designed. The final work was tested with its operations observed and recorded for discussion on their effect in the progress and purpose of the research, in order to conclude on the achievements base on the overall aim and objectives.

3.1. Design Specifications

This system has the following design specifications:
Input voltage: 220/230VAC
Operating frequency: 50HZ
Temperature Sensor type: Platinum RTD (PT100)
Temperature Range: -200 to 660 C.
Display type: 16 x 2 liquid crystal display (LCD).
Current sensor type: ATS712 current sensor
Display Information: Displays Temperature value in Degree Celsius.
System Type: Microcontroller Based (PIC16F877A).
Output: Analogue (Voltage: 0-5V)

3.2. Design Details

3.2.1. Selection of Temperature Sensor Unit

This unit measures the temperature of the transformer and gives a

Signal that is proportional to the temperature measured.

(i) Requirements of the Temperature Sensor

a. Reasonable Temperature Range able to operate above below the transformer fault tap
b. High Precision and Accuracy
c. Easy to Mount and Use
d. Easy to Bias
e. Availability and Cost Effective

(ii) Selection of the Temperature Sensor

The Temperature Sensor selected is PT100 Platinum RTD, (All details are shown in the Appendix)

a. Temperature Range of -200 to 660 C
b. High Accuracy of 0.001.
c. Easy to Bias using the voltage divider Circuit.
d. Easy to Mount and Cost Effective.

The PT100 RTD has a resistance of 100 ohms at 0°C and temperature coefficient of resistance of 0.0038. The circuit diagram of temperature sensor is shown in figure 1 biased with a 100 ohms Resistor in a voltage Divider Circuit in this design, the output from the voltage divider is connected directly to the Microcontroller through its internal Analog to Digital Converter Module. Below is the Circuit diagram of the configuration.

In practice, temperature-resistance relationship of the RTDs is approximated by an equation known as the Callendar-Van Dusen which gives very accurate results.

$$R_T=R_o\ [1 + aT + bT_2 + c\ (T - 100)3] \quad (1)$$

A, b and c are constant which depend on the material.

If T is more than O°C, the constant C is=O

So, equation (1) becomes;

$$R_T=R_o\ [1 + a + b + T_2] \quad (2)$$

From the equation, the relationship between temperature and relative resistance R_t/R_o can be drawn.

From T=0 to 100°C the relationship between R_t/R_o

T can be considered linear

$$\therefore\ T=\frac{-R_oA+\left[R_0^2A^2-4R_0B(R_o-R_T\right]^{0.5}}{2R_0B} \quad (3)$$

Where

T=Temperature
R_o=Resistance at 0°C
R_t=The resistances at T°C
A and B are constants

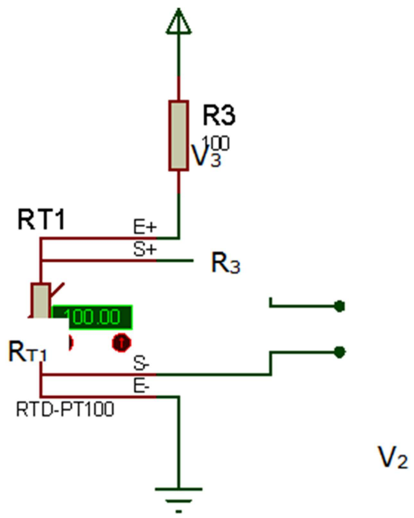

Figure 1. *PT100RTD Sensor.*

From Voltage divider Equation:

