Automated Monitoring and Reporting System for Faulty Distribution Transformer Using GSM Technology

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ABSTRACT--The research work entails the design of an automated, real-time system that ensures prompt reporting of lost transformer phase caused by blown low voltage fuse, over-voltage supply to consumers. The research is based on microcontroller monitoring of low voltage fuse and GSM based reporting of the blown fuse, neutral failure and transformer trip to the Distribution System Operator (DSO) for immediate action in restoring power supply from the affected transformer. The work comprises blown fuse detector unit, main phase voltage sensor, main controller unit, GSM modem and LCD unit. The main controller unit is the ATMEGA328P microcontroller with its instruction set written in C language. It sends signals to both the GSM modem and the LCD unit whenever over-voltage supply, blown fuse, no voltage supply from transformer is detected. The GSM modem sends a pre-programmed SMS to the DSO indicating either an over-voltage supply or blown fuse or no voltage supply, by stating the particular transformer involved in the SMS for quicker identification and restoration. The LCD unit displays a confirmation of the sent SMS and shows the over-voltage value and as well the phase with blown fuse. The system was developed, tested and it worked satisfactorily.

Keywords: Distribution transformer, GSM Modem, Microcontroller, LCD.

1.0 Introduction

In recent years, greater emphasis has been made on the reliability of power and economy. Frequent changes in the power industry led to increased interest in more economical and reliable methods to generate, transmit and distribute electric power. In this regard, monitoring the status and operational posterity of equipment that constitute the system is critical to ensure that the supply of power can meet the demand.

The inability of electric power distribution service providers in Nigeria to set up an automated, proactive technical process that ensures prompt response in reporting either lost phase of distribution transformer resulting from blown low voltage fuse or over-voltage supply by the transformer caused by the transformer low voltage neutral failure, affects the reliability of the distribution network, availability of power and supply of proper voltage value to three (3) phase consumers in the network.

Electric power systems comprise generation system, transmission system and distribution system as shown in figure 1.

The transmission system involves the transfer of electric power from power generators to customer area, whereas a distribution system provides an ultimate link between high voltage transmission systems and consumer services. In other words, power is distributed to different customers in distribution system through feeders, distributors and service mains. Power from the transmission grid is conveyed to distribution injection substations where the voltage is stepped down(typically 11kV) and carried by distribution lines (feeders) to supply commercial, industrial users and as well further stepped down by distribution transformer and carried by distributors to supply residential users. [1]

Monitoring in the context of this research entails remote collection of data/information for real-time application.

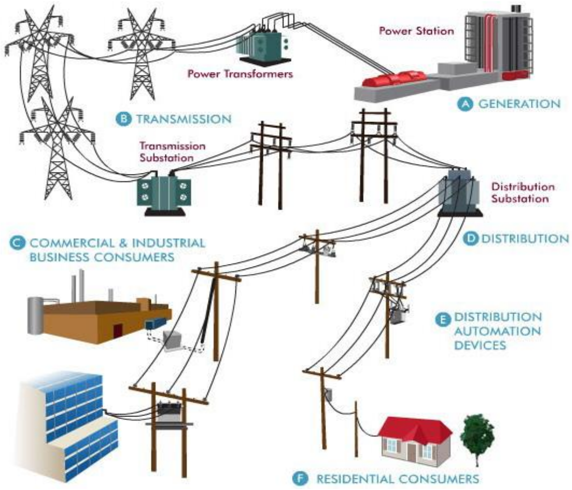

Figure 1: Electric Power System showing Generation, Transmission and Distribution Systems

1.1 Distribution Transformer

A distribution transformer is a transformer responsible for final voltage transformation in the electric power distribution system, stepping down the voltage used in distribution line to the level used by the power consumer.

Among different purposes of transformers, distribution transformers are one of the most important equipment in power network. Data acquisition and condition monitoring is very necessary due to the large number of distribution transformers installed over a wide area in power electric systems. Since it is an integral part of substation, strategic bottle necks occur if we fail to monitor the transformer.

In electric power systems, distribution transformer is electrical equipment whose responsibility is to distribute power to the low-voltage consumers, and its operation condition is an important component of the entire distribution network operation. A typical Distribution transformer is shown in figure 2.

Operation of distribution transformer under rated condition (as per specification in their nameplate) guarantees their long life. However, their life span is significantly reduced when they are subjected to overloading, resulting in unexpected failures and loss of phase/supply to a large number of customers thus affecting the system reliability [2],[3].

The present use of mobile networks and GSM devices such GSM modems and their cheap operational and maintenance costs have made them an attractive option not only for voice media but for other wide area network applications.

