Real-time Health Monitoring of Electrical devices - Distribution Transformer

A PROJECT REPORT

Submitted by

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in partial fulfilment for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS & INSTRUMENTATION ENGINEERING

AMRITA SCHOOL OF ENGINEERING, BENGALURU

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MAY-2021

BONAFIDE CERTIFICATE

This is to certify that the project report entitled **" Real-time Health Monitoring of Electrical devices - Distribution Transformer"** submitted by

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in partial fulfilment of the requirements for the award **Degree Bachelor of Technology** in "Electronics & Instrumentation Engineering" is a bonafide record of the work carried out under my guidance and supervision at Amrita School of Engineering, Bengaluru during the year 2021.

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This project report was evaluated by us on 27th May, 2021.

EXAMINER 1 EXAMINER 2

EXAMINER 3 EXAMINER 4

ACKNOWLEDGEMENT

We take this opportunity to express our gratitude to everyone who contributed to the completion of this project. First and foremost, we would like to express our sincere gratitude to our beloved **Amma**, **Mata Amritanandamayi Devi** for her blessings.

We are very thankful to **Br. Viswamrita Chaitanya Swamiji**, Director, Amrita School of Engineering, Bangalore, for his valuable support.

We would also like to thank **Dr Sriram Devanathan**, Associate Dean of Amrita School of Engineering, for providing us the opportunity to undertake this project.

We would also like to express our sincere thanks to our project guide and Mentor **Dr. Navin Kumar**, Chairman, Department of Electronics and Communication Engineering, for his constant feedback and support for the entirety of this project.

We extend our gratitude towards to our project examiners, **Dr. Sreeja Kochuvila, Ms. R V Sanjika Devi, Ms. Jeyanthi R, Ms. Jayashree M Oli** Department of Electronics and Communication Engineering, for their encouragement and suggestions.

ABSTRACT

Distribution transformer is an important asset in distribution network. Its operation and control are important aspects which determine the reliability and quality of power supply. The flow of harmonic current encountered in nowadays electrical installations causes numerous undesirable issues to the power grid. The most detrimental consequence is the premature aging or even failure of the in-service power distribution transformers from industrial facilities (originally designed to cope with the linear loads). Increase in transformer loss is mostly the source of the damages, and caused by increased harmonic contents, especially current harmonic. These losses will result in an increase in temperature of various parts of transformer, especially its hot-spot temperature, and this temperature increase brings about insulation life reduction. Therefore, it seems necessary to know the harmonic orders and decrease in transformer loading capacity, and calculating hot-spot temperature of the transformer, which can help predicting the remaining life of the transformer. Harmonics create heating affect which degrades insulation life, which deteriorates the life of a transformer. Hence, a real time monitoring system was considered essential to ensure reliability and sustainability of the transformer. Calculation of parameters like health index(HI) and loss of life(LOL) helps us in estimating the life of a distribution transformer. Continous real time monitoring gives informaion about health and reliability of the trasformer at each instance of time helping us economically and saving power.

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CHAPTER 1
INTRODUCTION

1.1 Overall System

A Transformer is a static electrical machine which transfers AC electrical power from one circuit to the other circuit at the constant frequency, but the voltage level can be altered that means voltage can be increased or decreased according to the requirement. On the basis of the supply i.e., single phase power supply or three phase power supply, transformers are classified in to 4 types [2] such as Step-up and Step-down transformer, Power transformer, Distribution transformer, and Instrument Transformer. In general, construction of transformer contains two coils, primary coil and secondary coil which are differed in number of turns the coil have. We see distribution transformer regularly and our power supply to households is distributed from them. Step-up and Step-down transformers are used to convert high voltage to low voltage or vice versa. Power transformers are used and operated at high voltages. [3] So, health of an electrical device plays an important role while calculating the efficiency and the life of an electrical device. There are many parameters (external and internal of device) and which are affecting the health. Distribution transformers are used below 33KVA and also distributes the power to household electrical devices. There will be fluctuations in the usage of the electrical devices, this is described by the loading effects on the transformer. Which results in increase of temperature in the transformer. The transformer contains oil in it, used for cooling, insulating the windings and protecting from the moisture.

Distribution transformer is an important asset in distribution network. Its operation and control are important aspects which determine the reliability and quality of power supply. Distribution transformer is one of the most important component of distribution power system. It is important to measure the health of the transformer in a power grid. Due to the large number of distribution transformers in the distribution grid, the status of distribution transformers plays an important role in ensuring the safe and reliable operation of these grids. The distribution grid is also the area that is affected significantly by smart technologies. Automating and controlling the grid remotely will help reduce operating costs, increase information accuracy as well as quickly fix faulty areas in the electricity power system. For each HV/MV primary substation, there are tens of secondary substations. As a result [4], in a medium-sized city with 40 HV/MV primary stations, there is around one thousand distribution transformers. Many of them are damaged every year due to various reasons. Accelerated degradation and failure of distribution transformers can occur because of several conditions such as oil leakage, overloading, unbalanced loading and harmonics. However, the majority of failures are caused by a combination of these electrical, mechanical and thermal stresses acting upon the power transformer components over time.

The rated normal life of a distribution transformer is 20.55 years [5]. There are many factors that affect the health of the distribution transformer such as Aging, Insulation, Oil temperature, Harmonics, Hotspot temperature, Ambient temperature, Reactive power, Climate change and Optimality. [6] We can’t do much about environmental or external factors that affect distribution transformer health. There are few parameters where constant monitoring on them allows us to predict life of a distribution transformer. Harmonics is a major issue which leads to degradation of insulation which in turn reduces life of a distribution transformer.

Real-time monitoring of distribution transformer is important to prevent losses therefore, Harmonics creates heating affect which degrades insulation life, which deteriorates the life of a transformer. Hence, a real time monitoring system was considered essential to ensure reliability and sustainability of the transformer. Calculation of reliability parameters like health index(HI) and loss of life(LOL) helps us in estimating the life of a distribution transformer. Continous real time monitoring gives informaion about health and reliability of the transformer at each instance of time helping us economically and saving power.[6] The applications and uses of distribution transformmer in daily life Used in pumping stations where the voltage level is below 33 KV. Power supply for the overhead wires’ railways electrified with AC. In urban areas, many houses are fed with single-phase distribution transformer and in rural areas, it may be possible that one house requires one single transformer depending upon the loads. Multiple distribution transformers are used for industrial and commercial areas. Used in wind farms where the electrical energy is generated by the windmills. There it is used as a power collector to connect the substations which are away from the wind energy generation system.

In order to measure the health and detect the errors the monitoring system must perform physical measurements. There are different methods to calculate transformer's health [11]. [13] The advantages of this method in project are that number of samples required is small. [14-19] It is reliable as it is measuring physically with the sensors attached to it. These parameters are flexible and can be regulated depending on the assets under investigation. [11] There are disadvantages, the accuracy highly depends on the weighted parameters. This may cost high and the results only reflects the preferences of human-expert. The challenges are the sensors should be placed near the transformer.

Transformers are major components in power systems. The significance of harmonics in power systems has substantially increased due to the use of high frequency producing devices [1]. An important consideration when evaluating the impact of harmonics is their effect on power system components and loads. Supplying non-linear loads by transformer leads to higher losses, early fatigue of insulation, and reduction of the useful life of transformer[1]. Hot-spot temperature and remaining lives of the transformer are estimated based on a MATLAB written algorithm[9]. These losses will result in an increase in temperature of various parts of transformer, especially its hot-spot temperature, and this temperature increase brings about insulation life reduction. Therefore, it seems necessary to know the harmonic orders and decrease in transformer loading capacity, and calculating hot-spot temperature of the transformer, which can help predicting the remaining life of the transformer. [7] The health of the transformer is dependent on many factors, out of which these are the main factors which directly affects the health: Hot-spot temperature, Load Factor, and Insulation life. [1][2]

1.2 OBJECTIVE

Real time monitoring of distribution transformer. Analyzing and monitoring the reliability parameters such as Loss of Life (LOL), Health Index Factor (HIF) to get the health of the distribution transformer (DT).

1.3 METHODOLOGY

We are using both hardware and software for this project. Hardware consists of CT, PT, ADE 9000 board, Jetson nano. We are monitoring the setup in real-time and data through the sensors is used by ADE 9000and deep-learning engine to predict life of a distribution transformer. We are using Jetson nano as deep learning engine for developing an algorithm to calculate the reliability parameter (LOL) and in turn predict the health of a distribution transformer.

We are working on circuit of high temperature Transformer by interfacing sensors (PT100 and LM35), collecting the required data and sending it to Arduino to monitor the health of the distribution transformer. The data from Arduino is sent to cloud using ESP8266 module, the data is stored in excel sheet and then given to MATLAB.

1.4 Obtained Results

The hotspot temperature and the ambient temperature are being related to the health of the transformer and calculates the remaining life of the transformer. The relationship between the temperatures and health is studied and how the temperatures are affecting the health is observed. The hotspot temperature of transformer is calculated till the temperature is over 120˚C and the changes of other parameters which are dependent on the temperature has being recorded. The theoretical and the practical values have been compared. This is an attempt to predict the Life of the transformer and its behaviour in practical conditions and to find the cause which is affecting the life of transformer.

The rated life of the transformer is calculated under constant and controlled environment conditions. When it comes to the real time the conditions are way different with many factors influencing it. Like, the surrounding temperature, temperature, losses due to practical conditions. The values are calculated taking rated values into consideration and also the practical conditions. Increased transformer losses with non-linear loads leads to increase in temperature which intend leads to aging, early fatigue and deterioration of transformer insulation.

1.5 CONTENT OF REST OF THE THESIS

This paper demonstrates about how the life of the distribution transformer is changing with respect to the hotspot temperature, Ambient temperature and many more. It also explains about the major factors that have adverse negative effect on health of the transformer. After that it also calculates the required values computationally. This paper also tells the hardware and software used and also compares the theoretical and the practical values obtained from research papers and practical real time monitoring.

CHAPTER 2

STATE OF ART

2.1 INTRODUCTION

This chapter introduces to various technologies and computations across the world in order to calculate the health of the transformer. This briefly explains the parameters involved in calculating the health. It also discusses about the factors effecting the health and also explains how these parameters are related and effecting to the transformer's health. This also gives an insight about construction and overall performance of the transfer in regulated and normal conditions.

2.2BASIC BACKGROUND

2.2.1 Transformers

A **Transformer** is a static electrical machine which transfers AC electrical power from one circuit to the other circuit at the constant frequency, but the voltage level can be altered that means voltage can be increased or decreased according to the requirement.

It works on the principle of **Faraday's Law of Electromagnetic Induction** which states that "the magnitude of voltage is directly proportional to rate of change of flux."

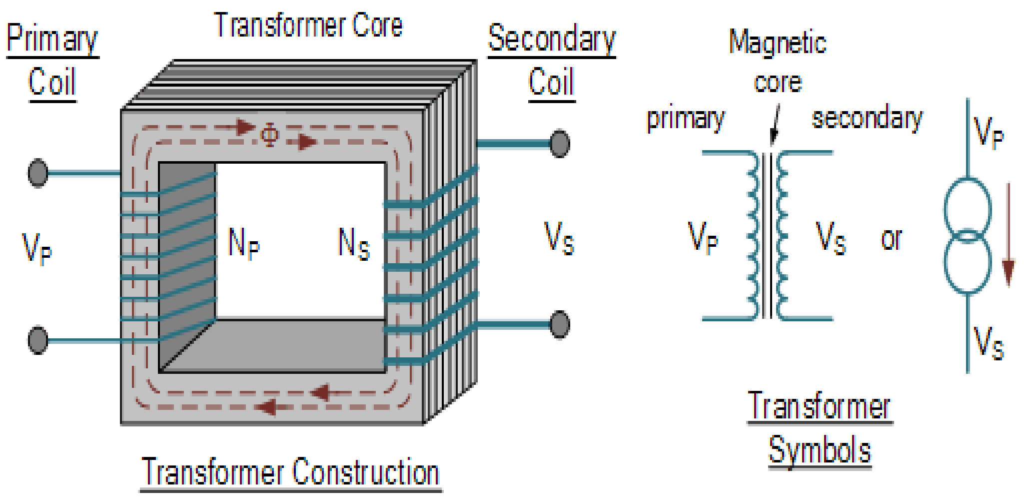

Figure 1. Transformer

2.2.2 Distribution Transformer

Distribution Transformer is an electrical isolation transformer which convert high-voltage electricity to lower voltage levels acceptable for use in homes and business. A distribution transformer's function is straightforward: to step down the voltage and provide isolation between primary and secondary. Electrical energy is passed through distribution transformers to reduce high-distribution voltage levels down to end-use levels. Nearly all energy passes through at least one distribution transformer before being consumed by an end-use appliance, motor, or other piece of equipment. Distribution Transformers are found in all sectors of the economy: residential, commercial, and industrial.

This type of transformer has lower ratings like 11 KV, 6.6 KV, 3.3 KV, 440 V and 230 V. They are rated less than 200 MVA and used in the distribution network to provide voltage transformation in the power system by stepping down the voltage level where the electrical energy is distributed and utilized at the consumer end.

The primary coil of the distribution transformer is wound by enamel coated copper or aluminium wire. A thick ribbon of aluminium and copper is used to make secondary of the transformer which is a high current, low voltage winding. Resin impregnated paper and oil is used for the insulation purpose.

The oil in the transformer is used for

i. Cooling
ii. Insulating the windings
iii. Protecting from the moisture

2.2.3 Losses in distribution transformer

There are various types of losses in the transformer such as iron loss, copper loss, hysteresis loss, eddy current loss, stray loss, and dielectric loss [1]. The hysteresis losses occur because of the variation of the magnetization in the core of the transformer and the copper loss occurs because of the transformer winding resistance.

