DEDAN KIMATHI UNIVERSITY OF TECHNOLOGY.

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING.

TITLE:

GSM-BASED DISTRIBUTION TRANSFORMER PARAMETERS MONITORING AND TAMPERING DETECTION SYSTEM

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This project report is submitted in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical and Electronics Engineering, Dedan Kimathi University of Technology

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DECLARATION

This project report is our original work, except where due acknowledgement is made in the text, and to the best of our knowledge has not been previously submitted to Dedan Kimathi University of Technology or any other institution for the award of a degree or any certification.

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LIST OF ABBREVIATIONS

AC - Alternating Current

CT - Current Transformer

DC - Direct Current

EN - European Norm

GPS - Global Positioning System

GSM - Global System for Mobile Communications

HMI - Human Machine Interface

HV - High Voltage

I/O - Input/Output

IEC - International Electrotechnical Commission

IR - Infra-Red

kV - kilovolt

LV - Low Voltage

RMS - Root Mean Square

RTDs - Resistance Temperature Detectors

SCADA - Supervisory control and data acquisition

SIM - Subscriber Identity Module

SMS - Short Message Service

U.S. - United States

ABSTRACT

In an electrical distribution network, distribution transformers are one of the most vital assets and yet the most prone components to failures and vandalism. To effectively manage these frequent transformer failures and tampering, power companies have delved deeply into this issue by employing various methods to curb this. Still, proper parameters monitoring and intruder detection methods had not been realized. An effective parameter monitoring and tampering detection system will continuously monitor the transformer's conditions for immediate action to be taken.

Therefore, GSM-based technology was developed to monitor distribution transformer parameters for fault detection and tampering detection since it is real-time, wireless, economical, and reliable. This project was prototyped to monitor load currents, voltage, transformer temperature, and oil level and for tampering detection. Parameters monitoring will ensure the safety of the transformer and reduce human reliance. The results from the system sensors were processed to determine the status of distribution transformer. If there is any abnormality or an emergency situation the system sends SMS (Short Message Service) messages to designated mobile telephones containing information about the abnormality according to some predefined instructions and policies. This mobile system will help the utilities to optimally utilize transformers and identify problems before any catastrophic failure.

CHAPTER 1: INTRODUCTION

1.1 Background

Electric energy has experienced improvements over time in energy sources, such as the construction of electric grid networks to ensure its supply has been endless since its inception and widespread use in the past centuries. The fulcrum between the consumer loads and the grid is the distribution transformer. The significance is only matched by the excessive expenditures on obtaining and maintaining them. An electrical equipment distribution transformer distributes power directly to low-voltage users in power systems, and the condition of its operation is an essential criterion for the overall network functioning [1]. As a result, engineering professionals are concerned about distribution transformer failure.

Distribution transformers operated at rated conditions (as specified on their nameplate) have a long service life [2]. However, suppose they are overloaded, heated, or exposed to low or high voltage/current. In that case, they will experience sudden breakdowns and loss of power to many consumers, compromising system reliability. Different factors such as winding temperature, oil temperature, ambient temperature, load current, moisture, dissolved gas in oil, oil level, and bushing condition affect the performance and efficiency in distribution transformers [3]. Oil pollution, overloading, moisture in the oil/insulation, design/manufacturing flaws, and insulation failure are all possible causes of transformer failure. Insulation failure is the most common cause of failure [4].

The core fails to owe to D.C. magnetization or core steel displacement during transformer construction. Short circuit and transient overvoltage are the most common causes of winding failure [5]. Internal arcing in an oil-filled transformer can evaporate the surrounding oil, causing a high gas pressure inside the transformer and potentially rupturing the tank. The movement of the transformer or the forces created during short circuits causes mechanical damage to solid insulation. Cooling coil failure can be caused by either a problem with the oil circulation system or a lack of heat transfer to the secondary cooling circuit [6]. The primary failure mode of the bushing is a short circuit. It may be due to material faults in the insulation or damage [7]. In most developing countries, Kenya included, distribution transformers (11kV to 415V) are manually monitored, with a person visiting the transformer site regularly for maintenance and recording these parameters: load current, over-voltage, oil level, oil temperature, winding temperature, and ambient temperature. Overloads and overheating of transformer oil and windings cannot be detected using manual monitoring since, currently, overloads and overheating can only be detected after the fault has already occurred. All of these parameters can shorten the life of your transformer [8]. The electric and thermal parameters related to these failure causes must be monitored and regulated to remedy them.

The primary way to protect the distribution transformer is to keep track of load current, over-voltage, oil level, oil temperature, winding temperature, and ambient temperature. GSM technology to monitor these parameters generates an SMS notification when operating limits are exceeded, allowing for early fault correction. Passive instruments with deflection dials are used in developing countries to measure top oil and winding temperature, oil level, and pressure levels [9]. The readings are recorded by the maintenance crews once a day. The lack of real-time information allows for unnoticed failure, but it also prevents decisions like maintenance scheduling from being guided by the current transformer state. Human-in-the-loop transformer inspection procedures are prone to many errors and allow for the development of defects and consequent mishaps.

This project entails the creation of a system that overcomes human error limitations, avoids disruption due to sudden and unexpected failure, and provides real-time data on the monitored parameters. Attempts made include a microcontroller-based cooling control system. Monitor for pole transformers using the MSP430-F2013 microprocessor, SCADA system, and manual inspection by technicians [10]. These may have attempted to address the problem of transformer monitoring. Still, they include weaknesses such as complex communication topologies, inadequate hardware for severe conditions, and the utilisation of expensive equipment [11]. Therefore, an effective system that monitors the key parameters whose variations affect the distribution system is still a need by utility company. Loading distribution transformers above their rated capacities and power cooling systems are the two significant causes of transformer failure. Accurate time monitoring of these critical parameters is necessary for evaluating the performance of the distribution transformer and is also helpful in avoiding or reducing outages and consequent loss of revenue to the company. These are just a few of the issues that necessitated using a GSM-based parameters monitoring and tampering detection system that is flexible, economical, real-time, and reliable. While the transformer is energised, it will collect real-time data and relay it to the specified mobile system via SMS. Practical actions may be made to correct faults and extend the life of the distribution transformers [12].

Moreover, many transformers that deal with voltages such as 33KV/11kV are usually situated in various distribution network substations. But the 11kV/0.415KV transformers are typically placed on electric power poles near household areas. As most of the substations are manned by service and security personnel and equipped with surveillance systems, few occurrences happen to these transformers. On the other hand, transformers placed on the electric poles usually do not have adequate or zero surveillance and maintenance facilities. Therefore, theft or vandalismof distribution transformer by miscreants is common; moreover, several reports of thieves stealing transformer oil from oil-cooled transformers [13], [14]. As a result, due to vandalism, theft or failure, various communal area face terrible power outages for which both the government and the people suffer a huge loss.

This project focused on using GSM technology to monitor distribution transformer parameters such as load current, over-voltage, oil level, oil temperature, winding temperature, and ambient temperature. Also, the project emphasized on developing a transformer tempering system so as to minimize thefts and vandalism.

1.2 Problem Statement

The conventional distribution transformer inspection techniques have led to unexpected power outages, financial losses in repairing the damaged power grids, and replacement of some parts. A manual monitoring method does not allow regular monitoring of the transformer's parameters like voltage, current, oil level, and transformer temperature. Additionally, transformer theft and vandalism is a common scenario that is a crucial impediment in the way of advancement in the power sector.

1.3 Objectives

1.3.1 Main Objective

To design a GSM-based distribution transformer parameters monitoring and tampering detection system.

1.3.2 Specific Objectives

- To develop a GSM-based distribution transformer parameters monitoring system.
- To develop a GSM-based distribution transformer tampering detection system.
- To evaluate the reliability of the designed system through prototype implementation

1.4 Justification

Distribution transformer faults resulting from over-voltage, overloading, overheating, and low oil level, when not detected early, may lead to the breakdown of the whole equipment. Moreover, intruders may cause a massive disruption to the power system when they steal or vandalise the distribution transformer, leading to unexpected failures and loss of supply to many customers, thus affecting system reliability. This project is focused on detecting the distribution transformer partial condition problems and detecting any theft or vandalism by intruders, then alerting the operators with the specific details about the fault or interference via SMS notifications; this will help evaluate the status and safety of the transformer. By accessing transformer status, asset managers, such as utility corporations and power supply businesses, will find it easier to maintain transformers with this project. There will also be a reduction in power interruption cases due to transformer breakdowns and theft, which means that production in general within the grid goes on uninterrupted.

1.5 Scope

This project uses a GSM-based system to monitor parameters and tampering of oil-immersed distribution transformer. This project does not cover the physical integration of power grid components. In addition, this project monitor transformer parameters such as oil level and temperature, overload and overvoltage. The selected parameters are likely to create faults and losses, necessitating continuous monitoring. The focus was on microcontroller algorithm development and system performance evaluation.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

This section entails the theory setting up the essence of this research project. The significant areas of focus of the project, which include the various distribution transformer faults, transformer protection, and the methods of monitoring and security that multiple researchers have delved into, are discussed. Finally, the footprint of this research study is laid after carefully identifying the research gap based on the research works done in the past.

Over the years, distribution transformers have been essential in power distribution. Their construction is such that each phase has primary and secondary windings. The windings are usually made of copper and are on a thin laminated steel core, each covered with an insulator made of special paper or wood. Lamination helps reduce losses, but steel cores can lower the resistance path of magnetic flux. The main transformer tank contains transformer oil, a coolant, and an insulator for the windings and the cores. The on-load tap changer, breather, conservator, radiator, a transformer [15]

Figure 2.1:Distribution transformer [16]

2.2 Distribution transformer health parameters

To evaluate the distribution transformer health, there are parameters to be considered. These parameters include electrical, thermal, and oil level. These tools will support the transformer operators in predicting the status of the distribution transformer and responding effectively. They are discussed below [16]:

2.2.1 Electrical parameters

Every transformer has a maximum output current that it can deliver at its standard output voltage. This VA rating (KVA or MVA for large power transformers) is dependent on the ambient temperature or cooling provided. Exceeding the VA rating will cause over-heating of the core and windings and subsequent damage [17].