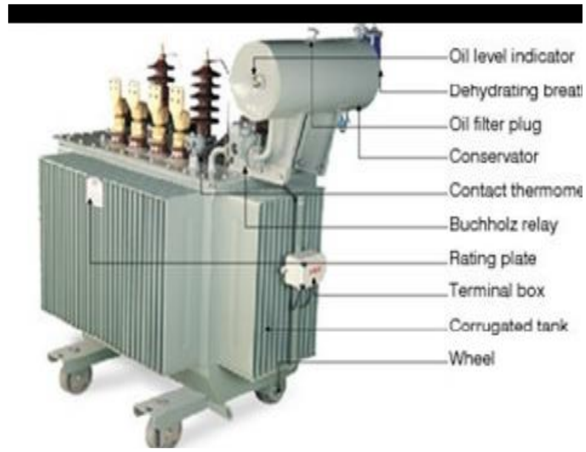

Figure2: Typical Distribution Transformer

This research work is based mainly on the low voltage (LV) step down distribution transformer such as the transformers of ratings; 11/0.415KV, 33/0.415KV etc. The work shows automated, real-time monitoring and reporting of loss of transformer phase or blown low voltage fuse for the particular phase and reporting of over-voltage supply by transformer to consumers due to the transformer neutral failure. Distribution transformers in rural or remote areas have their blown low voltage fuse or the affected phase remains open due to the absence of an automated transformer phase monitoring system. This problem affects the reliability of the distribution network and availability of power to consumers on demand.

Also non automated remote reporting of over-voltage supply due to transformer neutral failure to DSO for prompt isolation of the faulty transformer causes heavy damage to consumers' electronic equipment by high voltage.

1.2 Microcontroller Unit

The Arduino Uno is a microcontroller board used by the ATmega328 microcontroller. It has 14 digital input/output pins (of which 6 can be used as pulse width modulation, PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, a reset button and System Programmer header as shown in figure 3. The board has all that microcontroller needs but it needs to be connected to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Uno board is different from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega328 programmed as a USB-to-serial converter. “Uno" in Italian means "One". The Uno is the latest version of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions.

The technical Specifications are:

- Microcontroller ATmega328 with its Pinout shown in figure 4.
- Operating Voltage 5V
- Supply Voltage (recommended) 7-12V
- Maximum supply voltage (not recommended) 20V
- Digital I/O Pins 14 (of which 6 provide PWM output
- Analog Input Pins 6
- DC Current per I/O Pin 40mA
- DC Current for 3.3V Pin 50mA
- Flash Memory 32 KB (ATmega328) of which 0.5 KB used by boot loader
- SRAM 2 KB (ATmega328)
- EEPROM 1 KB (ATmega328)
- Clock Speed 16 MHz

Figure3: The Arduino uno microcontroller board

Figure 4: The Pin-out of ATmega328 microcontroller

1.3 GSM Modem

GSM Modem offers high speed wireless connection. It is attached to the microcontroller RS-232 data adapter and can be used as a standalone modem. It can be connected to a personal computer, standalone embedded system or other devices through their serial ports. The GSM modem is used as a short message server (SMS) device. This GSM modem can only send and/or receive messages having a maximum of 160 characters. In this application, GSM modem is interfaced with the microcontroller through its RS-232 adapter. The modem receives a message from the microcontroller that contains the transformer information such as transformer ID or name and its location. It will then transmit the parameters as an SMS to pre-stored GSM device number according to a preset policy. The receiver can be the utility personnel such as the system operator, maintenance technician. [4]

A GSM modem is a wireless component that can work in a GSM wireless network. A wireless modem is like a dial-up modem. The major difference the dial-up modem and GSM wireless modem is that dial-up modem sends and receives data through a fixed telephone line while the GSM wireless modem sends and receives data through waves. Like a GSM mobile phone, a GSM modem also requires a SIM card from a wireless carrier to operate. A typical SIM900A GSM modem is shown in figure 5.

Figure 5: SIM 900A GSM Modem

1.5 Liquid Crystal Display (LCD)

LCD (Liquid Crystal Display) is an electronic or digital display component. A 20x4 LCD display is a very basic system and commonly used in various devices and circuits. The advantages of LCD's are as follows:

- LCDs are economical.
- They are easily programmable.
- A number of characters can be displayed.
- Very compact and light.
- Low power consumption.

A 20x4 LCD means it can display 20 characters per line and 4 such lines are there. For this LCD type each character is displayed in 5x7 pixel matrix. LCD possesses two registers: Data and Command registers. The command instructions given to the LCD are saved or stored in the command register. A command can be explained as a directive or instruction given to LCD to do a predefined or designated task. For example resetting the screen, initialize the LCD, controlling the cursor position, and controlling the display. Data that are usually displayed on the LCD screen are stored in the data register which include the ASCII value of the character that are usually displayed on the LCD screen. A typical LCD type and Pin diagram is shown figures 6 and 7 respectively.