The voltage across the sensor=R_{T1}

$$V_t = V_S \ R_T \ / \ R_t + R_3 \qquad (4)$$

The resistance of the RTD element can be calculated as:

$$R_t = R_3 \, {V_t}/{(V_s - V_T)} \qquad (5)$$

Where $R_S = R_3 \ \Omega$
V_t=RTD Output Voltage, 5Vand R_T=Resistance of the RTD
Assuming a V_T of 2V, V_S of 5V, R_S of 100 ohms
From equation (3.5)

$$R_T = (100x2) / (5-2) = 200/3 = 66.67 \text{ ohms.}$$

Applying R_T into: $T = (-Ro\ A + [R^2_o\ A^2 - 4R_o\ B\ (R_o - R_T)]^{0.5}) / (2R_0B)$
Where the Constants A and B are given as

$$A = 3.9083x10^{-3} \text{ and } B = -5.775x10^{-7},$$

Where A and B are Constants
$A = 3.9083x10^{-3}$
$B = -5.775x10^{-7}$
For RTD

$$T = (-0.39083 + [0.15274 - 2310 \text{ x } 10^{-7} (66.67-100)]^{0.5}) / (-1155 \text{ x } 10^{-7}).$$

$$= 2.54 \text{ x } 10^{-10}$$

3.2.2. The Display Unit

This unit serves the purpose of giving a visual presentation of the temperature and current load of the transformer Measured by the RTD sensor and the current sensor. It show the temperature value in degree Celsius, and shows the current drawn from the transformer in Amps. It is directly controlled by the controller unit.

(i) Requirements of the Display Unit

a. Be Large Enough to Represent the Temperature Values in degree Celsius.
b. Easy to interface with a Microcontroller.
c. Reasonable operating Voltage.
d. Cost Effective and Available.
e. Should be x 4

(ii) Selection of the Display Unit

The 16 by 4 LCD Standard Hitachi HD44780 was selected. Below are some of its features:

a. It has two (2) Rows and 16 Characters per Row, Enough to represent the Temperature Values in degree Celsius, Kelvin and Fahrenheit.
b. It is Cost Effective and Easy to Interface with a Microcontroller using its Data lines and three Control lines.
c. Operate with 5V DC at 200mA.
d. It is available.

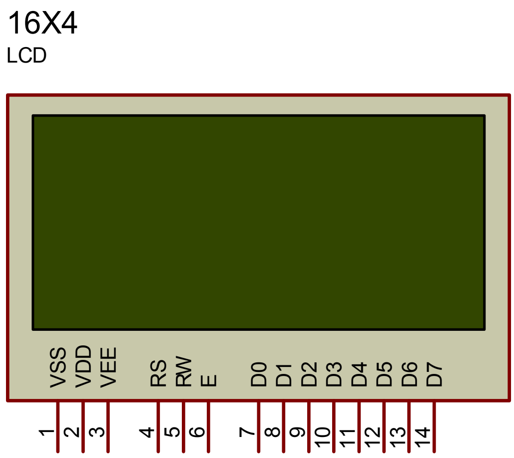

Figure 2. *16 by 2 LCD (The Display Unit).*

3.2.3. The Controller Unit

This Unit is the Heart of the Design. It controls the entire system. It receives signal, i.e. from the RTD through its internal ADC, and also from the current sensor through another ADC pin, computes it (Calibration, Scaling and Linearization) and sends the computed Temperature values in degree and current in amperes, to the Display unit for visual presentation and also sends the computed value of temperature and current as an SMS message when requested by the user through the GSM module.

(i) Requirements of the Controller

Below are the Requirements for the selection of the Microcontroller:

a. The Microcontroller should have an internal ADC to receive analog signal i.e.
b. From both sensor unit (temperature and current).
c. The Microcontroller should also have an internal EEPROM to enable it store the Range of the PT100 RTD temperature sensor.
d. The Microcontroller should have enough input/output Pins so that it can easily interface the 16 by 2 LCD that requires 11 pins for its Configuration.
e. The Controller should Available and Cost Effective.
f. The controller should be Easy to use in terms of Hardware interface and Software (Programming).

(ii) Selection of the Microcontroller

The PIC16F877A Microcontroller from Micro-chip Corporation Was selected because:

a. It has 40pins i.e. enough General Purpose input and Output
b. It has internal ADC required to interface the sensor unit.
c. It has an internal PWM Module for DAC Purpose.
d. It has internal EEPROM required to store the Temperature and current range of both Sensors (PT100 and ATS712).
e. The Microcontroller is available and Cost Effective.
f. Its Programming Interface is very simple using MPLAB IDE.

