

Design and Construction of an IoT Based Distribution Transformer Condition Monitoring System

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-----ABSTRACT-----

A Power distribution as well as any bulk energy consuming companies have a strong demand for reliable power so far as revenue generation and production are concerned. Research will prove that transformers are great assets to companies and therefore maintenance as well as replacement of the transformer is found to be a luxurious exercise for every company. Keeping this factor in mind, IoT based distribution transformer health condition monitoring system is developed in this work to monitor the health conditions of distribution transformers remotely and at regular intervals. Health index is determined on the basis of change in current values on phases, oil level moisture content as well as load ability, which are measured using sensors. Arduino has been selected as the processor for transmitting the sensed data while Blynk App has been selected as the IoT platform for displaying the received data. This low-cost system can be installed in transformer at any location to get monitored remotely, which not only determines health condition but also to assist in predicting the life span as well.

Keywords: transformer, monitoring, IoT, microcontroller, sensors, transmission, data.

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I. INTRODUCTION

1.1 Background of the Study

Abnormality in distribution transformer is accompanied with variation in different parameters such as, Load current (which strongly has a major role to play in terms of the temperature variations), Moisture in oil which looks at the humidity content of the transformer cooling medium, dissolved gas in oil, bushing condition, Integrated Inductor, Transformer, Capacitance, (LTC) monitoring, oil level. However, we are dealing with oil level, humidity content and load current.

Online monitoring system consists of embedded system, Global Systems for Mobile communications (GSM) modem, mobile-users and GSM networks and sensors installed at transformer sites. Sensors are installed on transformer side which reads and measures the physical quantity from the distribution transformer and then it converts it from analogue to digital signal. The embedded module is located at the transformer site. It is utilized to acquire process, display, transmit and receive the parameters to/ from the GSM modem. The second is the GSM module. It is the link between the embedded system and the public GSM network. The third is utility module that has a PC-based -server located at the utility control centre. The server is attached to GSM modem and received transmits SMS from/to the transformer site via the GSM module. (Susmita et al., 2013)

Distribution transformers are sometimes heavily loaded without frequent monitoring of their Kilo Volt Ampere (KVA) demand, operating temperature, oil level and the moisture content developed in the transformer cooling medium. These acts normally lead to sudden breakdowns of transformers and cause a lot of damages to the system.

In other to reduce frequent breakdown of transformers because of lack of monitoring, the researchers intend to develop an IoT based distribution transformer monitoring system which is a fully human machine interface device and does not require any human interference during its operations. The system will provide accurate information since the sensors provide real time information on the critical conditions of the transformer.

1.2 Problem Statement

Distribution transformers are normally heavily loaded without frequent monitoring of their Kilo Volt Ampere (KVA) demand, operating temperature (i.e., that of the core winding and of the ambient) oil level and

the moisture content developed in the transformer cooling medium, which is the oil. This results in sudden breakdown of transformers leading to loss of revenue. Again, during peak hours, field technicians and engineers travel to transformer sites to pick load amps to ensure transformers are overloaded. Modern power system requires accurate, reliable technique for detection of faults, real time data monitoring and fast response speed.

The reliable operation of the power system depends upon the effective functioning of the distribution transformer. Microcontroller based system has real time data monitoring, detection of abnormal condition, fast processing speed, reduced installation cost, low maintenance cost and more flexibility. Hence the development of an IoT based distribution transformer monitoring system which is a fully human machine interface device and does not require any human interference during its operations.

1.3 Objectives of the Study

The general objective of the project is to develop an Internet of things (IoT) based remote monitoring system for multiple distribution transformers of an area, so that life expectancy of distribution transformer can increase with regular maintenance which could help companies to reimburse their capital investment on transformers.

The Specific Objectives are:

- To design a system which uses level, humidity, and current/load sensors to monitor the defined parameters of the transformers.
- To develop programmable codes and to implement it in the hardware of the transformer condition monitoring system using ATmega328P AVR MC and sensors.
- To ensure that all analogue signals are converted digital signals by the ADC to enable the microcontroller to understand it.
- The parameters recorded from the sensors will be sent over the internet of things (IoT) through the GSM Module to constantly inform the engineers when a threshold of a set parameter is exceeded.

1.4 Significance of the Study

This system is useful in optimizing the transformer operation and reduces the manual labour. It is the improved system for transformer monitoring to prevent the distribution transformer from catastrophic failure. The project also seeks to eliminate any sudden breakdowns of transformers which could be avoided if proper monitoring systems are put in place.

The IoT based distribution transformer monitoring system is a fully human machine interface device and does not require any human interference during its operations. The system will provide accurate information since the sensors provide real time information on the critical conditions of the transformer.

1.5 Scope and Limitations of the Study

The scope of this project is strictly focused on Distribution transformers parameter monitoring. This work is strictly focused on the design and constructions of the IoT based distribution condition monitoring system.

There will be Wi-Fi connectivity to the system to enhance the transformer parameters to be monitored on the web server. The device is limited to areas where Wi-Fi is available.

II. LITERATURE REVIEW

2.1 Introduction

This section primarily aimed at reviewing related works that have been done in the area of Distribution transformers parameter monitoring as well as the theoretical review.

2.2 Overview of the IoT based Distribution Transformer Monitoring System

Distribution transformers exist everywhere, from our homes to the industries. Distribution transformer consists of an electromagnetic circuit within it. Proper design, good insulation system and selection of transformer auxiliaries increase the reliability of a transformer. Power distribution companies are very keen to monitor transformer to keep up reliability and to extend its usage. Distribution transformers are most important part of distribution system. Every electrical work would be at stand still position without distribution transformers. Distribution's transformer life can be predicted by monitoring the health of its oil and winding. The life of a distribution transformer will be shortened by unexpected high temperatures.

Monitoring vital parameters improves the reliability of a system by regularly keeping an eye over them (Ballal, 2017). The companies need regular monitoring system to compete with the competition in the market place. Sudden breakdowns need to be curtailed in order to minimize the break down time, to reduce the maintenance cost and to extend the life time of distribution transformers.

2.3 Transformer Monitoring

Transformer can undergo two types of faults, which are internal and external faults. Different causes of internal as well as external faults are given below in Table 2.1.

Table 2.1 Causes of failures of transformer Faults (Wang, 2002)

Internal	External
Partial Discharge	Lighting Strike
Insulations Deterioration	System Fault
Humidity	System Overload
Moisture	Switching operations
Overheating	
Winding resonance	
Designing Defects	
Loss of Winding clamping	
Insulating oil solid Contamination	

2.4 Wireless Monitoring of Distribution Transformer

Technologies used are GPRS Technology and GSM based online condition monitoring system. In above technologies, GPRS/GSM technology is used to monitor all online parameters of distribution transformer. Online parameters like current, humidity, winding temperature, oil level sensors etc. are used to calculate health index of transformer. Health index calculations are based on the parameters.

In GPRS technology, whenever certain limits of health index are crossed, a message is sent to operator for further actions and maintenance.



Fig. 2.1 GSM based transformer Monitoring System

2.5 Transformer Parameters to be monitored by the condition Systems.

2.5.1 Humidity

There are several causes of moisture ingress in transformer insulation medium (oil). Some of these could be;

1. Leaks: Gasket and joints could leak
2. Temperature variations could lead to condensation, developing the moisture content of transformer. Moisture in oil and winding paper if not critically accessed and eliminated could lead to the reduction of the dielectric strength of the oil as well as reducing the lifespan of the transformer oil. At high load, moisture in the winding paper can increase the risk of high bubbling which is a potential damage to the transformer. To avoid the error caused by taking the moisture value of a non- saturated solution as solubility, or solution with excessive free water, an alternative easily implemented method is proposed for measuring moisture solubility in transformer oil. The linearity between the relative humidity of the oil and the moisture content of the oil is utilized to find the solubility:

$$r = r_s \times \frac{R}{100} \tag{1}$$

Where R is the relative humidity (%), T the water concentration in ppm at temperature T, and r, is the water solubility in ppm at the same temperature T. By measuring the slope of the curve of moisture concentration vs. relative humidity, or the intercept of the curve at R=100%, one can find the water solubility instead of trying to directly measure the moisture content at 100% relative humidity.

2.5.2 The Current

A transformer has two or more electrical coils that are wound around an iron core. One coil is called the primary and is part of the primary circuit. The other coil is called the secondary and is part of the secondary circuit. There is no electrical connection between the primary and the secondary coils. When an alternative current flow in the primary circuit, a magnetic field builds up and a magnetic flux flows inside the core. The magnetic flux changes its direction 120 times per second. These changes create a current through the secondary coils. The energy transforms from the primary to the secondary circuit, and the voltage converts according to turn ratio:

The current demand of the transformer must basically satisfy the transformer turns ratio.

The ampere-turn equation in this case is equal to;

$$T.R. = n = \frac{N_p}{N_s} = \frac{I_s}{I_p} \quad (2)$$

From the above equation;
Secondary equations,

$$I_s = I_p = \left[\frac{N_p}{N_s} \right] \quad (3)$$

Electrical current transforms according to reciprocal of the turn ratio:

N_p = Primary coil's turns of the transformer,

N_s = Secondary coil's turns of the transformer

N = turns ratio of the transformer.

Where I_p and I_s are primary and secondary currents of the transformer accordingly.

2.5.3 Oil level

The presence of oil in transformers provides cooling of the winding, insulation of the winding from the transformer housing and finally serving as a quenching medium to quench arcs which occur at termination points (tapings, terminals) within the transformer windings arrangement. Conditions such as temperature variation could reduce the oil level. A sudden puncture in the transformer tank/housing will accidentally 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.