The available winding insulation is the governing factor for the voltage rating on the transformer. As well as the rated operating voltage, the rated transient (spike) voltage that the transformer can withstand is usually included. This is listed as the impulse level [18].

2.2.2 Transformer temperature parameter

One of the simplest and most effective ways to monitor a transformer externally is temperature sensors. Abnormal temperature readings almost always indicate some type of failure in a transformer. For this reason, it has become common practice to monitor the hot spot, main tank, and bottom tank temperatures on the shell of a transformer [17]. As a transformer begins to heat up, the winding insulation begins to deteriorate, and the dielectric constant of the mineral oil begins to degrade. Likewise, as the transformer heats, insulation deteriorates at even a faster rate. As the next section describes, monitoring the temperature of the load tap changer (LTC) is critical in determining if LTC would fail. In addition to the LTC, abnormal temperatures in the bushings, pumps, and fans can be signs of impending failures [19].

2.2.3 Oil level parameter

The presence of oil in transformers provides cooling of the winding and insulation from the transformer housing. Finally, it serves as a quenching medium to quench arcs at termination points (tapings, terminals) within the transformer windings arrangement. Conditions such as temperature variation could reduce the oil level [20]. A sudden puncture in the transformer tank/housing will drastically reduce the transformer oil. A reduction in transformer oil beyond the required level is very detrimental to the operation of the transformer and adversely affects the cooling and insulation function of the oil [21].

Figure 2.2: Failed transformer on fire due to low level of oil[22]

2.3 Types of faults in distribution transformer

2.3.1 Over Voltage Fault

There may always be a chance of system overvoltage due to the sudden disconnection of a large load. The magnitude of this voltage is higher than its average level, but the frequency is the same as it was in normal operating conditions [12]. Overvoltage in the power system causes stress on the transformer's insulation. The overvoltage fault will occur when the operating voltage increases to the upper limit of the voltage rating. This fault can also detect by a voltage sensor [23].

2.3.2 Over-current Fault

Overcurrent fault is mainly due to overload on the secondary side of the distribution transformer. Over-current conditions are typically very short in duration (less than two seconds) because protection relays usually operate to isolate the faults from the power system line [24]. The load currently draws overload, a load current more than the transformer nameplate rating at the secondary side. Current increases the hottest-spot temperature (and the oil temperature), decreasing the insulation life span. When the recent operating increases to the upper limit of the current rating, the overcurrent fault will occur. The current sensor can detect this fault [23].

2.3.3 Over Temperature Fault

Overload current may not damage the transformer, but the absolute temperature of the windings and transformer oil remains within specified limits. The transformer ratings are based on a 24-hour average ambient temperature of 30°C (86°F) [25]. Due to over-voltage and over the current, the temperature of oil increases which causes failure of insulation of transformer winding. When the temperature of the transformer increases to the upper limit of the temperature rating, the over-temperature fault will occur. A temperature sensor like a thermistor can detect this fault [23].

2.3.4 Oil Level Fault

Maintaining the proper oil level is extremely important because if the oil level falls below the story of the radiator inlet, flow through the radiator will cease and will cease, and the transformer will overheat. A deficient level can expose energized and current-carrying components designed to operate in oil and result in overheating or an electrical flashover [16]. If the oil level is too high, it could cause over-pressurization when the oil expands. When the oil reduces in tanks, it causes winding insulation reduction. Tank fault causes an abnormal temperature rise of the transformer.

This oil loss usually happens due to leakage, While the leakage can be checked visually on the tank body.

The most common reason for the leakage is [26]:

1. Loss of tightening of tank body screws.
2. Corrosion at the tank body.
3. Mechanical damage due to a solid hit to the tank body.

Transformer oil leakage could cause flashover between windings and end connections. The cooling system must function properly for the transformer to operate at full capacity. Failure in the cooling system will badly affect the performance of the transformer [20].

2.4 Fault detection techniques in distribution transformer

The goals of on-line monitoring, according to ABB, are to prevent significant failures, improve load capacity utilization, optimize maintenance, and extend the remaining lifetime [19]. They achieve their goal by collecting data while the transformer runs irregular cycles, such as every three minutes, as specified by IEC. Sensors attached to the transformer tank, bushings, instrument transformer, and surrounding capture relevant data. Temperatures, gas in oil, and moisture are examples of factors that can be measured. The partial discharge affects currents, voltages, and tap changer locations. Others choose to create analytic monitoring models utilizing design-dependent elements [27], whereas sensor data is a quick approach.

The measured values are then utilized to generate derivative values, then employed in algorithms to create more conclusions. If measurements are taken correctly, and frequently enough, an on-line system should be capable of performing cooling management, overload forecasting, and guidance, detecting defective accessories and sensors. Lifetime consumption management, raising alarms on faulty risky operating conditions, and dictating condition-based maintenance—the transformer's on-line monitoring functions as both protection and control.

Regardless of the different metrics that monitory systems examine, they all have equal value in terms of transformer protection. According to the research, temperature, electrical loading, insulation health, and protective accessory conditions are all factors. As a result, we'll look at the underlying principles and the proposed monitoring strategy. Figure 2.2 shows sample transformer monitoring.

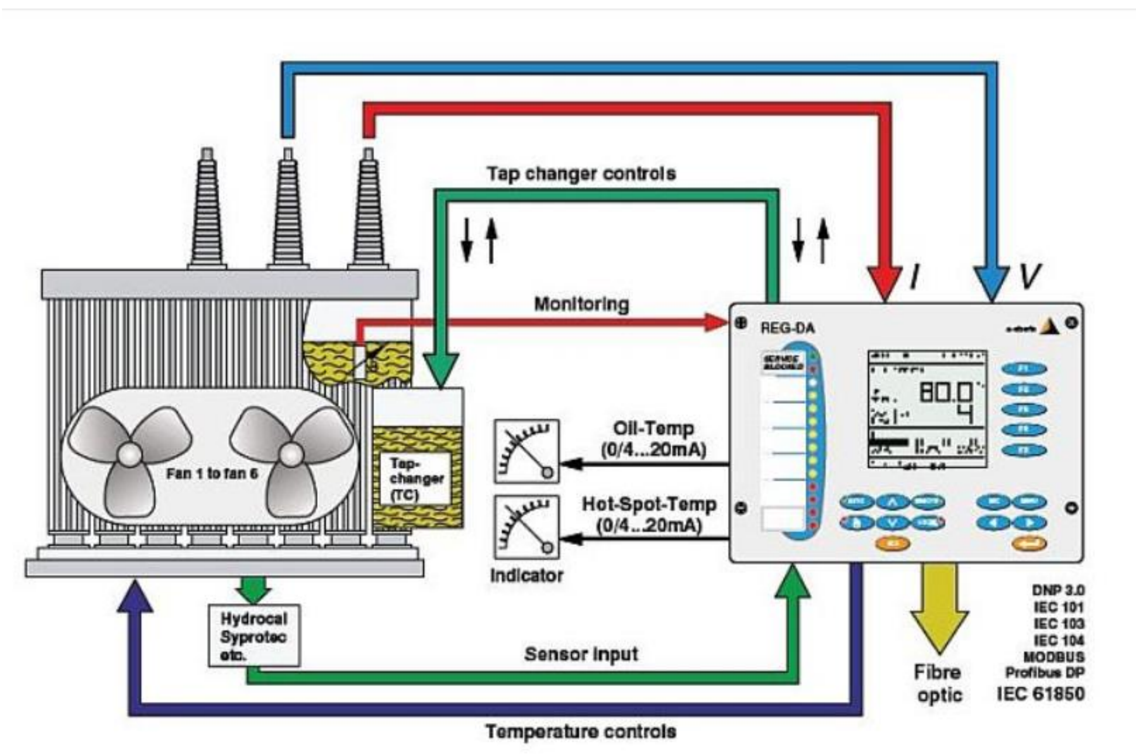

Figure2.3:Block diagram depicting sample transformer monitoring [28]

2.4.1 Temperature monitoring

According to the U.S. Bureau of Reclamation, internal losses (I^2R), loading, high ambient temperatures, and solar radiation produce heat in a transformer. They further claim that using the transformer at just eight °C above its rated temperature will cut its lifetime. High temperatures have been shown to limit transformer loading to less than its stated capacity for safety reasons [15].

Temperatures are often measured using sealed spiral-bourdon-tube dial indications with liquid-liquid-filled bulb sensors placed in a thermometer well within the tank. Remote temperature indicators are electro-mechanical thermometers with mercury switches for alarm trip signals, control circuits, and a potentiometer. These indicators are utilized for winding temperature (WTI) and oil temperature. However, the enormous magnetic fluxes and strong electric fields associated with distribution transformers limit other temperature measurement options. Pt 100 RTDs can also be employed for distant measurements, and fiber optic temperature probes can be put into the winding spacers during construction to provide some immunity to common electromagnetic disturbances [28]. Temperature indicators offer on-line monitoring as a feasible solution for transformer temperature monitoring. Bushan designed a microprocessor-based cooling management system [29] they address excessive temperatures by assuming that the data provided by the indicators is underutilised due to manual check-ups rather than being used to adjust cooling proportionally. During normal cyclic loading of transformers, these systems effectively implement IEC temperature guidelines of 105°C for top oil temperature and 120°C for winding temperatures (IEC 60076-7) [7]. Monitoring systems have developed analytic thermal models that function in tandem with simple temperature monitoring. Djamali demonstrates some of the processes for detecting malfunctions [30]. They offer a method that may be used to detect temperature indications and cooling system malfunctions. They can anticipate the top oil and winding temperatures using the transformer's design dimensions and the oil and cooling system parameters. Any discrepancy between the measured and computed values is interpreted as a malfunction. Others utilize thermal models to calculate hotspot temperature and proper transformer life consumption. Of course, they do so per IEC loading guidelines. The hot spot temperature is the hottest temperature in the transformer winding, especially in parts where the transformer geometry does not allow adequate oil cooling. Ew-dossier creates a commercial monitoring system that uses IEC 60354 standards to compute the hotspot temperature and lifetime consumed over the transformer's working period. Unfortunately, the current IEC 60076-7 standard has superseded the IEC 60354 [24] as shown in figure 2.3

Figure 2.4:Transformer monitoring according to IEC 60354 [31].