Iron losses:

Iron losses are caused by the alternating flux in the core of the transformer as this loss occurs in the core it is also known as **Core loss**. Iron loss is further divided into hysteresis and eddy current loss.

Hysteresis losses:

The core of the transformer is subjected to an alternating magnetizing force, and for each cycle of emf, a hysteresis loop is traced out. Power is dissipated in the form of heat known as hysteresis loss

Eddy current loss

When the flux links with a closed circuit, an emf is induced in the circuit and the current flows, the value of the current depends upon the amount of emf around the circuit and the resistance of the circuit.

Since the core is made of conducting material, these EMFs circulate currents within the body of the material. These circulating currents are called **Eddy Currents**. They will occur when the conductor experiences a changing magnetic field. As these currents are not responsible for doing any useful work, and it produces a loss (I^2R loss) in the magnetic material known as an **Eddy Current Loss.** The eddy current losses are minimized by a

Copper or ohmic losses

These losses occur due to ohmic resistance of the transformer windings. If I1 and I2 are the primary and the secondary current. R1 and R2 are the resistance of primary and secondary winding then the copper losses occurring in the primary and secondary winding will be I1 2R1 and I2 2R2 respectively. Therefore, the total copper losses will be These losses varied according to the load and known hence it is also known as variable losses. Copper losses vary as the square of the load current.

Stray losses

The occurrence of these stray losses is due to the presence of leakage field. The percentage of these losses are very small as compared to the iron and copper losses so they can be neglected.

Dielectric losses

[1] Dielectric loss occurs in the insulating material of the transformer that is in the oil of the transformer, or in the solid insulations. When the oil gets deteriorated or the solid insulation gets damaged, or its quality decreases, and because of this, the efficiency of the transformer gets affected.

2.2.4 METHODS

There are various methodologies available to calculate the health of the distribution transformer. Such as, using Machine Leaning, IoT, Health Index Calculations, GSM and etc. Here we are concentrating on physical examination which is indulged in Health Index Calculation and with the help of few sensors to find the faults and accurate values. In this project we are referring to many research papers for theoretical and have built the hardware.

There are many factors that affect the health of the distribution transformer such as Aging, Insulation, Oil temperature, Harmonics, Hotspot temperature, Ambient temperature, Reactive power, Climate change and Optimality. We can’t do much about environmental or external factors that affect distribution transformer health. There are few parameters where constant monitoring on them allows us to predict life of a distribution transformer. Harmonics is a major issue which leads to degradation of insulation which in turn reduces life of a distribution transformer.

2.3RECENT AND RELEVANT WORK

The Author of this [1] deals with the relations associated with transformer losses. Increase in transformer loss is mostly the source of the damages and caused by increased harmonic contents. These losses will result in an increase in temperature of various parts of transformer, especially its hot-spot temperature, and this temperature increase brings about insulation life reduction.

Transformer Loss of Life (LOL) Calculation under Harmonic Load Conditions:

The Author [1][3] says Transformer life depends on its insulation life, and insulation life depends on thermal, mechanical and chemical effect, but thermal effect is more important. Therefore, transformer life mainly depends on hottest spot temperature of transformer and can be calculated with following equations (Dhingra Arvind, 2008). Increase in transformer loss is mostly the source of the damages and caused by increased harmonic contents. These losses will result in an increase in temperature of various parts of transformer, especially its hot-spot temperature, and this temperature increase brings about insulation life reduction.

Transformer Losses under Harmonic Loads:

$PT = PNL + PLL$ Equation (1)

where, PNL is no-load loss

PLL is load loss and PT is total loss.

No-load loss is due to the induced voltage in core.

Load losses consist of ohmic loss, eddy current loss, and other stray loss

$PLL = Pdc + PEC + POSL$ Equation (2)

where, Pdc is loss due to load current and dc resistance of the windings

PEC is winding eddy loss

POSL is other stray losses in clamps, tanks, etc.

For liquid-filled power distribution transformers, the windings hot-spot temperature θH is a function of ambient temperature θA, the oil temperature rise in respect to ambient temperature θTo, and the conductor hot-spot temperature rise relative to oil temperature θg.

$$\theta_{TO} = \theta_{TO-R}\left(\frac{P_{LL}+P_{NL}}{P_{LL-R}+P_{NL}}\right)^{0.8} \quad \text{Equation (3)}$$

$$\theta_g = \theta_{g-R} \times \left(\frac{P_{LL}}{P_{LL-R}}\right)^{0.8} \quad \text{Equation (4)}$$

$$\theta_H = \theta_{TO} + \theta_g + \theta_A \quad \text{Equation (5)}$$

Where,

$\theta To - R$ - rated oil temperature rise with respect to the ambient temperature,

$\theta g - R$ is the rated conductor temperature rise relative to oil temperature

$PDC - R,\ PLL - R,\ PEC - R$ are the rated ohmic, load and eddy current losses respectively.

The rated winding eddy current losses PEC−R and rated other stray losses POSL−R are conservatively estimated in accordance with the international standard recommendations

$$PEC_R = 0.33\,(PLL_R - PDC_R) \quad Equation\ (6)$$

$$POSL_R = 0.67\,(PLL_R - PDC_R) \quad Equation\ (7)$$

Where, $PDC\_R,\ PLL\_R,$ are the rated ohmic and load respectively

Climate change and effects:

Climate change can affect the reliability and the load ability of electric power systems. The transformer is an important component for maintaining power system reliability. Failure of a transformer could potentially lead to blackouts and economic losses. Hence, power transformer reliability and efficiency are critical concerns in the operation of power system networks. Recent research state that climate change leads to high temperature and might change many factors such as the ambient temperature and operation temperature of power system network assets. This could affect the thermal behaviour of transformers.

Other factors can affect thermal management of a transformer such as loading condition that are classified in into four types of loading:

i. Normal life expectancy loading
ii. Planned overloading
iii. Long-time overloading
iv. Short-time overloading.

In [4] the permissible loading of a transformer for normal life depends on:

i. Transformer design
ii. Temperature rise at rated load
iii. Cooling temperature
iv. Duration of the overloads
v. Load factor
vi. Altitude above sea level.

Transformer models

Multiple models are discussed and explained in [4][6] to obtain accurate results and a good prediction for the three factors: ambient temperature, operation temperature, and DR.

1. IEEE Standard C57.91

2. IEC 354 standard

3. IEC 60076 Standard

IEEE Standard C57.91

According to the Author [4], It is the most common model used in calculations germane to distribution transformers. According to this model, the maximum ambient temperature of a transformer is 40°C, and the average ambient temperature should not exceed 30°C. Maximum hot spot temperature should not exceed 110°C, and the average temperature of the winding cannot exceed 65°C over ambient temperature. This model is not accurate as desired and does not correctly account for the effect of ambient temperature variation and top oil temperature variation on hot spot temperature. It just captures the basic idea, which is a proportional relationship between the loading and transformer temperature.

$$T_h \frac{d\theta h}{dt} + \theta h = \theta_{hu} \qquad \text{Equation (8)}$$

The temperature of the winding and insulation are the basic factors that limit the transformer loading. Therefore, transformer loading is highly dependent upon the operating temperature of the transformer, which means any change in transformer temperature could change the load capabilities and vice versa. Further, temperature and aging of the transformer would affect the insulation level. The heat in the transformer, caused by losses in the transformer, must be transferred to the transformer oil and from the oil to the atmosphere. External conditions such as ambient temperatures, wind velocity and direction, and solar heating affect the heat dissipation from a transformer. Also, ambient temperature versus loading can be drawn for different types of transformer cooling. Based on this, the hot spot temperature and ambient temperature are important factors in determining transformer-aging rate while different load levels affect the aging of the insulation.

The loading conditions of a transformer can be classified into four types: normal life expectancy loading, planned overloading, long-time overloading and short-time overloading.

To explain the relationship between ambient temperature and the transformer loading is such that it causes:

a. An increase in ambient temperature, will result in increased need for loading, and thus increase the supply needed.

b. Ambient temperature is considered in the calculation of hot spot temperature in all transformer thermal models.

Hot Spot Temperature Calculation:

The HST model from [7][2] in the transformer winding is the sum of the ambient temperature, the top oil rise over ambient temperature, and hot spot rise over top oil temperature. This model is used in determining thermal behaviour of the distribution transformer and given in

$\theta_H = \theta_A + \Delta\theta_H + \Delta\theta_{Toil}$ Equation (9)

The relation of insulation deterioration to time and hot spot temperature of the transformer is expressed as

Per unit life= $9.8*10^{-18}\ e^{\frac{15000}{\theta H+273}}$ Equation (10)

The curve of the transformer per unit insulation life, shown Figure 1, depicts the relation between transformer insulation life and hot spot temperature. It indicates that aging is accelerated above the average for temperature over 110 °C and reduced below normal for temperature under 110°C.

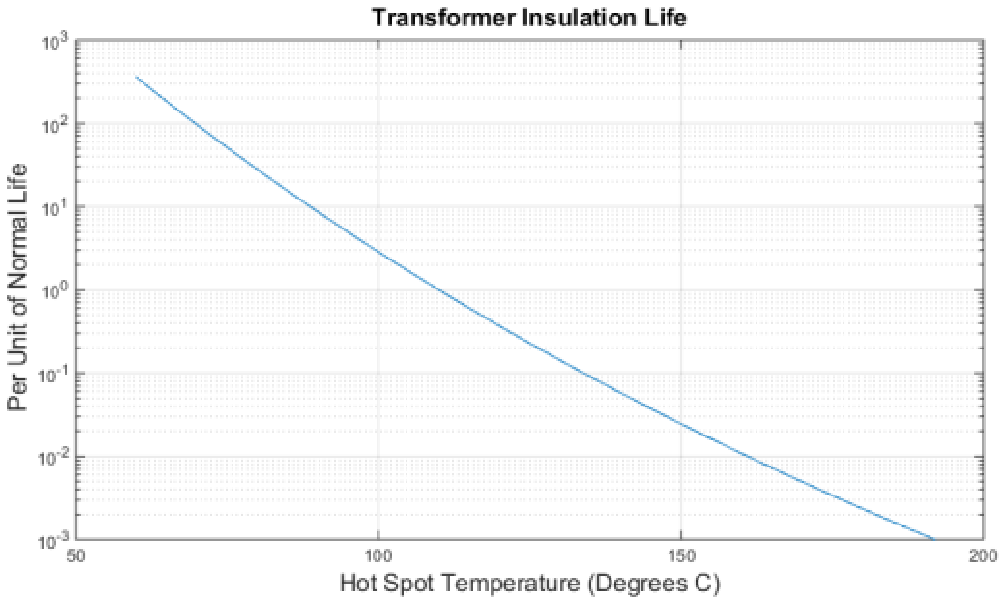

Figure 2. Transformer Insulation life

The curve above is used as a basis for calculation of the aging acceleration factor (FAA),for a given load and temperature or for a 25 hour period for load and temperature.

$F_{AA} = e^{[\frac{15000}{383} - \frac{15000}{\theta H+273}]}$ Equation (11)

Loss of life is given as

$$\text{LOL (\%)} = \frac{FEQA*t*100}{Normal\ insulation\ life} \qquad \text{Equation (12)}$$

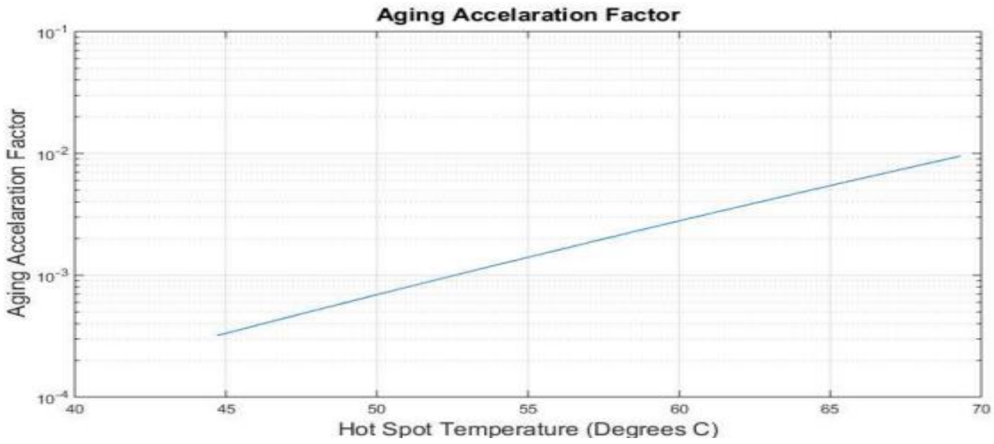

Figure 3. Aging Accelaration Factor

Transformer Aging Due to the Harmonic Currents:

The Authors [Emil CAZACU, Valentin IONITA, Lucian PETRESCU][3] describes that the aging process of any electrical equipment from an installation occurs, during its operation, mainly due to the deterioration of the equipment insulation materials.

This paper quantitatively examines the major thermal operating parameters of these transformers and predicts their lifetime expectancy under a certain harmonic load spectrum. The aging process of any electrical equipment from an installation occurs, during its operation, mainly due to the deterioration of the equipment insulation materials.

This complex process is influenced by numerous factors such the mechanical stress or chemical aggression, moisture or oxygen content and, above all, the working temperature of the appliance. The latter is the most dominant parameter that ultimately determines the device lifespan. Since, in most appliances, the temperature is not uniformly distributed, the part that is operating at the highest temperature will commonly experience the greatest deterioration. Hence, in aging studies, it is usual to consider the aging effects produced by the highest (hot spot) temperature.