2.6 Empirical Review

The Internet of Things (IoT)

An IoT based environment consists of different sensors, communication medium and devices *etc.* through which they process information among each other. IoT based devices share sensor data through cloud and processes accordingly which can be analyzed and can be used for decision making. All IoT based devices perform without human intervention, and even people can interact with devices. In IoT based systems, accumulated data can be further processed to be analyzed or sent to different user interfaces like smart-phones, human-machines *etc.* for desired actions to be taken. It is a big technology advancement; where, a human interacts with the machines and perform work more accurately and swiftly. As per studies, billions of the devices will be connected to internet by 2025. Interconnection of devices will create an intelligent network and will build smart devices. Thus, when they are interconnected, they can analyze the data in countless ways which creates better and faster products at low costs. All tasks can be performed more accurately and automatically with combination of IoT and automated devices. IoT offers us an opportunity for saving our time, money and utilizing our resources optimally, (Shuvam, 2019)

The project intended to communicate with many power distribution transformer stations which are far from the city. The wireless GPRS transmission provides a good communications solution to supervise power distribution transformer stations. The scheme of remote wireless monitoring system for power distribution transformer stations on GPRS wireless network was designed. A control terminal system was implemented which adopted LPC2132 as main processor, GR47 as the data communications module. The monitor terminal software and flow chart were also designed. At last, the way of configuring the GPRS module to connect the network was analysed. (Petkar *et al.*, 2016)

The IoT based distribution transformer monitoring system was designed and implemented on a mobile embedded system to monitor and record key parameters of a distribution transformer like load currents, oil level and ambient modem, with a standalone single chip microcontroller and different sensors. It is installed at the distribution site and the above parameters are recorded using the analogue to digital converter (ADC) of the embedded system. The obtained parameters are processed and recorded in the system memory. If any abnormality or any emergency occurs, the system sends an SMS (Short Message Service) messages to the mobile phones containing information about the abnormality according to some predefined instructions programmed in the microcontroller. This mobile system enables the transformers to operate smoothly and identify problems before any catastrophic failure. (Rajan, 2015).

III. METHODOLOGY

3.1 Introduction

This session deals with the methods deployed in the design processes, the tools and components, design and construction of the system.

3.2 Hardware Components for the Study

- Arduino Uno
- SHT31-D Humidity Sensor
- Current Sensor
- Ultrasonic level sensor
- Nodemcu esp8266 Wi-Fi Module
- Lm317 Voltage Regulator
- 330-ohm resistors pack
- Female DC power jack socket
- 470uf capacitor
- 5x7cm vero board
- Female headers
- Connecting wires
- Jumper wires
- Bread Board
- 12V Adaptor
- PCB Plate
- Variable Power Supply
- ADC

3.3 System Design

3.3.1 Variable Power Supply/Power Jack:

Arduino can be powered either from the PC through a USB or through external source like adaptor or a battery. It can operate on an external supply of 7 to 12 V. Power can be applied externally through the pin vin or by giving voltage reference through the I/O Ref pin. The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically. External power can come either from an AC to DC power adaptor (wall-wart) or battery. The adapter can be connected by plugging. The board can operate on an external supply of 9 to 20 volts. If supplied with less than 9 V, however, the 5 V pin may supply less than five volts and the board may be unstable. If using more than 12 V, the voltage regulator may overheat and damage the board. The recommended range is 9 to 12 volts.

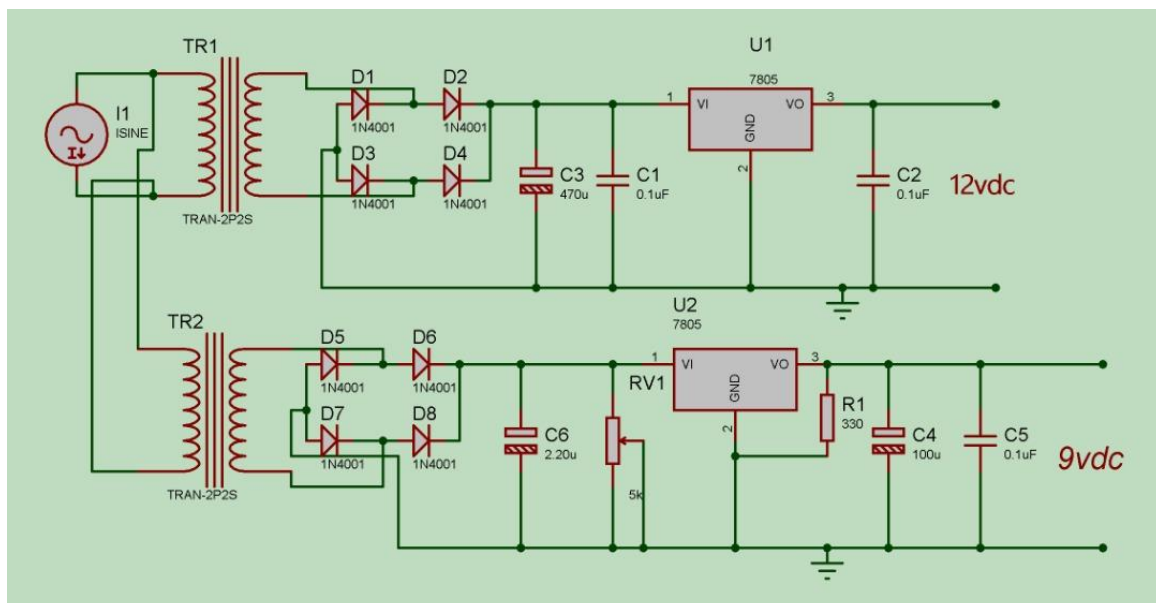


Fig. 3.1 230 Vac to 12 VDC and 9 VDC Power Supply for the various Part of the Circuit. microprocessor board

The LM317 is a voltage regulator chip which is capable of producing output voltage from 1.2V to 37 V with 1.5 A of current to the load. The output can be altered by using the Adj pin of the IC. The IC was built in such a way it develops a nominal voltage of 1.25 V from the Output pin to the Adj pin. So, putting resistor across these two terminals and applying a varied voltage to adj pin will give varied output voltage in V_{out} pin.

LM317 Voltage Regulator Circuit

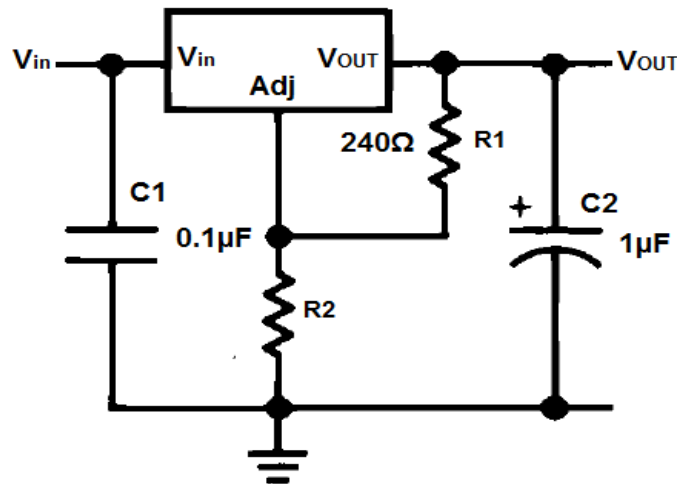


Fig. 3.2 LM317 Voltage regulator

The above schematic shows the simple voltage regulator set up using LM317. Here a potential divider was used to feed the adjusting voltage to the adj pin. The output voltage obtained is given by the formula.

$$V_{out} = 1.25 V \left[1 + \frac{R_2}{R_1} \right] \quad (4)$$

Where R_2 and R_1 denotes the lower and upper leg of the potential divider used to feed the Adj pin. According to the V_{out} formula for LM317 varying the resistance in voltage divider will alter the output voltage. Keeping the Resistor R_1 fixed and alter the lower leg of the divider with different resistors R_2, R_3, R_4, R_5 and R_6 which gives output voltages of 12, 9, 6, 5 and 3.3. To calculate the resistance value (lower leg) for our required output voltages we have to rearrange the basic LM317 formula in equations (4) R_2 Becomes;

$$R_2 = \left[V_{out} \times \frac{R_1}{1.25} \right] - R_1 \quad (5)$$

This formula gives the resistance value (lower leg) for required voltage. To obtain 12 V in the output the R_2 will be

$$R_2 = \left[12 \times \frac{240}{1.25} \right] - 240$$

$$R_2 = 2064 \quad \Omega$$

Approximating this value will give $2K\Omega$ resistance and therefore we have fixed R_2 as $2K\Omega$ in our schematic diagram. Using the same formula for 9, 6, 5 and 3.3 V we will get resistances $1.5K\Omega, 1K\Omega, 750$ and 390 ohms approximately. This forms the resistances R_3, R_4, R_5 and R_6 respectively. Summing the above things selecting R_2, R_3, R_4, R_5 and R_6 using the rotary switch will give 12, 9, 6, 5 and 3.3 V in the V_{out} pin of LM317

3.3.2 Digital Inputs

It consists of 14 digital pins which are inputs/output pins, each of which provide or take up 40mA current. There are some special functions like pins 0 and 1, which act as RX and TX respectively for serial communication, pins 2 and 3 which are external interrupts, pins 3, 5, 6,9,11 which provides PWM output and pin 13 where LED is connected.

3.3.3 Arduino Uno

Arduino Uno consists of 14 digital pins which acts as an input/output pins (of which 6 can be used as PWM outputs), 6 analogue pins acts as inputs, a 16 MHz crystal oscillator USB, a power jack and a reset button. It comes with an open-source hardware feature which enables users to develop their own kit using already available one as a reference source. We can develop an Arduino based project which can be completely stand alone or projects which involve direct communication with the software loaded in the computer.