A 4MHz crystal oscillator is connected to XTAL1 and XTAL2 pins of the microcontroller, biased with two 15pf capacitor as specified in the datasheet that determines the speed of execution.

Below is a brief systematical operation of the Microcontroller:

a. Receives signal from the Voltage divider used to bias the RTD i.e. The Sensor Unit Through its internal ADC.
b. Converts the analog signal to Digital using its ADC.
c. Computes the digital value i.e. using the V_T to get R_T which is the resistance of the RTD at the V_T.
d. Applies the R_T into the Equation (2) to get T in Celsius, where A and B are known Constants.
e. Converts the T to Kelvin and Fahrenheit in Printable characters and sends it to the Display Unit for visual presentation.
f. Based on the RTD range (-200 to 660°C), the Duty cycle of the PWM is set in a linear proportion to out the signal in 0-5V Range.
g. Repeat the above five steps for the current sensor to get the amps of the load connected to the transformer.
h. Sends temperature and current value to user wirelessly when requested by the user.

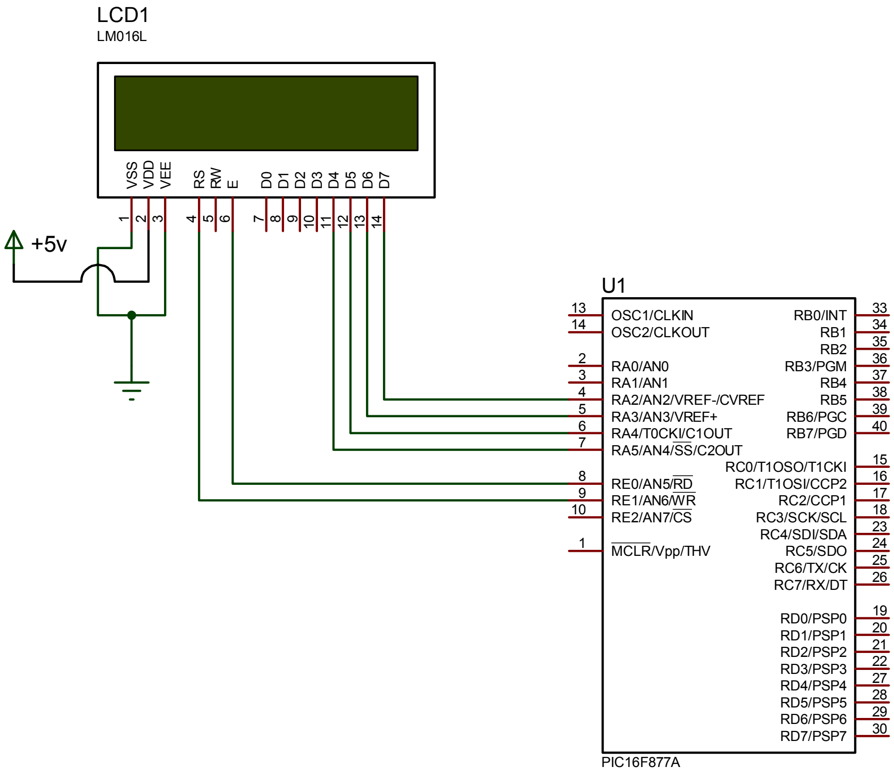

Figure 3. *Microcontroller and the Display Unit.*

3.2.4. The Power Supply Unit

This unit converts the 220v AC to 5V DC required by the circuit.