2.4.2 Monitoring of electrical parameters

Transformers are pieces of equipment that use electromagnetic induction to convert voltages. The voltages and currents must be monitored to portray the transformer's activity. Voltage is measured using potential transformers with secondary ratings of 50 to 200 VA at 120 volts, while current is measured using current transformers with secondary ratings of 5 amps. Interfacing circuits may be included in these instrument transformers to obtain the conventional 4-20 milliamps or 0-10 volts signals. Where they aren't available, researchers create their interfaces, such as a clamp-on current transformer on Qualitrol's C.T. secondary terminals or a rectifier and filter circuit, as demonstrated by Anand. The former produces an attenuated current waveform, whereas the latter has a D.C. signal indicating the current and voltage magnitude.

Monitoring these two metrics has the potential to serve as the quickest indicator of defects, remarkably abrupt faults such as short-circuits or lightning strikes. By comparing the current data to a fingerprint image of the electrical parameter under normal, they can detect a mechanical defect. These prints are made by graphing the voltage differential (H.V. voltage-LV voltage) against the H.V. current and help find significant variances in voltage and conditions current frequencies and amplitudes [32].

In other circumstances, oscillography monitors and observes currents and voltages. During his research on transformer failures, Michael emphasizes the need to monitor the loading parameters in this manner. He looked at the oscillography records of the three transformers, which show that once a defect has been initiated, it will produce high currents and voltages for 50 milliseconds, or three cycles of a 60 Hz source. He also mentioned that harmonic distortion in current waveforms might be used to detect mechanical problems [24]. By recognizing these spikes as soon as they occur and highlighting failures as they develop, voltage and current measurements can indicate these flaws.

2.4.3 Oil level monitoring

Insulation is used to separate conductive surfaces with various potentials, which in this case are classified as high voltages. The windings are dielectrically protected by both the oil and the insulation. Kraft paper, made up of cellulose molecules, is a common type of insulation. Pyrolysis (heat), oxidation, acidity, and moisture all contribute to the breakdown of insulation [15]. Furthermore, the mineral oil used to improve paper insulation and cool the transformer is prone to hydrocarbon chain breakup—insulation failure due to deterioration risks short-circuiting or the growth of combustibles in the tank. The gas dissolved in the oil, measured in parts per million for each gas, indicates degradation. Hydrogen, methane, acetylene, and carbon oxides are examples of such gases.

Oil analysis for gas concentrations is an uncommon occurrence that requires complex and costly equipment. Some have suggested that the Dissolved Gas Analysis be performed every two years, while others have advised that gas monitoring be left entirely to the Buchholz relay [9]. This enables incorrect situations to grow without the operators' knowledge. A sudden malfunction during this blind period could result in transformer flames and explosions.

Fortunately, recent improvements have resulted in the availability of gas detectors. This type of sensor determines how much gas is present in the oil. The problem is that they operate as isolated sensors that do not communicate with other systems. Increased gassing may be tracked from an HMI with this in a monitoring system, and Dissolved Gas Analysis as shown in figure 2.4 can be requested to understand the defect better. As a result, the oil's condition can be examined and monitored [33].

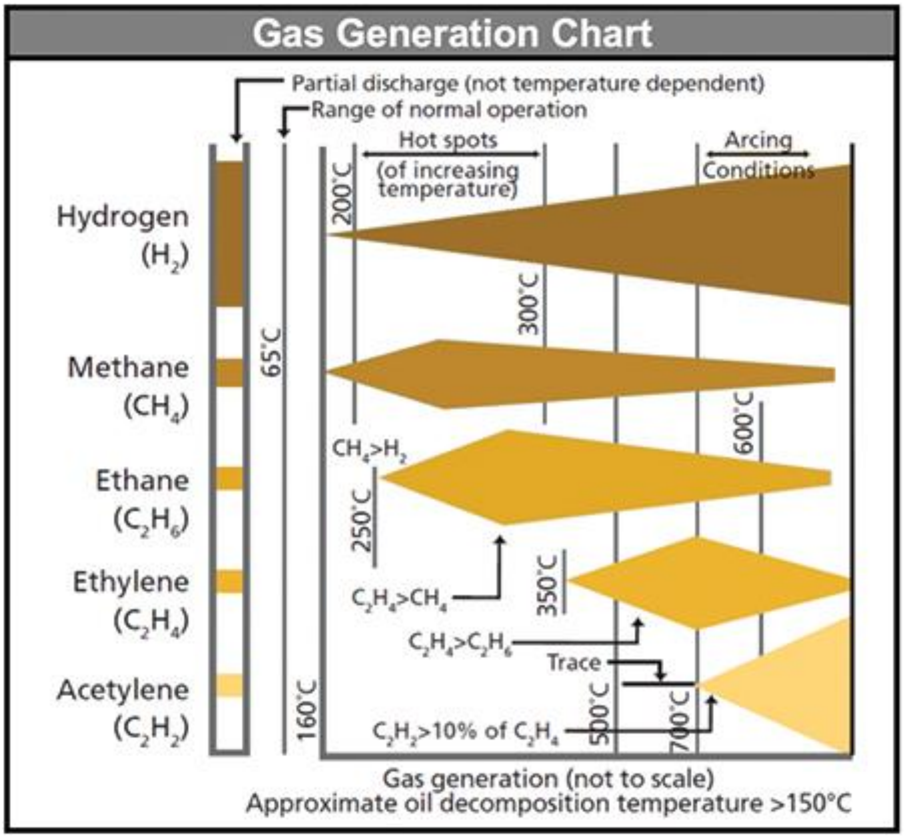

Figure 2.5: Dissolved Gas Analysis [34]

2.5 Distribution transformer tampering detection

Many developing countries have been going through rapid economic growth over the last decade. Much of this economic development is fueled by the development of their power generation. Unfortunately, transformer theft is a common scenario in these countries, which is a crucial impediment in the way of advancement in the power sector. Therefore GSM technology-based transformer parameter monitoring and tampering detection system has been proposed [35]. The system uses an IR sensor and Hall Effect sensors to protect the transformer from being tampered with. The problem with using these two sensors is that they add to the project's complexity and are expensive to implement. This paper proposes a GSM-based parameter monitoring and tampering detection system that utilizes two sensors, IR and hall effect sensors, which achieve the same purpose as the weight sensor and thus reduce the complexity and cost of implementing the project.

2.6 Tampering detection techniques

In most cases, distribution transformers, are seen near the housing areas mounted on electric poles. In most cases, these transformers, transformer oil, or copper windings get stolen due to a fragile security line. In addition to the security concern, these sorts of transformers also face monitoring and servicing issues. Although for monitoring purposes, techniques such as Power Line Carrier Communication (PLCC) and SCADA [36].

Although the systems mentioned above attempted to address the issues or partially address the problem, in most cases, they failed to address the problem completely. This paper proposes a GSM-based parameter monitoring and tampering detection system that covers the techniques mentioned above' absences. Unlike the approach discussed in the paper [37], it can be seen that only a mere buzzer is used to alert the authority about an ongoing attempt to steal the transformer. Moreover, the same buzzer rings when the oil level of an oil-cooled transformer goes below a certain threshold. Therefore, if there is no authorized staff near the transformer, there is a very high chance that the transformer may get tampered with.

Another problem is deciphering the meaning of the buzzer's sound since the buzzer rings for both low oil levels and changes in weight. But the system described in this paper uses both buzzer and SMS service to notify the authority about any theft and vandalism attempts. The system will notify the authority via SMS service [38].

Figure 2.6: Manual monitoring of distribution transformer [39].

2.7 Research Gap

Distribution transformers that are monitored will be protected against undetected flaws and dire operating circumstances, resulting in extended life expectancy. It has been recognized, however, that some parameters have been overlooked. Commercial monitoring systems focus on specific monitoring aspects, such as temperature or gas. Not to mention the fact that they are expensive and reliant on their designers for customization. They might not be the most suitable for transformer parameter monitoring. In addition transformers which are placed on the electric poles usually do not have proper tampering detection system. For these reasons this project will assess the possibility of improving the existing distribution transformer parameter monitoring and tampering detection system.

CHAPTER 3: METHODOLOGY

3.1 Overview

In this chapter, action steps towards achieving the specific objectives, which led to project completion, have been detailed. The area further indicates the hardware specifications. Firstly, the steps that were used to develop a GSM-based parameters monitoring system are discussed. Secondly, the steps that were used to develop a GSM-based tampering detection system are outlined. These are summarized in the diagrams detailing the design.