Table 2.2 Parameters of the design and their Specifications, (Patrick, 2020)

No.	Parameters	Specification
1.	Operating Voltage	5 V
2.	Input Voltage	9 -12 V
3.	Microcontroller	Atmega328P
4.	Number of analogue pins	8
5.	Digital Input/output Pins	14
6.	Flash Memory	32KB
7.	Pulse Width Modulation (PWD)	6 out of 14 Digital Pins
8.	Maximum Current Rating	40Ma
9.	Crystal Oscillator	16MHz
10.	EEPROM	1KB

3.3.4 Current Sensor ACS712

Current transformer of CT ratio 50 A/10mA is used at the secondary of transformer to measure variation in load current. It is expected that transformer overloads with a load exceeding 90% of its capacity. Secondary current of transformer is needed to calculate harmonic load current which builds excessive heat as well as winding losses during overloading. An arduino based current sensor ACS712 produces an analog output voltage proportional to the current sensed by the terminals. The current sensor can operate from a voltage of 5 VDC. Even high AC mains current can be measured. The sensors are based on the Allegro ACS712ELC chip. These sensors are available full-scale reading of 5 A, 20 A and 30 A. For a 30 A sensor the output sensitivity is 66mV/A, and it can measure a current from 30 A to – 30 A range.

ACS712 consists of a low offset, precise linear Hall Effect sensor circuit having a copper conduction path around the die surface. The Hall Effect circuit converts the electromagnetic field produced during current flow through the copper part to output voltage.

- Low noise analog signal path
- Device bandwidth is set via the new FILTER pin.
- 5 μ s output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at TA = 25°C
- Small footprint, low-profile SOIC8 package
- 1.2 m Ω internal conductor resistance
- 2.1 kV RMS minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation• 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis

Current produced in secondary of CT is converted to voltage with a parallel resistor across its secondary terminals. As shown in figure below:

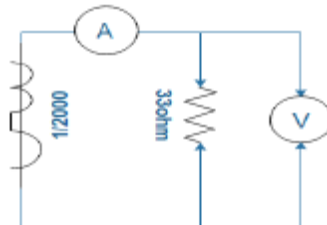


Fig. 3.3 CT Circuit

1. Ultrasonic Sensor

ITEM	COMPONENTS	PARAMETERS
1.	Power Supply	±5 VDC
2.	Quiescent	≥2 mA
3.	Working Current	-15 mA
4.	Effective Angle	15°
5.	Ranging Distance	2cm – 400cm/1 – 13ft
6.	Resolutions	0.3 cm
7.	Measuring Angle	30°

3.3.5 Printed Circuit Board:

A printed circuit board mechanically supports and electrically connects electronic components or electrical components using conductive tracks, pads, and other features fetched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it. The system required 12 VDC which was much lower than the supply voltage from the mains. A transformer was therefore required to step the voltage down to from 240 to 12 V. Because the output of the step-down transformer was in the form of an alternating current (AC), a rectifier was introduced to convert the AC signal to direct current (DC). The microcontroller, however, operates on 5 V. Thus, a 5 V regulator is placed after the rectifier to step the 12 V signal down to 5 V. A 3.3 V regulator is then placed after the 5 V regulator to get the voltage down to a clean 3.3 V for the ESP8266 Wi-Fi module. The sensors, the Wi-Fi module, and the LCD are all connected to the microcontroller which serves as the heart of the entire system.

3.3.6 Analog to digital converter (ADC)

The Arduino ADC or Analogue to Digital Converter takes an input voltage and converts it into a digital value. With the standard setup you can measure a voltage between 0 V and 5 V with a resolution of 4.9mV so you can get a lot of detail when measuring analogue voltages. There are six pins on the Arduino Uno (shown below 0 A ~ 5 A) that can be selected for an ADC measurement; A multiplexor feeds one of the six analogue input pins into the ADC.

How the Arduino Uno ADC Works

- This ADC is known as a successive approximation ADC and requires several clock cycles to zoom in on the correct ADC output.
- The ADC converter compares the input analogue voltage to a portion of V_{ref} using a divide by two sequence. The sample and hold capacitor are charged to the input voltage and then the input disconnected so that the same voltage is measured throughout the conversion process.
- It first checks whether the input voltage is higher or lower than half the V_{ref} voltage, by using a DAC to generate half the reference voltage. The DAC voltage is the fed into a comparator.
- The output of the DAC forms the high bit of the result (stored in a shift register). If the input voltage is higher, then the bit is one, otherwise the bit zero.
- If the input is lower than half V_{ref} then control logic generates a DAC voltage that is 1/4 the reference voltage. The comparison is made again, and this forms the next bit in the ADC output.

3.3.7 The ADC Clocks

For the Ardduino, the conversion process takes 13 cycles of the ADC clock - which you set using a prescaler in the ADC module. The ADC clock must be between 50 kHz and 200 kHz so you choose the prescaler value to get a valid ADC clock. The ADC clock prescaler can be set as a 2ⁿ division from 2 to 128. You obviously want the fastest conversion rate for the clock in use so for a 16MHz system clock you would calculate $16e6/200e3 = 80$ so the closest could be 64. However, $16e6/64$ is 250 kHz and is too big. Therefore, choosing a divisor of 128 must be used so the ADC clock will be $16e6/128 = 125kHz$.

3.3.8 SHT31-D Humidity Sensor

The digital SHT3x humidity sensor series takes sensor technology to a new level. As the successor of the SHT2x series it sets the industry standard in humidity sensing. The SHT3x humidity sensor series consists of a low-cost version with the SHT30 humidity sensor, a standard version with the SHT31 humidity sensor, and a high-end version with the SHT35 humidity sensor. The SHT3x humidity sensor series combines multiple functions and various interfaces (I²C, analog voltage output) with an applications-friendly, very wide operating voltage range (2.15 to 5.5 V).

3.3.9 NodeMcu

NodeMcu is an eLua based firmware for the ESP8266 Wi-Fi SOC from Espressif. The firmware is based on the Espressif NON-OS SDK and uses a file system based on spiffs. The code repository consists of 98.1% C-code. The NodeMCU firmware is a companion project to the popular NodeMCU development kits, ready-made open-source development boards with ESP8266-12E chips. ESP8266 Arduino Core. As Arduino.cc began developing new MCU boards based on non-AVR processors like the ARM/SAM MCU and used in the Arduino Due, they needed to modify the Arduino IDE so that it would be relatively easy to change the IDE to support alternate tool chains to allow Arduino C/C++ to be compiled down to these new processors. This is what is popularly called the “ESP8266 Core for the Arduino IDE” and it has become one of the leading software development platforms for the various ESP8266 based modules and development boards, including NodeMCUs.

Advantages of NodeMCU platform relative to the Arduino

- Low cost
- Integrated support for WIFI network
- Reduced size of the board
- Low energy consumption
- Disadvantages
- Need to learn a new language and IDE.
- Reduced pin-out
- Scarce documentation

The NodeMCU programming can be as easy as in Arduino. The main difference is in the pinning of the board, described below:

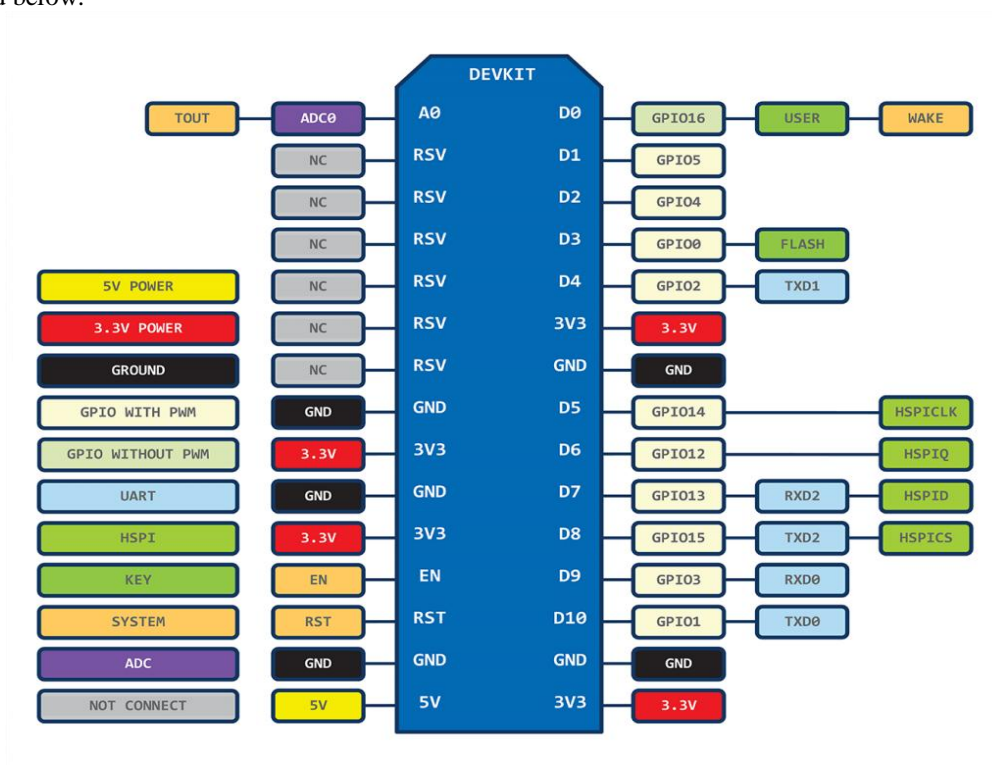


Fig. 3.6 Pin diagram

3.4 System Flow Chart

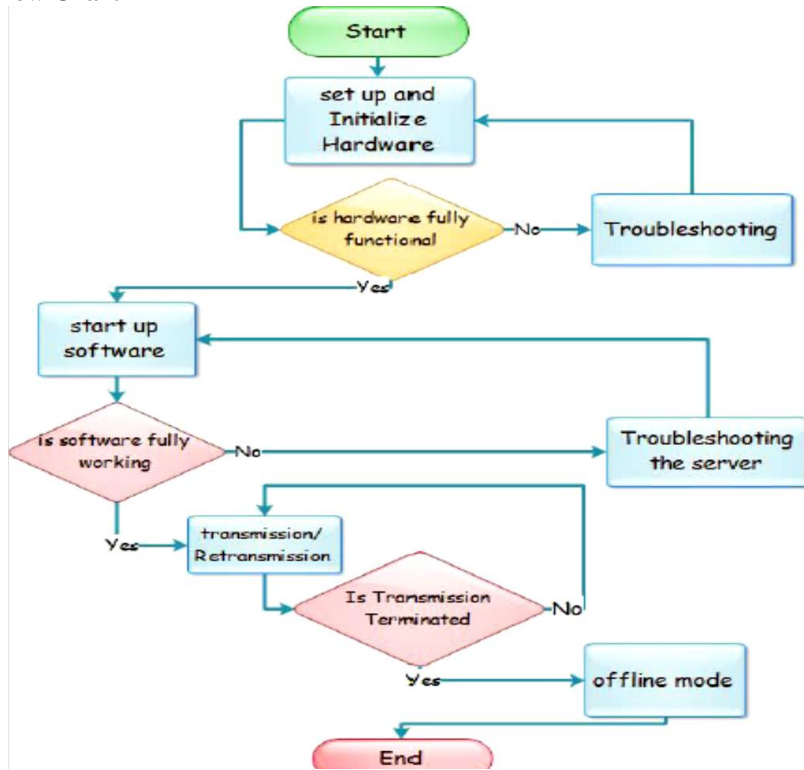


Fig.3.7 Overall Process Is Shown in Flow Diagram

3.5 Overall Circuit Diagram (Proteus 8.0 Professional)

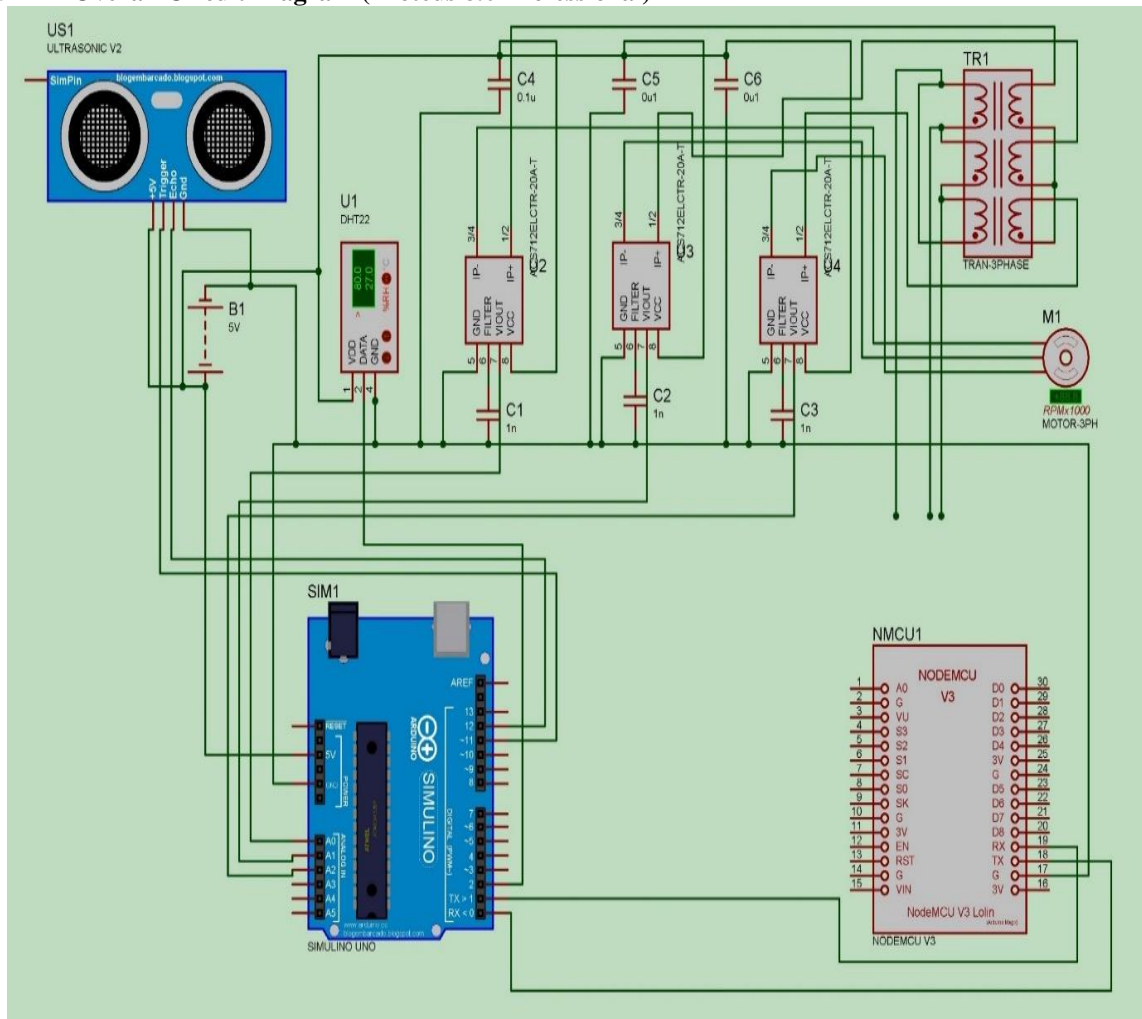


Fig. 3.8 Circuit Diagram for Project

3.6 Setting Up Internet of Things Data Transfer

To share the sensor data over the internet for virtual data reading, the Blynk software application is used. Blynk is an Internet of Things (IoT) online platform that supports hardware platforms such as Arduino, Raspberry Pi, and similar microcontroller boards to build hardware for your projects. Blynk uses platforms architectures such as an app builder, server and libraries for implementing projects using communication channels like ethernet, Bluetooth, wifi, cellular and serial communication. For the purposes of this project, the wifi communication channel is used in communicating to the Blynk server by the Nodemcu device.

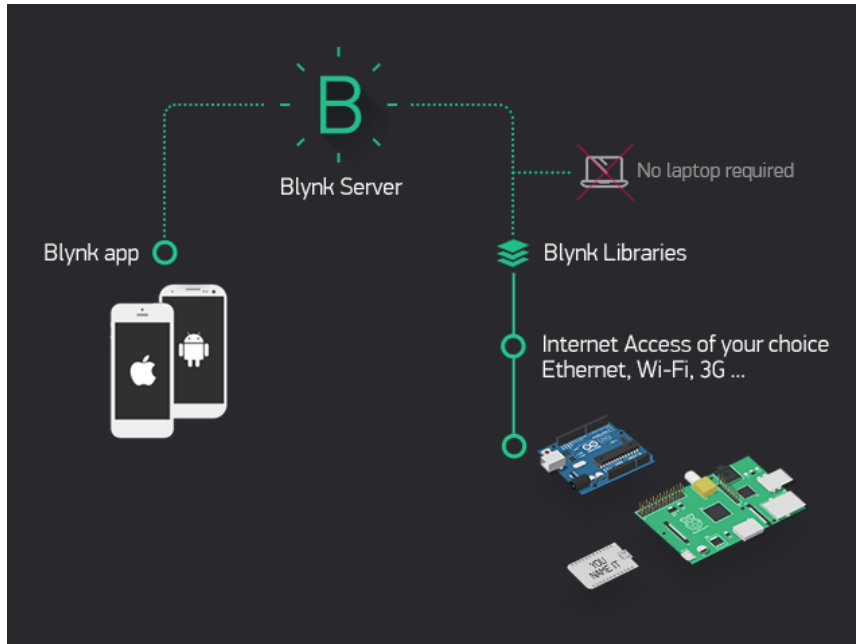


Fig. 4.13 Blynk Platform

Setting up the Blynk app requires basic steps which includes;

1. Downloading the Blynk app for either an Android or an IOS(Apple) device from the Appstore or playstore.
2. create new project (use hardware model esp8266)
3. generate AUTH TOKEN
4. send E-mail TOKEN (copy TOKEN in the esp8266 sketch)
5. in the app Blynk use Value Display widget, Gauge widget and Terminal Widget to display sensor values.
6. Assign various input pins in widget and play project to view live data.

