IoT BASED DISTRIBUTION TRANSFORMER HEALTH MONITORING SYSTEM

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in

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Submitted by
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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "**IoT Based Distribution Transformer's Health Monitoring System**", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar Institute of Engineering & Technology (Deemed to be University) is as authentic record of my own work carried under the supervision of Dr. S.K. Agarwal. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Place: Patiala (**Shuvam Pathania)**
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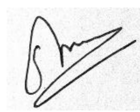

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Abstract

Distribution companies have a strong competition among them to provide reliable power at a low cost. As per reports, maintenance as well as replacement of transformers is found to be an expensive exercise for all companies. Keeping this factor in mind, IoT based distribution transformer monitoring system is developed in this work to monitor health conditions of distribution transformers on regular intervals. Health index is determined on the basis of change in voltage, temperature variations and load ability, which are measured using sensors. Arduino has been selected as the processor for the sensed data while ThingSpeak has been selected as the IoT platform. This low cost system can be installed in transformer at any location to get monitored remotely, which not only determines health condition but also is helpful in predicting its life span as well.

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CHAPTER 1 INTRODUCTION

1.1 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 accordingly [1]. All IoT based devices perform without human intervention, and even people can interact with devices as shown in Figure 1 [2].

The system given below shows an example of IoT environment, where different IoT based devices are sending data to a hub and here accumulation of data occurs. Accumulated data can be further processed to be analyzed or sent to different user interfaces like smart-phones, human-machines *etc* and desired actions can be taken.

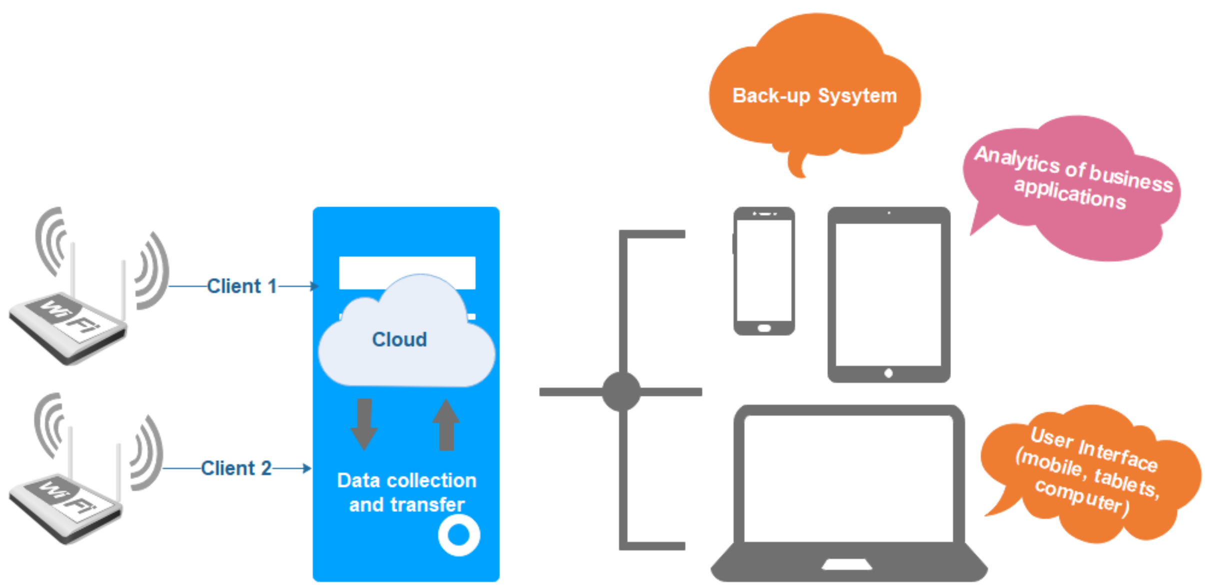

Figure 1 Overall operation of Internet of Things

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 [2]. 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.

1.1.1 Benefits of IoT [2]

Overall system and process monitoring is faster with the introduction of IoT and automation. Not only had this, but Internet of Things also improved customer's usage experience with a product or service, which provides better value and higher reliability. IoT also saves time and money of companies for the establishment of monitoring systems *e.g.* post-fault clearing time can reduce if such a monitoring system is used in electrical distribution networks. By the implementation of IoT based devices in offices or homes, it has been found that autonomous systems like thermostat, air-conditioners, lightning *etc*. make the overall daily routine faster as human can now spend more time in other tasks. An IoT based system can be operated remotely and is also easy to monitor even in extreme weather and working conditions. Thus, IoT based systems are more reliable, fast, accurate, economical and safe to use.

1.2 Applications of Internet of Things (Iot)

1.2.1 Application of IoT in Energy Systems

As shown in Figure 2. Australian energy market operator (AEMO), here electricity market as well as gas market are governed and managed by a single operator, so use of Internet of things finds a good application [3]. IoT is used to display data at every instant and helps the market participants to keep an eye on the various data points.

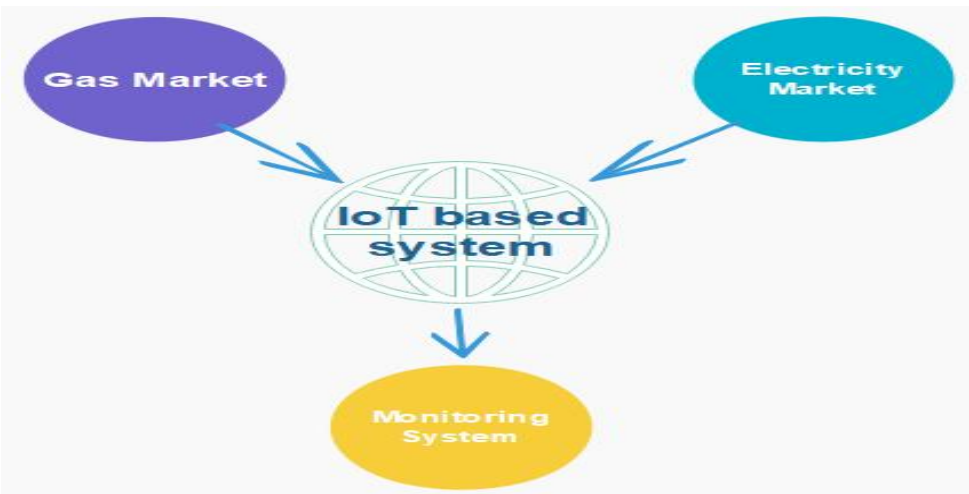

Figure 2 Application of IoT in Energy Market

Using IoT system two different distribution companies can get synchronized and lead to a single management company. Different sensors placed at the different points in the distribution network can avoid or reduce fault clearance while smart energy meters speed up billing process. Even, inter-communicating IoT sensors can vary gas pressure as per limits set while on other side, these sensors can manage power flow on the basis of sanctioned load to a particular user. As, two companies are under a single management system, so communication methods used can be made universal either for gas distribution or for electricity distribution.

Thus, IoT bypassed need of separate companies which saved time and money. This system also increased reliability of distribution system. The measuring sensors placed throughout the distribution system synchronize all the data to the servers systematically and swiftly.

1.2.2 IoT Based Monitoring of Transmission Systems

A power transmission line is one of the important need and features of an IoT based monitoring system. High voltage transmission lines come under many natural disasters which can affect stability and reliability of the system [3]. At present, many wireless network systems have been put into practice, but there are some problems of high maintenance and operation costs.

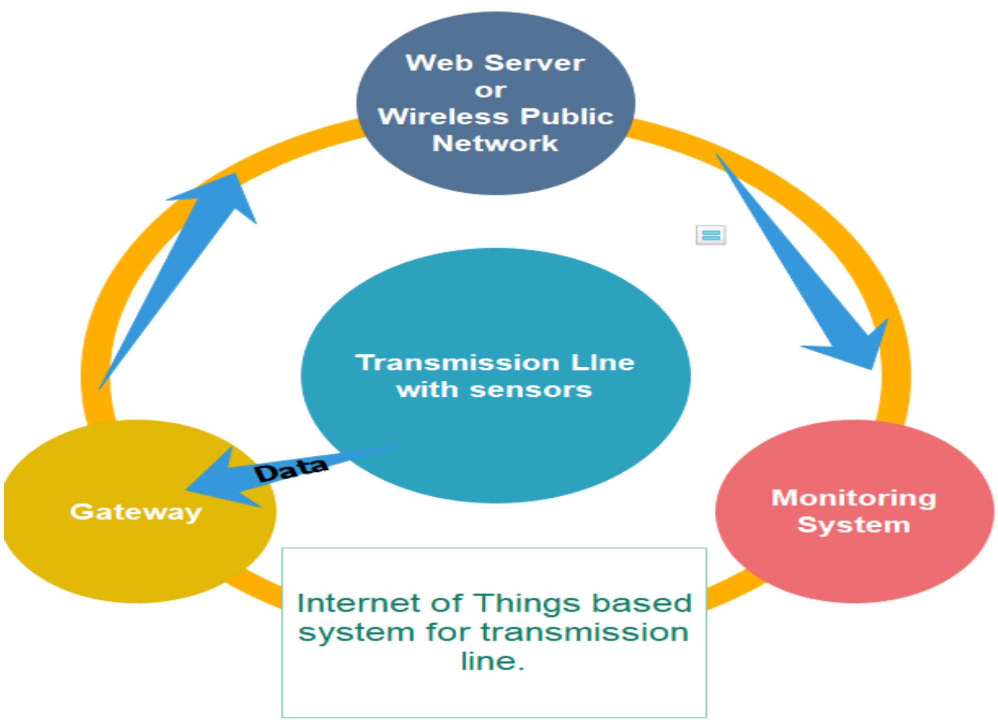

Figure 3 IoT based Transmission Line

IoT monitoring of transmission lines is composed of two parts: one is to monitor the transmission line conductor state while the other is to monitor tower condition state.
Different sensors like temperature, humidity, wind and other meteorological sensor, vibration sensor, ultrasonic sensor, tower leaning sensor, infrared sensor, leakage current sensor and camera build the monitoring system of transmission line and tower [3].