Transformer Hot-Spot Temperature Evaluation

The expected lifetime of a distribution transformer [3] [2] is also very responsive to the machine hot-spot temperature. The harmonic currents of the supplied nonlinear loads cause supplementary losses within the transformer and may determine hot-spot temperatures that exceed the rated (reference) value. Therefore, a rapid degradation of the transformer insulation materials is expected followed by the reduction of transformer initial designed lifetime. For liquid-filled power distribution transformers, the windings hot-spot temperature θH is a function of ambient temperature θA, the oil

temperature rise in respect to ambient temperature θT o, and the conductor hot-spot temperature rise relative to oil temperature θg.

$$\theta_H = \theta_A + \theta_{TO} + \theta_g. \qquad \text{Equation (13)}$$

Where,

θH is the winding HST,

θA is the average ambient temperature during the load cycle

$\Delta\theta H$ is the winding hot spot rise over top oil temperature.

$\Delta\theta Toil$ is the top oil rise over ambient temperature.

The last two terms involved in the above relation could be evaluated considering the machine rated data and losses distribution inside the transformer (ohmic losses PDC, load losses PLL, eddy current losses PEC, other stray losses POSL and no load PNL losses)

$$\theta_{TO} = \theta_{TO-R}\left(\frac{P_{LL}+P_{NL}}{P_{LL-R}+P_{NL}}\right)^{0.8}, \qquad \text{Equation (14)}$$

$$\theta_g = \theta_{g-R}\left(\frac{P_{DC}+P_{EC}}{P_{DC-R}+P_{EC-R}}\right)^{0.8}, \qquad \text{Equation (15)}$$

where θT o−R is the rated oil temperature rise with respect to the ambient temperature, θg−R is the rated conductor temperature rise relative to oil temperature and PDC−R, PLL−R, PEC−R are the rated ohmic, load and eddy current losses respectively.

The operating transformer losses could be expressed in term of the load factor β (computed as the root mean square current I relative to transformer rated sinusoidal current IR2 at the low-voltage winding) and two power quality parameters that accounts the load current harmonic spectrum: harmonic loss factor (FHL or K) and harmonic loss factor for other stray losses (FHL−ST R).

$$\begin{cases} P_{LL} = P_{DC} + P_{EC} + P_{OSL}, \\ P_{DC} = \beta^2 P_{DC-R}, \\ P_{EC} = \beta^2 P_{EC-R} F_{HL}, \\ P_{OSL} = \beta^2 P_{OSL-R} F_{HL-STR}, \end{cases} \quad \text{Equation (16)}$$

with:

$$F_{HL} = \frac{1}{I^2} \sum_{k=0}^{N} k^2 I_k^2,$$

$$F_{HL-STR} = \frac{1}{I^2} \sum_{k=0}^{N} k^{0.8} I_k^2,$$

$$\beta = \frac{S}{S_R} \cong \frac{I}{I_{R2}}, \; I^2 = \sum_{k=0}^{N} I_k^2, \quad \text{Equation (17)}$$

where Ik is the effective value of the k current harmonic order, N is the highest accounted harmonic order (in our computations N = 50), S represents the apparent power and SR is the transformer rated power under normal (sinusoidal) condition. The rated winding eddy current losses PEC−R and rated other stray losses POSL−R are conservatively estimated in accordance with the international standard recommendations

$$P_{EC-R} = 0.33\,(P_{LL-R} - P_{DC-R}), \quad \text{Equation (18)}$$
$$P_{OSL-R} = 0.67\,(P_{LL-R} - P_{DC-R})\,. \quad \text{Equation (19)}$$

Supplementary, the transformer rated ohmic losses PDC−R are computed on the basis of primary and secondary rated currents (IR1, IR2) and the windings DC ohmic resistances indicated by the manufacturer (R1, R2), respectively.:

Since in the actual industrial power distribution systems the supply voltages waveforms are balanced and sinusoidal, the transformer no-load losses PNL are invariable in respect to the current harmonic spectrum.

The Transformer Maximum Load Factor and Operating Capacity

In order to derive the admissible load factor βmax and its corresponding maximum permissible non-sinusoidal current IMP C (effective value), one has to constrict the transformer operating hot-spot temperature θH (under any harmonic current conditions) to equal its initial reference value θHref (assumed for pure linear rated load).

$$\theta_A + \theta_{TO-R}\left(\frac{P_{LL\max} + P_{NL}}{P_{LL-R} + P_{NL}}\right)^{0.8} + \\ +\theta_{g-R}\left(\frac{P_{DC\max} + P_{EC\max}}{P_{DC-R} + P_{EC-R}}\right)^{0.8} = \theta_{Href},$$ Equation (20)

with:

$$\begin{cases} P_{LL\max} = P_{DC\max} + P_{EC\max} + P_{OSL\max}, \\ P_{DC\max} = \beta^2_{\max} P_{DC-R}, \\ P_{EC\max} = \beta^2_{\max} P_{EC-R} F_{HL}, \\ P_{OSL\max} = \beta^2_{\max} P_{OSL-R} F_{HL-STR}. \end{cases}$$

The equation above is numerically solved (regarding the ambient temperature), and consequently, the transformer Reduction in Apparent Power Rating (RAPR) and its maximal operating capacity SM are estimated:

Transformer Lifetime Estimation:

Finally, the Authors has come up with the formulas which are described below. The power distribution transformer lifespan is directly associated with the winding's conductors' insulation life. Consequently, the actual standards provide the rate at which the transformer insulation aging is accelerated compared with the aging rate at a reference hot-spot temperature θHref by a factor called aging acceleration factor FAA. Its expression mainly depends on the transformer operating hot-spot temperature θH:

$$F_{AA} = \exp\left(\frac{B}{\theta_{Href} + 273} - \frac{B}{\theta_H + 273}\right),$$ Equation (21)

where B is an insulation type material constant [18]. It is also important to reveal that if the relative aging acceleration factor has less than unity values, the transformers initial lifetime expectancy Normal Insulation Life (NIL) is preserved.

Considering the above-mentioned assumptions, the percent loss of life (%LOL) of the transformer insulation can be evaluated:

$$\%LOL = \frac{F_{AA}}{NIL} t \cdot 100. \qquad \text{Equation (22)}$$

where t is a certain period (indicated in years)

Practically, the author [] machine lifetime is regarded as its insulation lifespan. Hence, the machine Remaining Life RL can be expressed in terms of the operating transformer hot-spot temperature.

$$RL = \frac{NIL}{F_{AA}} \qquad \text{Equation (23)}$$

where NIL is Normal Insulation Lifetime

Transformer Lifetime Estimation

In [4] the standard by IEEE explained The IEEE Standard C57.91 has given the information that the power distribution transformer lifespan is directly associated with the windings conductor's insulation life. Consequently, the actual standards provide the rate at which the transformer insulation aging is accelerated compared with the aging rate at a reference hot-spot temperature $\theta Href$ by a factor called aging acceleration factor FAA.

Its expression mainly depends on the transformer operating hot-spot temperature θH:

Aging acceleration factor FAA is given by

$$F_{AA} = \exp\left(\frac{B}{\theta_{Href} + 273} - \frac{B}{\theta_H + 273}\right),$$

Where, $\theta Href$ is reference hot-spot temperature

θH is operating hot-spot temperature

B is an insulation type material constant

The percent loss of life ($\%LOL$) of the transformer insulation can be evaluated:

$$\%LOL = \frac{F_{AA}}{NIL} t \cdot 100.$$

where, t is a certain period (indicated in years)

NIL- Normal Insulation Life

In paper [5] Author described the non-sinusoidal load current effect on the electrical and thermal operating parameters of oil filled power distribution transformers.

Thermal aging parameters of the transformer (rated)	Various nonlinear loads
Top-oil-rise over ambient temperature under rated conditions θTO	60°C
Winding rise over ambient temperature under rated condition $\theta w(\theta w=\theta TO+\theta g)$	65°C
The transformer hottest spot winding temperature θH (◦C)	110°C
Ambient Temperature	40°C
Normal Insulation life(years)	20.55 years
Remaining Life RL (years)	20.55 years
Losses distribution within the transformer (W) (rated)	
No load PNL	980W
DC Ohmic PDC	3933.33W
Eddy current PEC	649W
Other stray POSL	1317.666W
Total PT	6800W

TABLE 1. Current effects on electrical and thermal parameters

- The table1 contains all the parameters which affect the insulation life of a distribution transformer.[5]
- The parameters like hotspot temperature, aging acceleration factor(FAA) and Loss of life(LOL) have been calculated for load factor.[5][3][4]
- Here the load factor is computed as the root mean square current relative to transformer rated sinusoidal current at the low-voltage winding.
- The parameters mentioned in table1 are used for our simulation and the following results are obtained.

CHAPTER 3

DESIGN AND ANALYSIS

3.1 INTRODUCTION

Distribution transformer life is expected to be 20.55 years, but we are observing that most of the transformers are made early fatigue or producing a huge difference between the income and expenditure. The errors/faults are mainly due to the increase in different transformer temperatures (Hotspot Temperature, Ambient Temperature) and that intend is by different loads. This may lead to hazardous situation. The sudden change will have less effect compared with overlading for longer time will affect the insulation life and also decreases the remaining life of the transformer exponentially. Hence, it's important to know the loss of life of the transformer, to find the reliability of distribution transformer. Here, we are making a model to predict the remaining life the distribution transformer.

3.2 SYSTEM DESIGN

The project idea with ADE9000 and Jetson Nano will be demonstrated first.

ADE 9000 Design

Description of ADE 9000 Board:

The ADE90001 is a highly accurate, fully integrated, multiphase energy and power quality monitoring device. Superior analog performance and a digital signal processing (DSP) core enable accurate energy monitoring over a wide dynamic range. An integrated high-end reference ensures low drift over temperature with a combined drift of less than ±25 ppm/°C maximum for the entire channel including a programmable gain amplifier (PGA) and an analog-to-digital converter (ADC).

The ADE9000 offers complete power monitoring capability by providing total as well as fundamental measurements on rms, active, reactive, and apparent powers and energies. Advanced features such as dip and swell monitoring, frequency, phase angle, voltage total harmonic distortion (VTHD), current total harmonic distortion (ITHD), and power factor measurements enable implementation of power quality measurements. The ½ cycle rms and 10 cycle rms/12 cycle rms, calculated according to IEC 61000-4-30 Class S, provide instantaneous rms measurements for real-time monitoring. The ADE9000 offers an integrated flexible waveform buffer that stores samples at a fixed data rate of 32 kSPS or 8 kSPS, or a sampling rate that varies based on line frequency to ensure 128 points per line cycle. Resampling simplifies fast Fourier transform (FFT) calculation of at least 50 harmonics in an external processor. The ADE9000 simplifies the implementation of energy and power quality monitoring systems by providing tight integration of acquisition and calculation engines. The integrated ADCs and DSP engine calculate various parameters and provide data through user accessible registers or indicate events through interrupt pins. With seven dedicated ADC channels, the ADE9000 can be used on a 3-phase system or up to three single-phase systems. It supports current transformers (CTs) or Rogowski coils for current measurements. A digital integrator eliminates a discrete integrator required for Rogowski coils. The ADE9000 absorbs most complexity in calculations for a power monitoring system. With a simple host microcontroller, the ADE9000 enables the design of standalone monitoring or protection systems, or low-cost nodes uploading data into the cloud. Note that throughout this data sheet, multifunction pins, such as CF4/EVENT/DREADY, are referred to either by the entire pin name or by a single function of the pin, for example, EVENT, when only that function is relevant.

FEATURES

i. 7 high performance ADCs
ii. 101 dB SNR
iii. Wide input voltage range: ±1 V, 707 mV rms FS at gain = 1
iv. Differential inputs
v. Power quality measurements
vi. Enables implementation of IEC 61000-4-30 Class S
vii. VRMS ½, IRMS ½ rms voltage refreshed each half cycle
viii. 10 cycle rms/12 cycle rms
ix. Dip and swell monitors
x. Line frequency—one per phase
xi. Zero crossing, zero-crossing timeout Phase angle measurements
xii. Supports CTs and Rogowski coil (di/dt) sensors

xiii. Multiple range phase/gain compensation for CTs

xiv. Integrated temperature sensor with 12-bit successive approximation register (SAR) ADC ±3°C accuracy from −40°C to +85°C

xv. Digital integrator for Rogowski coils

xvi. Flexible waveform buffer

xvii. Able to resample waveform to ensure 128 points per line cycle for ease of external harmonic analysis

xviii. Events, such as dip and swell, can trigger waveform storage

xix. Simplifies data collection for IEC 61000-4-7 harmonic analysis

xx. Advanced metrology feature set

xxi. Total and fundamental active power, volt amperes reactive (VAR), volt amperes (VA), watthour, VAR hour, and VA hour