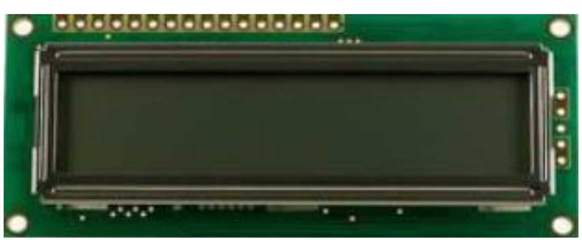

Figure 6: 4x20 LCD Display

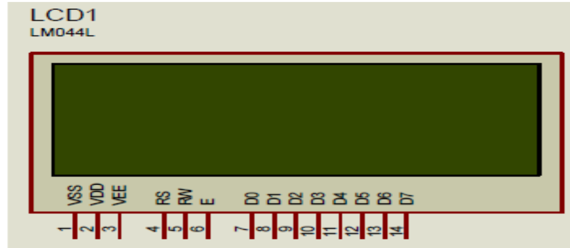

Figure7: LCD Pin Diagram

2.0 Review of Related Research Works

During the past years, a number of researches were conducted with the help of microprocessors and controllers for continuous monitoring of distribution transformer parameters like voltage, current and temperature fluctuations. The level of voltage and current at the substations may vary drastically due to increase in temperature at the distribution transformers. It is capable of recognizing the breakdowns caused due to overload, high temperature and low level of oil and will shut down the unit if the increase in temperature rises higher than the desirable temperature [5].

Authors of [6]-[8], developed a mobile system that monitors and diagnoses condition of transformers, by recording key operational indicators of the distribution transformer like load currents, transformer oil temperature, ambient temperature and voltages. Their proposed on-line monitoring system integrates a Global Service Mobile (GSM) Modem, with a solid state device named PLC (programmable logic controllers) and sensor packages. Data for the operation conditions of transformer were received in form of SMS (Short Message Service).

In [9], the authors developed GSM based Distribution Transformer Monitoring System that monitors and records key parameters of a Distribution transformer like load currents, oil levels and ambient temperature. The idea of this real-time monitoring system integrates a global service mobile (GSM) modem, with microcontroller and different sensors. The system is installed at the distribution transformer site and the above parameters are recorded using the analog to digital converter (ADC) of the embedded system. The obtained parameters are processed and recorded in the system memory. If any abnormality or an emergency situation occurs the system sends SMS message to the mobile phones containing information about the abnormality according to some predefined instructions programmed in the micro-controller.

The authors in [10] designed and developed a real-time distribution Transformer Health Monitoring System using GSM technology. This system presents design and implementation of a mobile embedded system to monitor load currents, over voltage, transformer oil level and oil temperature.

Other method of monitoring transformer is the manual approach. In earlier works, oil level, float level, temperature level, overload was measured manually by the maintenance team always visiting the transformer site. These levels were checked periodically by the operating personnel but were very tedious and inefficient way of monitoring the transformer.

The reviewed works showed various monitoring, control and protection measurements of distribution transformers and power supply, but failed to provide a robust, prompt and sophisticated embedded system that will improve the performance metrics or status of the distribution network.

3.0 Automated Monitoring and Reporting System using GSM Technology

The block diagram of GSM-based monitoring and reporting system is shown in figure 8.

For simplicity, the block diagram is shown for the system that can monitor one distribution transformer.

The proposed system consists of power supply unit, blown fuse detector units, main phase voltage sensor, main controller unit, GSM modem and LCD unit.

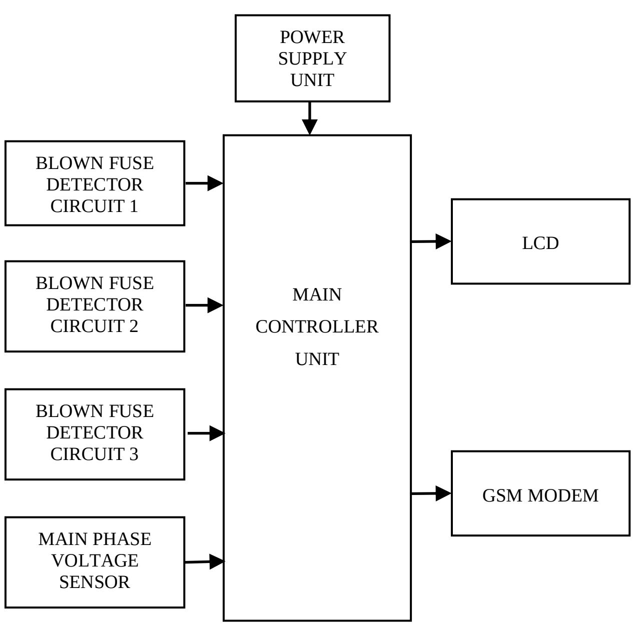

Figure 8: Block diagram of automated monitoring and reporting system using GSM technology

3.1 Power Supply Unit

The power supply unit is an electronic circuit which supplies regulated 5VDC to components in the system. This circuit comprises of 220/12V, 300mA step down transformer, a bridge rectifier and also voltage regulator (7805). It also has a 12VDC rechargeable battery back-up. The circuit diagram for the power supply unit is shown in Figure 9.