It was implemented with the following components:

a. 220v/12v step down transformer
b. Bridge Diode
c. Capacitor
d. Voltage regulator

Below is the circuit diagram of the power supply unit:

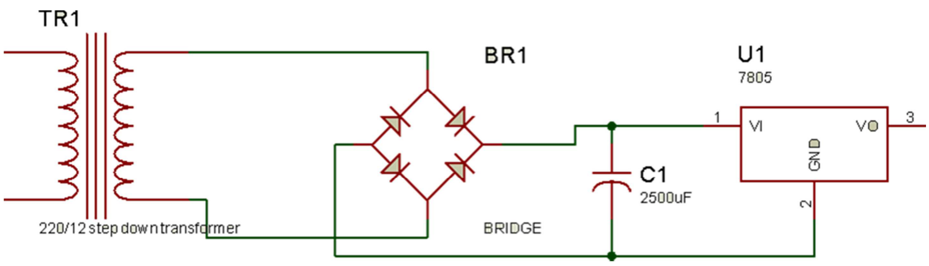

Figure 4. *Power Supply Unit.*

3.2.5. Voltage Regulator

As we require a 5V we need LM7805 Voltage Regulator IC.

7805 IC Rating:

a. Input voltage range 7V-35V
b. Current rating Ic=1A
c. Output voltage range V_{Max}=5.2v, V_{Min}=4.8v

3.2.6. Transformer

Selecting a suitable transformer is of great importance. The current rating and the secondary voltage of the transformer is a crucial factor.

a. The current rating of the transformer depends upon the current required for the load to be driven.
b. The input voltage to the 7805 IC should be at least 2V greater than the required output voltage; therefore it requires an input voltage at least close to 7V.
c. So I chose a 12V centre tapped transformer with current rating 500mA (Since $12*\sqrt{2}=16.97V$).

3.2.7. Rectifying Circuit

Full wave bridge rectifier was adopted

The bridge rectifier converts the ac voltage input to dc voltage at its output.

The choice of the bridge rectifier depends on:

a. Peak inverse voltage.
b. The forward current rating

The diode forward current rating is the maximum current the diode can conduct before failing. The diode should be selected in such a way that the current passing through it should be less than the forward current rating.

The peak inverse output is the reverse voltage that the diode has to block when not conducting.

$$\text{Peak inverse voltage} = \sqrt{2}\ \text{x}V_{rms}$$

Where Vrms=transformer output=12Vac

peak inverse voltage= $\sqrt{2}$ x 12=16.97v

The diodes used has forward current ≥ 500mA and Piv ≥16.97V

The diode IN4007 was used.

3.2.8. Selection of the Filter Capacitor (C1)

The filter capacitor smoothens the dc voltage from the bridge rectifier.

The choice depends on

a. The capacitor breakdown voltage
b. The ripple percentage required

Capacitor breakdown voltage (Vc) is gotten by taking Kirchhoff Voltage Law from the bridge rectifier output to capacitor terminal. Using Figure 5;

$$V_{peak} - V_d - V_c = O \quad (6)$$

Where V_{peak}=bridge rectifier output

V_d=drop across bridge rectifier diodes

V_c=capacitor terminal voltage

$$16.97V - 1.4V - V_c = 0$$

For full wave rectification, on each half section, 0.7V is drop across each of the two conducting diodes. Which gives 1.4V (2 x 0.7V), so that equation (6) becomes

$$15.57 - V_c = 0$$

Where V_c=15.57V

In practices, the rule is to use a capacitor with breakdown voltage double of the terminal voltage

$$V_{C1} = 2 \text{ x } V_c$$

$$V_{C1} = 2 \text{ x } 15.57 = 31.14V$$

A 35V capacitor was chosen.

Capacitance of capacitor

$$C = I\ load / 2fV\Delta \text{for full wave}$$

Where VΔ is the difference between the maximum peak voltage and the Minimum peak voltage.

Maximum peak=15.57v

Minimum peak=15.57 - % ripple

% ripple=15.57 – minimum peak

taking minimum peak=13.57v

% ripple=(15.57 – 13.57)v=2v

$$\therefore C \quad \frac{0.5}{2\ x\ 50\ x\ 2} = 0.0025\,Farad$$

$$= 0.0025F\ x\ 10^6$$

$$= 2500\mu f$$

So, a 2500uf capacitor was selected.