1.2.3 Application of IoT in Electrical Distribution System

Distribution transformer 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 particular 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 [4]. These 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 DTs.
The electricity distribution network is mostly monitored in high and medium voltage areas. In low-voltage networks, where most customers are connected, there is no monitoring capability, so operators basically do not know what happens when a client's load profile changes. In addition, the affected network devices may be 30, 40, or even 50 years old and may have a significant impact on non-project working conditions, such as reverse energy flow.
As a result, monitoring is needed to understand the design and distribution of patterns. The maintenance engineers should have ways to ensure the proper condition of the equipment so that they can manage their property and can avoid working conditions which are harmful for them. [4].
One option is to connect all electrical systems to the control panel, where the data is compiled and evaluated. However, this would require a bigger business to establish communication and thereby generate a lot of growth in staffing control and consequent increase in operating costs.

Another option is to use the industrial internet of things by installing low cost sensors and wireless communication gates that collect and process the data locally. They can distinguish between important events and warnings to be sent to the control room, and those that are within the expected operating values and do not require further action. This option is a more cost effective way to collect and process the required information.

1.3 Transformer Monitoring

Transformer can undergo two type of faults, which are internal and external faults. Different causes of internal as well as external faults are given below in Table 1:

Table 1: Causes of failures of transformer Faults [5]

Internal	**External**
• Partial Discharge	• Lightning Strike
• Insulation Deterioration	• System Faults
• Humidity	• System Overload
• Moisture	• Switching Operations
• Overheating	
• Winding Resonance	
• Designing Defects	
• Loss of winding clamping	
• Insulating oil solid contamination	

1.3.1 Transformer Condition Monitoring

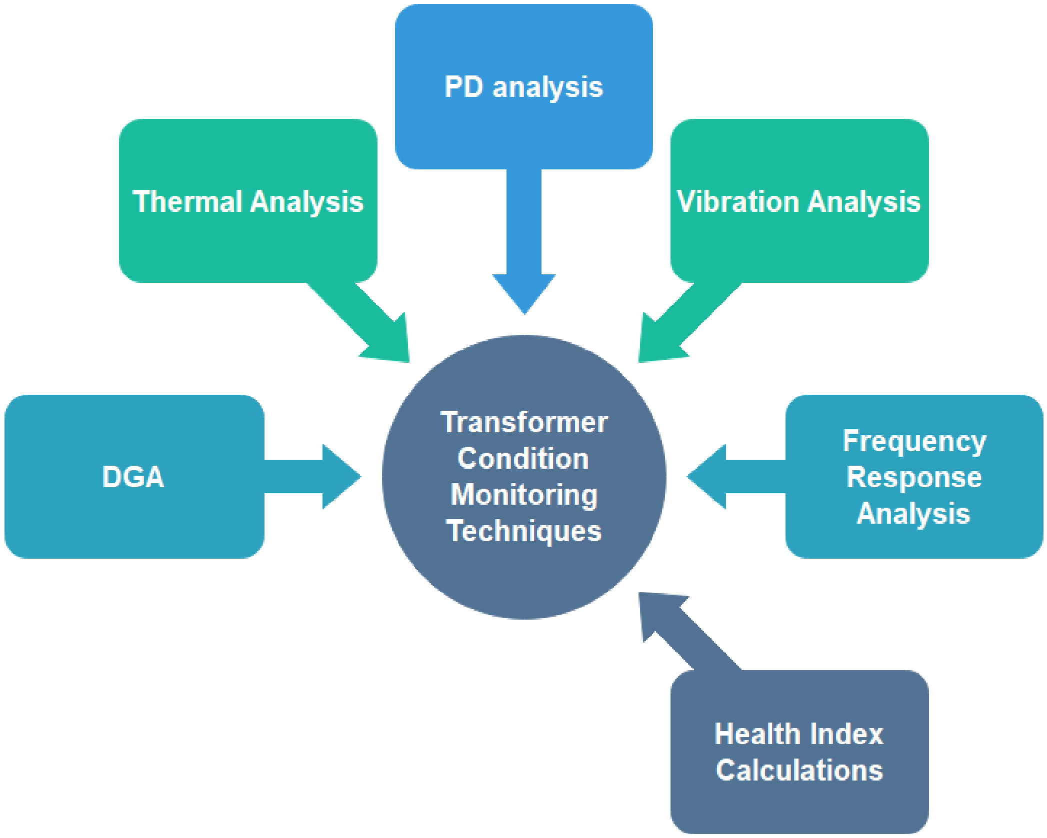

Figure 4 Different transformer condition monitoring system

Partial Discharge Analysis

The partial emission or partial discharge (PD) occurs in a transformer, when the intensity of the electric field exceeds the breakdown intensity in a particular local area, the electrode partially separates the insulation between the conductors. Diesel activity of the agent deteriorates if the agent is stopped from regularly discharging the parts.

Piezo-electric sensors and UHF sensors can be used to measure partial discharge. Also, optical sensors were being used in the past studies to capture PD signals [6]. On-site, it is difficult to capture PD signals since it gets coupled with electromagnetic interference (EMI) that increases the difficulty in signal capturing. This is because value of PD signal is very low and on-site coupling with EMI can't be distinguished with simple visual inspector. So, noise reduction technique is applied on it. The most common method for PD de-noising is the usage of the Wavelet Transform (WT), the gating method, and the directional sensing.

Thermography

Infrared emission testing method is used to test the transformer external surface temperature. Overheating in a transformer is an evidence of improper machinery condition, progressive deterioration of machinery elements, or bad operating parameters, such as current, voltage or temperature. Cooling system blockages, hotspot locations and electrical connection problems can be detected using this method [7].

Temperature is a key element in ensuring working status of a distribution transformer. Regular monitoring can help in catching failures by using an advanced thermography camera [7]. Thermal imaging camera can see what naked eye can't see, so such cameras can be helpful in detecting different hotspots. The FLIR T660 features options with a 24° or 45° lens, which will gives a larger field of view when there is limited space in front of transformers. This thermal camera can measure temperatures up to 2000°C (3632°F), and it provides 640 x 480 thermal resolution for superior image quality and clarity [7] [8].

Dissolved Gas Analysis (DGA)

Paper and hydrocarbon are main ingredients of winding insulation. Degradation of insulating paper is observed with high operating temperature. This leads to emission of different gases [8]. Transformer fault release these gases which are H_2, CO, $C0_2$, CH_4, C_2H_2, C_2H_4 and C_2H_6 [9]. DGA technique is mostly used for fault analysis.

Dissolved gases are analyzed by the following two methods:

1) Photo-acoustic emission spectroscopy
2) Laboratory gas chromatography (GC)

These steps are involved in performing DGA:

A) Extraction of all gases in oil sample
B) Measurement of quantity of each gas
C) Calculation of concentration of each gas in every sample

Table 2. Different faults and gas emission

Gases	Faults
1) O_2 & N_2	Non fault related gases
2) CH_4 & C_2H_6	Low temperature oil breakdown
3) C_2H_2	Arcing
4) H_2	Corona
5) CO and CO_2	Cellulose insulation breakdown
6) $C_2 H_4$	High temperature oil breakdown

Frequency Response Analysis

Analyzing the frequency response allows the deformation of winding, core and clamping devices to be detected, which is an effective tool for diagnostics. Cut-off of transformer for the purpose of FRA is its main drawback, which results interruption in power supply. Determination of type of fault can be done by using digital image-processing technique [10].