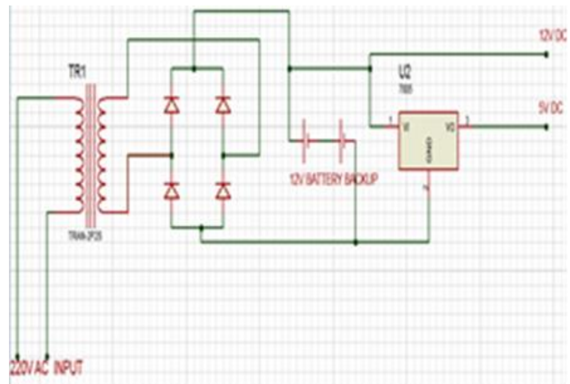

Figure 9: Power supply circuit diagram

3.2 Blown Fuse Detector Unit

The blown fuse detector unit in this system is a voltage sensor that always monitors the status of the transformer low voltage fuses. Its input terminals are connected across the low voltage fuse at each of the three phases of the low voltage side of the distribution transformer. The blown fuse detector senses the phase voltage value (normal voltage) across the fuse and sends an analog voltage signal (5V or HIGH digital signal) to the microcontroller when the fuse is still intact. It senses a no voltage value (no voltage) across the fuse and sends an analog voltage signal (0V or LOW digital signal) to the microcontroller when the fuse is blown. The blown fuse detector unit is shown in figure 10. It comprises of a 415/12V transformer, bridge rectifier, paper capacitor, and a potentiometer. The output voltage of the rectifier and filter circuit serves as input to a voltage divider network of resistors R1 and R2 as shown infigure11.

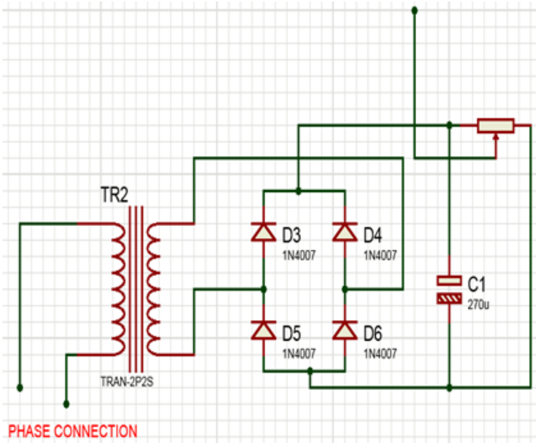

Figure 10: Blown Fuse Detector circuit diagram

3.2.1 Signal Conditioning in a Voltage Sensor Circuit

The circuit diagram for the fuse detector unit and main phase voltage sensor connected at transformer low voltage side are the same, since both of them sample and sense phase voltages and also have same operating principle. The analog signal realized after the bridge rectifier is 12V filtered DC voltage. This value is not suitable for the ADC of the microcontroller used in the system which tolerates a maximum of 5VDC.Thus, the need for a simple signal conditioning circuit as shown in the figure 11 arises.

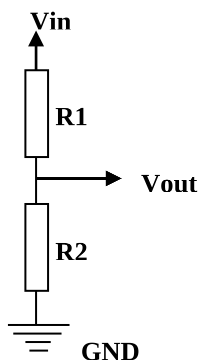

Figure 11: Signal conditioning circuit (Voltage divider network)

Note;

- Vin is the output voltage of the voltage sensor circuitry.
- Vout is the conditioned signal.
- R1 and R2 are conditioning resistances.

In our design we replaced the above circuitry with a variable resistor of 10kΩ.

From voltage divider principle;

Vout = [(R2 x Vin) / (R1 +R2)]

But R1+R2 =10kΩ since we are using a 10kΩ variable resistor.

Vin = 12VDC

Vout = 5VDC

We need to find the value of R2, which corresponds to the resistance the variable resistor will be tuned so as to give a maximum voltage of 5VDC.

R2 =50/12 = 4.1kΩ

Therefore it is either we use a 10kΩ variable resistor and tune it to get 4.1kΩ or we use two fixed resistors of 5.9kΩ and 4.1kΩ to condition the Vout to 5VDC, which is the maximum the microcontroller ADC can take.

Practically, the variable resistor should not be tuned to the maximum and to be on the safe side, we used 4VDC and calibrated to get exactly what we want.

We used a 10bit ADC.

The 4VDC will be divided into $4/2^{10}$ = 4/1024 = 0.00390625V

This implies that every change in voltage of about 0.00390625V will be detected by the ADC.

So we mapped 4VDC to 220VAC (415VAC), thus calibrating the system to achieve what we are expecting.