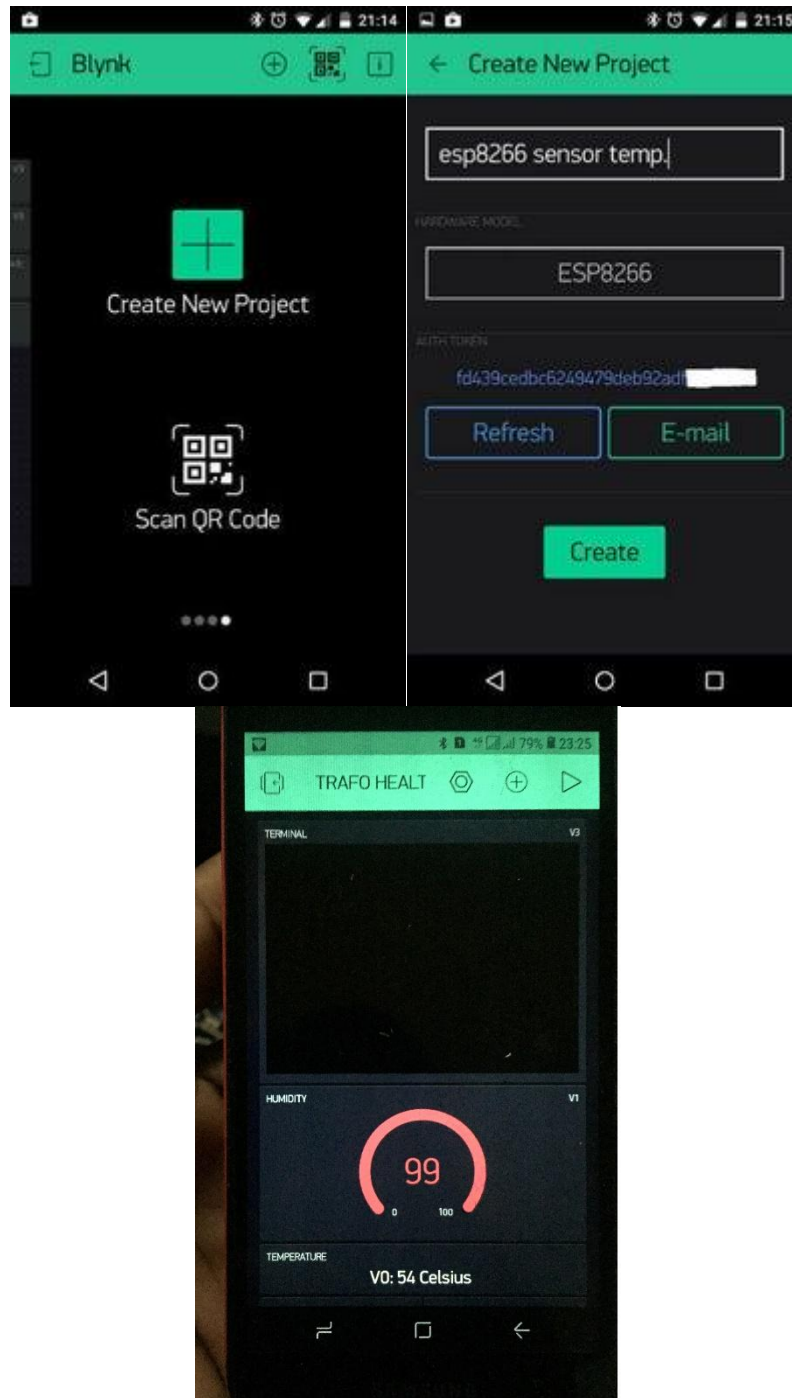


Fig.4.14 Blynk App Configuration

To programme the Arduino Uno and the Nodemcu (ESP8266), the Arduino IDE software is required. This allows the coding and uploading of the programme commands to read and send the sensor values which have been read to the server to be able to be displayed on the app successfully. The Arduino IDE version 1.8.12 was used in programming both the Nodemcu and the Arduino Uno microcontroller.



Fig. 4.15 Arduino IDE 1.8.12

IV. RESULTS AND ANALYSIS

4.1 Introduction

This session contains results gathered from the testing of the design and construction of the transformer health monitoring system. It also deals with the analysis and the discussions of the results.

4.2 Nodemcu with the Humidity Sensor Test

The DHT22, Humidity Sensor, is a three-pin sensor device labelled VCC, DATA and GND which are to be connected directly to the Nodemcu. It takes a source voltage between 3-5vdc for operations and gives out a digital signal. This digital signal is sent out to the Nodemcu from the DATA pin. The Nodemcu subsequently transmits the digital reading it receives from the DHT22 sensor via a virtual pin to an IP (Internet Protocol) address which allows the readings to be received by a mobile phone app and to display the real time sensor readings with 2 seconds delay in refreshing for new sensor readings from the device.

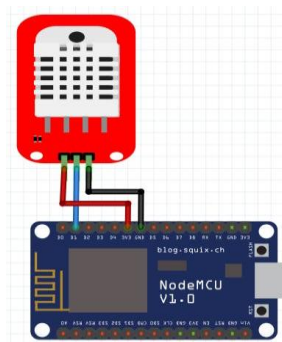
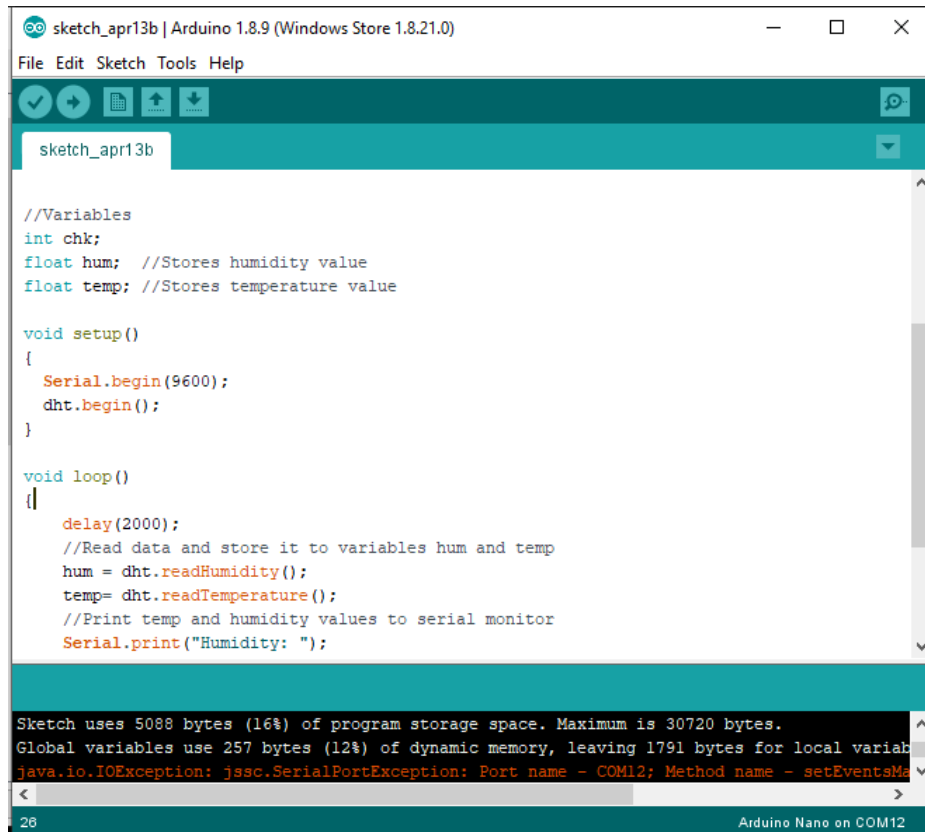


Fig. 4.1 Nodemcu with DHT22

The testing codes and results for the DHT22 sensor readings is shown in Fig. 4.2 and 4.3.



```
sketch_apr13b | Arduino 1.8.9 (Windows Store 1.8.21.0)
File Edit Sketch Tools Help
sketch_apr13b
//Variables
int chk;
float hum; //Stores humidity value
float temp; //Stores temperature value

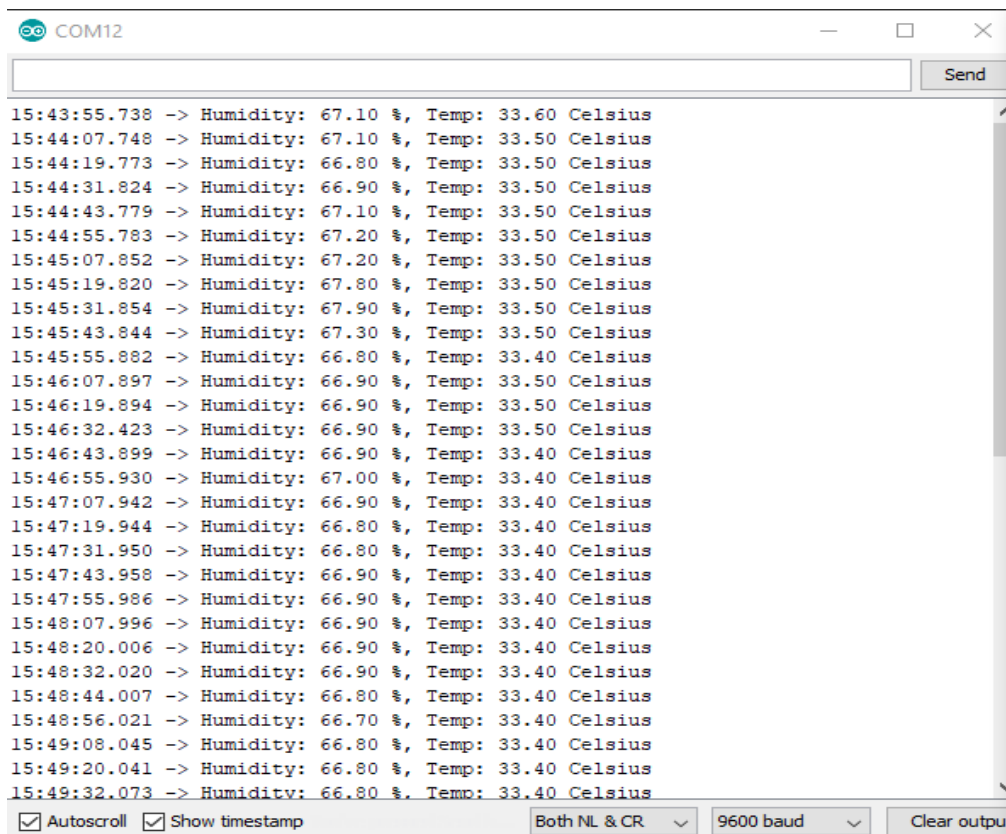
void setup()
{
  Serial.begin(9600);
  dht.begin();
}

void loop()
{
  delay(2000);
  //Read data and store it to variables hum and temp
  hum = dht.readHumidity();
  temp= dht.readTemperature();
  //Print temp and humidity values to serial monitor
  Serial.print("Humidity: ");

Sketch uses 5088 bytes (16%) of program storage space. Maximum is 30720 bytes.
Global variables use 257 bytes (12%) of dynamic memory, leaving 1791 bytes for local variables.
java.io.IOException: jssc.SerialPortException: Port name - COM12; Method name - setEventsMask

28 Arduino Nano on COM12
```