Health Index Calculations

Health Index (HI) is procedure of connecting dots of complex information and form a single result which is an indication of transformer's health. It is calculated based on formula given below [4]:

$$\text{HI}=S_{max}\frac{\sum_{\text{n}=1}^{\text{m}} S_{pi}.W_{pi}}{\sum_{\text{i}=1}^{\text{m}} W_{pi}} \qquad (1)$$

Where, S_{max} is the maximum score for influenced parameter, S_{pi} score of each parameter based on permissible limit, W_{pi} is the associated weight is taken and m is no. of parameters involved. Weightage of parameters decide overall weight of transformer.

Reports say factors like ageing and overload contributes most to failures in transformer. According to literature [4], offline parameters contribute 30% to health monitoring while online parameters contribute 70% to health monitoring. Thus,

$$Health\ Index\ (HI) = 30.HI_{OFP} + 70.HI_{ONP} \qquad (2)$$

After calculating health index using equations (2),(3) and (4) categorization of Health index as per transformer's health state is done considering table 3.

Table 3. Health Index levels

%HI	Health State	Requirement
85-100	Good	Normal maintenance
65-80	Fair	Increase periodic maintenance
50-65	Poor	Replacement required
0-50	very poor	Risk of any time failure

Following are two sources of influenced parameters:

a) Offline Parameters

b) Online Parameters

a) Offline Parameters

These are the parameters which do not change suddenly and have very little effect on Health index calculations. Health index based on offline parameters is calculated using given formula:

$$HI_{OFP} = S_{max} \frac{\sum_{n=1}^{5} S_{pi}.W_{pi}}{\sum_{i=1}^{5} W_{pi}} \qquad (3)$$

Where, S_{max} is the maximum score for offline parameter, S_{pi} score of each parameter based on permissible limit, W_{pi} is the associated weight is taken and m is no. of parameters involved. Weights are decided based on influence of a parameter on DT. All permissible limits are taken from table 4.

These are as shown in Figure 5 below:

Figure 5 Different offline Parameters

1) Age

It is the number of years for which a transformer has actually been put into service. Normally, for a substation transformer has a life span of 15-30 years and for distribution transformer it is about 20-30 years [11]. Weight assigned for health index calculations is minimum for this parameter.

2) Loading History

Reading history provides an important step change in determining fatigue. It has a direct effect on the flaws as well as the life of the converter. The continuous temperature changes produces a big amount of heat which affects life expectancy [4].

3) Location

Based on reports, it is noted that transformers at different locations have different failure cycles. [4]. This parameter has most high weight assigned.

4) Type of transformer

Age of transformer is indicated by this parameter. Generally, old transformers bear internal winding failures. They are repaired and re-installed in system [4].

5) Inspection and Maintenance

As per MSEDL, substation as well as service transformers above 100kVA are scheduled to be serviced at least once in a year [4]. These transformers are to be maintained per annum for maintenance. As per report, delay in inspection may cause failures.

Offline Parameter Values as Per Maharashtra State Electricity Distribution Company [4]

a) Weight is abbreviated as W.
b) *S* is score of each parameter is based on permissible limit.
c) Offline parameters are abbreviated as OFP.

Table 4 : Offline Parameters

Pi	OFP	4(S)	3(S)	2(S)	1(S)	W
1.	Age (years)	0-5	6-10	11-15	16-20	4
2.	Average loading,%	<60	61-75	76-85	>85	2
3.	MPA	1	2	3	>3	3
4.	Type of transformer	0	1	2	>2	4
5.	Location	A	I	R	B	1

b) Online Parameters [4]

Heat produced by transformer under particular limit define its good health condition. Increment in losses leads to more production of heat which ultimately effects life expectancy of transformer.

Health index based on online parameters is calculated based on formula given below:

$$HI_{OFP}=S_{max}\frac{\sum_{n=1}^{3} S_{pi}.W_{pi}}{\sum_{i=1}^{3} W_{pi}} \qquad (4)$$

Where, S_{max} is the maximum score for online parameter, S_{pi} score of each parameter based on permissible limit, W_{pi} is the associated weight is taken and m is no. of parameters involved. Weights are decided based on influence of a parameter on DT. All permissible limits are taken from Table 5.

Following are the parameters which may be the reason for involvement in over-heating of transformer:

Figure 6. Different online parameters

1) Unbalanced Voltage levels

Increased over voltage cause high change in flux and lead high iron losses. Voltage variations of $\pm 6\%$ is allowed in distribution transformer [12].

Voltage condition varies with load variations. Reducing the voltage deviation and attenuating the voltage dispersion is one of the most important goals that needs to be done by engineers [12]. Measured secondary side voltages of distribution transformers are termed as V_a , V_b and V_c.

$$\Delta V = \frac{1}{3}\left(\left(\frac{V_{rated} - V_a}{V_{rated}}\right) + \left(\frac{V_{rated} - V_b}{V_{rated}}\right) + \left(\frac{V_{rated} - V_c}{V_{rated}}\right)\right) \quad (5)$$

2) Harmonic load currents

At overload conditions, copper losses get increased by high currents [13]. Heat generation also gets incremented by the increment of these losses. Further this results in increasing winding temperature. Different phase currents are termed as I_a, I_b and I_c . Rated value of secondary current is termed as I_{rated} .

$$\Delta I_{DT} = \sqrt{\frac{1}{3}(|I_{rated} - I_a|^2) + (|I_{rated} - I_b|^2) + (|I_{rated} - I_c|^2)} \quad (5)$$

3) Winding Temperature

Thermal behavior of hottest portion of winding is detected using winding temperature indicator [13] .Winding temperature limits loading capability of power transformer i.e. with the increase in loading of transformer, winding temperature also increases.

$$\Delta\emptyset_{To} = (\Delta\emptyset_{TO,U} - \Delta\emptyset_{TO,i})(1 - e^{\frac{-t}{\tau_{To}}}) + (\Delta\emptyset_{TO,i}) \quad (6)$$

Where $\Delta\emptyset_{TO,U}$ is the ultimate top ambient temperature for load in °C, $\Delta\emptyset_{TO,i}$ is earlier temperature at beginning *i.e.* $t = 0$, t is time in durations in hours, τ_{To} is time constant of DT for any load L, and $\Delta\emptyset_{TO,i}$ is specific temperature difference between high top and initial top temperature.

4) Efficiency deviation due to internal faults

Overall efficiency of transformer gets deviated by generation of internal faults in transformer. Electronic energy meter measure transformer's input as well as output power [4]. Ratio of output power to input power determines the efficiency of a transformer measured by an electronic energy meter, which is given as

$$\eta_T = \frac{Power_{output}}{Power_{input}} \quad (7)$$

Efficiency deviation at a particular load condition *i.e.* $\eta_{dev} = \eta_{actual} - \eta_{expected}$, is also a parameter for health index calculations. This parameter indicates changes in losses.

Online Parameter values as per Maharashtra State electricity distribution company [4]

Different abbreviations used are following:

a) Weight is abbreviated as W.
b) S is score of each parameter based on permissible limit.
c) Offline parameters are abbreviated as OFP.

Table 5. Online parameters data

Pi	**ONP, pu**	**4 (S)**	**3(S)**	**2(S)**	**1(S)**	**W**
6	V_u	<0.05	0.05-0.075	0.075-0.1	>0.1	4
7	I_h	<0.6	0.6-0.85	0.85-0.95	>0.95	2
10	Wdg. Temp	<0.6	0.6-0.8	0.8-1.0	>0.1	1

1.4 Wireless monitoring of distribution transformer

Technologies used:

1) GPRS Technology [14]
2) GSM based online condition monitoring system [15]

In above technologies, GPRS/GSM technology is used to monitor all online parameters of distribution transformer. Online parameters like voltage, current, winding temperature, oil level sensors etc. are used to calculate health index of transformer [14]. Health index calculations are based on parameters taken from table 4.

In GPRS technology, whenever certain limits of health index are crossed, a message is sent to operator for further actions and maintenance [15] [16]. This is as shown in Figure 7.