3.2.9. The Current Sensor Unit

This unit measures the current that flows in the output of the transformer. It is connected to the live LINE that supplies the LOAD.

(i) Requirements of the Current Sensor Unit

a. It should be able to accurately give a voltage signal that is proportional to the current that flow in the LIVE wire.
b. Easy principle of operation, easy to use and mount.
c. Easy to Bias i.e. it should involve less biasing components
d. Availability and Cost Effectiveness

(ii) Selection of the Current Sensor Unit

After research, the 45t30A Current sensor module was selected. The module is powered with 5V DC. It can measure up to 30A. Its output ranges from 2.5V to 5V for 0A to 30A linearly.

Below are some of its Features:

a. The current range is 30A.
b. Output type: Voltage from 2.5V to 5V for 0A to 30A linearly.
c. It uses HALL EFFECT method to method the current
d. Requires 5V DC for power.

No biasing components are required, as the output connects directly to the Microcontroller.

3.3. The GSM Unit

Thus unit enables the system send SMS alert showing the temperature and current load of the transformer. SIMCOM900 GSM modem is used here to send SMS containing the notification about the health of the transformer. The microcontroller detect temperature and current signals from both sensor and process it, then communicates with the SIM900 GSM Modem to send the SMS representing the temperature and current value. The interface between the PIC16F877A microcontroller and the GSM modem is serial communication, the GSM modem has USART port and PIC16F877A has USART module, making the communication interface compactable.

All GSM modem operations are controlled by what is called "AT Commands". A Brief explanation is introduced here to show how to send SMS using AT Commands as shown in table1.

Table 1. *Commands sequence to send SMS.*

Syntax	Response
AT + CMG=1 (Press Enter)	OK
AT + CMGS="09xxxxxxxx" (Press Enter)	+CMGS: xx
This is a text (Press Ctrl + z)	OK

Then the algorithm to send SMS will be:

a. Initialize the microcontroller:
b. Serial communication settings: USART (baud=9600, parity=N, 1 stop bit)
c. Send AT to check the GSM connection is ok
d. Send (AT+CMGF=1) to set modem to the text mode.
e. Send (13 and 10) ASCII characters (equivalent to press Enter).
f. Wait one second for the modem response.
g. Send (AT+CMGS="09xxxxxxxx").
h. Send (13 and 10) ASCII characters.
i. Wait one second for the modem response.
j. Send the message content.
k. Send (26) ASCII character (equivalent to press Ctrl+z).
l. Wait one second for the modem response.