xxii. Total and fundamental IRMS, VRMS

xxiii. Total harmonic distortion

xxiv. Power factor

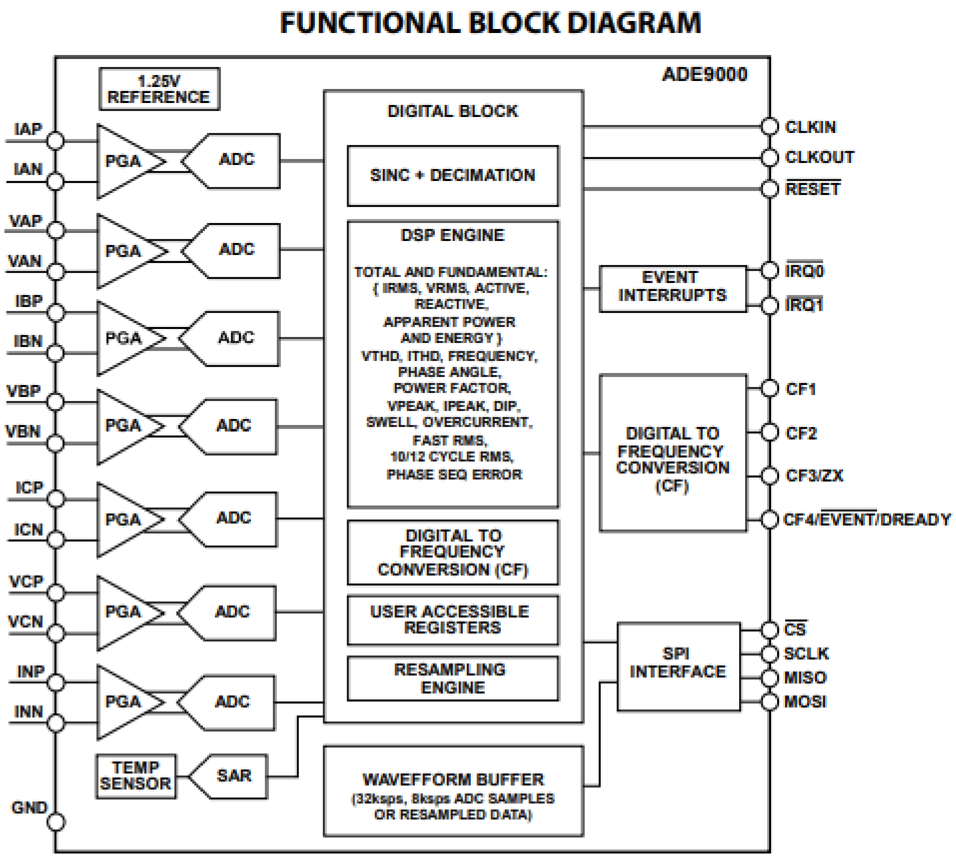

Fig 8: Functional Block Diagram of ADE9000

APPLICATIONS

i. Energy and power monitoring
ii. Power quality monitoring s
iii. Protective devices
iv. Machine health

SPI port in ADE 9000

The ADE9000 has an SPI-compatible interface, consisting of four pins: SCLK, MOSI, MISO, and SS. The ADE9000 is always an SPI slave; it never initiates SPI communication. The SPI interface is compatible with 16-bit and 32-bit read/write operations. The maximum serial clock frequency supported by this interface is 20 MHz.We are using our Host Controller Board to communicate with ADE9000 through SPI port.

We are using P2 connector of ADE9000 to communicate with our Host Controller board

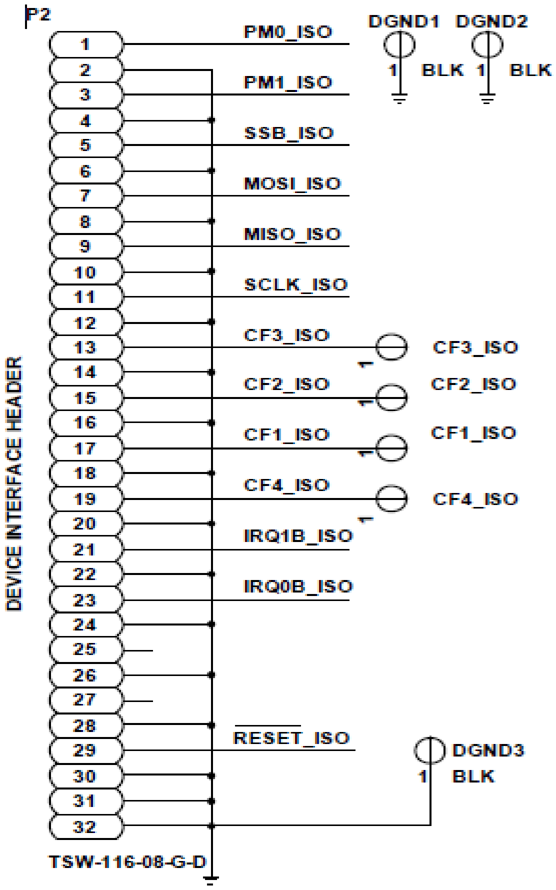

Figure 4. ADE9000 HEADER

The ADE9000 provides SPI burst read functionality on certain registers and the waveform buffer that allows multiple registers to be read after sending one CMD_HDR.

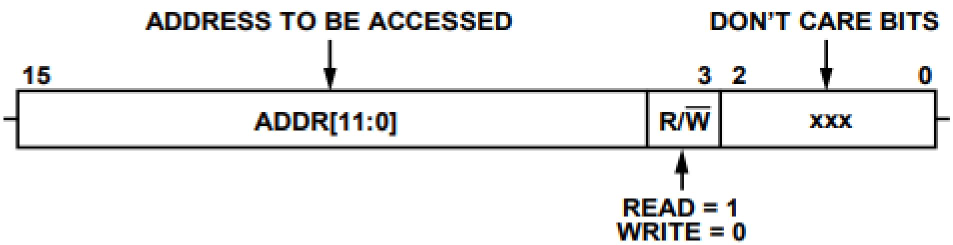

Figure 5. SPI Register

The ADE9000 SPI port calculates a 16-bit cyclic redundancy check (CRC-16) of the data sent out on its MOSI pin so that the integrity of the data received by the master can be checked. The CRC of the data sent out on the MOSI pin during the last register read is offered in a 16-bit register, CRC_SPI, and can be appended to the SPI read data as part of the SPI transaction.

SERIAL PERIPHERAL INTERFACE (SPI):

The SPI controllers operate up to 65Mbps in master mode and 45Mbps in slave mode. It allows a duplex, synchronous, serial communication between the controller and external peripheral devices. It consists of four signals, SS_N (Chip select), SCK (clock), MOSI (Master data out and Slave data in) and MISO (Slave data out and master data in). The data is transferred on MOSI or MISO based on the data transfer direction on every SCK edge. The receiver always receives the data on the other edge of SCK

FEATURES:

i. Independent Rx FIFO and Tx FIFO.
ii. Software controlled bit-length supports packet sizes of 1 to 32 bits.
iii. Packed mode support for bit-length of 7 (8-bit packet size) and 15 (16-bit packet size).
iv. SS_N can be selected to be controlled by software, or it can be generated automatically by the hardware on packet boundaries.
v. Receive compare mode (controller listens for a specified pattern on the incoming data before receiving the data in the FIFO).
vi. Simultaneous receive and transmit supported
vii. Supports Master mode. Slave mode has not been validated

WORKING:

The outputs of CT and PT i.e., current and voltage respectively are given to ADE 9000. The ADCs present in ADE 9000 will sample the current and voltage signals. All the power and energy computations take place in ADE 9000. The ADE9000 offers complete power monitoring capability by providing total as well as fundamental measurements on rms, active, reactive, and apparent powers and energies. Advanced features such as dip and swell monitoring, frequency, phase angle, voltage total harmonic distortion (VTHD), current total harmonic distortion (ITHD), and power factor measurements enable implementation of power quality measurements.

All the parameters in discrete time domain are converted into discrete frequency domain (DFT) for transmission. The data is transmitted through SPI port in ADE 9000 to Jetson nano. SPI is one master and multi slave communication. Here, in SPI interface ADE 9000 acts as slave and Jetson nano is master.

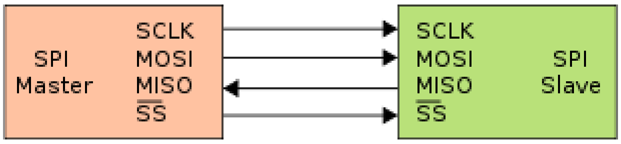

Figure 6. SPI PORT WORKING

At Jetson nano the received data is converted back into discrete time domain (IDFT). An algorithm is written here for calculating health of a distribution transformer. Using the data we got from ADE 9000, parameters like health index (HI), loss of life (LOL) are calculated here which gives us the health of a distribution transformer.

Jetson Nano:

Nvidia Jetson is a series of embedded computing boards from Nvidia. The Jetson TK1, TX1 and TX2 models all carry a Tegra processor (or SoC) from Nvidia that integrates an ARM architecture central processing unit (CPU). Jetson is a low-power system and is designed for accelerating machine learning applications.

It is an AI computer for makers, learners, and developers that brings the power of modern artificial intelligence to a low-power, easy to-use platform. This board contains Serial Port Header. Which is easy and flexible to communicate with other boards. It has a advantage over the other boards as it is intelligent and it makes the decision on its own. Therefore it predicts the health of the transformer with few codes and computational Algorithms.

Jetson Nano Design

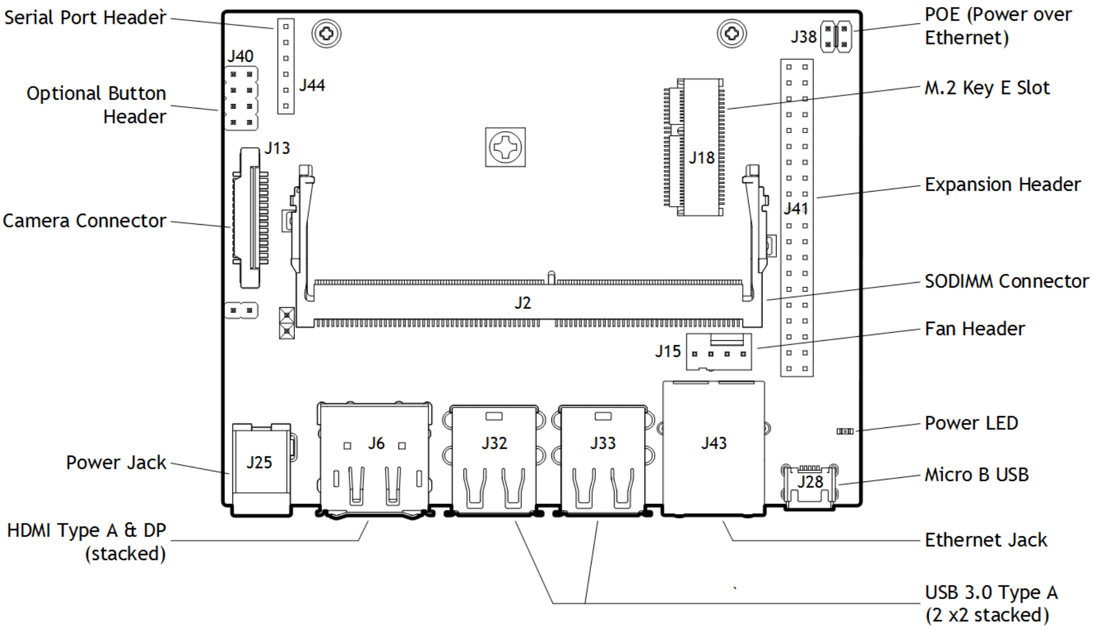

Figure 7. Jetson Nano layout design

Jetson Nano Specifications:

GPU	128-core Maxwell
CPU	Quad-core ARM A57 @ 1.43 GHz
Memory	4 GB 64-bit LPDDR4 25.6 GB/s
Storage	microSD (not included)
Video Encode	4K @ 30 | 4x 1080p @ 30 | 9x 720p @ 30 (H.264/H.265)
Video Decode	4K @ 60 | 2x 4K @ 30 | 8x 1080p @ 30 | 18x 720p @ 30 (H.264/H.265)
Camera	1x MIPI CSI-2 DPHY lanes
Connectivity	Gigabit Ethernet, M.2 Key E
Display	HDMI 2.0 and eDP 1.4
USB	4x USB 3.0, USB 2.0 Micro-B
Others	GPIO, I^2C, I^2S, SPI, UART
Mechanical	100 mm x 80 mm x 29 mm

Figure 8. Jetson Nano Specifications

3.3 Circuit Designing

Arduino UNO

- Arduino is an open-source electronics platform based on easy-to-**use** hardware and software.
- Arduino boards are able to read inputs (both analog and digital) and gives the output (both analog and digital).
- Arduino Uno is a microcontroller board based on the ATmega328.
- It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button.
- It contains everything needed to support the microcontroller, simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.
- You can tinker with your UNO without worrying too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again.
- Arduino Uno works on a platform called Arduino IDE

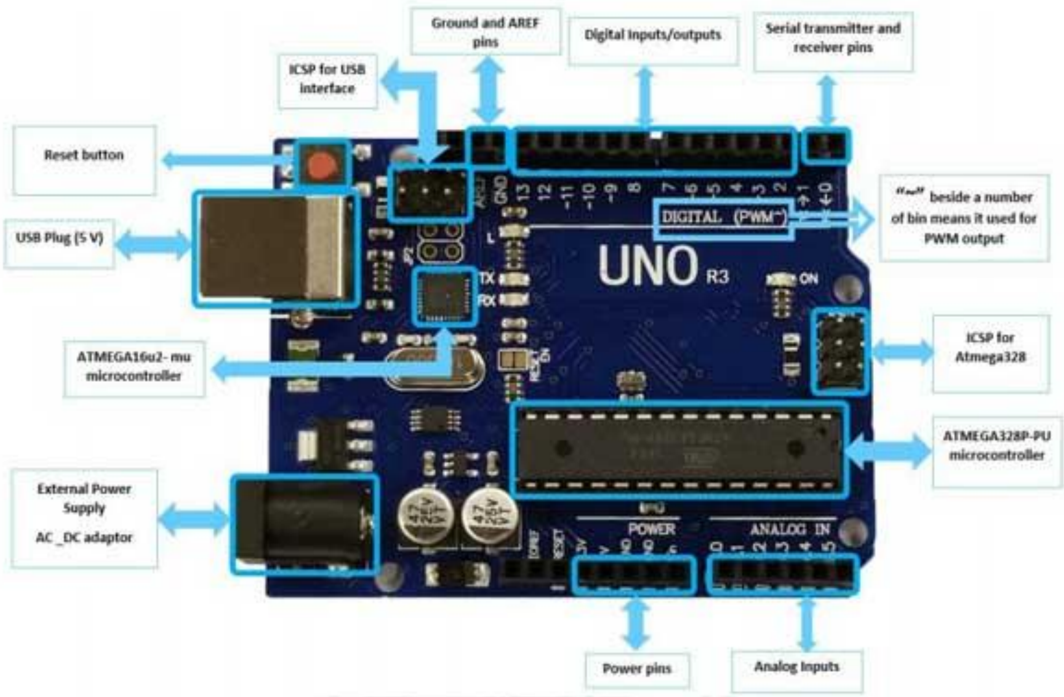

Figure 9. Arduino UNO pin layout

The Arduino Specifications

Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Figure 10. Arduino UNO Specifications

PT100

- RTDs (Resistance Temperature Detectors) are temperature sensors that contain a resistor that changes resistance value as its temperature changes.
- The most popular RTD is the Pt100. They have been used for many years to measure temperature in laboratory and industrial processes, and have developed a reputation for accuracy, repeatability, and stability.
- The pt100 is one of the most accurate temperature sensors.
- It is a RTD (Resistance temperature Detector) sensor whose resistance changes as its temperature changes.
- Ideally, at 0 ˚C the value of resistance is 100Ω.