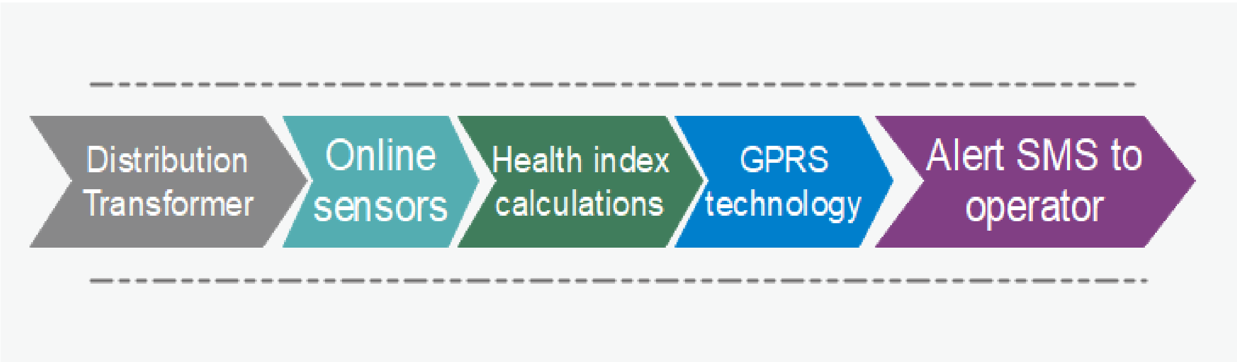

Figure 7 GSM based transformer monitoring system

1.5 Source of Motivation

Power distribution companies try to maximize profits by attracting customers and ensure a regular, reliable and high-quality power. Even utilities minimize their maintenance costs. The main component of the distribution company is the transformer, the distribution transformer and the high voltage wires. Reliable substations in distribution companies are numerous and even in urban or rural areas. The distribution or service transformers for these substations are in quantum of number. Substation transformers are equipped with overcurrent protection, ground protection and differential power protection, while service transformers use horn fault protection. As the amount of service transformers is optimal, regular maintenance will be difficult. In this way, most of the time troubleshooting is reactive Maintenance. The current trend is utilizing devices to highest potential and the repayment of all capital investments offered for renovation or installation. Figure 8 shows the general problem of distribution companies.

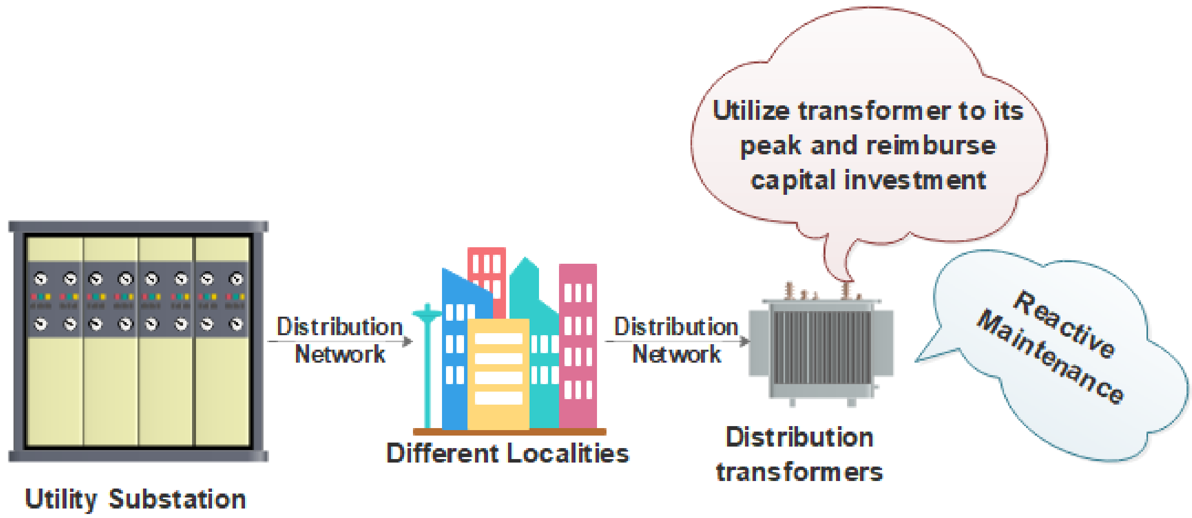

Figure 8. Distribution System

1.6 Objective of Thesis

Our aim is to develop an 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. Remote monitoring is based on health index calculations of transformers based on parameters like current, voltage and winding temperature. Data syncing is done through a web server called as data hub, and synced data is processed in MATLAB software at a utility substation based all-in one server which calculates health of distribution transformers. Health index can be used to predict life expectancy of transformer and can prevent reactive maintenance. An overview of operation is given as in figure below.

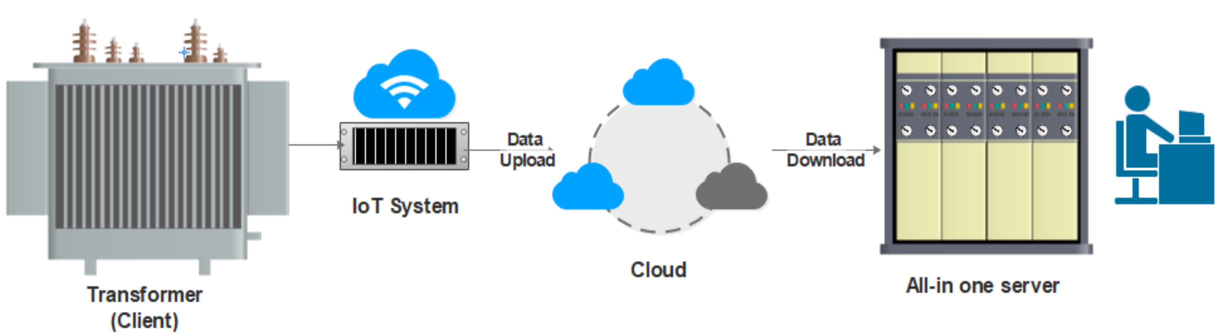

Figure 9 An overview of proposed system

CHAPTER 2 PROBLEM FORMULATION AND LITERATURE SURVEY

2.1 Problem Formulation

Distribution companies need to compete in a market place to provide reliable and regular power supply to large as well as residential customers. These service transformers installed are in not so easily accessible areas. Since, these service transformers are very large in number, therefore all these transformers cannot be provided preventive and routine maintenance by the staff of distribution utility, thus many a times a *post-facto* maintenance is carried out, i.e. when the transformer get failed, then after incident maintenance is carried. The present practice in the electric supply industry is to utilize existing equipment at the higher end of capacity levels. This is done in order post-pone the capital investment, which is needed for refurbishment of existing facilities.

2.2 Literature Survey

The main aim of IoT is to unify real world objects and create an intelligent virtual world of it [16]. An overview of IoT and its uses which can be implemented in real world have been discussed in literature [16]. Many technologies like NFC, Zigbee, Wifi, Bluetooth etc. were discussed, these technologies find a big application in building IoT environment.

Millions of heterogeneous devices connect peer to peer to form a wide virtual network. Different applications of IoT in power systems were discussed [17]. IoT can be used in smart grid and solve problems related to energy by compacting energy demand. Implementation of IoT in creating sophisticated market were discussed [17].

In literature and in actual practice, there are several methods which have been prescribed for assessment of condition of a transformer [5]. There is an increasing need for better and non-invasive diagnostic and control tools to assess the internal state of transducers.

CIGRE Working Group, has identified and elaborated upon the causes of failures of the transformers [18]. Problems related with the reliability of power transformer in service have been studied.

Many aspects of sample storage, gas-in-oil extraction and analysis and interpretation techniques have been studied [5]. These are important for the diagnostic significance of the gas-in oil analysis results.

Utility experience with different faults and non-faulty conditions of power transformers and reactors has also been studied [18]. It is noted that the most powerful diagnostic tool is DGA. Can be used to identify dielectric, thermal and chemical aging problems. Methods such as dissolved gas analysis, flow response reaction analysis, partial discharge analysis, analysis of transformation conditions. [19]. But these are offline methods and need expert analysis. Very costly and not suitable for the monitoring of distribution systems.

In literature, application of UHF measurement of partial discharge in the monitoring of transformers has been discussed [20]. A condition monitoring methodology has also been described, which is good at diagnosing data.

Development and implementation of the transformer inter turn fault detection system (TIFDS) for power transformers have been studied [13]. The algorithm eliminates the necessity of secondary side current transformers; however at the same time, the preliminary recognition of the load profile encountered by the transformer is required to determine the turning error.

An approach based on the use of transformer no-load and light load current harmonic analysis to detect the presence of an inter turn fault at the incipient stage has also been investigated [17]. This paper also presents offline to online transformation of the no-load current harmonic analysis method by demonstrating applicability at reduced load conditions. At high load, this no-load harmonic analysis is of no use since no-load current is constant regardless of load [21].

A simple algorithm based on existing current and voltage sensors has been proposed [22]. This use of algorithm is used to calculate the different numbers for identifying the error and twisting of the line, regardless of the OLTC on-line tap changer issue.

A sensitive, simple and stable approach based on symmetric components before troubleshooting between speeds before the severe short circuit occurred has been discussed [23].

This paper describes the calculation of (Health Index) HI for oil-immersed transformers using fuzzy set theory [24]. This is an offline method which needs usage of furan analysis, and DGA.

A technique to formulate the HI based on load data and results of different tests of transformer has been proposed [25].

In this literature, development and implementation of transformer's HI determination has been proposed. Information is sent to asset owner or utility engineer in case of abnormality by SMS [4].

Completion of the state-of-the-art industrial application monitoring, distribution monitoring system and state analysis has been introduced in the literature [13]. Health Index (HI) stress is calculated from weight gain associated with healthy sensor input optimized by genetic algorithm (GA).