Fig. 4.2 Codes for Testing DHT22 with Arduino



```
COM12
Send
15:43:55.738 -> Humidity: 67.10 %, Temp: 33.60 Celsius
15:44:07.748 -> Humidity: 67.10 %, Temp: 33.50 Celsius
15:44:19.773 -> Humidity: 66.80 %, Temp: 33.50 Celsius
15:44:31.824 -> Humidity: 66.90 %, Temp: 33.50 Celsius
15:44:43.779 -> Humidity: 67.10 %, Temp: 33.50 Celsius
15:44:55.783 -> Humidity: 67.20 %, Temp: 33.50 Celsius
15:45:07.852 -> Humidity: 67.20 %, Temp: 33.50 Celsius
15:45:19.820 -> Humidity: 67.80 %, Temp: 33.50 Celsius
15:45:31.854 -> Humidity: 67.90 %, Temp: 33.50 Celsius
15:45:43.844 -> Humidity: 67.30 %, Temp: 33.50 Celsius
15:45:55.882 -> Humidity: 66.80 %, Temp: 33.40 Celsius
15:46:07.897 -> Humidity: 66.90 %, Temp: 33.50 Celsius
15:46:19.894 -> Humidity: 66.90 %, Temp: 33.50 Celsius
15:46:32.423 -> Humidity: 66.90 %, Temp: 33.50 Celsius
15:46:43.899 -> Humidity: 66.90 %, Temp: 33.40 Celsius
15:46:55.930 -> Humidity: 67.00 %, Temp: 33.40 Celsius
15:47:07.942 -> Humidity: 66.90 %, Temp: 33.40 Celsius
15:47:19.944 -> Humidity: 66.80 %, Temp: 33.40 Celsius
15:47:31.950 -> Humidity: 66.80 %, Temp: 33.40 Celsius
15:47:43.958 -> Humidity: 66.90 %, Temp: 33.40 Celsius
15:47:55.986 -> Humidity: 66.90 %, Temp: 33.40 Celsius
15:48:07.996 -> Humidity: 66.90 %, Temp: 33.40 Celsius
15:48:20.006 -> Humidity: 66.90 %, Temp: 33.40 Celsius
15:48:32.020 -> Humidity: 66.90 %, Temp: 33.40 Celsius
15:48:44.007 -> Humidity: 66.80 %, Temp: 33.40 Celsius
15:48:56.021 -> Humidity: 66.70 %, Temp: 33.40 Celsius
15:49:08.045 -> Humidity: 66.80 %, Temp: 33.40 Celsius
15:49:20.041 -> Humidity: 66.80 %, Temp: 33.40 Celsius
15:49:32.073 -> Humidity: 66.80 %, Temp: 33.40 Celsius
 Autoscroll  Show timestamp Both NL & CR 9600 baud Clear output
```

Fig. 4.3 Results for Humidity and Temperature Sensor.

4.3 Test Report Obtained from the transformer parameters over 24hours.

Table 4.1 Test Results

Time	DHT Humidity (%) ²²	DHT Temperature (Celsius) ²²	Oil Level	Current Sensor 1	Current Sensor 2	Current Sensor 3
08:00:00	82	27	4	7.62	7.32	7.22
09:00:00	82	27	4	7.62	7.32	7.22
10:00:00	82	28	4	7.62	7.32	7.22
11:00:00	83	34	4	7.62	7.32	7.22
12:00:00	84	37	4	7.62	7.32	7.22
13:00:00	85	51	4	7.62	7.32	7.22
14:00:00	84	47	4	7.62	7.32	7.22
15:00:00	84	46	4	7.62	7.32	7.22
16:00:00	84	46	4	7.62	7.32	7.22
17:00:00	83	40	4	7.62	7.32	7.22
18:00:00	82	35	4	7.62	7.32	7.22
19:00:00	75	27	4	7.62	7.32	7.22
20:00:00	73	27	4	7.62	7.32	7.22
21:00:00	72	27	4	7.62	7.32	7.22
22:00:00	72	27	4	7.62	7.32	7.22
23:00:00	72	27	4	7.62	7.32	7.22
00:00:00	69	27	4	7.62	7.32	7.22
01:00:00	69	27	4	7.62	7.32	7.22
02:00:00	69	27	4	7.62	7.32	7.22
03:00:00	69	27	4	7.62	7.32	7.22
04:00:00	69	27	4	7.62	7.32	7.22
05:00:00	71	27	4	7.62	7.32	7.22
06:00:00	73	27	4	7.62	7.32	7.22
07:00:00	80	27	4	7.62	7.32	7.22
08:00:00	80	27	4	7.62	7.32	7.22

From the table above, it can be summarised that over 24hours of monitoring the transformer conditions over the internet or the IoT platform, the humidity level of the transformer oil is minimal over the night as compared to the daytime likewise the temperature values. The current values seem to be constant since there has not been any significant load variations. The test result has been further explained in a graphical representation in the figure 4.1 below.

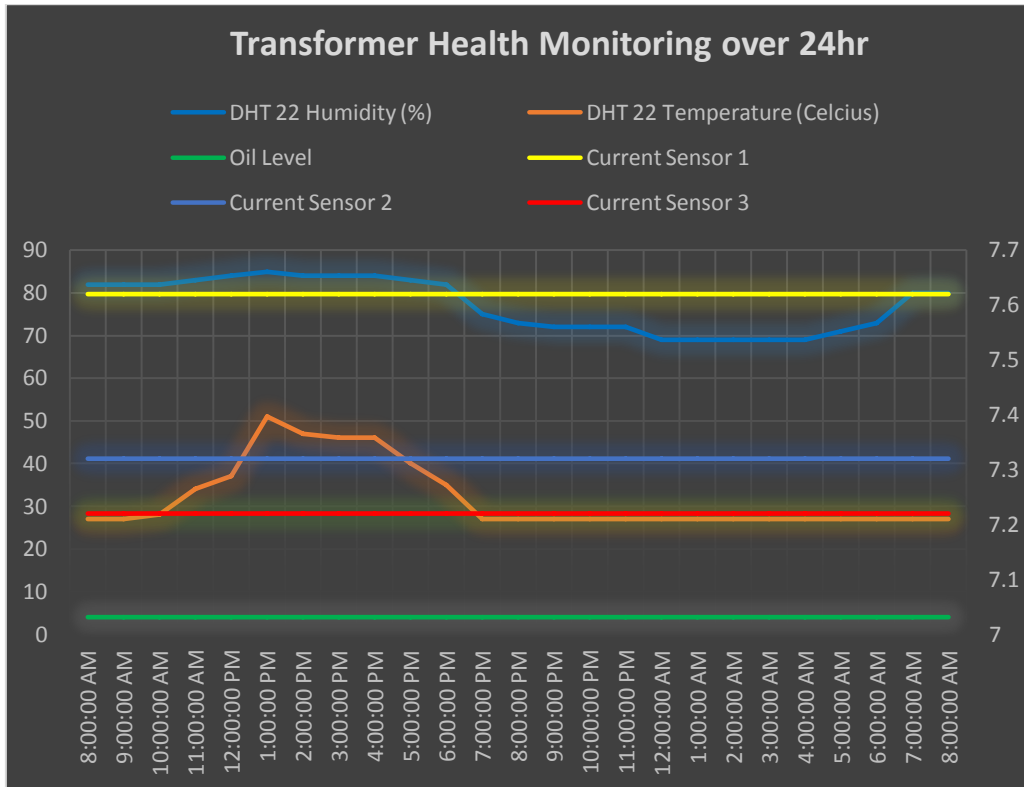


Figure 4.1 Graphical Representation of the Online Parameters

4.3 Arduino with the ACS712 Current Sensor Test

The ACS172 current sensor is also a five-pin device used in current measurement. This device usually produces an analogue output when supplied a 5vdc power supply. Since three of these sensors will be used, the analogue output is wired to the analogue pins of the Arduino Uno. The Current carrying cable is passed through the sensor which measures and convert the current reading to a voltage output which is read as an analogue sensor data by the Arduino and then a conversion of the voltage level is made to depict the actual current value.

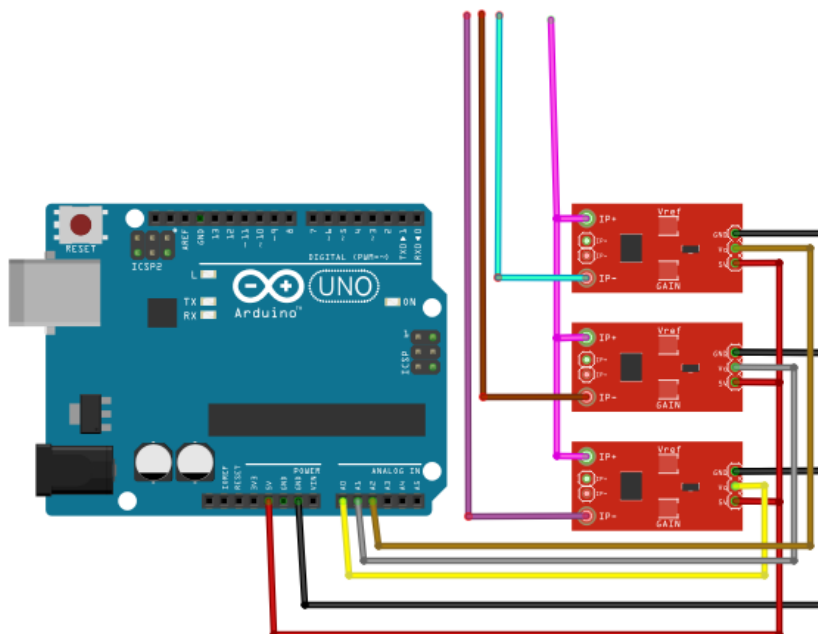


Fig. 4.4 ACS712 with Arduino Uno

The required power supply to the current sensor plays a key role in the accuracy of the current reading converted by the module. For this reason, a 5 VDC DC- DC buck converter was used to supply just the right amount of voltage to the current sensor. This buck converter is a 2 A rated LM2596 voltage regular module which was prefabricated.