3.2 Parameters monitoring system

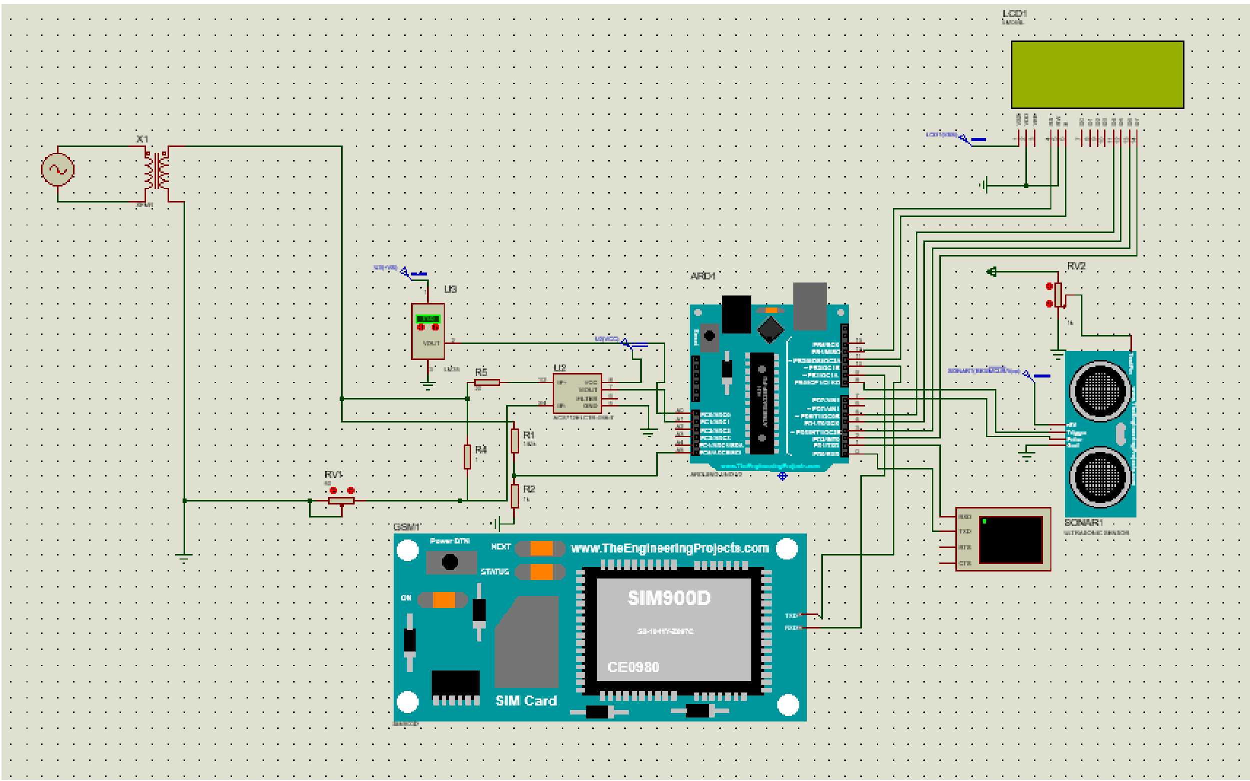

Figure 3.1:Circuit Design of Parameters monitoring System

The monitoring processes comprise three submodules addressing electrical, thermal, and oil level parameters monitoring. These modules were then be translated into the GSM language.

The system circuit was designed, serial communication was then established between the microcontroller and GSM modem; after a successful communication, the system checks the parameters—Baud rate of the established communication.

The system utilizes specific threshold values to send a notification to the authority about the parameters mentioned above. If the system sees any anomaly in the parameter values, it will notify the authority immediately, mentioning that particular transformer's parameter values. Figure 3.1 shows the algorithm of distribution transformer parameter monitoring.

The parameters that were identified and studied from the field are:

a) Load Currents
b) Line Voltage
c) Transformer Temperature
d) Oil Level

3.2.2 Electrical parameters monitoring

Monitoring of electrical parameters involves current and voltage variables from the three phases of the secondary sides, then through an ADC channel of Microcontroller. The voltage transformer sensor and Current transformer sensor are used for measurement purposes. The measured values frequently vary between the number of 1000 samples taken and the average value calculated and then multiplied with a specific constant to get the real AC RMS value.

3.2.3 Oil temperature monitoring

The temperature sensor measures temperatures from 0 to 150 degrees Celsius. It's a three-terminal gadget that outputs an analog voltage proportional to temperature—the output voltage increases as the temperature rises. The output analog voltage can be converted to digital form using an ADC and processed by a microcontroller.

3.2.4 Oil level monitoring

Ultrasonic sensor is used to monitor the oil level. There is a specific threshold oil level value below which the system will send an SMS notification to the authority. Also oil level sensor helps in detecting oil theft by checking the level of oil whenever an object is detected at the transformer.