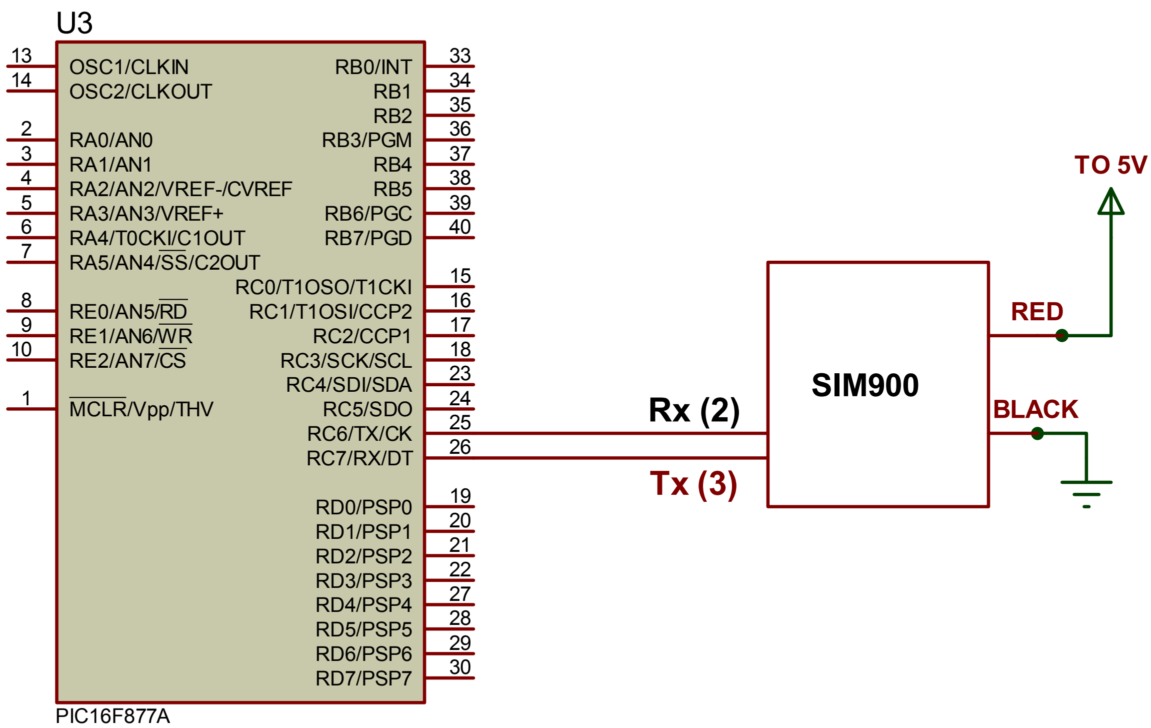

Figure 5. *Interface between the microcontroller and the GSM Module.*

3.4. Software Design

The software design is divided into three stages.

a. The Algorithm Generation
b. Flow Chart representation
c. The Coding.

3.5. Algorithm Generation

An algorithm is a statement of the procedure adopted in solving a problem.

The sequence of the system operation is stated below,

a. Initialize the system on start.
b. Wait for the ADC to finish conversion

c. Read ADC to working memory
d. Compute the ADC value to get the temperature and current
e. Displaying temperature value and current on LCD
f. Send temperature value and current as SMS through GSM module
g. End Process.

3.6. Flow Chart

The flow chart gives a graphical representation of the sequence of program execution. The flow chart for the system is given in figure 6.