Development of an embedded cellular system for monitoring and recording of distribution transformer parameters such as currents, temperature, height or drop in oil, vibration and humidity.

[15]. In the event of any deficiencies, the body sends certified messages to mobile phones as well as verification of units containing information about disability in some packets of information attached to a microcontroller.

In the literature, the design and implementation of a mobile license system were used to monitor the load currents, overvoltage, voltage oil and oil temperature. [26]. The on-line monitoring system integrates Global Service Mobile (GSM) Modem, with single chip microcontroller and sensors. Unusual information about operational parameters has been sent to the mobile device via the GSM network.

CHAPTER 3 DEVELOPING AN IOT BASED TRANSFORMER'S HEALTH MONITORING SYSTEM

3.1 Methodology

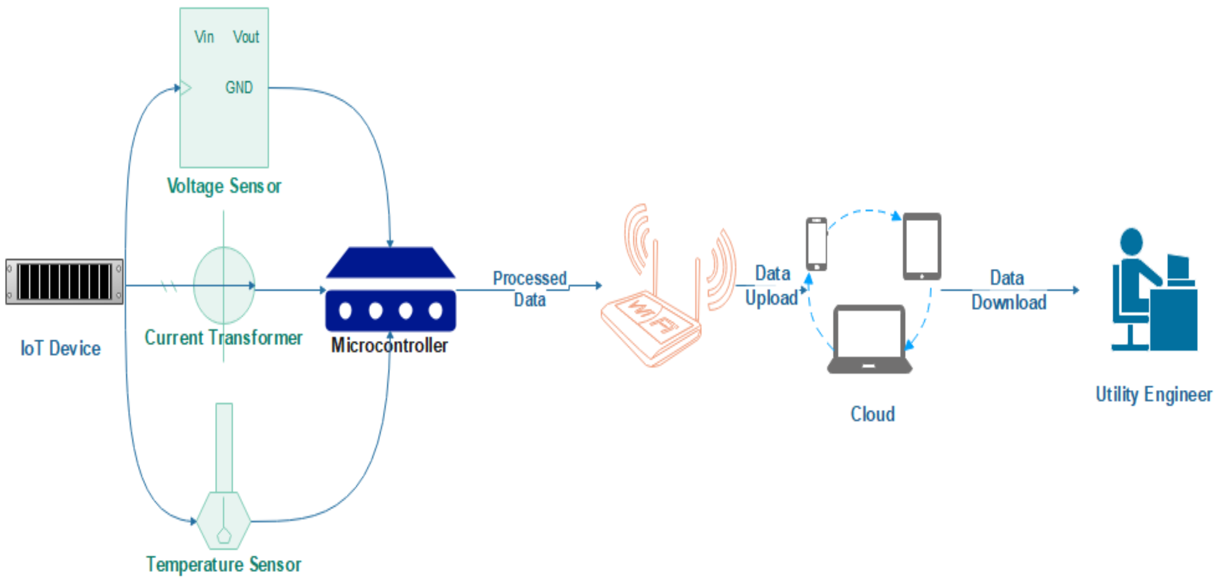

Figure 10 Proposed System

Main efficacy of this system is to monitor and predict health status of a distribution transformer by estimating health index levels as per data given in Table 3.

3.1.1 Cloud Server

In this system, ThingSpeak platform is used for data analytics and processing. ThingSpeak retrieve data from things in the form of small messages through HTTP protocol over Internet. ThingSpeak provide an instant visualization of data uploaded, location tracking and a link with social network. ThingSpeak also provides a MATLAB tool for data processing either over cloud or in our all-in one data server. Proposed system sends data to ThingSpeak at a rate of 3000 bytes per 15 seconds.

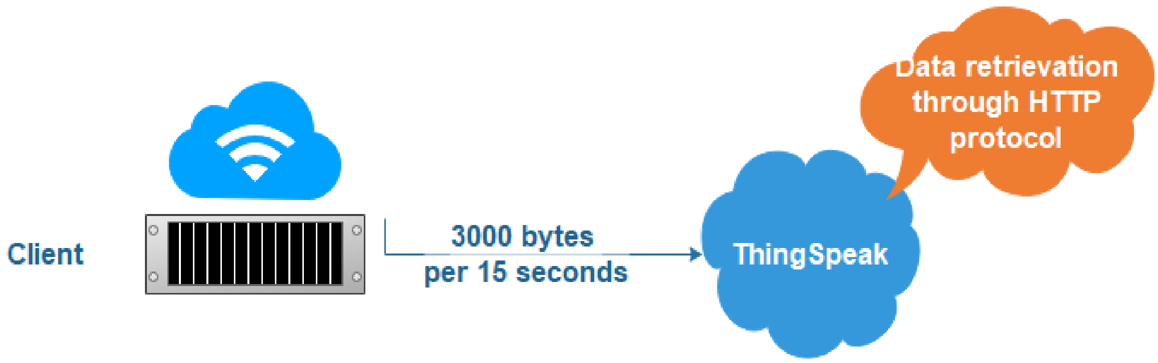

Figure 11 ThingSpeak cloud server

3.2 Workflow of the proposed system

Workflow of system is completed in following steps:

a) Collect sensor based data
b) Deploy data to cloud and data visualization
c) Develop health index algorithm

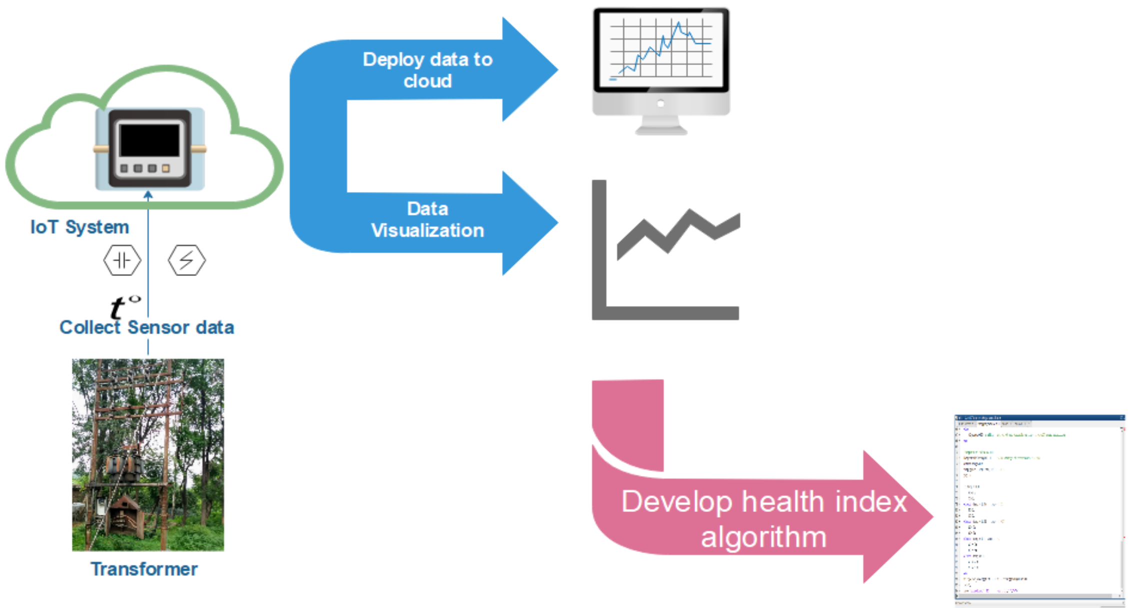

Figure 12 workflow of system

a) Collect sensor based data

System begins by collecting transformer data using different sensors. Client system is written in C- sharp and uses open-source ThingSpeak communication libraries for embedded devices.

b) Deploy data to cloud

Sensor based data is deployed to cloud and is visualized accordingly. Figure 13 displays data uploaded to ThingSpeak server.