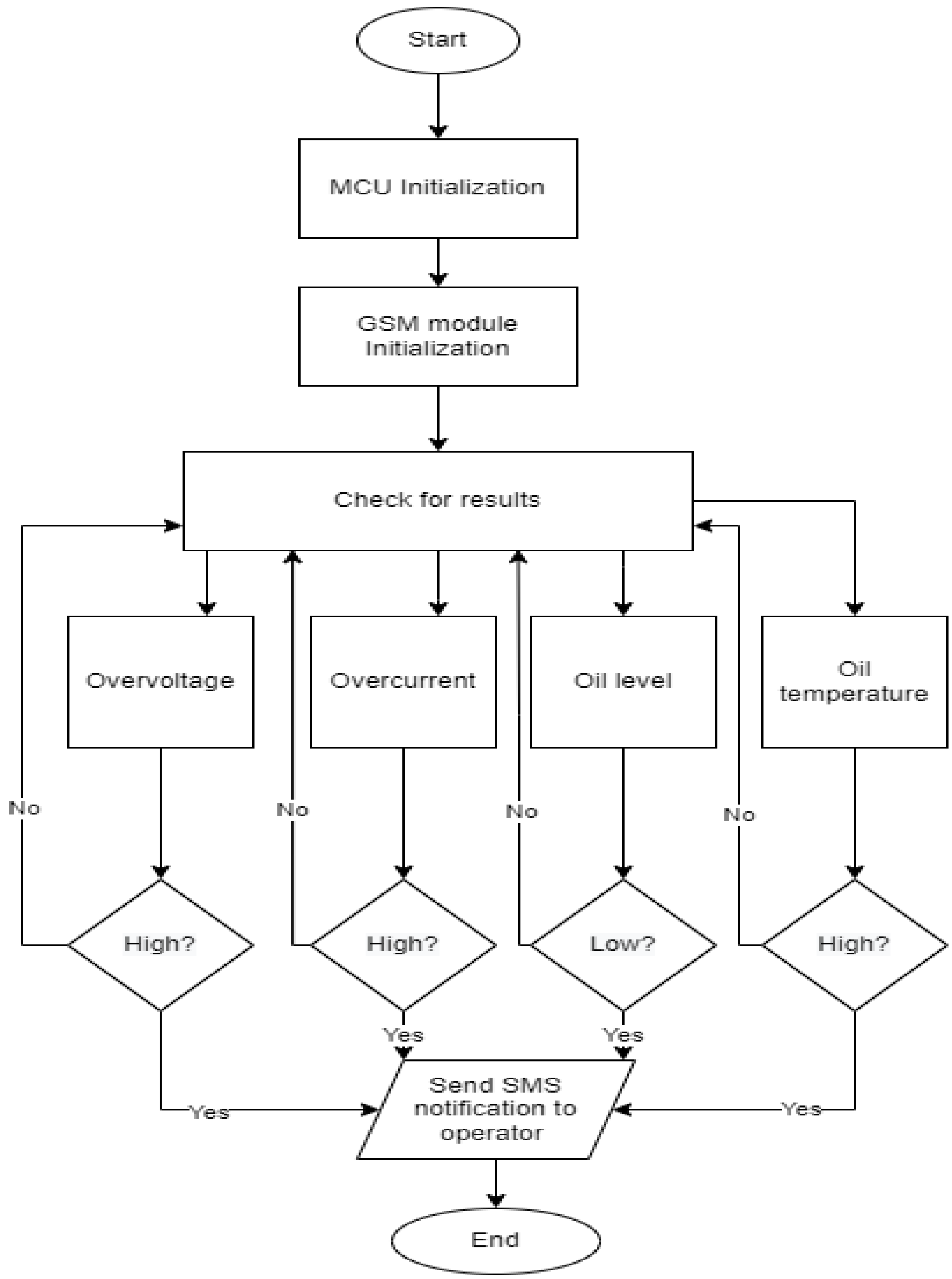

Figure 3.2: Distribution transformer parameters monitoring

3.3 Tampering detection system

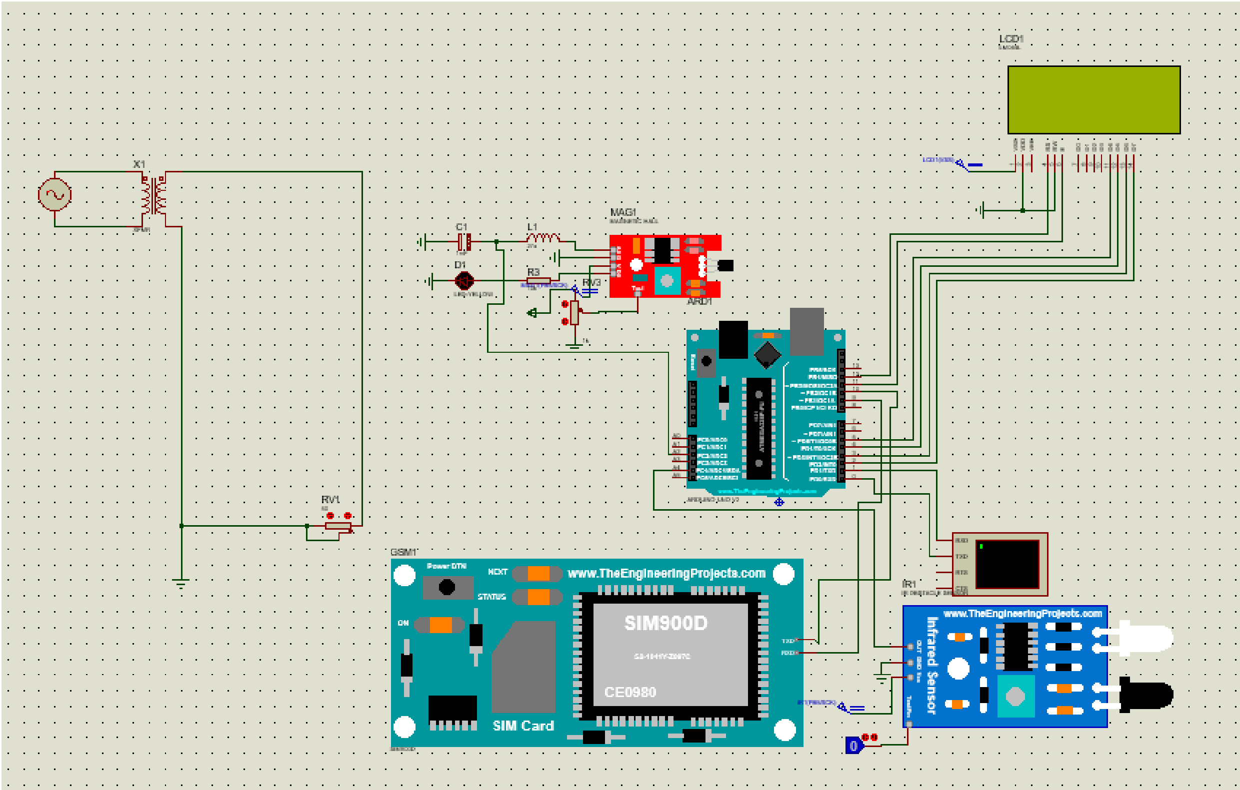

Figure 3.3: Circuit Design of Tampering Detection System

The tampering detection which were identified and studied from the field are:

a) Changes in the magnetic field
b) Proximity detection

The system utilizes three sensors ; infrared sensor, hall effect sensor and ultrasonic sensor to protect the transformer from intruders: two IR sensors to detect proximity near the transformer and a Hall effect sensor to detect both magnetic field and proximity. There are specific threshold values for the two sensors below which the transformer will send a notification to the authority via SMS. Figure 3.6 shows distribution transformer tampering detection algorithm.

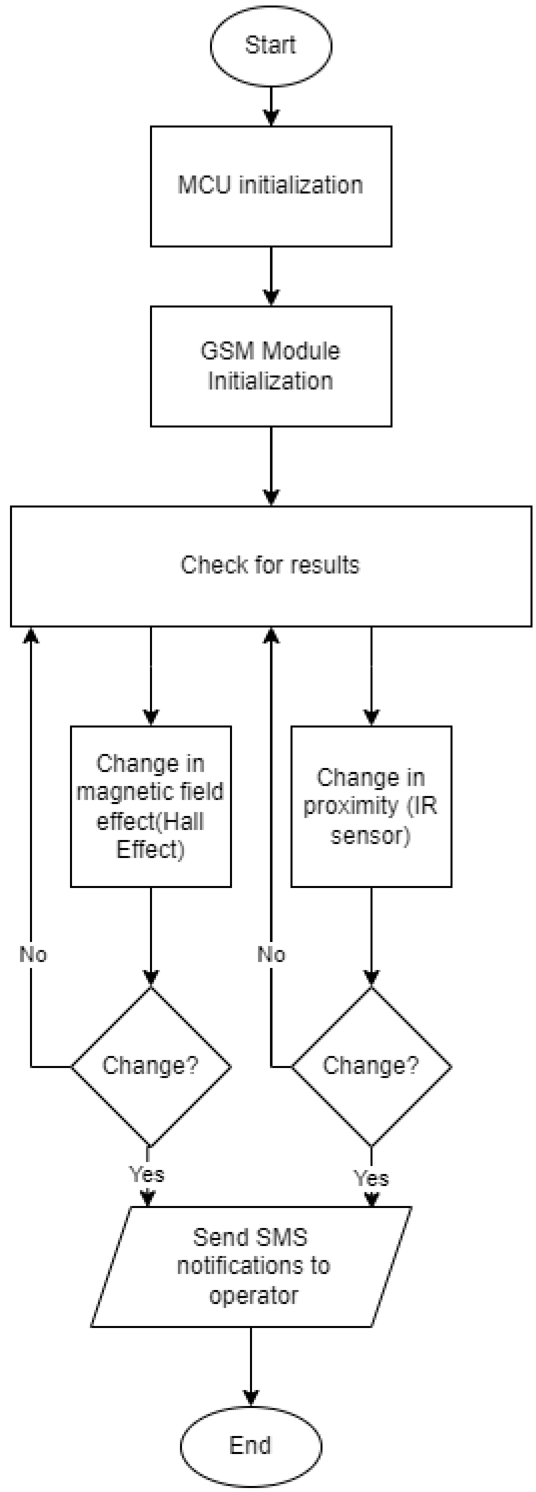

Figure 4.4: Distribution transformer tampering detection

3.4 Prototype implementation and performance evaluation

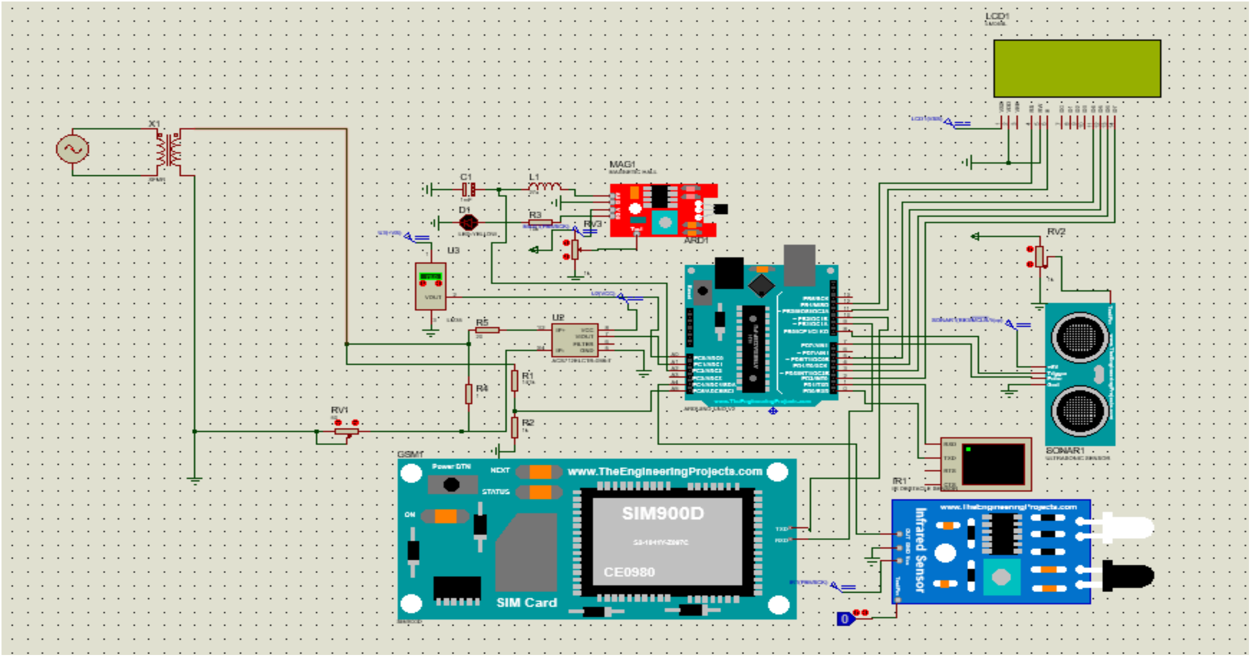

Figure 3.5: Circuit Design of the Cascaded System

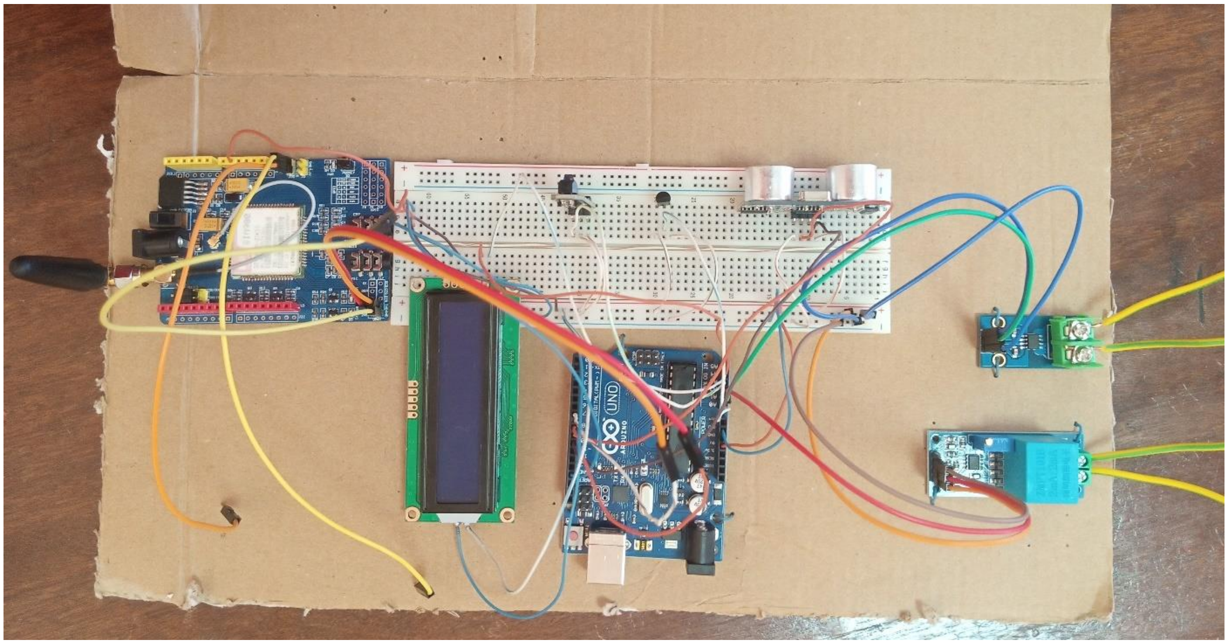

Figure 3.6: Implemented prototype of the System

The functionality of the designed system underwent some acceptance tests and was deemed successful. The system was investigated by evaluating the performance of the prototype developed. Figure 3.7 shows cascaded system. The prototype gives the option of inputting fabricated datasets and observing their behavior in terms of outputs.