- The PT100 provides high accurate values than other temperature sensors.
- It is used to calculate the hotspot temperature of the transformer.
  Used to measure temperature. (Hot spot temperature which ranges from 51 °C to 127 °C)
- As temperature increases, resistance increases at 10mV/ °C.
  Used Wheatstone bridge to get the voltage from the increase in resistance and subsequently the temperature.

Formula for calculating Resistance:

Rt=Ro(1+A*T) Ω

Where, Rt is the resistance of the PT100

Ro is the reference temperature (100 Ω)

A is the co-efficient of the temperature (0.00385Ω/˚C)

T is the temperature of PT100

Voltage = Sensor value * 5.0/1023 Equation (24)

5V is the maximum voltage and in Arduino there are 10bits so 2^10=1024 values

Voltage is output volage and Sensor value is the voltage value sensed across the Wheatstone bridge

Figure 11. PT100

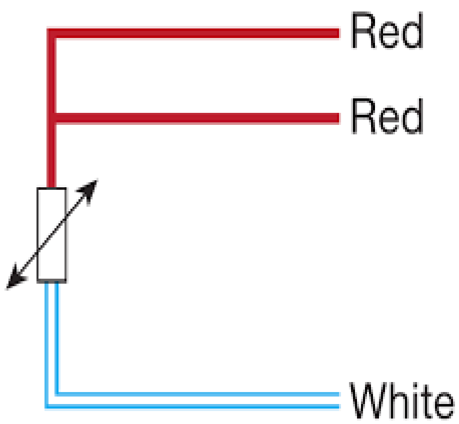

Figure 12. PT100 Wiring diagram

LM35

- LM35 is an Integrated circuit Temperature sensor, whose output voltage varies, based on the temperature around it.
- It is a small and cheap IC which can be used to measure temperature anywhere range between -55°C to 150°C.
- There will be rise of 0.01V (10mV) for every degree Celsius rise in temperature.
- It has a accuracy to measure 0.5°C change.

Formula for calculating Temperature:

Ambient Temperature = LM35 sensor value *(5/1024) Equation (25)

5v is the maximum voltage and in Arduino there are 10bits so 2^10=1024 values

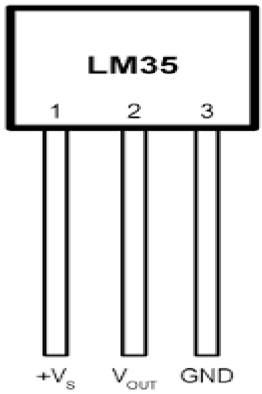

Figure 13. LM35 Pinout Diagram

LM358

- It is an Integrated Circuit (IC) which consist of two op-amps with low supply current drain.

- LM358 is a dual op-amp IC integrated with two op-amps powered by a common power supply.
- LM358 can be used as transducer amplifier, DC gain block etc. It has large dc voltage gain of 100dB
- There are 2 comparators in LM358. Here it is used as a comparator

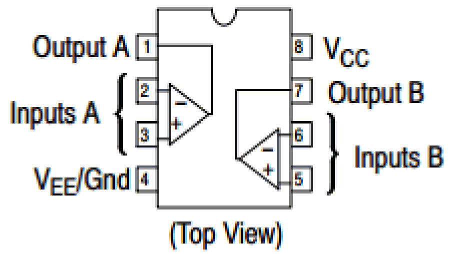

Figure 14. LM358 Pinout diagram

ESP 8266-01

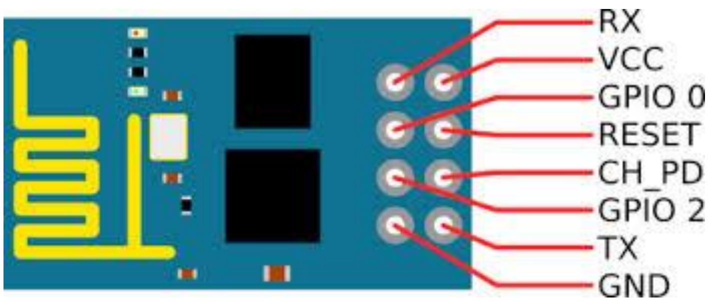

Fig 15. ESP8266 – 01 and Pin diagram

- Wi-Fi module used to transfer data from Arduino to cloud easily.
- It allows microcontrollers access to a Wi-Fi network.
- Remote monitoring of the data stored in the cloud using Wi-Fi router can be done.
- It is also used for IoT applications using Tx and Rx pin.
- We can only give 3.3V supply to ESP8266 module. Because the pins can't tolerate 5V supply. If given, it will not work and gets damaged.

3.4 SOFTWARES AND COMMANDS USED

3.4.1 Arduino IDE

The Arduino Integrated Development Environment or simply Arduino Software (IDE). It contains a text editor for writing code, a toolbar with buttons for common functions and a series of menus. Here you can write your own program/code to execute. It connects to the Arduino and Genuino hardware to upload programs and communicate with them. The Arduino IDE supports the languages C and C++ using special rules of code structuring. Using AT commands in the serial monitor we can connect ESP8266 to the Wi-Fi. Below are the commands which we will use to connect to Wi-Fi and send the data to cloud.

Commands	**Description**	**Type**
AT+RST	Reset module	WIFI
AT+CWMODE	Wifi mode	WIFI
AT+CWJAP	Join AP	WIFI
AT+CWLAP	List AP	WIFI
AT+CWQAP	Quit AP	TCP/IP
AT+CIPSTATUS	Get status	TCP/IP
AT+CIPSTART	Set up TCP or UDP	TCP/IP
AT+CIPSEND	Send data	TCP/IP
AT+CIPCLOSE	Close TCP or UDP	TCP/IP
AT+CIFSR	Get IP	TCP/IP
AT+CIPMUX	Set multiple connections	TCP/IP
AT+CIPSERVER	Set as server	TCP/IP

TABLE 2. AT Commands for ESP8266

3.4.2 MATLAB

It is a platform to analyse and design systems and products that transform our world. The heart of MATLAB is the MATLAB language, a matrix-based language allowing the most natural expression of computational mathematics. It can access the data in the computer if the commands are passed. It is a high-level language. It has a graphical representation.

3.5 FLOW CHART DESCRIPTION

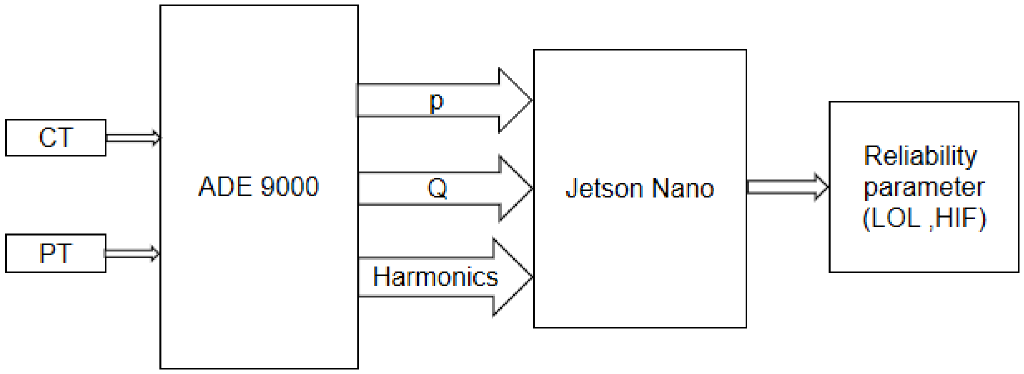

Figure 16. Flow chart of reliability parameter

The outputs of CT and PT i.e., current and voltage respectively are given to ADE 9000. The ADCs present in ADE 9000 will sample the current and voltage signals. All the power and energy computations take place in ADE 9000. The ADE9000 offers complete power monitoring capability by providing total as well as fundamental measurements on rms, active, reactive, and apparent powers and energies. Advanced features such as dip and swell monitoring, frequency, phase angle, voltage total harmonic distortion (VTHD), current total harmonic distortion (ITHD), and power factor measurements enable implementation of power quality measurements.

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CHAPTER 4

HARDWARE IMPLEMENTATION AND DEMONSTRATION

4.1 INTRODUCTION

In this chapter we will discuss about the hardware implementation and also demonstrate how actually the parameters are affecting the health of the transformer. This section also discusses about the connections. Following by a detailed description of the process. Arduino is interfaced with the two temperature sensors and WiFi module ESP8266. The components that are used in this project have been discussed in the above chapter. Here we will explain how the connections are made.

4.2 BLOCK DIAGRAM

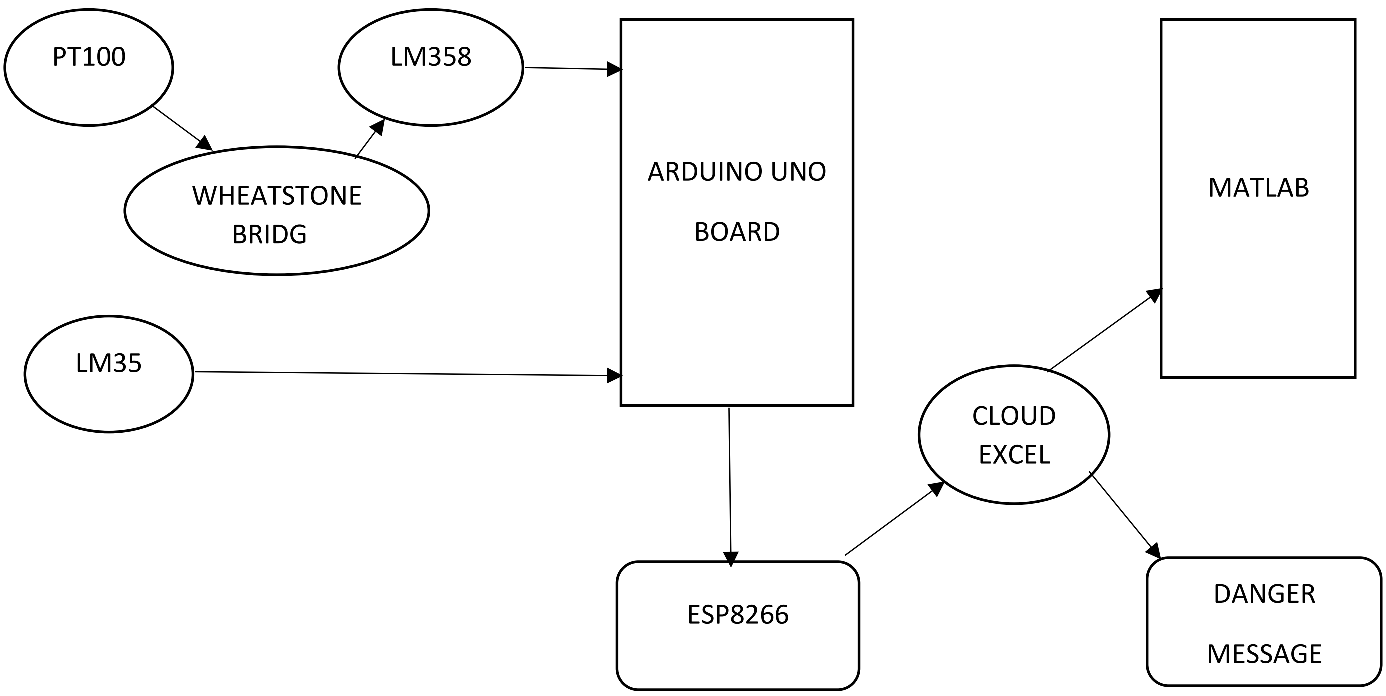

Figure 17. Block Diagram of the project/proposed solution

Practical:

For, calculating Hotspot temperature, PT100 is connected in Wheatstone with 100Ω and 1kΩs and heated, the output is very small to detect by an Arduino. So, the output is given to a LM358 which amplifies the signal by 10 and this is given to an analog pin (A1) of Arduino

Uno board. For, calculating ambient temperature, LM35 is used and the output is connected to Analog pin (A0) of Arduino Uno. Then we code on Arduino IDE to read the values from the sensors. This is monitored in real time and values are taken to the excel sheet and that is given to the MATLAB. If the hotspot temperature exceeds more than 120˚C then it sends a message “DANGER”.