3.3 Main Controller Unit

The main controller unit is the ATmega328P microcontroller. It receives and analyzes analog signals from blown fuse detector units and main phase voltage sensor connected at transformer low voltage side through its analog to digital converter (ADC) ports. When the microcontroller receives a no voltage (0V or LOW digital signal) analog signal from both the blown fuse detector unit and main phase voltage sensor, it sends two signals simultaneously; the first signal to the LCD that displays “BLACK-OUT” on the LCD, signifying that there is no voltage supply from the transformer and the second signal, to the GSM modem for onward SMS to the Distribution System Operator (DSO) indicating that the transformer is OFF. When the microcontroller receives a normal voltage (5V) analog signal from both the blown fuse detector unit and main phase voltage sensor, it sends a signal to the LCD that displays “FUSE ACTIVE” on the LCD, signifying that the fuse is still intact while there is real voltage supply from the transformer. When the microcontroller receives normal voltage (5V) analog signal from the main phase voltage sensor and a no voltage (0V) analog signal from the blown fuse detector unit, it sends two signals simultaneously; the first one to the LCD that displays "FUSE BLOWN" on the LCD, signifying that the fuse is blown while there is real voltage supply from the transformer and the second signal, to the GSM modem for onward SMS to the Distribution System Operator (DSO) indicating that the fuse is blown. Also, the microcontroller continuously compares the voltage values received from the fuse detector units for the three phases with the standard maximum voltage limit as stated by ANSI C84.1(90% $\leq$ V $\leq$ 106% of the nominal voltage value)and whenever the received value is greater due to transformer neutral failure leading to over-voltage supply, the microcontroller sends signal to both GSM Modem and LCD unit for onward transmission of SMS to the DSO and display of the over-voltage value on the LCD unit.

Table 1: Digital Explanation of the Role of Microcontroller using Logic Table.

Blown Fuse Detector	Main Phase Voltage Sensor	Result	Comment
0	0	0	Transformer trip (OFF)
0	1	0	Fuse blown
1	0	0	Does not exist
1	1	1	Fuse is ACTIVE

3.4 GSM Modem

The GSM modem receives three signals from the main controller unit, the first signal signifies that the particular transformer is OFF (not supplying voltage) and it sends a pre-programmed SMS to Distribution System Operator indicating that transformer is OFF. The second signal signifying a blown fuse, the GSM modem sends a pre-programmed SMS to the Distribution System Operator informing the personnel that a particular transformer has a blown fuse. The third one indicating over-voltage supply due to transformer low voltage neutral failure, the GSM Modem sends a pre-programmed SMS to DSO informing the personnel of a particular transformer with a neutral failure so that the DSO can isolate the transformer for quick repair, energization of the transformer and restoration of supply to consumers from that transformer.

3.5 LCD

LCD displays the status of the transformer it is monitoring. It is a type fault diagnostic display, showing the power provider maintenance team, who are on routine maintenance check or have been invited by the system's SMS on the transformer status or which of the transformer secondary phases has blown fuse or displays the over-voltage value from the transformer due to its neutral failure. This helps the maintenance team to be specifically directed to the faulty section, thus reducing the downtime spent in restoring the lost transformer phase. The LCD displays the particular phase whose low voltage fuse blew after displaying "FUSE BLOWN" and also displays "BLACK-OUT" when the transformer is not active or off.