Figure 3.7: Cascaded system block diagram

3.5 Hardware setup

A relevant definition of the hardware layout was required before a function description of the system was constructed. This is due to a variety of factors. To begin with, some of the transducers in the distribution transformer are passive, requiring some interfacing to acquire output signals that the GSM-based system can use. Second, some sensors that may assist in parameter monitoring and tampering detection may not be present in the field transformers.

Hence, the sensors and actuators' layout accompanied by interfacing were defined. This involved designing electrical diagrams and schematics. This project diagrams were constructed as per IEC and EN standards. These diagrams also illustrate how the sensors were connected to the microcontroller (microcontroller I/O list) and a sample HMI panel layout.

Components that were used are:

Sensor	**Model Name**	**Measurement Capability**
Temperature Sensor	LM35	Temperature Range: -55 to 125° C
Ultrasonic Sensor	HC-SR04	Measuring range: 0-1191cm
Voltage transformer sensor	ZMPTI01B	240V
Current transformer sensor	ACS712 Module	1 x 5A /10A / 20A
IR Sensor	CXH-201A	Sensing Distance: 2-60 cm
Hall Effect Sensor	SDK SH41F	Output Voltage: 0.25-4.65 V

Table 3.1:Sensor measurements specifications

CHAPTER 4: RESULTS AND DISCUSSION

A simulation of the system was made using Proteus Design Suit in order to understand the behavior of the system properly. The circuit is made up of the microcontroller Arduino Uno R3 SIM900 GSM module, ultrasonic sensor, lm35 temperature sensor, voltage sensor, current sensor, infrared sensor, hall effect sensor. The Arduino Uno R3 was fed with the program code from the Arduino software which provides signals and power to the whole system.

In the simulation, the system functioned properly and was able to establish a connection between the monitoring virtual cell phone of the authority and the system, to notify about any sort of discrepancies. Figure 3.5 portrays the system inside the simulation and the connection between the system and the monitoring virtual cell phone of the authority. After careful simulation of the system in Proteus, a prototype was built using the specified elements of processing units, sensor stack, and the communication unit. The system worked perfectly in establishing a communication link with the monitoring virtual cell phone via GSM technology and was able to send a notification to the authority. The illustration of the system prototype and SMS sent to the cell phone of the authority about the anomalies are shown in the Figure 4.1-4.3.

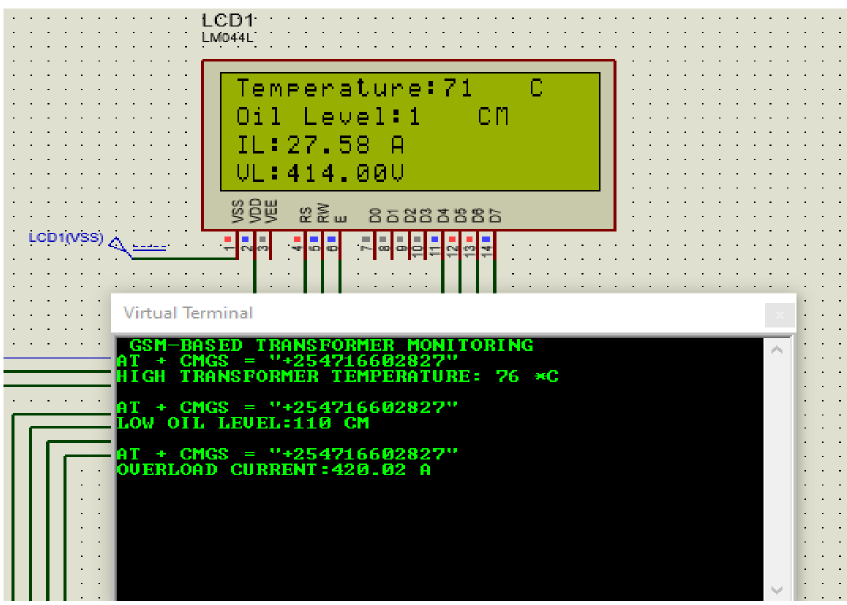

Figure4.1: Simulation Results of Parameters Monitoring System

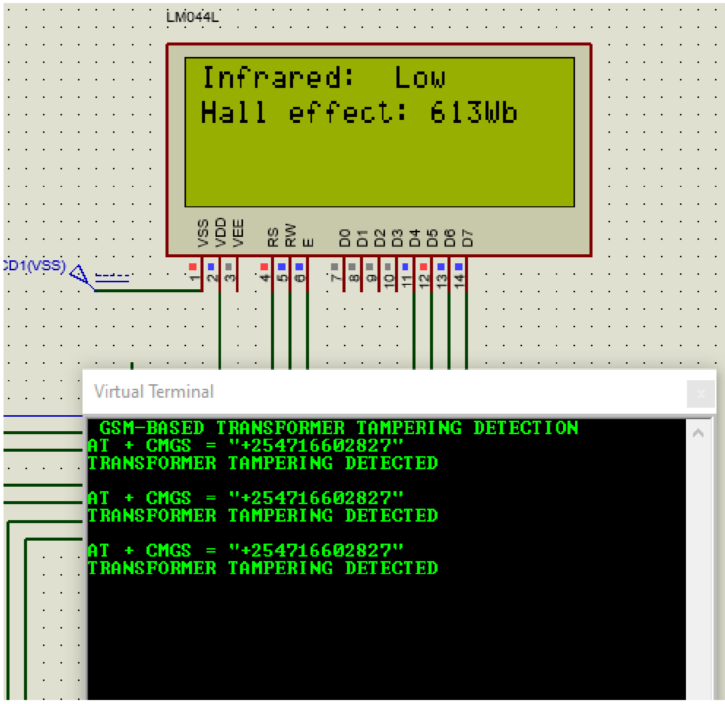

Figure 4.2: Simulation Results of Tampering detection System

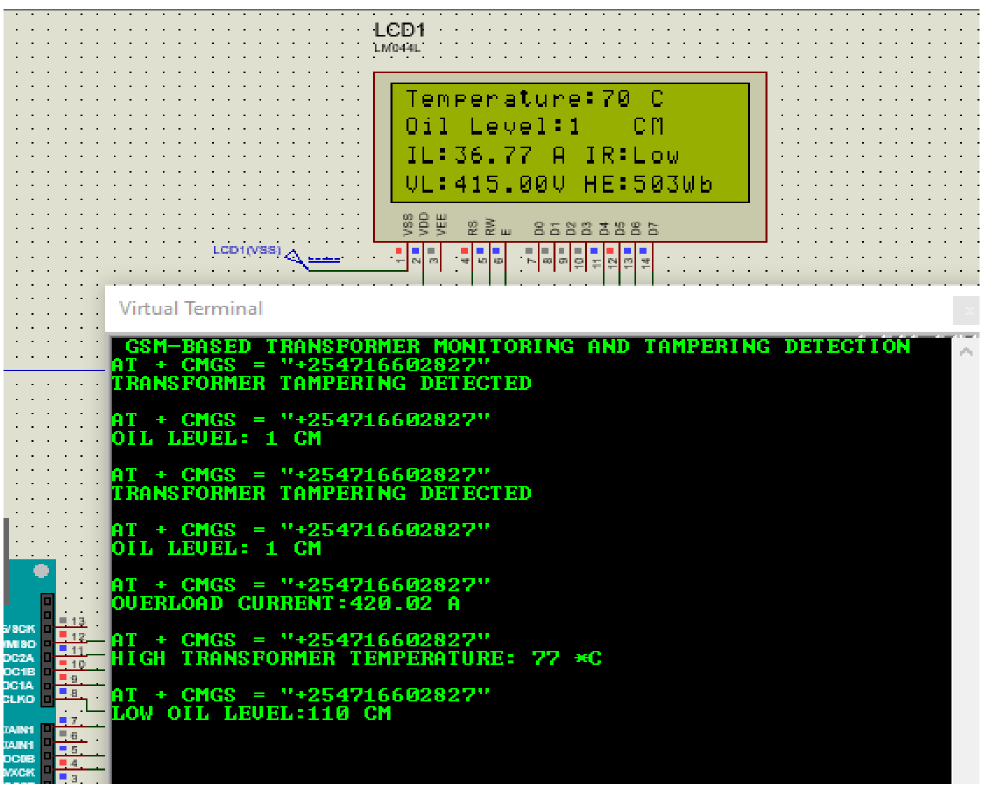

Figure 4.3: Simulation Results of Cascaded System

Both the simulation and the prototype of the system functioned properly and were able to create a stable communication linked between the system and the authority's cell phone to send notification about any sort of anomalies occurring at the distribution transformer. Therefore, under various conditions, the system was tested multiple times by triggering multiple sensors installed in the sensor stack unit. The sensors were able to perform within the sensing or measurement capabilities as shown in Figure 4.4-4.6. Besides, the communication unit of the system had a typical response time of 3-20 seconds. But the response time of the communication unit is mainly dependent on the network coverage of the telecom operator, which provides the SIM card for the unit.

In addition tampering detection system, when the system detects an object, oil level is also SMS is sent to operator to determine if the oil the has drained. Figure 4.7 shows two different messages that were received by a designated mobile user with mobile phone SIM card.