4.3 CIRCUIT DIAGRAM

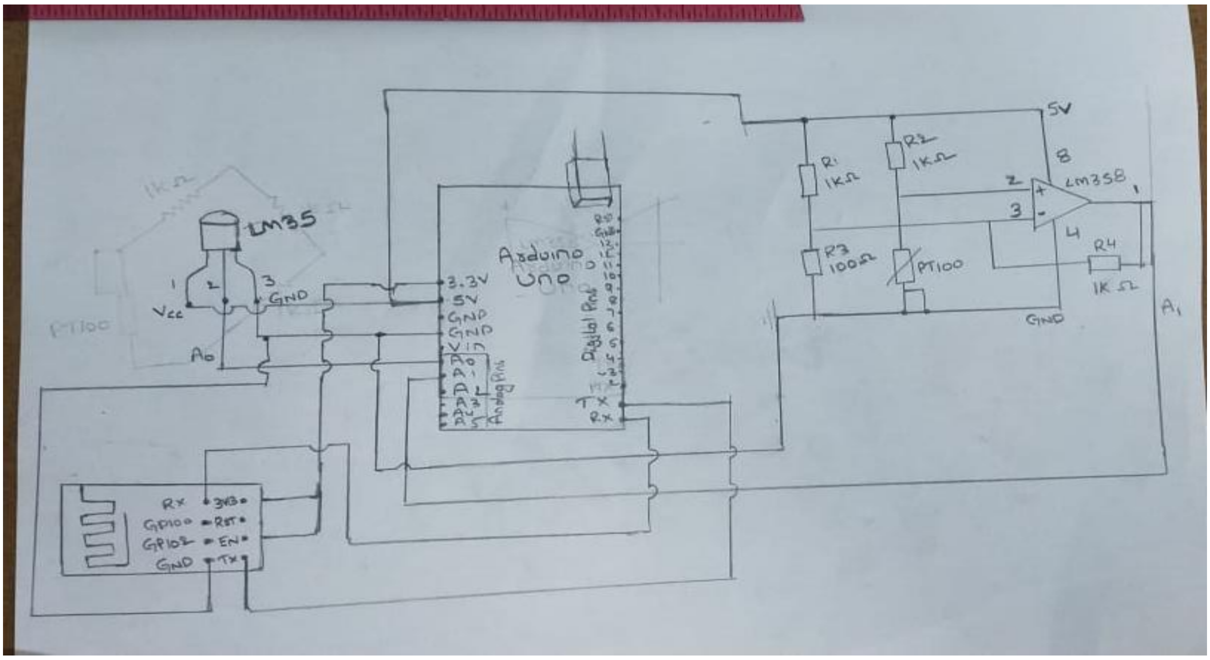

Figure 18. Circuit diagram of the project

4.3.1 CIRCUIT OVERVIEW

The circuit is made with Arduino Uno board, LM35, PT100, Resistances, LM358, ESP8266.

The power supply is taken from the Arduino, which is connected to the Laptop through USB port. We are using 5V and 3.3V power supply for Sensors and ESP8266 respectively.

To calculate the temperature value of the PT100 using Arduino, initially PT100 is connected in Wheatstone bridge to estimate the resistance value. Then the outputs are given to LM358 IC, in which it compares the voltage values and gives the amplified output. This Analog voltage output is connected to Analog pin (A1) of Arduino Board. Finally, the code is written to get the accurate values.

To calculate the temperature of LM35, it is a chip. It is connected to the power supply 5V and ground, remining pin is connected to the Analog pin (A0) of Arduino Board and the code is written to get the true values.

Now, the data is flowing through Arduino board. ESP8266 module is connected to WiFi using AT commands. Initially 3.3V supply is given. The data is transmitted from Arduino to cloud excel through ESP266 module. Finally, a message "DANGER" is printed in the excel sheet if the temperature value exceeds 120.

Lastly, the data from excel sheet is given to the MATLAB to monitor then changes in the graph.

4.3.2 CIRCUIT DESIGN AND EXPLANATION

The circuit is explained below, this consists of all the connections, and faults.

The power supply to the Arduino board is given through the USB port of Laptop. The Arduino has many pins it can provide a power of 5V and 3.3V simultaneously on their respective pins.

PT100 is a RTD (Resistance Temperature Detector) i.e., as temperature increases there is an increase in value of resistance. It is risky to measure the temperatures manually by a multi-meter and the output is in resistance. So to convert the output form from resistance to voltage it is connected to a Wheatstone bridge.

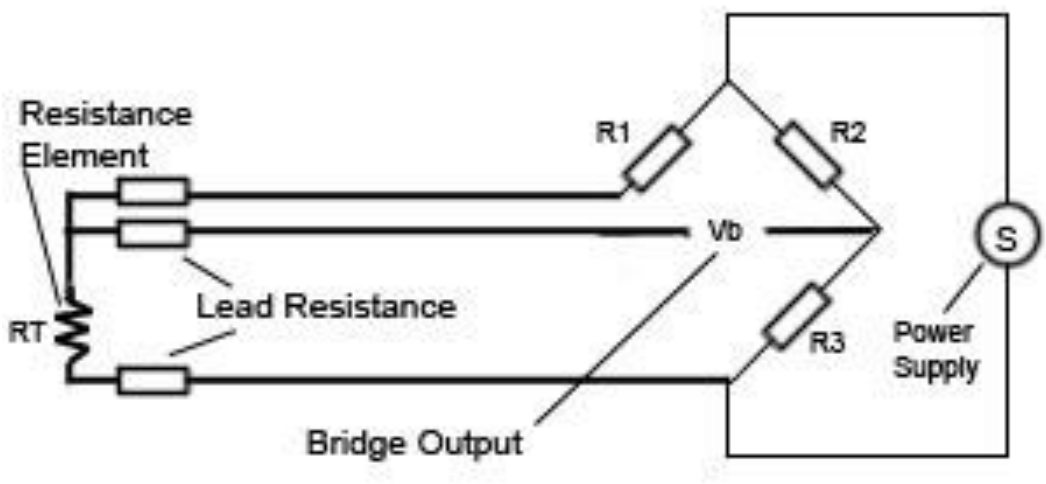

Figure 19. PT100 with Wheatstone Bridge

The above figure shows the connection of PT100 with a Wheatstone bridge. Here RT is the Resistance of PT100, R1 & R2 is 1KΩ, R3 is assigned to a resistance that is equivalent to PT100 to balance the bridge i.e., 100Ω. The 5V power supply is given across the junction between R1-R2 and RT-R3. The output voltage terminals are connected across the junction between RT-R1 (pin 3) & R2-R3 (pin 2) (this can also be said as Reference point).

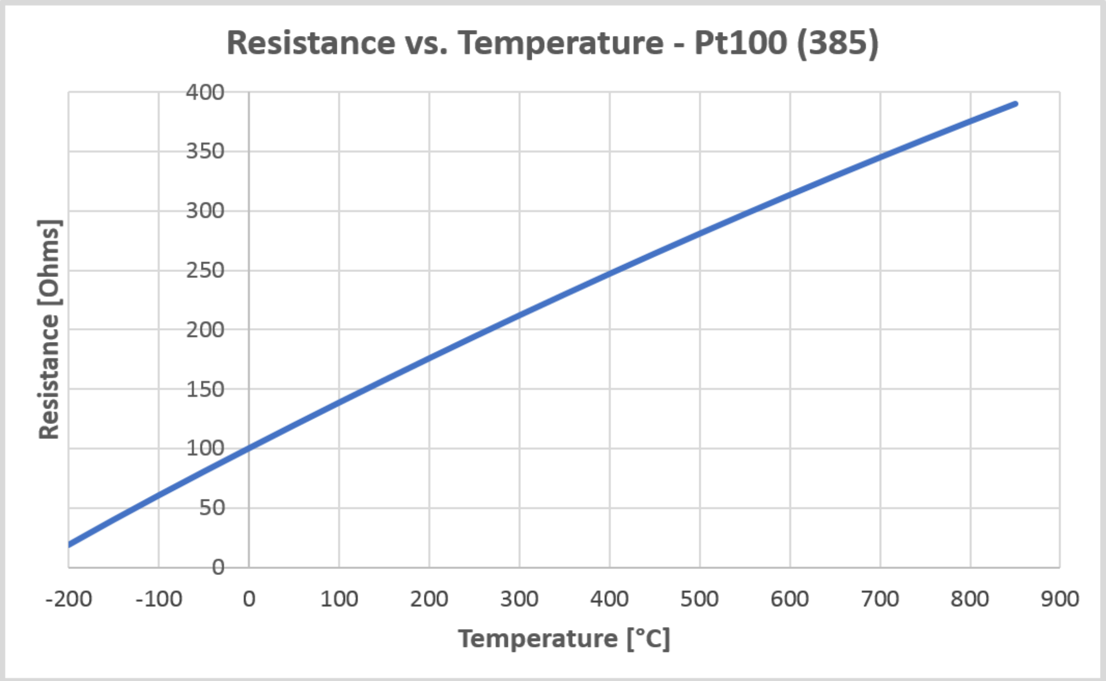

Figure 19. PT100 values Resistance vs Temperature

The output from the Wheatstone bridge is given to LM358 terminals to get the difference in the voltage which is very small so a resistance of 1KΩ is connected to across the output terminal and positive input terminal (pin 3). Then the value gets amplified and the output is analog sensor output value.

PIN 1	OUTPUT/ A1 pin of Arduino
PIN 2	R2-R3
PIN 3	RT-R1
PIN 4	GND
PIN 8	+Vcc (5V)

TABLE 3. LM358 pins to Wheatstone Bridge

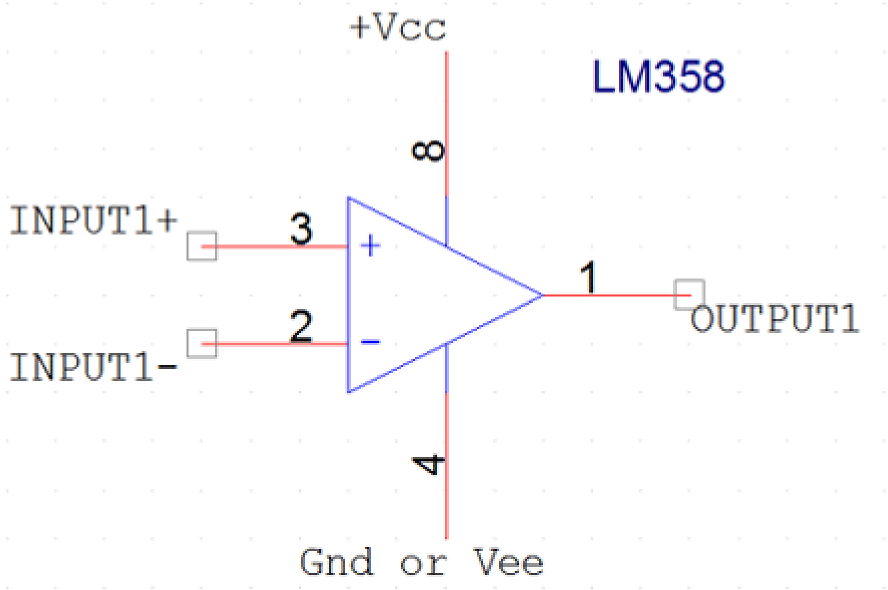

Figure 20. LM358 Pin Diagram

The LM35 has three pins, when looking from the flat side left pin is the Vcc connected to 5V. Middle pin is the Analog output pin connected to analog pin A0 and the last pin is connected to ground.

PIN 1	Vcc (5V)
PIN2	A0 pin of Arduino board
PIN 3	GND

TABLE 4. LM35 to Arduino

The Arduino is connected to the ESP8266 using the AT commands. To ensure the WIFI is connected open the serial monitor and type AT+ CWLAP if it shows the message then it is connected. The ESP8266 is connected as following

PINS	Connections to Arduino	After Wifi connection
3V3	3.3V	3.3V
EN	3.3V	3.3V
RX	RX	TX/D0
TX	TX	RX/D1
GND	GND	GND
GPIO0	GND	A0

TABLE 5. ESP8266 to Arduino

The pins of RX and TX in ESP8266 is changed to establish the serial communication as Arduino RX and TX may be busy.