Fig. 4.5 5 VDC LM2596 DC-DC Converter

4.4 Arduino with the Ultrasonic Sensor Test

The HC-SR04 Ultrasonic sensor for measuring distance is a four-pin device that sends and receives radio frequency signal. Once a signal is sent to the trigger pin, a radio signal is sent out and a respective echo signal is. This allows the calculation of the distance of the surface reflecting the transmitted signal as echo. The HC-SR04 device uses a 5vdc power supply making it unideal to be connected directly to the Nodemcu device.

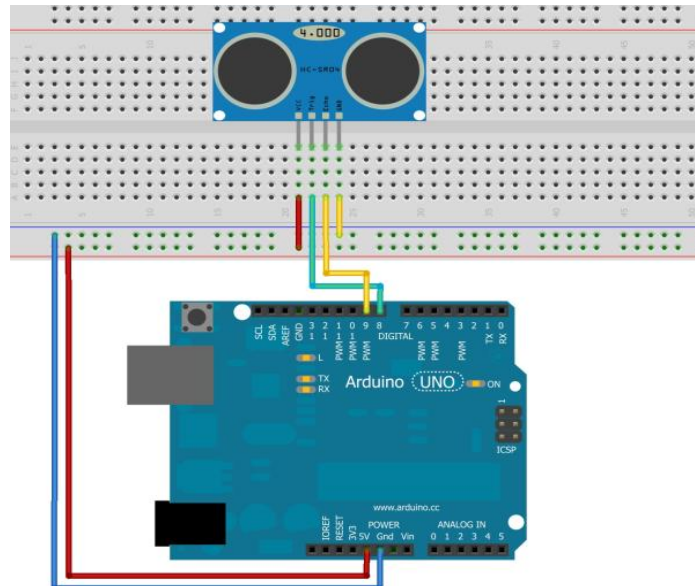


Fig. 4.6 Interfacing HC-SR04 with Arduino.

Testing results for the operability of the level sensor is as shown in figure 4.5.

```
COM12
16:15:36.949 -> 79in, 201cm
16:15:37.087 -> 79in, 203cm
16:15:37.198 -> 78in, 201cm
16:15:37.328 -> 79in, 203cm
16:15:37.422 -> 78in, 201cm
16:15:37.566 -> 78in, 200cm
16:15:37.662 -> 78in, 200cm
16:15:37.763 -> 78in, 200cm
16:15:37.867 -> 78in, 200cm
16:15:37.971 -> 79in, 201cm
16:15:38.107 -> 78in, 200cm
16:15:38.209 -> 79in, 202cm
16:15:38.312 -> 79in, 203cm
16:15:38.414 -> 79in, 201cm
16:15:38.552 -> 79in, 201cm
16:15:38.655 -> 80in, 204cm
16:15:38.766 -> 79in, 202cm
16:15:38.870 -> 79in, 201cm
16:15:39.006 -> 78in, 201cm
16:15:39.110 -> 79in, 201cm
16:15:39.214 -> 78in, 200cm
16:15:39.315 -> 78in, 200cm
16:15:39.455 -> 80in, 204cm
16:15:39.556 -> 79in, 203cm
16:15:39.659 -> 79in, 203cm
16:15:39.767 -> 79in, 203cm
16:15:39.904 -> 79in, 203cm
16:15:40.014 -> 79in, 202cm
16:15:40.118 -> 79in, 203cm
16:15:40.220 -> 79in, 201cm
16:15:40.357 -> 78in, 201cm
16:15:40.461 -> 78in, 201cm
16:15:40.566 -> 79in, 201cm
16:15:40.671 -> 79in, 204cm
16:15:40.807 -> 80in, 204cm
Autoscroll Show timestamp Both NL & CR 9600 baud Clear output
```

Fig. 4.7 Output of Ultrasonic Level Sensor Testing

```
sketch_apr13c | Arduino 1.8.9 (Windows Store 1.8.21.0)
File Edit Sketch Tools Help
sketch_apr13c
const int pingPin = 7; // Trigger Pin of Ultrasonic Sensor
const int echoPin = 8; // Echo Pin of Ultrasonic Sensor

void setup() {
  Serial.begin(9600); // Starting Serial Terminal
}

void loop() {
  long duration, inches, cm;
  pinMode(pingPin, OUTPUT);
  digitalWrite(pingPin, LOW);
  delayMicroseconds(2);
  digitalWrite(pingPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(pingPin, LOW);
  pinMode(echoPin, INPUT);
  duration = pulseIn(echoPin, HIGH);
  inches = microsecondsToInches(duration);
  cm = microsecondsToCentimeters(duration);
  Serial.print(inches);
  Serial.print("in, ");
  Serial.print(cm);
  Serial.print("cm");
  Serial.println();
  delay(100);
}

Sketch uses 2638 bytes (8%) of program storage space. Maximum is 32768 bytes.
Global variables use 196 bytes (9%) of dynamic memory, leaving 1864 bytes free.
Arduino Nano on COM12
```

Fig. 4.8 Arduino Code for Ultrasonic Level Sensor Test

4.5 Arduino Uno to the SIM900 GSM Module Test

The SIM900 GSM module is a 3G device which sends and receives mobile communications for the system. For the purpose of this project, the module was setup to send warning notification to a monitoring number to alert the person in charge of a possible drop in oil level. The communication of the GSM device with the Arduino is done via its serial port, in this case, a software serial port was used even though the module had an option for a hardware serial communication.

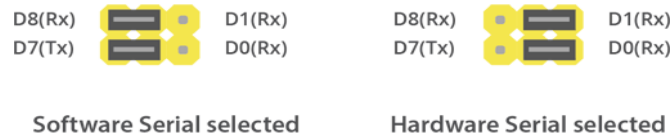


Fig. 4.9 Serial Communication Selection Pins

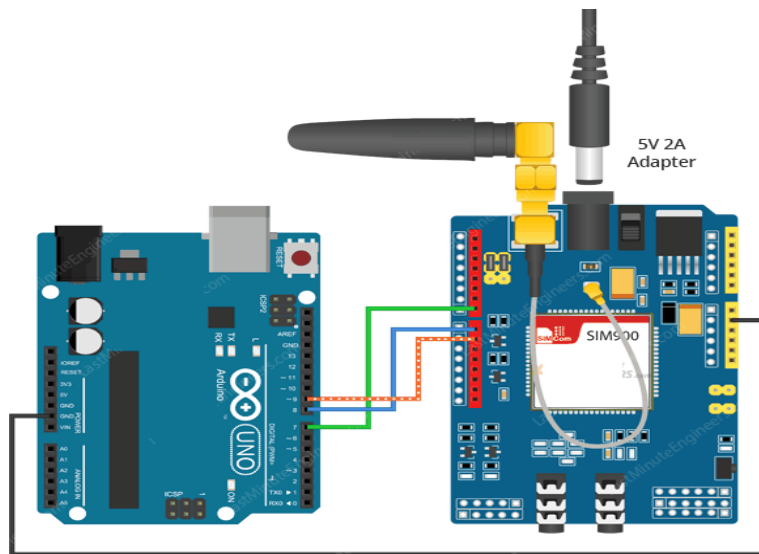


Fig. 4.10 Interfacing GSM Module with Arduino

The communication device needed a minimum of 2A transmission burst to be able to send a message effectively without the module switching off. For this reason, the prefabricated power supply for the systems was made to supply direct power to the GSM device. The output codes and test results are shown in figure 4.11 and 4.12.

```

ARduino_GSM_Interfacing | Arduino 1.8.9 (Windows Store 1.8.21.0)
File Edit Sketch Tools Help
ARduino_GSM_Interfacing
void setup()
{
  //Begin serial communication with Arduino and Arduino IDE (Serial Monitor)
  Serial.begin(9600);

  //Begin serial communication with Arduino and SIM900
  mySerial.begin(9600);

  Serial.println("Initializing...");
  delay(1000);

  mySerial.println("AT"); //Handshaking with SIM900
  updateSerial();

  mySerial.println("AT+CMGF=1"); // Configuring TEXT mode
  updateSerial();
  mySerial.println("AT+CMGS=\"+233501611224\"");//change ZZ with country code and xxxxxxxxxxxx with phone
  updateSerial();
  mySerial.print("GSM module TEst... Done"); //text content
  updateSerial();
  mySerial.write(26);
}

void loop()
{
}
}

Done uploading.
Sketch uses 3636 bytes (11%) of program storage space. Maximum is 30720 bytes.
Global variables use 381 bytes (18%) of dynamic memory, leaving 1667 bytes for local variables. Maximum
32 Arduino Nano on COM12
    
```

Fig. 4.10 Codes for Testing SIM900

```

COM12
Send
Initializing...
17:46:44.714 -> AT
17:46:44.714 ->
17:46:44.714 -> OK
17:46:45.229 -> AT+CMGF=1
17:46:45.229 ->
17:46:45.229 -> OK
17:46:45.779 -> AT+CMGS="+233501611224"
17:46:45.779 ->
17:46:45.779 -> > GSM module TEst... Done
Autoscroll Show timestamp Both NL & CR 9600 baud Clear output
    
```

Fig. 4.11 Output Test Results for Text Sending Option for SIM900

4.6 Arduino Uno with the Nodemcu Test

Even though both the Arduino and the Nodemcu are all microcontrollers that can operate in isolation, this project makes use of the two to execute the desired task of measuring three analogue input

signals. In implementing the IoT part of the project whereby sensor values and readings can be viewed in real time, the Arduino itself will not be able to execute that. The Nodemcu on the other hand is able to send real time data over the internet but has only one analogue input pin which means that it will not be able to be used in reading three different analogue sensor values. Secondly, the Nodemcu takes signal inputs at 3.3v and less of which the current sensor outputs data at 5vdc which means that should the output signal be fed to the Nodemcu directly, the device will fail over time since the increase in input voltage will reduce lifespan of the module.