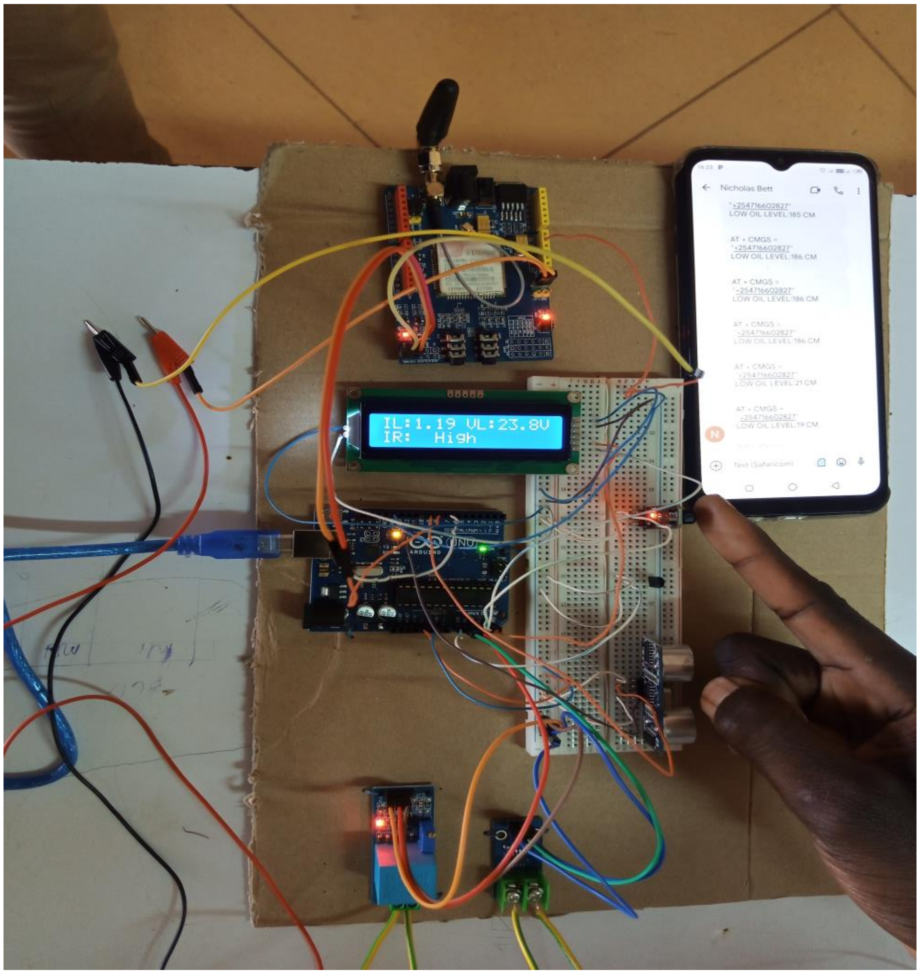

Figure 4.1: Load Current, Line Voltage and Infrared Status Display

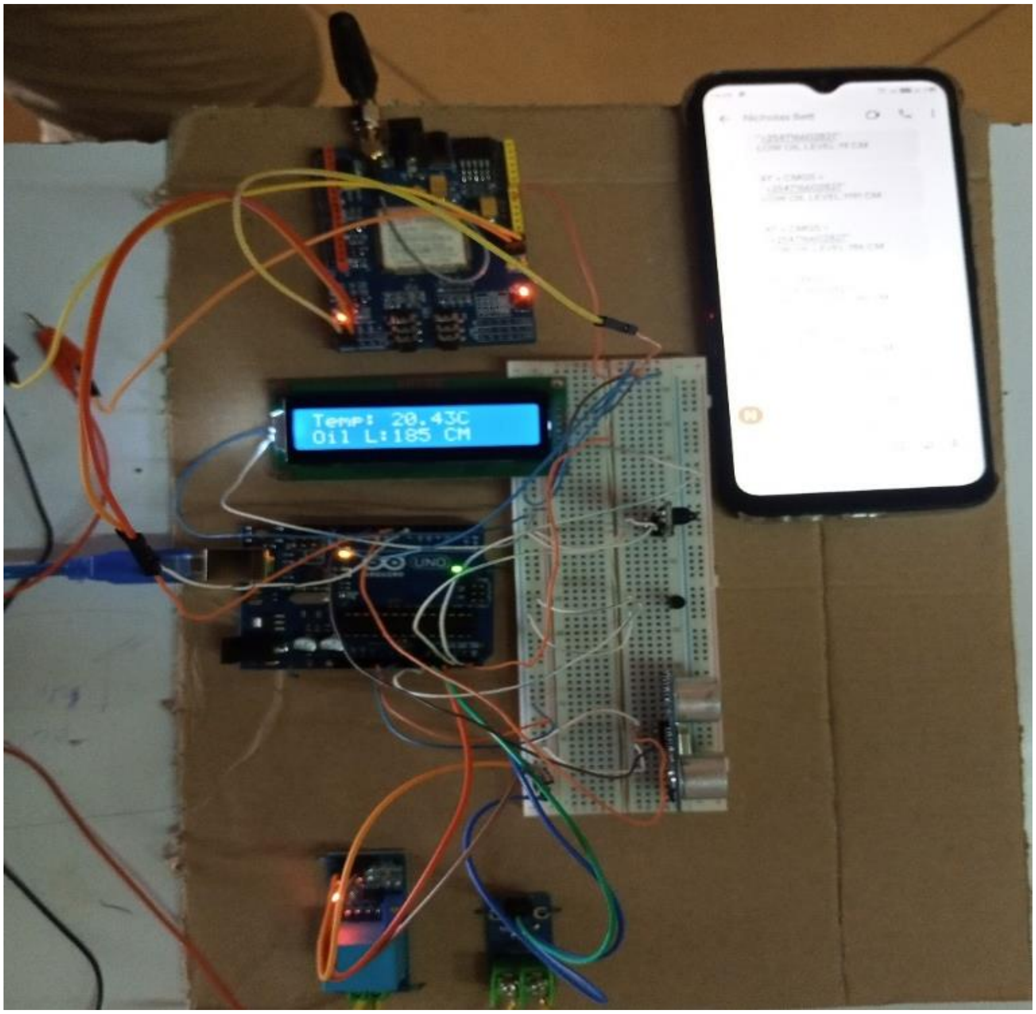

Figure 4.2: Temperature and Oil Level Display

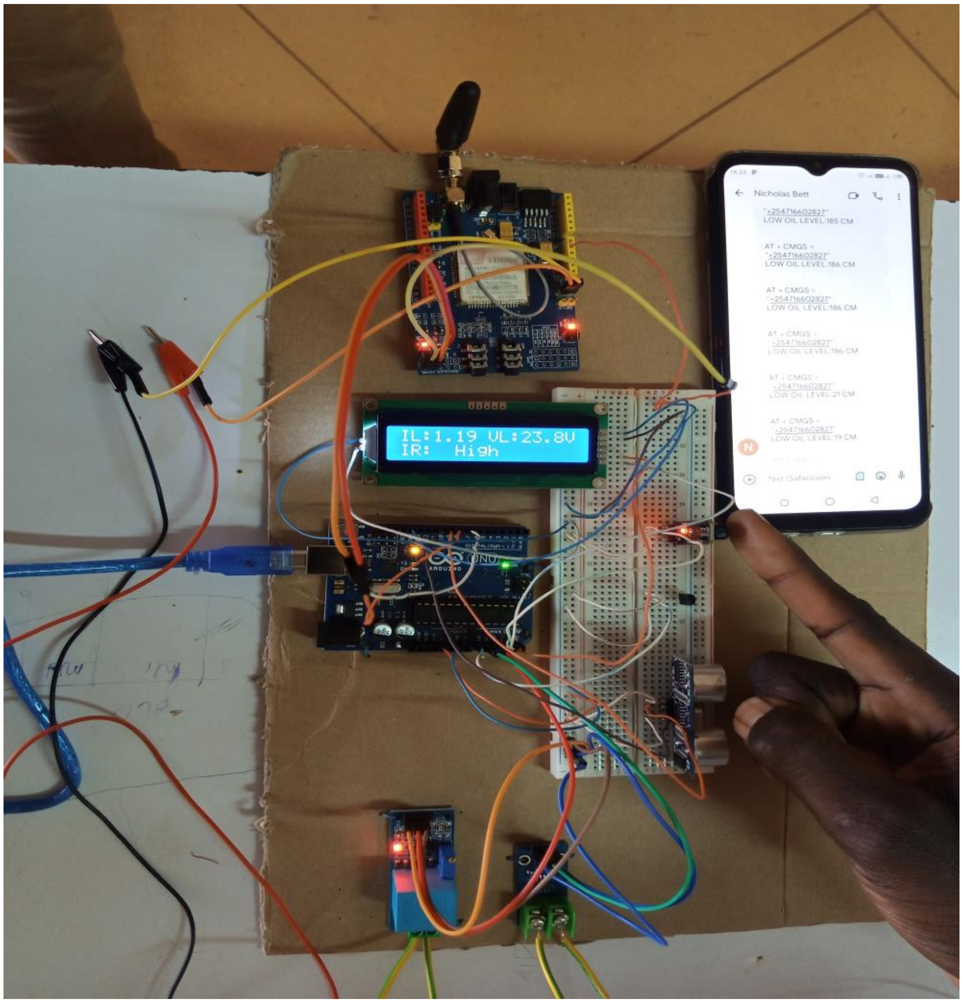

Figure 4.3: Object Detection Using IR Sensor

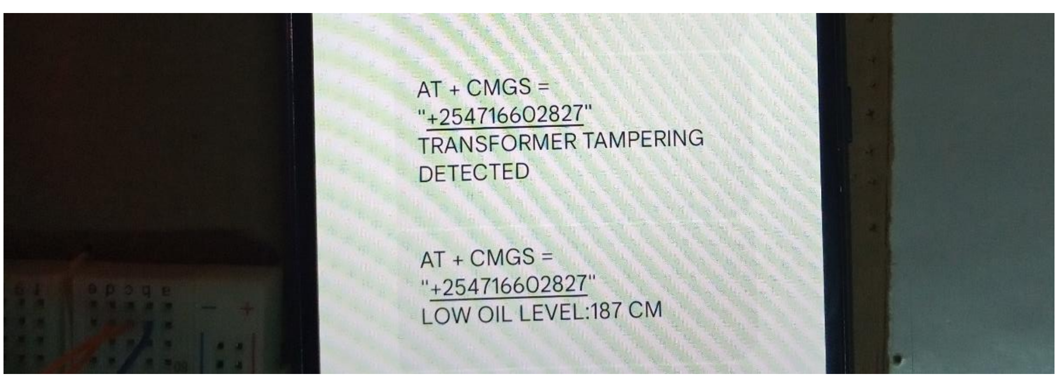

Figure 4.4: Low Oil Level Notification

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Conclusion

The GSM based system developed in this project provided a solution for keeping the distribution transformers safe from failure and vandalism; by detecting any sort of abnormalities at the transformer and reporting it to the proper authority via SMS service. The time to receive the SMS messages varies from 2-10 seconds and this is due to the public GSM network traffic.