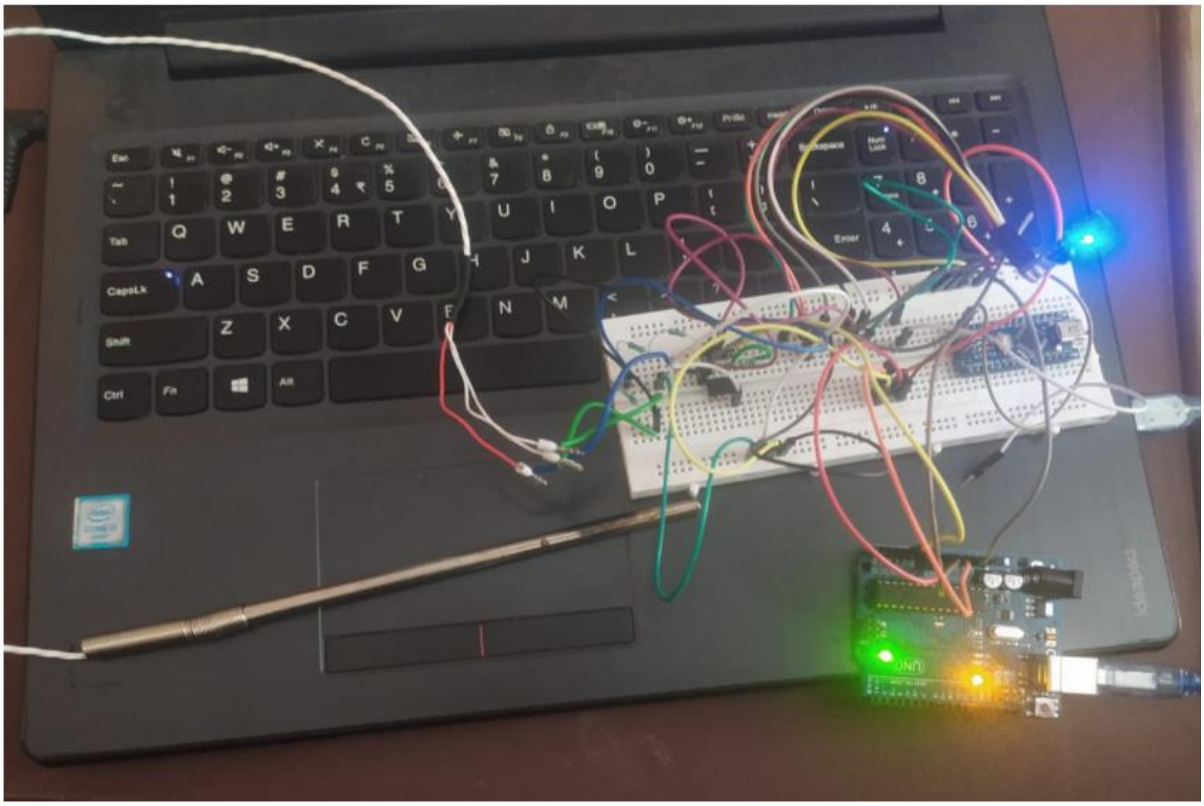

Figure 21. Hardware circuit diagram

CHAPTER 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

The project has both software and hardware implementation. The software implementation has mathematical analysis. The mathematical analysis is implemented using MATLAB. The MATLAB simulation discusses the characteristics of all the variables used in mathematical model. The hardware implementation is done using Arduino and sensors. All the results are obtained and discussed in the following sequence.

5.2 MATLAB SIMULATION

Load factor has a significant impact on insulation life of a transformer. The change in load factor is proportional to hotspot temperature. As load factor increases hot spot temperature increases which in turn affects the life of a transformer. Hence, load factor is an important parameter and all the other parameters which determine the remaining life of a transformer are studied here with respect to change in Load factor and hotspot temperature.

Code

```
b=0:0.0001:1; % b is load factor
A=2.*(10.^-18); % A and B are material constants
B=15000;
FHL=11.9416;    %Harmonic loss factor
Fstr=1.849;     %Harmonic loss factor of other stray losses
PNL=980;        %no load losses
PLLr=5900;      %load losses(rated)
temp_A=40;      %Ambient temperature
temp_TOr=60;    %TOPoil-rise over ambient temperature under rated conditions
temp_gr=5;      %Winding rise over ambient temperature under rated conditions
PDCr=3933.33;   %rated DC power losses
PECr=649;       %rated winding eddy current losses
POSLr=1317.666; %rated other stray losses
href=110;        %Reference hot spot temperature
PDC=b.*b.*PDCr;
```

```
href=110;        %Reference hot spot temperature
PDC=b.*b.*PDCr;
PEC=b.*b.*PECr.*FHL;
POSL=b.*b.*POSLr.*Fstr;
PLL=PDC+PEC+POSL;
temp_TO=temp_TOr.*((PLL+PNL)./(PLLr+PNL)).^0.8;
temp_g=temp_gr.(b.*b.(PDCr+(FHL.*PECr))./(PDCr+PECr)).^0.8;
h=temp_A+temp_TO+temp_g; %Hot spot temperature

C=B./(href+273);
D=B./(h+273);
FAA=exp(C-D);      %ageing acceleration factor
```

Figure 22. MATLAB code part-1

The parameters like Load losses, No Load losses, material constants, harmonic loss factor, harmonic loss factor of other stray losses have major impact on hot spot temperature and here these values are taken from a reference paper.

```
FAA=exp(C-D);      %ageing acceleration factor

LOL=(FAA*1*100)./(20.55);  % %loss of life

RL(FAA<1)=(20.55);    %Remaining life
RL(FAA>=1)=(20.55)./FAA(FAA>=1);

figure(1)
plot(b,h)
xlabel('load factor(b)')
ylabel('HST(h)(°C)')
grid on

figure(2)
semilogy(b,FAA)
ylim([0.0001 1000])
xlabel('load factor(b)')
ylabel('Ageing acceleration factor(FAA)(semilog representation)')
grid on
```

```
figure(3)
plot(b,RL)
ylim([0.0001 30])
xlabel('load factor(b)')
ylabel('Remaining life(RL) (years)')
grid on

figure(4)
semilogy(h,FAA)
xlabel('HST(h)(°C)')
ylabel('Ageing acceleration factor(FAA)(semilog representation)')
grid on

figure(5)
plot(h,RL)
xlabel('HST(h)(°C)')
ylabel('Remaining life(RL)(years)')
grid on
```

Figure 23. MATLAB code part-1

Simulation Results:

Load factor (b) vs Hotspot Temperature(h)(°C)

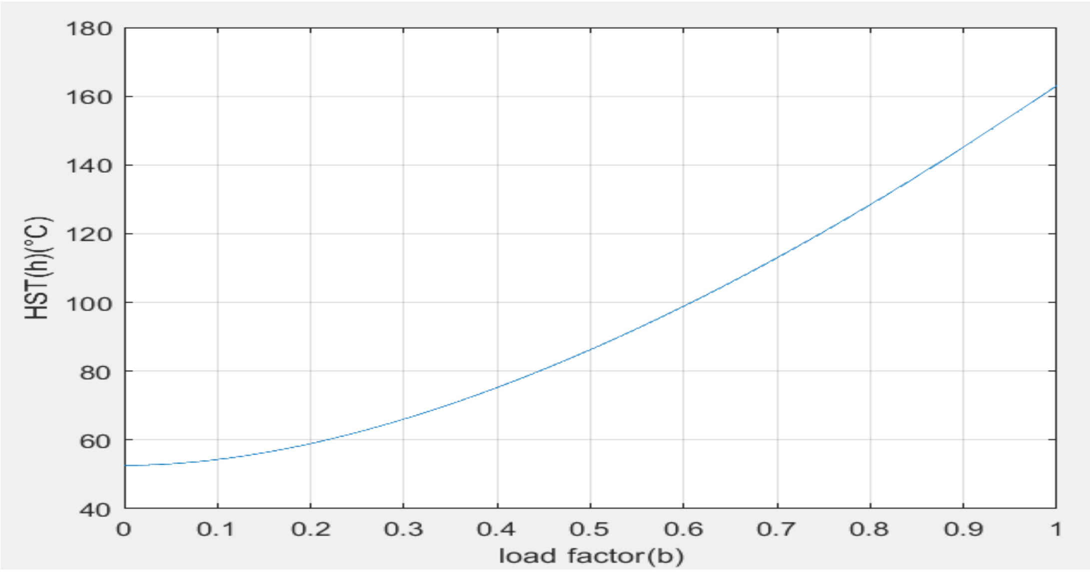

Figure 24. Load Factor vs Hotspot Temperature

As load factor increases hotspot temperature increases. When hotspot temperature is exceeded its reference temperature then the deterioration of insulation materials takes place.

Load factor(b) vs FAA(semilogarithmic plot)

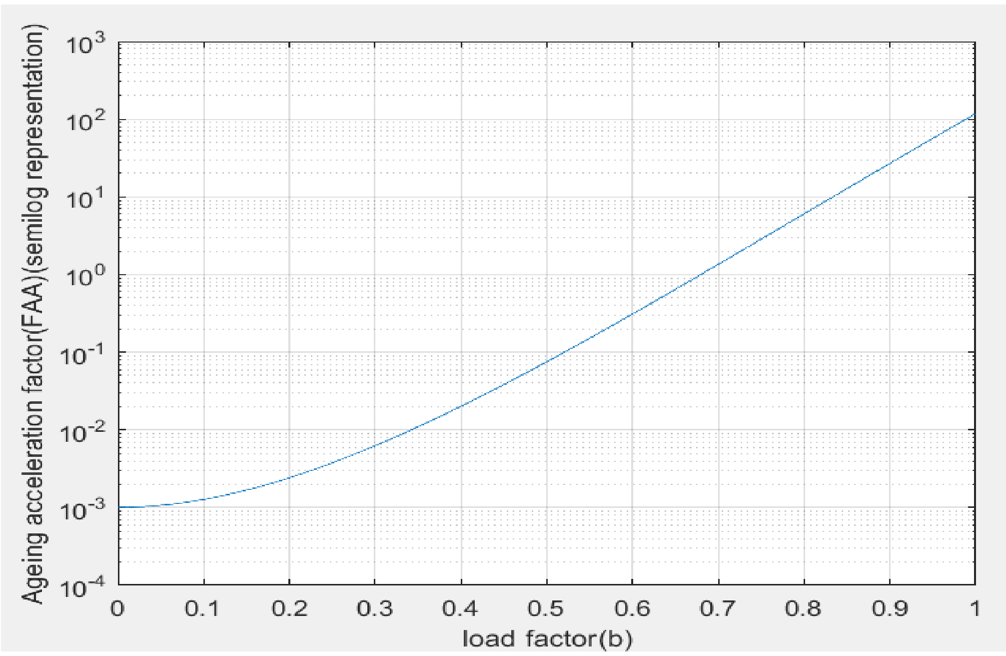

Figure 25. Semi-log Graph Load Factor vs FAA

The aging acceleration factor is a function of e. Hence here semi logarithmic graph is used to analyse its behaviour with change in load factor. With increase in load factor FAA increases exponentially.

Load factor(b) vs Remaining Life(RL)(in years)

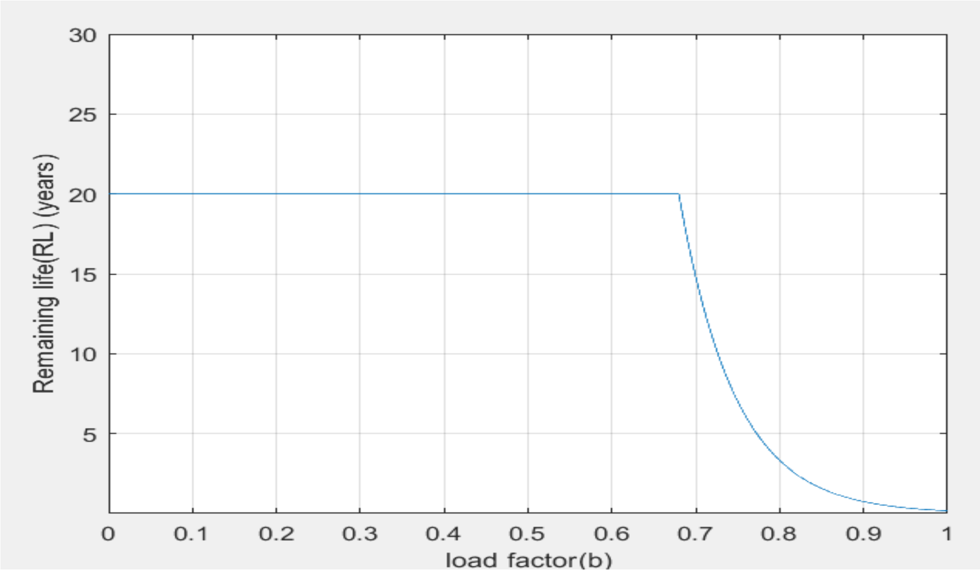

Figure 26. Load Factor vs Remaining Life (years)

Generally, the average life of oil-based transformer is around 20 years. When load factor increases, hotspot temperature increases. The aging acceleration factor depends on h. Hence, with increase in load factor FAA increases. Remaining life is directly proportional to FAA. Therefore, when hotspot temperature exceeds its reference value remaining life RL decreases.

Hotspot temperature (°C) vs FAA (semilogarithmic plot)

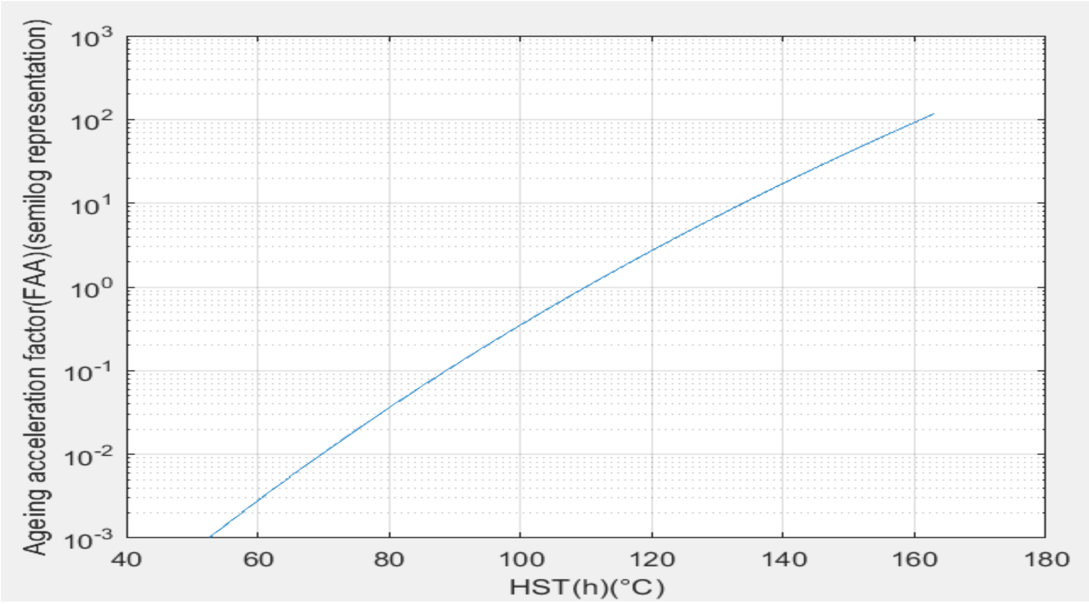

Figure 27. Hotspot Temperature (˚C) Vs FAA

As discussed earlier, FAA is function of exponential (e). So, semilogarithmic graph is used here. As h increases FAA increases exponentially.