For the Nodemcu to communicate effectively with the Arduino Uno in sending and receiving data values, the serial communication port of both devices is used. In this case, two different devices in the project makes use of the serial communication port, hence, the need to make one use a software serial port and the other, the hardware serial port.

The GSM module uses the same serial port for receiving message sending and message content command from the Arduino and at the same time, the Nodemcu receives and sends the current sensors values via same serial communication port.

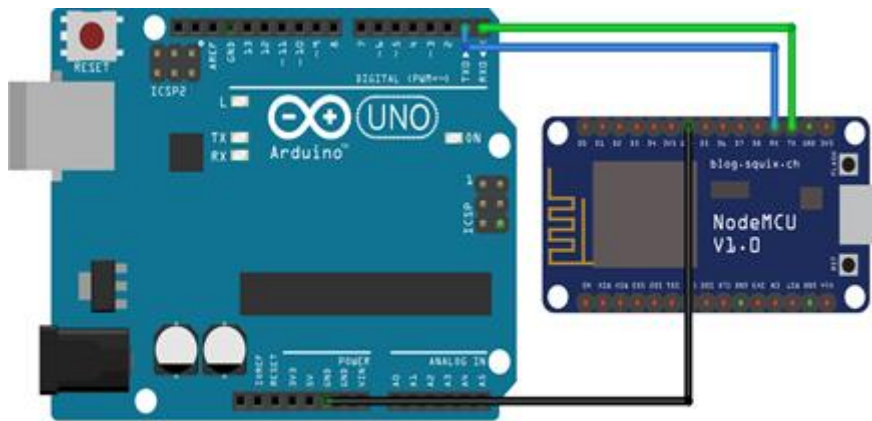


Fig. 4.12 Arduino -Nodemcu Serial Communication Interfacing

4.8 System Circuitry Set up and Test.

Once all the individual components of the system had been validated to be operational, the system was setup to function as desired in the design. Figure 4.16 depicts the start of the building process figure 14.17 depicts the test setup.

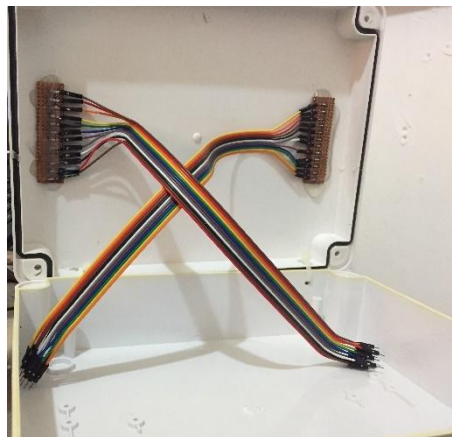


Fig. 14.16 Construction Start Up.



Fig. 14.17 Set Up Test

4.9 Discussion and Analysis

In conventional transformer health system that are currently prototyped, the designers look at reading either of the two data types which are analogue or digital sensor values. The analogue sensor data types are able to provide real time current and power consumption readings whereas the digital data types are able to provide humidity, oil level, oil temperature, transformer chamber temperature and the amount of moisture in the transformer oil. This is because, the combination of the two data types into a single microcontroller has its downsides. Usually, most prefabricated microcontrollers that can share analogue sensor values have only a single analogue input pins which makes it difficult to monitor a three-phase transformer.

To evaluate the efficiency and performance of this device, it is necessary to take into consideration the current local option of transformer health monitoring, which ideally is to have the maintenance team visit the transformer at a scheduled interval to assess the condition of the transformer. This system on the other hand can collect and send real time sensor data over the internet to a webserver which can also be viewed by a mobile phone application. This means that frequent visit to transformer sites to view oil levels and other physical parameters of the transformer can be done remotely. This will save a lot of cost which is used in funding visits to transformer sites.

The sharing of the transformer parameters over the internet to the IoT platform plays a key role in this development. Internet of things is the network of physical devices, which enable these objects to connect and exchange data to the cloud. Each thing is uniquely identified through the embedded computing system but is able to inter-operate only within the existing internal infrastructure. This concept may also have referred as internet of everything. The IoT helps in sharing real time characteristic information which can be used in operating or controlling various systems. The main parameters that are of importance to this project includes the phase load, humidity and oil level in the transformer chamber. All other parameters are hinged on either one or more of the aforementioned parameters which means that timely knowledge of these information about any transformer can help safeguard it for any catastrophic damage which can cost several financial losses including injury or even fatalities in the case of explosion.

4.9.2 Finished product

Figure 14.18 depicts the prototype once built and in operation or switched on.

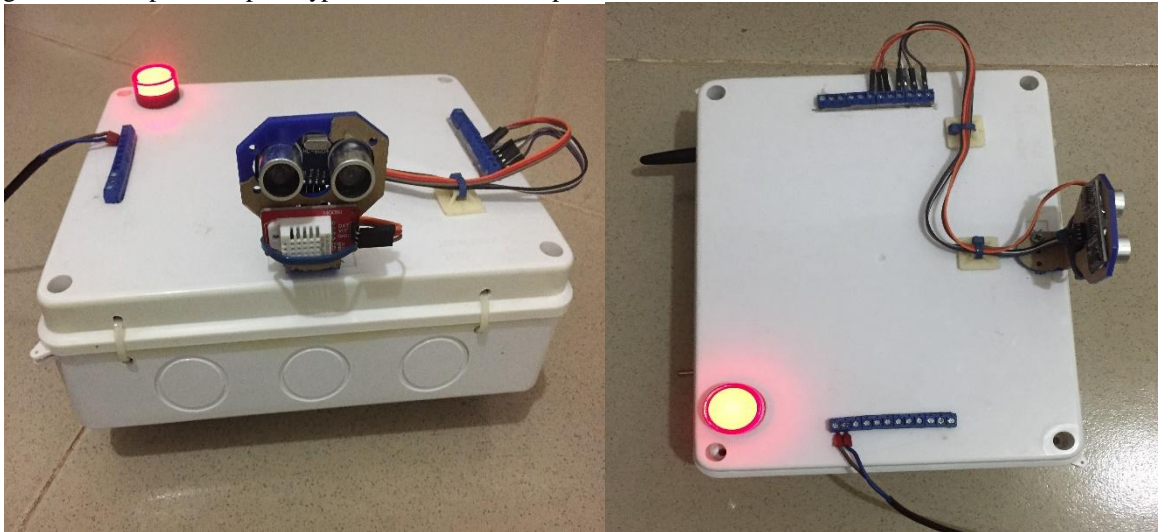


Fig. 14.18 Constructed Prototype

V. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

The microprocessor for the device is supposed to be small, low-powered, able to communicate with the communications board, and able to receive all sensor information. The communications system of the device is supposed to be low-cost and capable of transmitting small amounts of information over long distances. The system relies on the use of various sensors to gain the information to relay to the central hub computer.

The software system is designed to relay the information from the wireless receiver to the database and then from the database to the computer screen. The power for the logic board, wireless communication, and sensors was supplied by tapping the power lines and using a step-down transformer. The voltage sensors were built using a circuit that detects the amount of charge on a plate that is located close to the power line. The current and voltage sensors have an analog signal output and are connected to the analog to digital converters of the ATmega328 processor. It works by routing the information from device to device until it reaches the central hub through a device that exists within one mile of the station. It has the capability for compiling all sensor information and transmitting it through the wireless portion of the device. The power output was then be used to power a battery backup device and two voltage regulator circuits. All health monitoring information is transmitted as a string at set intervals, and it can send specific values when requested by the central hub. It suits the needs of this project well due to its ability to connect to all the sensors that will need to be used on the transformer monitoring system. These sensors consist of capacitive voltage sensors, inductive current sensors, and an infrared temperature sensor.

5.2 Conclusion

The main goal of the project is to design and construct an Internet of Things Transformer Monitoring System which can display real time state in the transformer. After the construction of the device, the system was tested successfully. That is the device can monitor the condition of the transformer and send data accumulated from the sensors through the Wi-Fi and displayed over the IoT platform. All parameters that are critical and needed and have exceeded their threshold can be sent through SMS for immediate action to be taken. Even though the construction of the system was successful, there were some challenges. The general use of prefabricated microcontrollers for such a project that require specific features increases the complexity and number of hardware modules to be used to execute a simple desire.

5.3 Recommendation

The developed system can reduce the frequent breakdowns of transformers because of monitoring problems. So, the researchers do recommend the government, electricity companies and other stakeholders to invest into it so as to develop it fully. To reduce the cost of production, we do also recommend a further study into the use of an analogue multiplexer to send all the analogue data straight to the Nodemcu without the use of an additional Arduino.

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