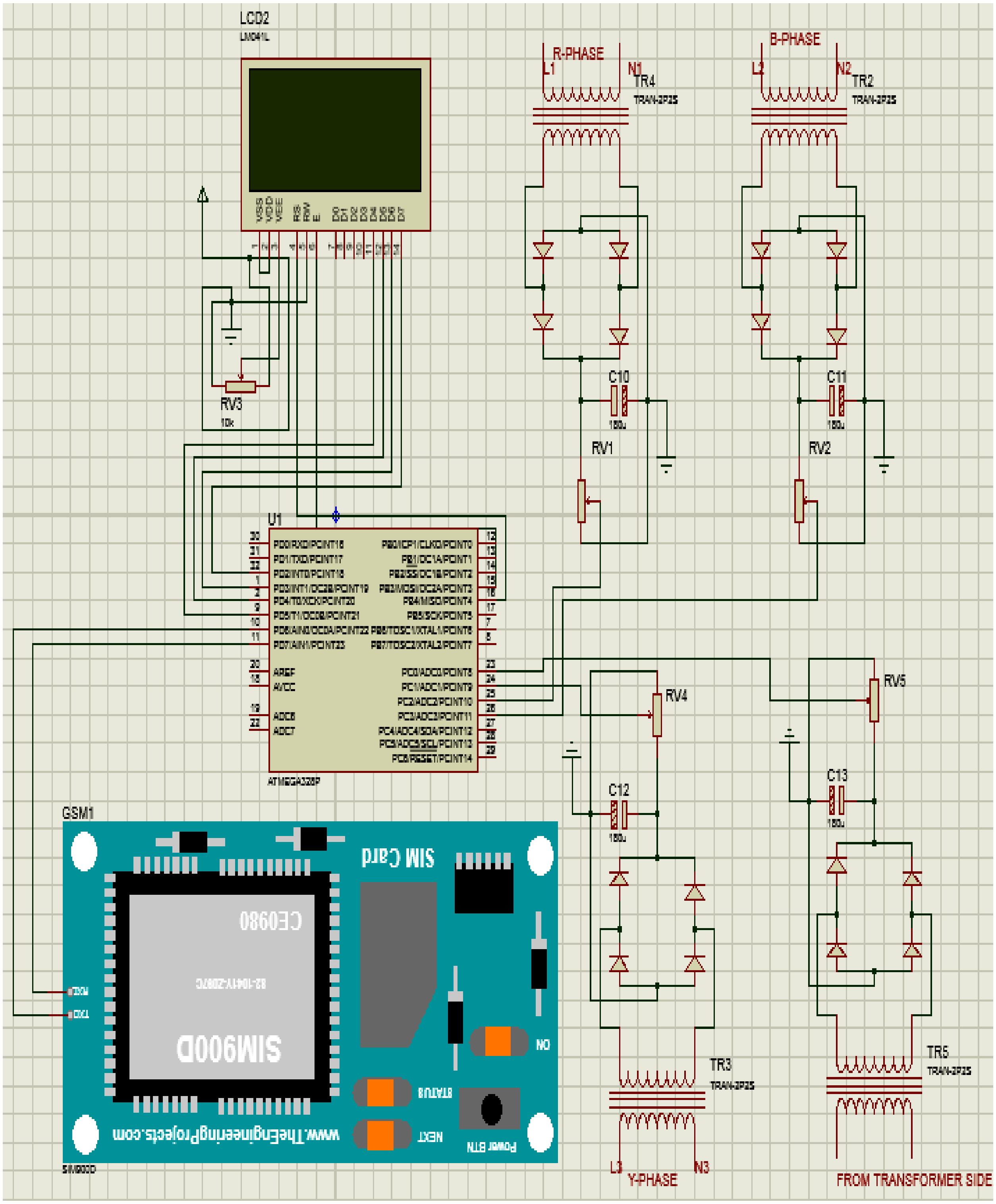

Figure 12: Circuit diagram of distribution transformer phase monitoring system using GSM technology

3.5 Operating Principle of the Automated Monitoring and Reporting System

The system provides an automated mode of contacting the agent of the power provider which is the Distribution System Operator (DSO) using GSM SMS, about the lost phase of transformer resulting from blown low voltage fuse, over-voltage supply from the transformer due to the transformer neutral failure, and no voltage supply from the transformer as a result of the transformer trips on fault despite the fact that the transformer's service 11KV feeder is still active or energized. The blown fuse detector unit monitors the low voltage fuses in each of the phases. When a fuse is blown, the detector circuit sends a no voltage (0V) analog signal to the microcontroller, who also analyzes the analog signal received from the main phase voltage sensor to ascertain if there is a real voltage supply from the transformer (if the transformer is active). Whenever the microcontroller receives a normal voltage (5V) analog signal from the main phase voltage sensor and a no voltage (0V) analog signal from the blown fuse detector unit, it sends two signals simultaneously; the first one to the LCD that displays “FUSE BLOWN” on the LCD, signifying that the fuse is blown while there is voltage supply from the transformer and the second signal, to the GSM modem. Also, when the microcontroller receives a no voltage (0V) analog signal from both the blown fuse detector unit and main phase voltage sensor, it sends two signals simultaneously; the first signal to the LCD that displays “BLACK-OUT” on the LCD, signifying that the transformer is not active and the second signal, to the GSM modem for onward SMS to the Distribution System Operator indicating that the transformer is OFF.

The microcontroller continuously compares the voltage values received from the fuse detector units for the three phases with the standard voltage limit as stated by ANSI C84.1 and whenever the received value is greater than the maximum limit of the standard range due to transformer low voltage neutral failure leading to over-voltage supply, the microcontroller sends signal to both GSM Modem and LCD unit for onward transmission of SMS to the DSO and display of the over-voltage value on the LCD unit.

The GSM modem, on receiving a HIGH signal from the microcontroller sends a pre-programmed SMS to the System Operator informing them that a particular transformer has either a blown fuse or a neutral failure.

The LCD displays “FUSE BLOWN” when it receives the specific signal from the controller and also displays the particular phase whose low voltage fuse blew after displaying “FUSE BLOWN”.

The LCD also displays “BLACK-OUT” when it receives the signal from output ports of the controller signifying that the transformer is OFF (not active).

It also displays the over-voltage value from the transformer whenever there is transformer neutral failure.