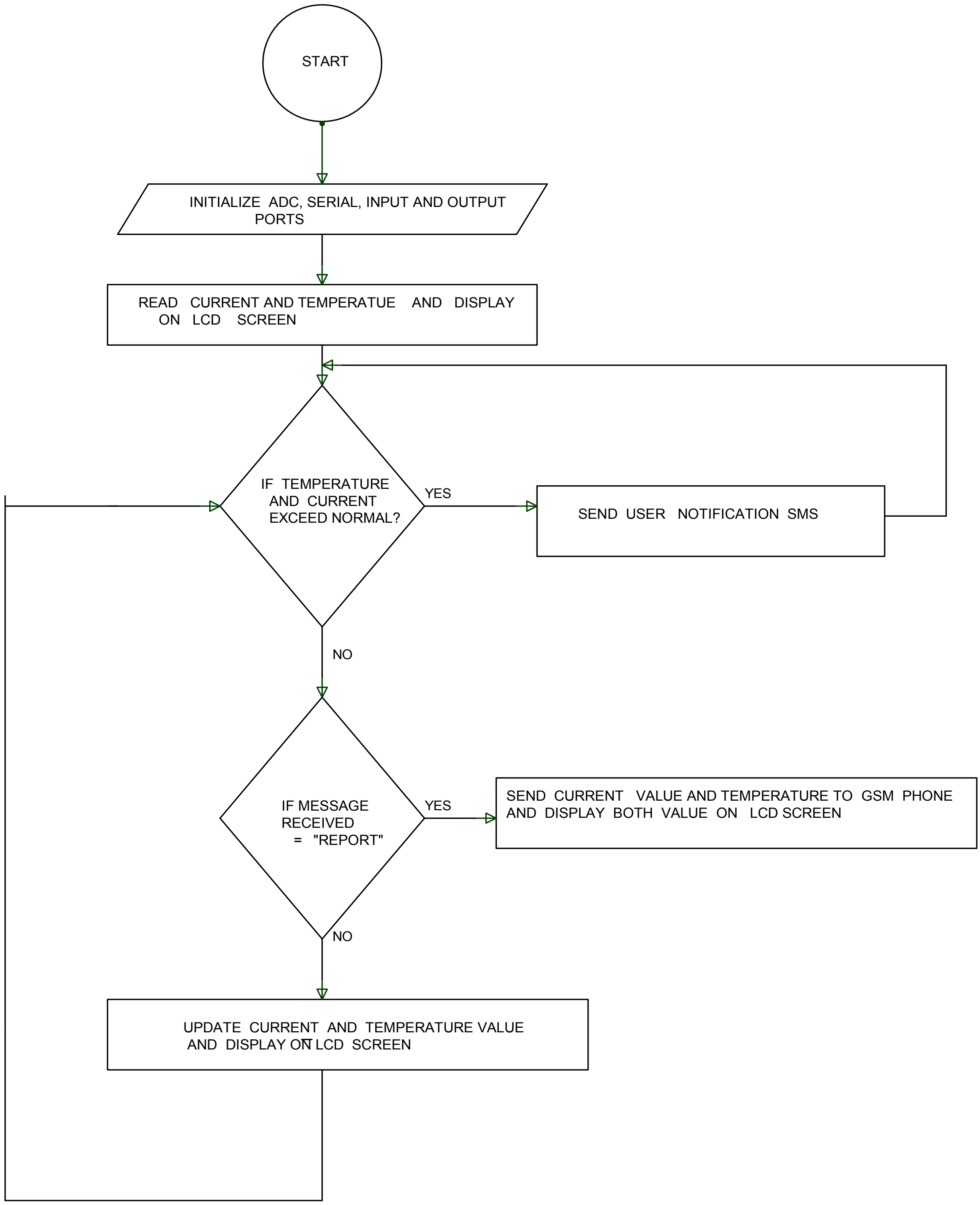

Figure 6. *Flow chart diagram.*

Circuit Diagram

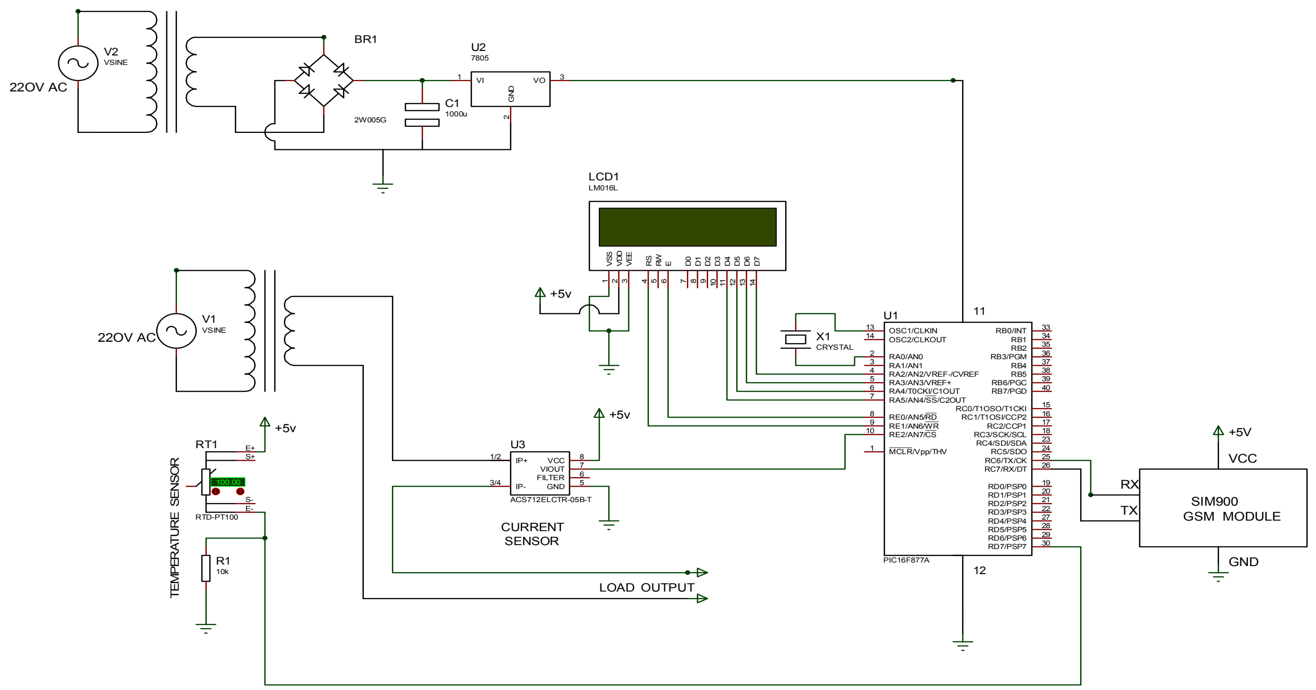

Figure 7. *Complete Circuit Diagram of a Transformer Monitoring System using GSM. s.*

3.7. Coding

The coding is done in C Language. The code contains the instruction of program to direct the affairs of the temperature Transmitter. There are five subroutines in the complete code. Each subroutine performs specific function as group of instructions. The subroutine and functions are stated as follows.

1. Initialization: This subroutine initializes the microcontroller including preloading the counters, ADC, LCD and reference values for the system.
2. Read ADC: This subroutine makes the controller to wait for the ADC to do its conversion, and after the conversion, reads the value into its data memory.
3. Binary to Hexadecimal Conversion: This subroutine converts the binary value of the ADC to Hexadecimal for display in the LCD.
4. Compute: The subroutine the ADC value with the equation 3.4 and 3.3 to get the temperature and current value of the transformer.
5. Display LCD: This subroutine enables the microcontroller to display value on the LCD.

Table 2. *Test and Result.*

Test	Aim	Equipment Used	Result	Conclusion
Open circuit test	To delete any possible open circuit fault on the open circuit board.	Digital multimeter.	The meter reads resistance less than one.	There is no open circuit fault on the circuit board.
Short circuit test	To delete any possible short circuit fault on the circuit board.	Digital multimeter.	The meter reads infinite resistance.	There is no short circuit fault.
Operation test	To ascertain the functionality of the project work.	The circuit was connected to the power supply and operated.	There was a feedback when the system was tested	The unit operated as required.

4. Discussion

During test, the detected values of transformers parameters such as voltage, current and temperature were displayed on the screen of the liquid crystal display. These values represent the ability of the device to sense the operating condition of the transformer under test. The incorporated GSM module transmitted the measured voltage, current as well as temperature that levels to stand-by telephone that was customized to receive signals from the module. So, in the event of any abnormal variation in the operating values in the transformer, the operator will be duly informed in order to act accordingly.

5. Conclusion

A remote microcontroller based sensor for monitoring power transformer during working condition has been developed and tested successfully, with an embedded GSM module for sending messages of measured parameters to the operator. And so, there is no need of any physical presence in the vicinity of the transformer substation to inspect or take measurement which is the usual practice by the power distribution companies operating in Nigeria. This method will drastically reduce the risk of damages caused by excessive and abnormal voltages, currents and temperature that often characterize power distribution transformers mostly when they operated beyond their standards. It also enhances the prevention of accidents which could be very severe as to causing loss of lives and property. Hence, there is improved reliability of power distribution to consumers as a result of minimum breakdown or power outage. Finally, maintenance and overhead cost of power distribution will also be reduced.

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