Hotspot temperature (°C) vs RL(in years)

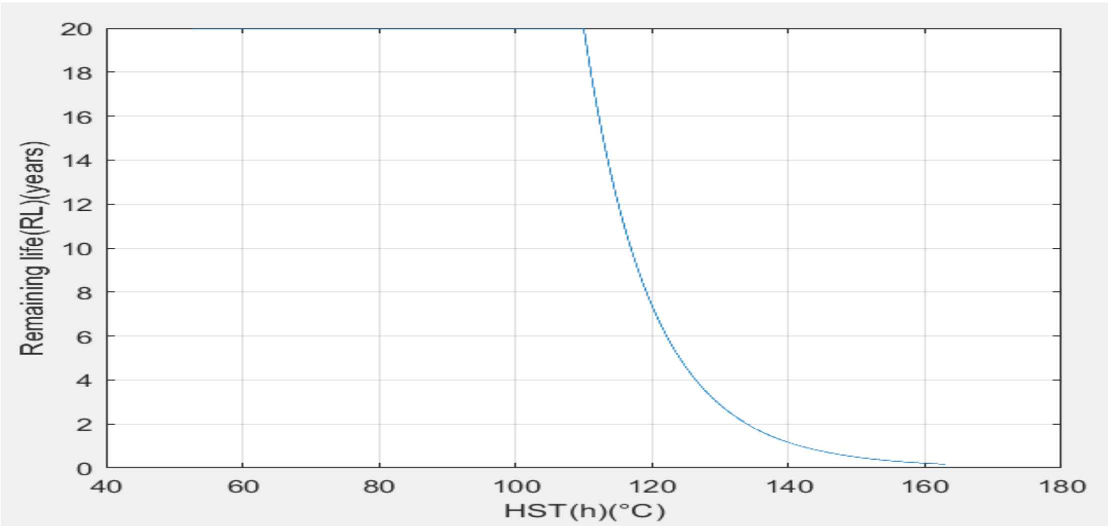

Figure 28. Hotspot Temperature (˚C) Vs RL (years)

The above graph is drawn by taking the practical values obtained, these values from excel sheet is given to the MATLAB. The Remaining Life of the transformer remains 20.55 (i.e., Normal Insulation Life) till 105˚C after that it is decreased exponentially.

5.3 REAL TIME IMPLEMENTATION

From the above analysis, it is clear that the hotspot temperature is the main parameter which is responsible for health of a transformer. Here RTD is used as temperature sensor. With change in temperature the resistance values of RTD changes which gives different voltage output for the implemented circuit. The RTD is interfaced with Arduino where all calculations take place. All the readings are recorded here and these values are used to determine health of the transformer.

5.3.1 Arduino code:

The below shown is the snapshot of Arduino code, the codes are written and processed to get the values from the sensors.

```
float temp_amb;
const float vt_factor = 1.88;
const float offset = -27;
float temp_hst;
float R;
const float B=15000;
const float NIL=20.55;
int href=95;
float C,D,LOL,FAA,RL;
int t=1;
void setup() {
  Serial.begin(9600);
  Serial.println("CLEARDATA"); //clears the previous data
  Serial.println("Voltage , Resistance, H_Temperature, Amb_Temperature, RLife");
}

void loop() {
  temp_amb = analogRead(A0);
  temp_amb = temp_amb * 0.48828125; //(5/1024)*100
  int sensorvalue = analogRead(A1);
  float voltage = sensorvalue * (5.0 / 1023.0);
  temp_hst = (((voltage * 100)/ vt_factor) +offset);
  R=(100*(1+(0.00385*temp_hst)));
  C=B/(href+273);
  D=B/(temp_hst+273);
  FAA=exp(C-D);
  LOL=(FAA*t*100)/NIL;
```

Figure 29. Arduino code part-1

```
  if(FAA>=1){
    RL=NIL/FAA;
  }
  else{
      RL=NIL;
  }
  Serial.print(voltage);
  Serial.print(",");
  Serial.print(R);
  Serial.print(",");
  //Serial.print("HST_Temp: ");
  Serial.print(temp_hst);
  //Serial.print("c");
  Serial.print(",");
  Serial.print(temp_amb);
  Serial.print(",");
  Serial.print(RL);
  Serial.print(",");
  if(temp_hst>=150){
    Serial.print("DANGER");
  }
  else{
    Serial.print(" ");
  }
  Serial.println();
  delay(1000);//for every 1sec read the value or continue the loop

}
```

Figure 30. Arduino code part-2

5.3.2 LIVE RECORDED DATA

It prompts DANGER message when the temperature is above or equals to 115˚C

444	2.40V	131.78Ohr	82.55c	39.55c	20.55	
445	2.45V	132.48Ohr	84.36c	40.04c	20.55	
446	2.51V	133.40Ohr	86.76c	41.02c	20.55	
447	2.56V	134.17Ohr	88.76c	40.04c	20.55	
448	2.62V	135.25Ohr	91.57c	42.48c	20.55	
449	2.70V	136.41Ohr	94.57c	42.48c	20.55	
450	2.79V	137.80Ohr	98.18c	41.50c	14.5	
451	2.88V	139.26Ohr	101.98c	43.95c	9.62	
452	2.97V	140.65Ohr	105.59c	39.55c	6.57	
453	3.09V	142.58Ohr	110.60c	42.48c	3.92	
454	3.20V	144.28Ohr	115.00c	44.43c	2.51	DANGER
455	3.29V	145.82Ohr	119.01c	40.04c	1.69	DANGER
456	3.38V	147.21Ohr	122.62c	37.11c	1.19	DANGER
457	3.47V	148.59Ohr	126.22c	37.11c	0.85	DANGER
458	3.48V	148.75Ohr	126.62c	45.41c	0.82	DANGER
459	3.48V	148.75Ohr	126.62c	41.02c	0.82	DANGER
460	3.48V	148.75Ohr	126.62c	42.97c	0.82	DANGER

Figure 31. Snapshot of recorded data

5.3.3 GRAPHICAL ANALYSIS

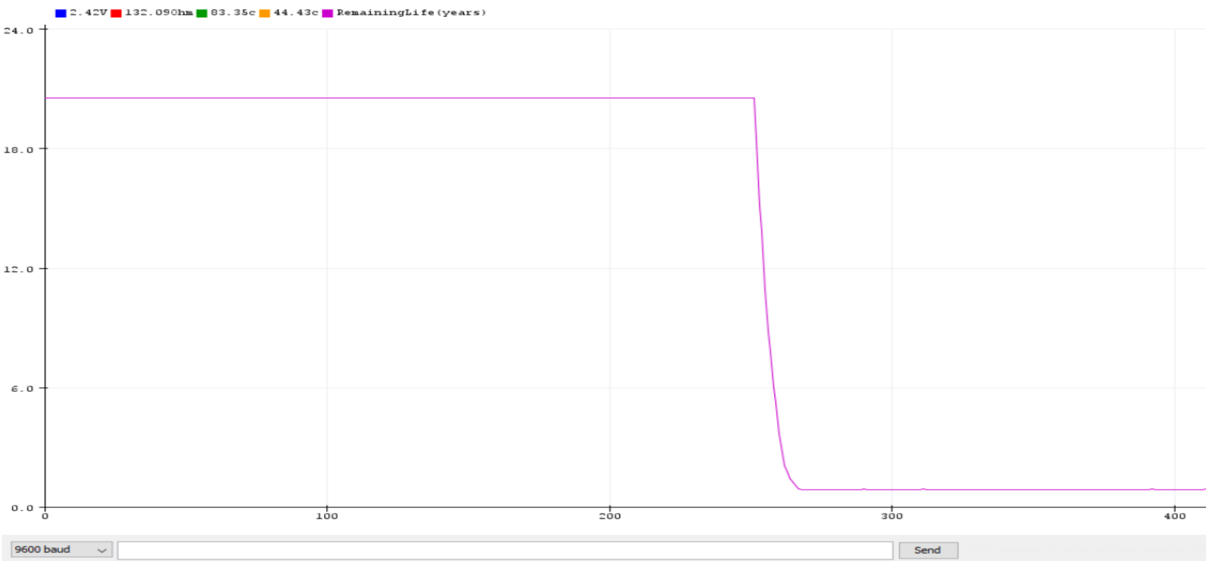

Figure 32. RL screenshot recorded in Arduino

The RL is at 20.55 years till the temperature is 95˚C, after that it has exponentially decreased.

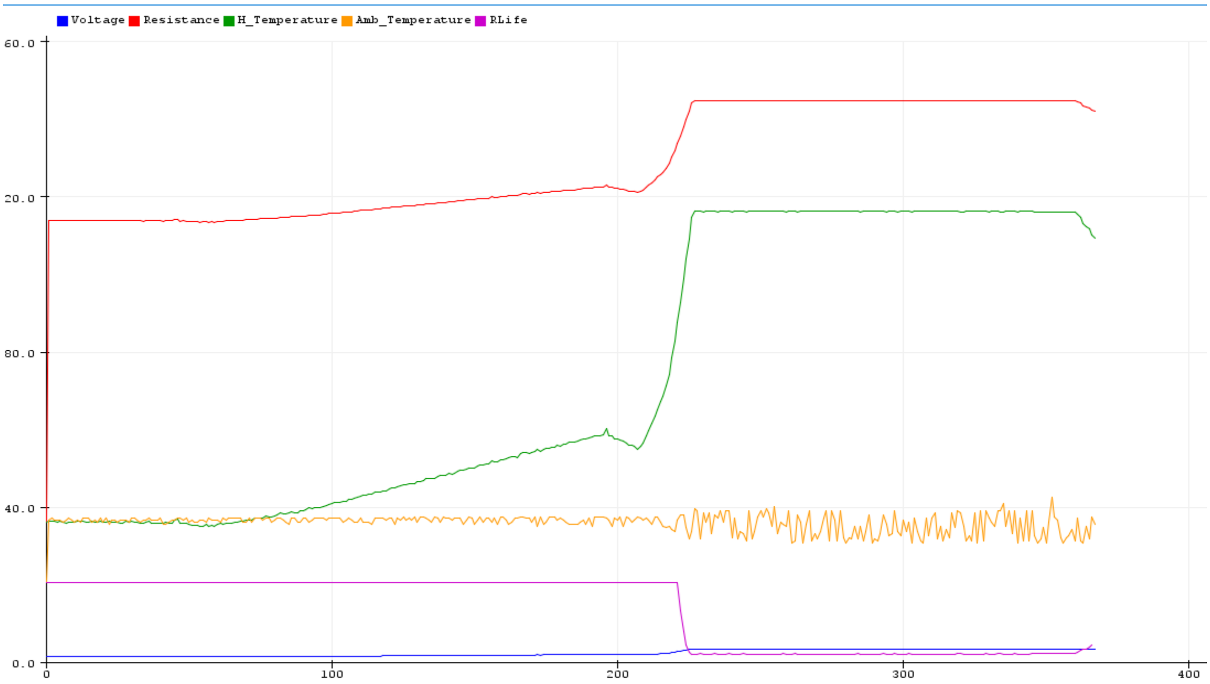

Figure 33. Graph of real time data and monitoring of data

The practical analysis graphs are similar to the results obtained by MATLAB simulation. As the hotspot temperature is increasing the remaining life of the transformer decreases. As the setup is measuring the temperature continuously and values are recorded the remaining life RL of the transformer is observed continuously at every instance of time. This real time monitoring has many advantages as we can act immediately if any necessary action is needed (to prevent transformer failure).

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Harmonics, Reactive power, ambient temperature could affect insulation life and in turn reduce the lifetime of the transformer. Here, impacts of harmonic components on transformers have been reviewed and analysed. Effects of non-linear loads on transformer losses based on the conventional method (IEEE standard C57-110) have been studied for derating purpose. The harmonic losses factor for eddy current winding and other stray losses has been computed in order to evaluate the equivalent KVA of the transformer for supplying non-linear loads. Transformer hot spot is extremely sensitive to dimensions and distribution of winding eddy current. Increased transformer loss, caused by non-linear load current, leads to an increase in transformer temperature, fatigue and premature failure of insulator and transformer life reduction. The main transformer aging indicators (hot-spot temperature, aging acceleration factor etc.) were continuously computed in accordance with the measured current harmonics. Finally, a monitoring system was considered essential to ensure reliability and sustainability of the transformer.

6.2 FUTURE SCOPE

A meter-based setup with deep learning has its merits to keep a track on life of a transformer. A deep learning engine like jetson nano is recommended for developing an algorithm which on taking continuous reading from transformer predicts the remaining life the transformer. Addition of IOT highly benefits us. The data can be stored in cloud and can be taken or recorded at any place. Taking the limited signals and decoding other parameters like harmonics which has significant affect on transformer health need a lot of working on deep learning. This prediction is necessary to ensure reliability and sustainability of the transformer.

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