The system provided distribution transformer parameters monitoring service to the authority by sending transformer parameter anomalies such as high transformer temperature, overload current, overvoltage and low oil level via SMS. With this system, the maintenance of distribution transformers is made efficient and error-free by limiting over-reliance on human judgment.

Secondly the project accurately detect distribution transformer tampering in real time. Therefore, the power utilities, is able to restrict the tampering hence supply interruptions, and the financial losses associated with distribution transformers tampering is significantly reduced.

The GSM-based system for distribution transformers parameters and tampering detection produces more accurate results compared to the conventional techniques.

Recommendation

The following are recommended:

- Cloud connectivity to the system, this will enable the system to store the measured parameters to the cloud server. From which the authorities can monitor the health condition of the distribution transformer.
- The system will be integrated with a camera network, which will activate immediately if the system senses any presence near the transformer and will stream real-time video to the authority via a cloud network.

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APPENDIX

Development of a program code.

The following program code is used to run the system

```
#include <Wire.h>
#include "DFRobot_RGBLCD1602.h"
#include<SoftwareSerial.h>
#include "EmonLib.h"
#define VOLT_CAL 592
DFRobot_RGBLCD1602 lcd(16,2);
SoftwareSerial SIM900(7, 8);
#define Motion_Sensor A3 //Button pin, on the other pin it's wired with GND
const int TempSensorPin = A0;
bool Sensor_State; //Sensor_State

const int colorR = 255;
const int colorG = 0;
const int colorB = 0;
const int trigPin = 10; // Trigger Pin of Ultrasonic Sensor
const int echoPin = 9; // Echo Pin of Ultrasonic Sensor
float duration;
int OilLevel;
const int currentPin = A1;
float adcValue= 0;
float offsetVoltage = 2.5;
double adcVoltage = 0;
double LoadCurrent = 0;
int delayTime = 300;
float vout;
const int voltageSensor = A2;
float vOUT = 0.0;
float vIN = 0.0;
```

```
float v = 0.0;
int value = 0;
float c = 0;
float sensitivity = 0.185;
int sensorValue = 0;
float temp;
float current = 0;
float supplyVoltage;
double sensorValue1 = 0;
double sensorValue2 = 0;
int crosscount = 0;
int climb_flag = 0;
int val[100];
int max_v = 0;
double VmaxD = 0;
double VeffD = 0;
double Veff = 0;
void setup() {
pinMode(TempSensorPin,INPUT);
pinMode(trigPin, OUTPUT);
pinMode(echoPin, INPUT);
 Serial.begin(19200);
 SIM900.begin(19200);
 delay(20000);
 SIM900.print("AT+CMGF=1\r");
 delay(100);
SIM900.print("AT+CNMI=2,2,0,0,0\r");
delay(100);

Serial.println(" GSM-BASED TRANSFORMER MONITORING");
lcd.init();
```

```
lcd.setRGB(colorR, colorG, colorB);
lcd.autoscroll();
lcd.print("PROJECT:GSM-BASED");
lcd.setCursor(0,0);
lcd.print("TRANSFORMER");
//lcd.setCursor(0,2);
lcd.print("MONITORING");
//lcd.setCursor(0,3);
lcd.print("SYSTEM");
delay (500);
lcd.noAutoscroll();
lcd.clear();
}
float get_maxv() {
  float max_v = 0;
  for(int i = 0; i < 100; i++) {
    float value = analogRead(voltageSensor);  // read from analog channel 3 (A0)
    float v = (value * 5.0) / 1024.0;
    if(max_v < v) max_v = v;
    delayMicroseconds(40);
  }
  return max_v;
}
float get_maxi() {
  float  max_i = 0;
  for(int i = 0; i < 100; i++) {
    float adcValue = analogRead(currentPin);
     adcVoltage = (adcValue *( 5/1023.0));
     c = ((adcVoltage - offsetVoltage)/sensitivity);
     current = c;
    if(max_i < current){
```

```
    max_i = current;
    }
    delayMicroseconds(40);
  }
  return max_i;
}
void loop() {
//temperature//
vout = analogRead(TempSensorPin);
vout = (vout * 50) / 1023;
temp = vout;
//LOAD CURRENT//
float current = get_maxi();
c = current;
c/=sqrt(2);
LoadCurrent = c;
// SENSING OIL LEVEL//
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
duration = pulseIn(echoPin, HIGH);
OilLevel = duration * 0.034 / 2;

//LOAD VOLTAGE
float v = get_maxv();
  v /= sqrt(2);
vIN = v+22.12;
//IR SENSOR
Sensor_State = digitalRead(Motion_Sensor);   //We are constantly reading the button State
```

```
//HALL EFFECT SENSOR
//sensorValue = analogRead(A2);
 //LCD DISPLAY
lcd.clear();
lcd.setCursor(0,0);
lcd.print("Temp:");
lcd.setCursor(6,0);
lcd.print(temp);
lcd.setCursor(11,0);
lcd.print("C");
lcd.setCursor(0,1);
lcd.print("Oil L:");
lcd.setCursor(6,1);
lcd.print(OilLevel);
lcd.setCursor(10,1);
lcd.print("CM");
delay(5000);
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("IL:");
lcd.setCursor(3, 0);
lcd.print(LoadCurrent);
lcd.setCursor(7, 2);
lcd.print("A");
lcd.setCursor(8, 0);
lcd.print("VL:");
lcd.setCursor(11, 0);
lcd.print(vIN);
lcd.setCursor(15, 0);
lcd.print("V");
lcd.setCursor(0, 1);
```

```
lcd.print("IR:");
lcd.setCursor(5, 1);
if (Sensor_State == HIGH){
lcd.print("High");
}
else {
lcd.print("Low");
}
delay(5000);
lcd.clear();
condition();
}
void sms1()
{
SIM900.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
SIM900.println("HIGH TRANSFORMER TEMPERATURE:"+String(temp)+" *C"); // message
to send
Serial.println("HIGH TRANSFORMER TEMPERATURE"+String(temp)+" *C");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}
void sms2(){
SIM900.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
SIM900.println("LOW OIL LEVEL:"+String(OilLevel)+" CM"); // message to send
Serial.println("LOW OIL LEVEL:"+String(OilLevel)+" CM");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
```

```
}
void sms3(){
SIM900.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
SIM900.println("OVERLOAD CURRENT:"+String(LoadCurrent)+" A"); // message to send
Serial.println("OVERLOAD CURRENT:"+String(LoadCurrent)+" A");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}
void sms4()
{

SIM900.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
SIM900.println("TRANSFORMER OVERVOLTAGE:"+String(vIN)+" V"); // message to send
Serial.println("TRANSFORMER OVERVOLTAGE:"+String(vIN)+" V");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}

void sms5()
{
SIM900.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
SIM900.println("TRANSFORMER TAMPERING DETECTED"); // message to send
Serial.println("TRANSFORMER TAMPERING DETECTED");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
```

```
}
void sms6()
{
SIM900.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+254716602827\"");// recipient's mobile number
SIM900.println("OIL LEVEL: " + String(OilLevel) +" CM"); // message to send
Serial.println("OIL LEVEL: " + String(OilLevel) +" CM");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}
//CONDITIONS
void condition()
{
  if (temp > 75)
{
lcd_tempPrint();
sms1();
 delay(1000);
  }
if (OilLevel > 10)
{lcd_oilLevelLOWPrint();
 sms2();
 delay(1000);
  }
if (LoadCurrent > 300)
{
  lcd_currentPrint();
 sms3();
 delay(1000);
  }
```

```
 if (vIN > 415)
{
  lcd_vINPrint();
 sms4();
 delay(1000);
  }
  if (Sensor_State == HIGH) {            //And if it's pressed
    lcd_tamperingPrint();
    //lcd_oil_level();
    sms5();
    sms6();
 //And this function is called
delay(1000);
 }
}

// LCD PRINTING CONDITION//
void lcd_currentPrint()
{
lcd.clear();
lcd.setCursor(1,1);
lcd.clear();                              //if condition temp for it to print.
lcd.print("OVERLOAD CURRENT");
}
void lcd_oilLevelLOWPrint()
{
lcd.clear();
lcd.setCursor(0,2);
lcd.clear();                              //if condition temp for it to print.
lcd.print("OIL LEVEL LOW");
}
```

```
void lcd_tempPrint()
{
lcd.clear();
lcd.setCursor(0,0);
lcd.clear();                    //if condition temp for it to print.
lcd.print("HIGH TEMPERATURE");
}
void lcd_vINPrint()
{
lcd.clear();
lcd.setCursor(0,0);
lcd.clear();                    //if condition temp for it to print.
lcd.print("OVERVOLTAGE");
}
void lcd_tamperingPrint()
{
lcd.clear();
lcd.setCursor(0,0);
lcd.clear();                    //if condition temp for it to print.
lcd.print("TAMPERING DETECTED");
}
```