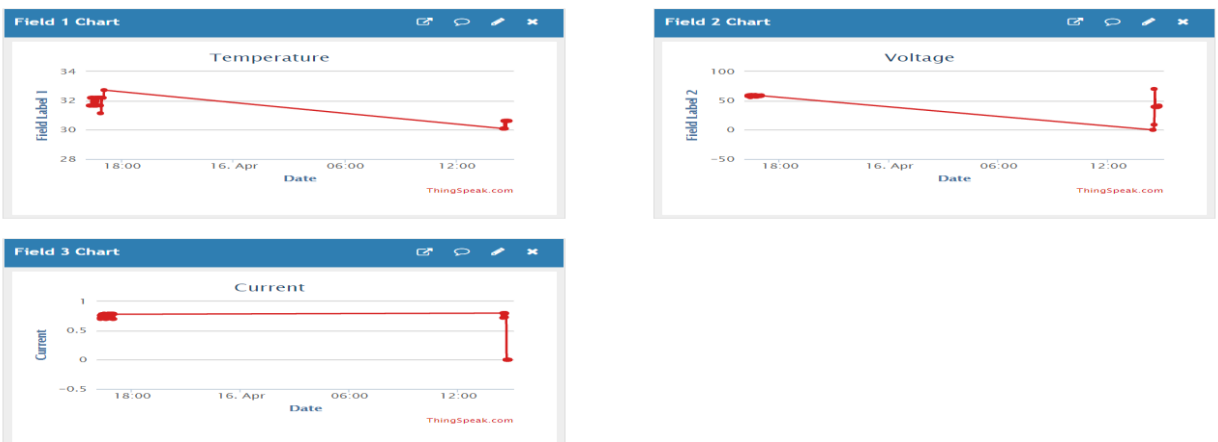

Figure 13 Displays 1-phase data

c) Develop health index algorithm

Algorithm for health index calculations is developed using MATLAB code. MATLAB code shown below is a timer function at a fixed rate with a period of 60 seconds.

```
a=timer
set(a,'ExecutionMode')
set(a,'ExecutionMode',fixedRate) %% use get(a) to diplay
defined properties in execution mode
set(a,'Period',60);  %repeat after an interval of 60 sec
set(a,'TimerFcn','thingspeak_dataRead')
start(a);
save
```

While code shown below is for health index calculations using ThingSpeak server based data. Here, used is a MATLAB code to read data from ThingSpeak using the *thingSpeakRead* function.

```
clear all
b=thingSpeakRead(753320,'Fields',[1,2,3],'NumMinute',100,'OutputFormat','table');   %   read
last 5 minutes value from field 1 into the table;

tic;    % starts a stopwatch for code

i=1;
j=1;
k=1;

load index1.mat

V_abase= 15;
bAvg1=table2array(b(:,3));
bAvg=mean(bAvg1,1);
bVphaseA= V_abase-bAvg;
V_a=(bVphaseA)/V_abase;

I_abase=2;
bAvg3=table2array(b(:,4));
bAvg2=mean(bAvg3,1);
I_a= sqrt((I_abase-bAvg2).^2);

S_max=5;
if V_a <0.88 || V_a >1.12
S1=1;
W1=4;
elseif (V_a >=0.88 && V_a <=0.9) || (V_a >=1.1 && V_a <=1.12)
S1=2;
W1=4;
elseif (V_a >=0.9 && V_a <=0.92) || (V_a >=1.08 && V_a <=1.1)
```

Overall system design

Overall system's design is split into two parts:

1) Hardware design and implementation
2) Software coding

3.3 Hardware design and implementation

Hardware components used in implementation are following:

a) Current Transformer
b) Rectifier based voltage sensor
c) Temperature sensor
d) ADC
e) Ethernet shield
f) Internet connection

a) Current Transformer

Current transformer of ct ratio 50A/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.

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

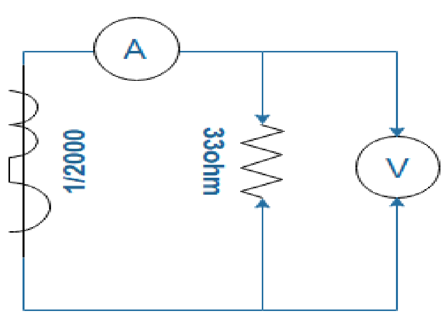

Figure 14 CT Circuit

b) Rectifier based voltage sensor

Voltage variation of ±6 % is allowed for distribution transformer. As change in flux induce proportional voltage so over voltage cause increase iron losses. Figure shown below is the circuit diagram of rectifier based voltage sensor.

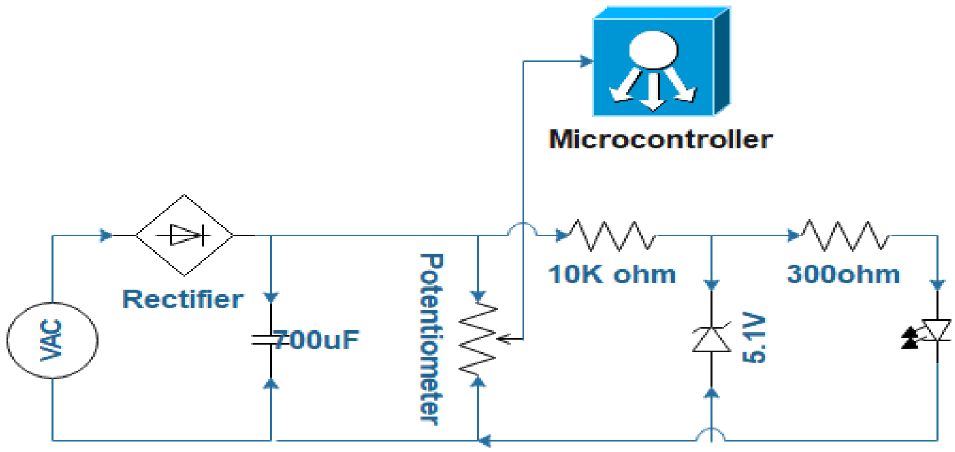

Figure 15 Voltage Sensor

Above circuit uses a filter circuit of *700uF*. Here, series resistor of $5K\ ohm\ 20W$ is connected to zener diode which is further connected to LEDs to discharge capacitors during voltage fall.

c) Temperature sensor

Winding temperature indicates the hottest portion in transformer winding. Winding temperature decides the loading capability of transformer. Winding temperature sensors are fixed in the transformer which are helpful in assessing transformer's life. Here, temperature sensor used is LM35, as its temperature range is between $-55°C\ to\ 150°C$ and as per literature [4], winding temperature can rise above 60°C.

d) Analog to digital converter (ADC)

In order to convert sensor based analog data to digital format, ADC used is ATMEGA 2560 based arduino mega with *16MHZ* clock speed, *128KB* flash memory and *8KB* sram.

e) Ethernet Shield and Internet Data card

Here, arduino based Ethernet shield is used which is connected to a wifi router plugged in with a 3G based data card.

Overall Circuit Diagram

Figure shown below is overall circuit diagram for 3φ system of distribution transformer.

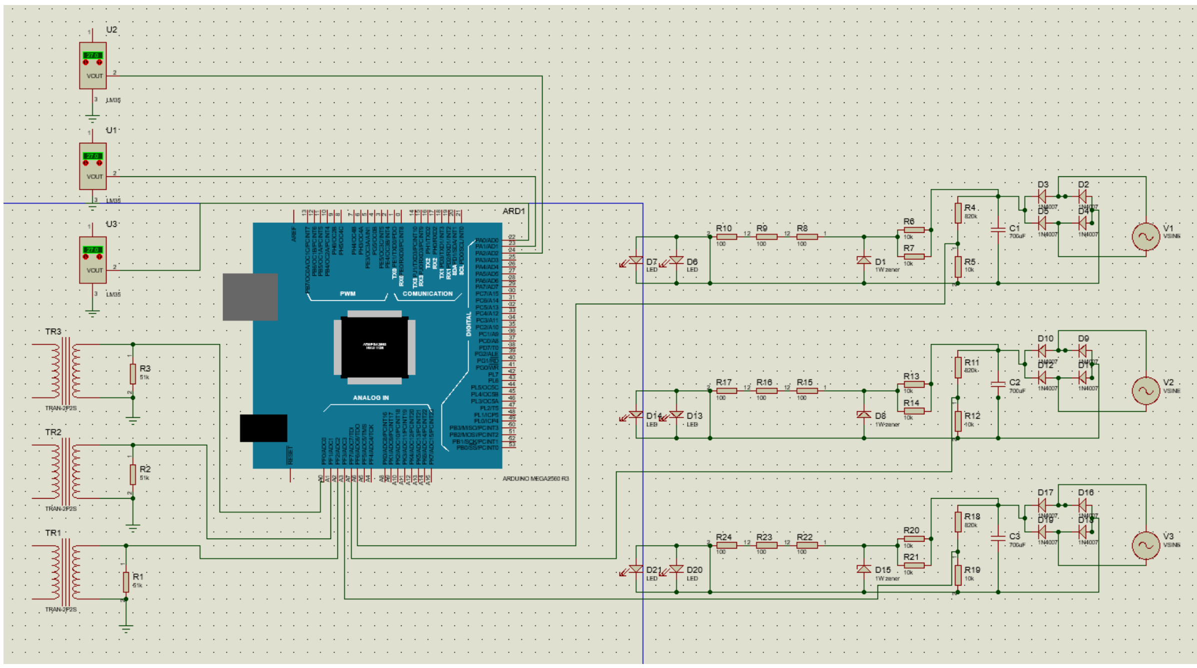

Figure 16 Overall Circuit Diagram

Hardware configuration and testing

Atmega 2560 based Arduino mega is configured to gather readings from all sensors and upload them to web server using Ethernet based internet connection. Microcontroller take readings and upload them at a regular interval of 15 seconds. Here, resistive load is used as a load to transformer.