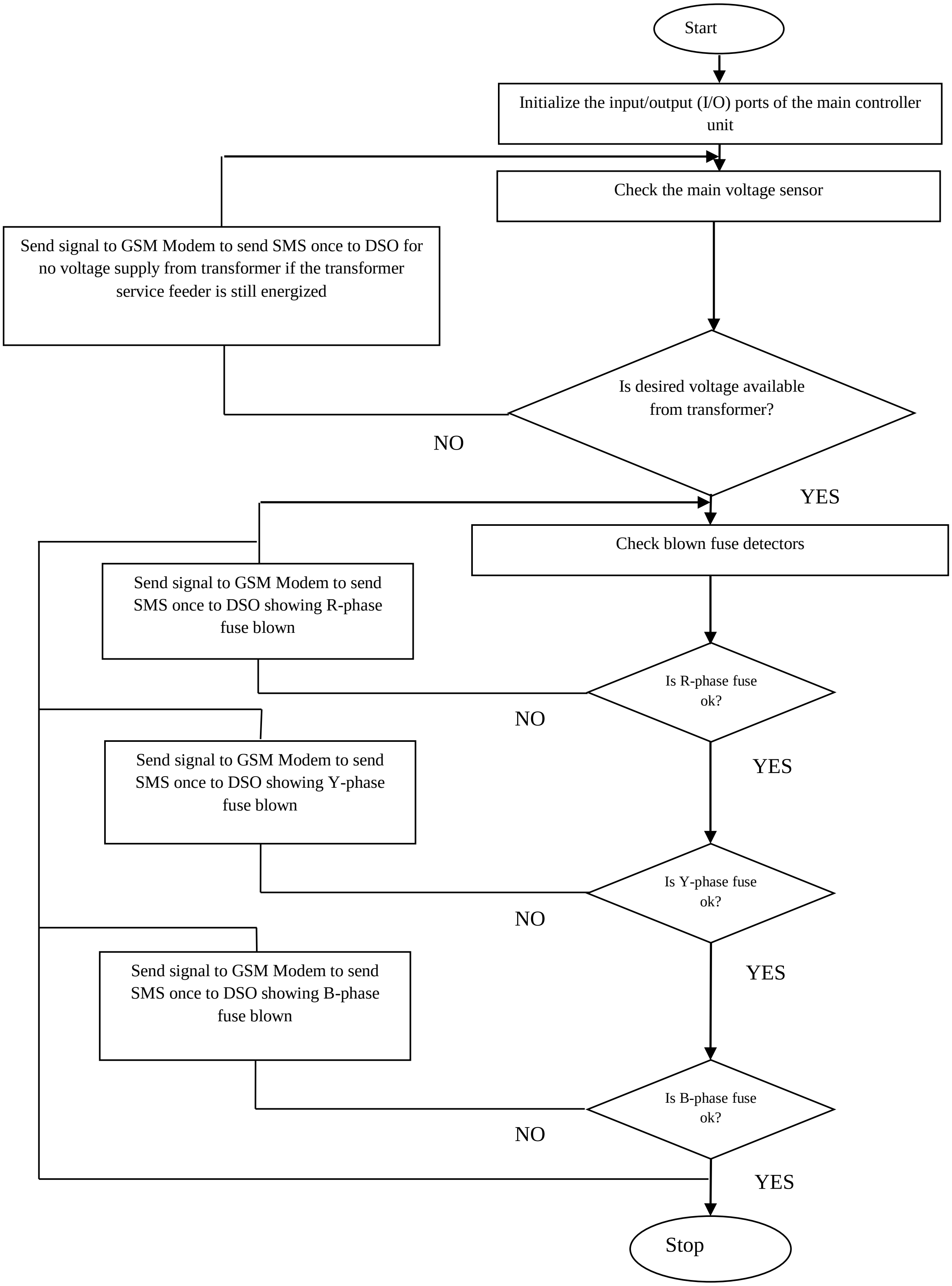
Start
Initialize the input/output (I/O) ports of the main controller unit
Check the main voltage sensor
Send signal to GSM Modem to send SMS once to DSO for no voltage supply from transformer if the transformer service feeder is still energized
Is desired voltage available from transformer?
NO
YES
Check blown fuse detectors
Send signal to GSM Modem to send SMS once to DSO showing R-phase fuse blown
Is R-phase fuse ok?
NO
YES
Send signal to GSM Modem to send SMS once to DSO showing Y-phase fuse blown
Is Y-phase fuse ok?
NO
YES
Send signal to GSM Modem to send SMS once to DSO showing B-phase fuse blown
Is B-phase fuse ok?
NO
YES
Stop

Figure 13: Flowchart diagram of Distribution transformer blown low voltage fuse/phase monitoring system using GSM technology

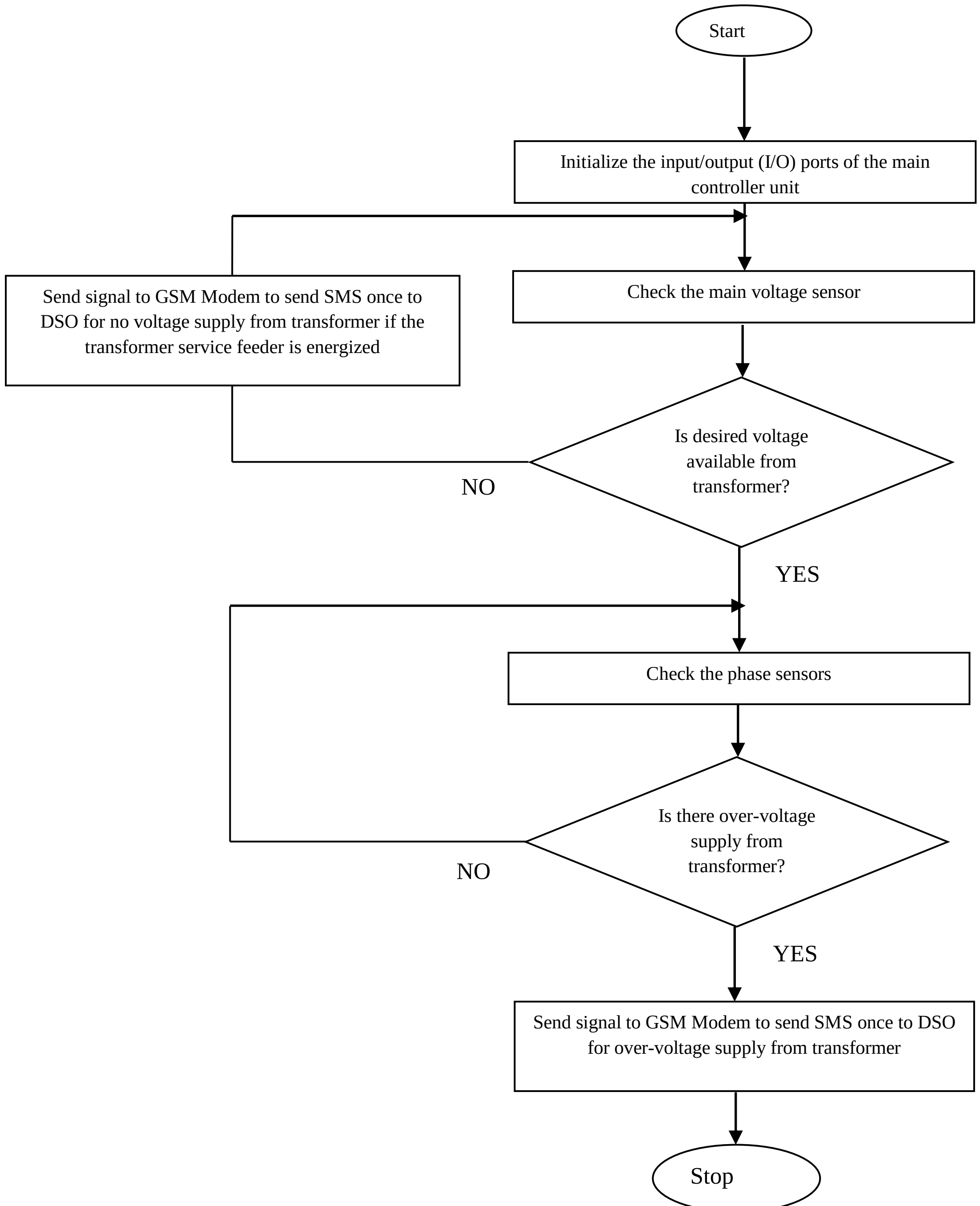

Figure 14: Flowchart diagram of Distribution transformer low voltage neutral failure monitoring system using GSM technology

4. Conclusion

This research work involves development of automated monitoring and reporting system using GSM technology to facilitate an automated and prompt notification to power distribution providers about blown low voltage fuse or loss of phase in a distribution transformer phases, over-voltage caused by transformer low voltage neutral failure and no voltage supply from transformer as a result of the transformer on fault.

The system was built around ATMEGA328P microcontroller as the main controller unit, together with blown fuse detector unit, main phase voltage sensor, GSM modem and LCD unit.

5. Recommendations

Power providers are encouraged to adopt this method of an automated reporting of blown low voltage fuses as this would enhance faster period of restoring the lost transformer phase and will as well reduce downtime associated with identification and location of the fault.

Power regulatory body (NERC) should enforce that power providers apply and implement this work since it informs power providers when a particular transformer trips on fault, notwithstanding that there is voltage on the 11KV feeder supplying it. This indication of transformer being off "BLACK-OUT" shown both as a display on LCD and as SMS sent to the Distribution System Operator (DSO) discourage wrong estimation energy bill calculation pattern used by power providers where they calculate for unmetered customers' energy bill by using the number of hours their 11KV feeder is ON irrespective of the fact that their particular distribution transformer tripped on fault and was not active due to some other faults.

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