3.3 Software coding

Software coding is divided into two parts:

a) Arduino Mega

Microcontroller's coding is done on arduino IDE. IDE Driver is a program running on the computer that allows to draw a sketch in microcontroller. Arduino relies on C-language of programming.

b) MATLAB software

MATLAB software used at server side, and as per algorithm designed, it processes data every 15 minutes taken from web server which calculates health index of transformer.

3.4 All-in one server algorithm

Algorithm flow chart of all-in one server is given below in figure 15.

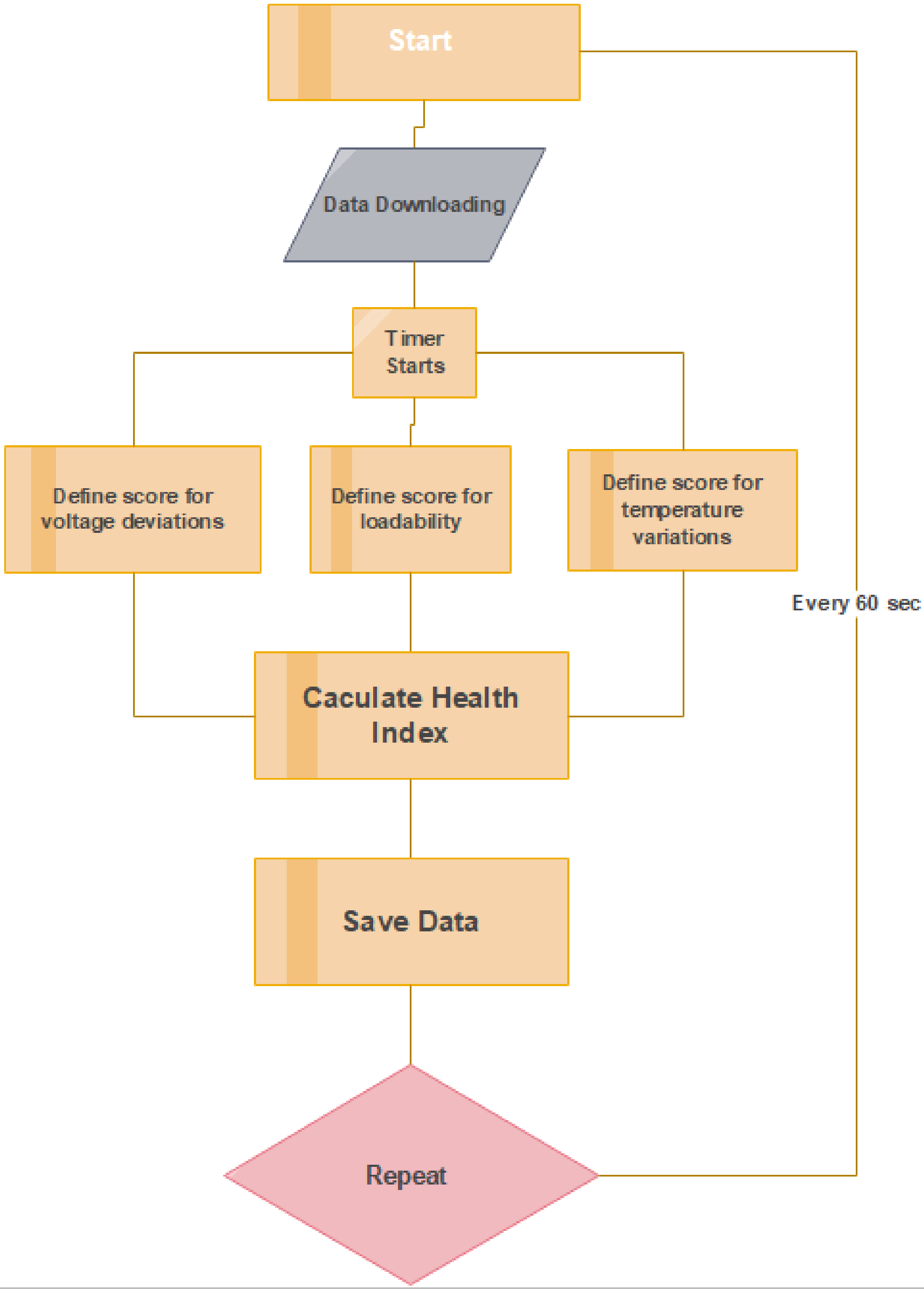

Figure 17 All-in one server algorithm

3.5 System flow diagram

Complete methodology is given in section 4.1.

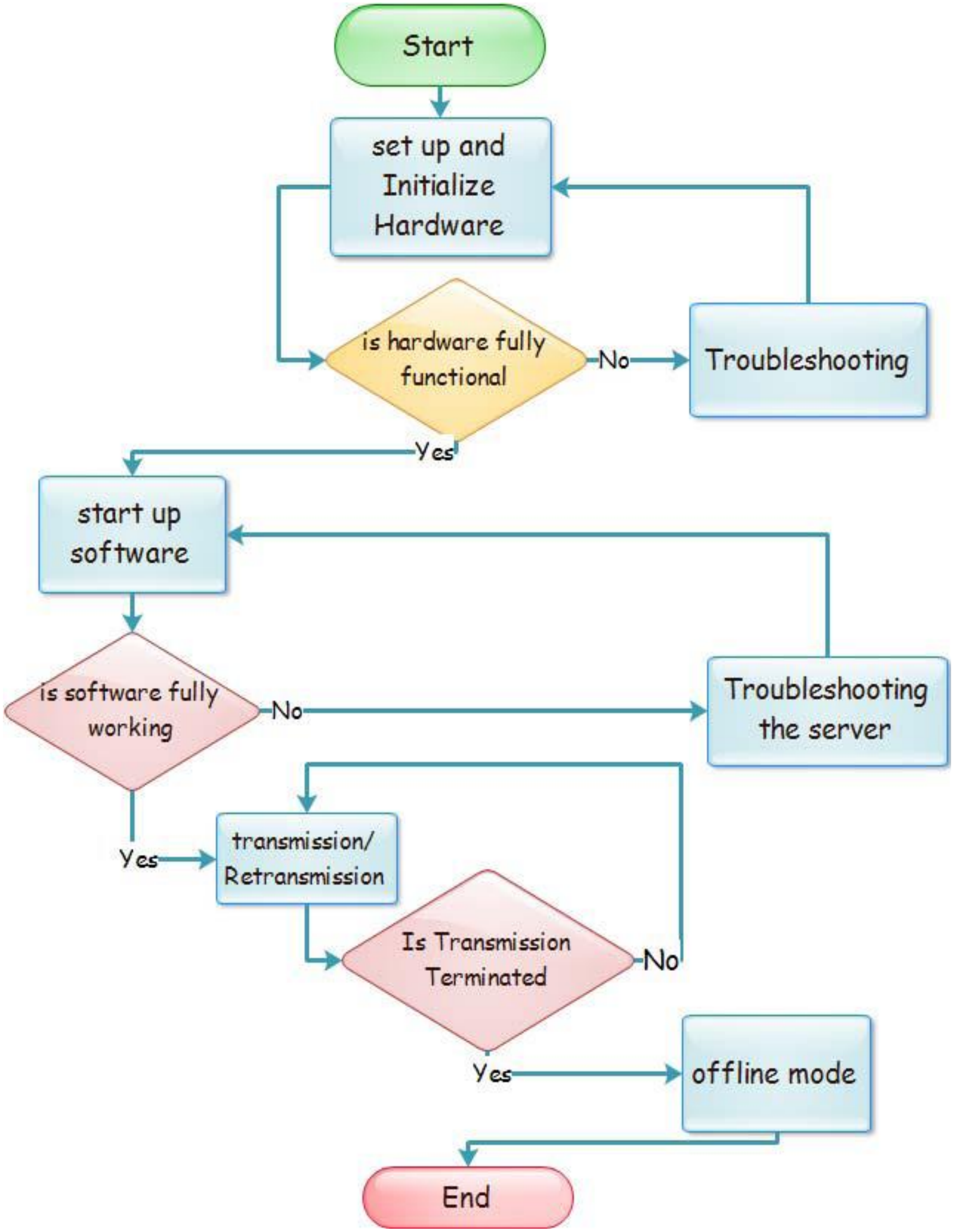

Figure 18 Overall process is shown in flow diagram

3.6 Improvements from Current Technology

Current GPRS based technology use microprocessors at every transformer unit to process whole data processing such as health index calculations, sensor parameter measurement etc., and then send alert messages to operator in-charge as discussed in Section 1.4 and shown in Figure 15.

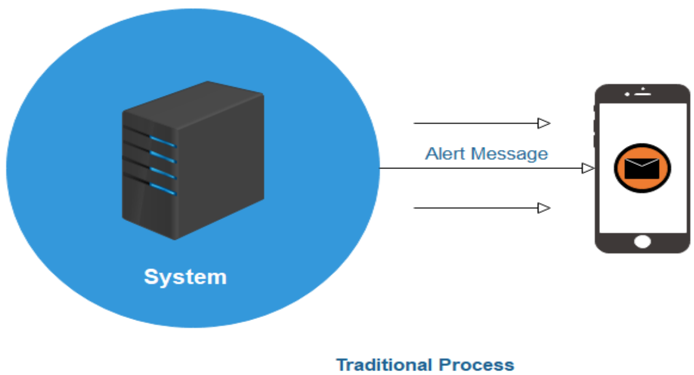

Figure 19 Traditional Process

As shown in figure 16, proposed IoT based system involves completely different processing scenario. An intermediate cloud based data processing is introduced which stores data from all tiny clients installed at different transformers. Thus, bypassed the need of expensive microcontrollers at all clients. Even, an all-in one ground based processing server is introduced which process cloud data for health index calculations. With introduction of this all-in one server, health index is not only processed in single unit but also has a possibility to process future data in new algorithm with no additional labor cost.

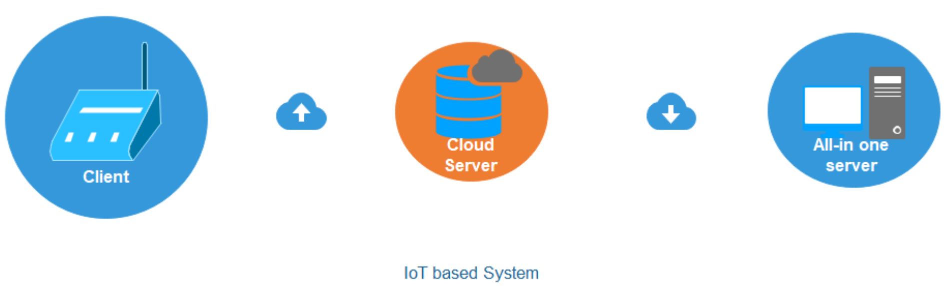

Figure 20 IoT System

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Hardware Setup

Figure 21 shown below is hardware setup for IoT based system, which includes whole circuitry, Internet modem fitted with 3G modem and Microcontroller.

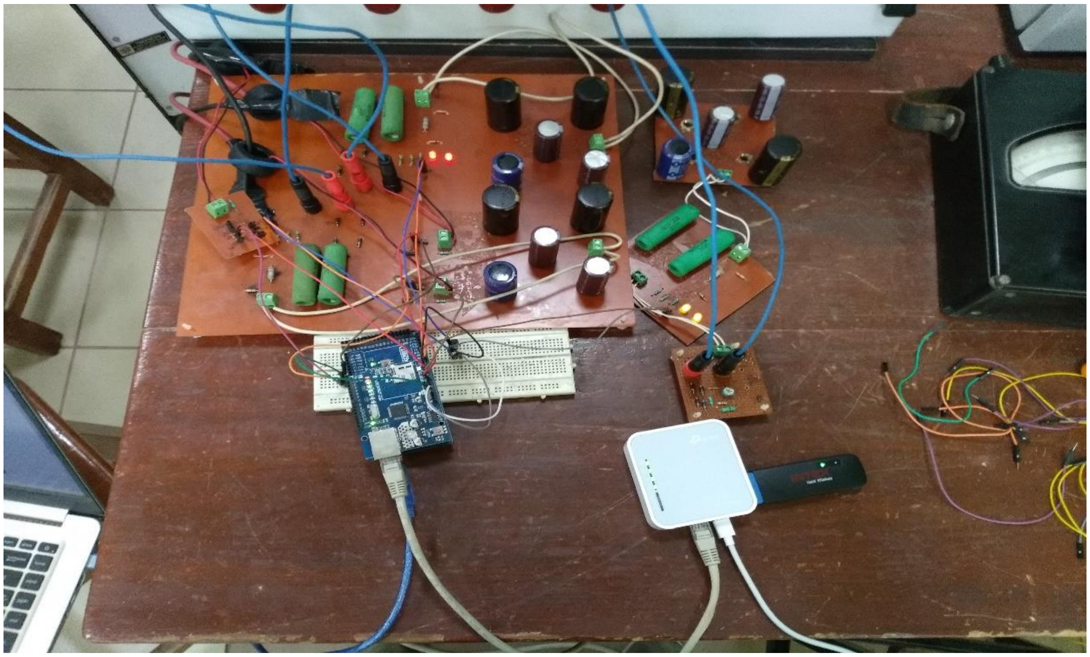

Figure 21 Hardware Setup

4.2 Testing and Results

Online parameters of 1Ø- transformer are given as shown in figure 22, field chart 1 displays temperature variations, field 2 display voltage variations while field 3 displays current variations.

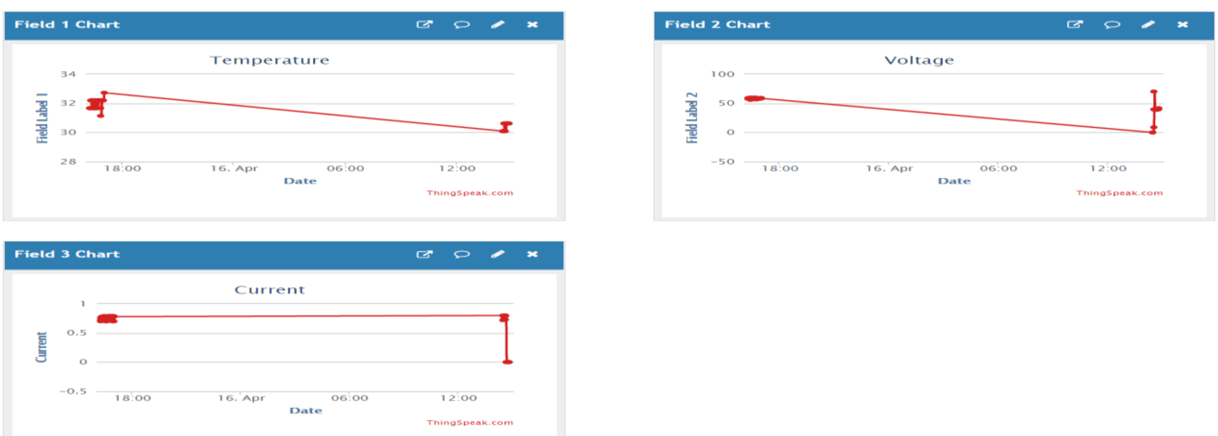

Figure 22 1-phase Transformer's online Parameters

Figure 23, shown below represents all measured parameters uploaded by client into cloud server, while figure 24 displays health index calculated by all-in one server which is 20%.

1 Voltage	2 Current	3 Temp
56	0.6000	34
55	0.6200	35
57	0.6100	35.4000
56	0.6300	37
57	0.6400	36
58	0.6500	36.7000
56	0.6000	34
55	0.6200	35
57	0.6100	35.4000
56	0.6300	37
57	0.6400	36
58	0.6500	36.7000

Figure 23 Parameters Measured

1	2	3
0.2000	0.2000	0.2000

Figure 24 Health index calculated

Health Index Categorization

Health index calculated above is categorized on the basis of limits shown in figure 6. As, health index calculated above, as shown in figure 24 is 20% so as per categorization, our system is at an any time of failure state.

Table 6. Health index categorization

HI%	Health State	Requirement
85-100	Good	Normal maintenance
65-80	Fair	Increase periodic maintenance
50-65	Poor	Replacement required
0-50	very poor	Risk of any time failure

4.3 Discussion

Above, IoT system is an improved and advanced version of GSM technology based system, where, no third party cloud as well as all-in one server was introduced. And, thus has very little or no scope of algorithm updation and also is an expensive technology. While, our introduced system has overruled all these limitations and has also introduced a new scope of time to time algorithm updation feature with no additional cost.

CHAPTER 5 APPLICATION AND FUTURE SCOPE

5.1 Application

Substations under distribution companies are large in number and so do the distribution transformers, even they are at different geographical areas, thus system introduced can be used in monitoring all distribution transformers of an area under a substation autonomously.

Distribution companies usually have large number of substations. These substations are situated at remote areas from urban headquarters of utilities. Moreover, these substations are situated at geographically dispersed locations.

5.2 Future Scope

1) This system finds a big scope in transmission lines by using other communication protocols like Laura, rf 434 MHz etc.
2) Using genetic algorithm in determining best sensor readings or faulty sensor readings can be helpful in calculating accurate health index during faulty sensor situations.
3) This system can be expanded to big campuses or societies with many acute substations which can be operated and monitored remotely.
4) This system can help in reducing post-fault clearing time in distribution network.
5) This system can be expanded to 3-phase transformer, which will display more accurate health indices.

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