Remote Condition Monitoring System for Distribution Transformer

Avinash Nelson A
M Tech student
Dept of Elect Engg, VNIT
Nagpur, India
nelsonmace@gmail.com

Gajanan C Jaiswal
Dy. Executive Engineer
MSEDCL
Nagpur, India
jaiswalgajanan1970@gmail.com

Makarand S Ballal
Associate Professor
Dept of Elect Engg, VNIT
Nagpur, India
makarandballal@yahoo.com

D. R Tutakne
Associate Professor
Dept of Elect Engg, RCOE
Nagpur, India
dhananjaydrt@rediffmail.com

***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. A remote condition monitoring system for distribution transformer is discussed here. Different parameters are acquired and processed in remote terminal unit. This communicates the data to the operator end using internet. According to parameter values, health index of a transformer is found out at the operator end interface. Analysis is based on health index. This system is different from power transformer condition monitoring systems in condition monitoring techniques used and communication. A cheaper system is designed which precisely evaluates the health status of a transformer. The test results are taken from a specially designed transformer.**

This article explains the system architecture and method of analysis used in the first sections. Then test results on a distribution transformer is discussed.

Keywords—Distribution transformer, condition monitoring, health index, human machine interface

I. INTRODUCTION

In this ever increasing need for quality power supply through the deployment of monitoring, protection and control strategies all over the power system network as part of smart grid is becoming so relevant. Distribution transformer is an integral part of distribution network. In Indian perspective, power system network is visible and controlled only up to this extent. Transformers have an average life of 20- 25 years. Most of the transformers installed are in the verge of their operational life. The current monitoring methods are only associated with electrical parameters which gives no clue about the internal condition of the distribution transformer [1]. Periodical maintenance is not enough for such a major asset in power system. Condition based maintenance will be effective only when an online monitoring system is present so that equipment condition will be known remotely and maintenance scheduling as well as control can be achieved in real time as evident from [2].

The way a doctor analyses the different symptoms in a human being to understand the disease and suggest cure, same way condition monitoring techniques make use of different internal as well as external parameters associated with a transformer and predicts its operational status and according to which a proper decision can be made. Decision can be to do maintenance or replace with a new one according to severity which is very important aspect in asset management [3].

Condition monitoring techniques are categorized as conventional and non-conventional techniques in [4]. Most of these techniques are made online and used for power transformer condition monitoring. Proposed online methods are given in [5-8]. These techniques are based on Dissolved Gas Analysis (DGA), Furan analysis, Frequency Response Analysis (FRA) etc. and are only applicable for power transformer when seen in economical perspective. Distribution transformer condition monitoring system should be developed by considering economic aspects also. Condition monitoring techniques are reviewed in a wider perspective in [9-12]. Those cannot be directly implemented in distribution transformers. A monitoring system for distribution transformer which is in use is described in [13]. But this is used for monitoring the loading on a transformer. In India, different utilities are monitoring their transformer end energy meter for energy billing and monitoring electrical failures.

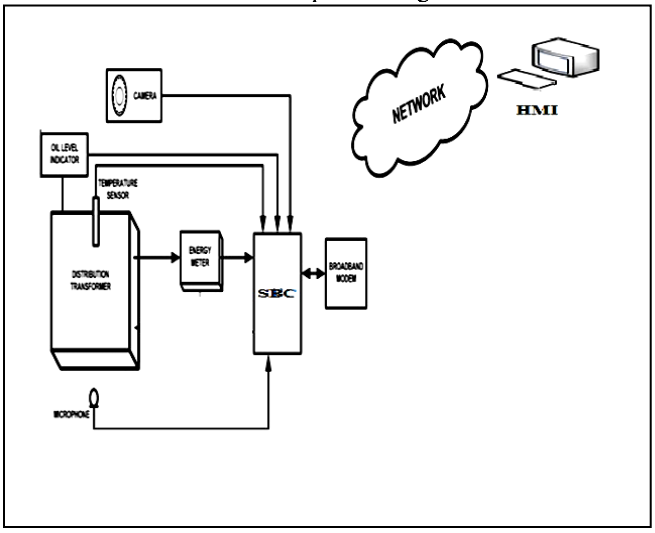
This system is not at all relevant in condition monitoring of transformer. For understanding the health status of transformer, a system which takes into account electrical as well as other mechanical parameters is needed. Here, a novel Remote Condition Monitoring System (RCMS) for distribution transformer is presented. Condition monitoring systems are in use for power transformers only. This novel method provides a condition monitoring system for distribution transformers. Technique is devised considering the economic aspects also. Health status of a distribution transformer is evaluated using Health Index (HI). The analysis is made easier by integrating MATLAB to the operator end application. The approach here is meant to make the distribution transformer's internal condition visible to the utility.

II. SYSTEM ARCHITECTURE

The developed model is described as data acquisition, processing, communication and Human Machine Interface (HMI). The different parameters are made available for monitoring using data acquisition system using sensors and signal conditioning systems. The digital values are then transferred to the HMI after processing using communication

978-1-4799-5141-3/14/$31.00 ©2014 IEEE

through internet. HMI consists of a windows application to monitor and analyze the health status of distribution transformer. Detailed description is given in this section.



Functional block diagram is shown in Fig. 1.

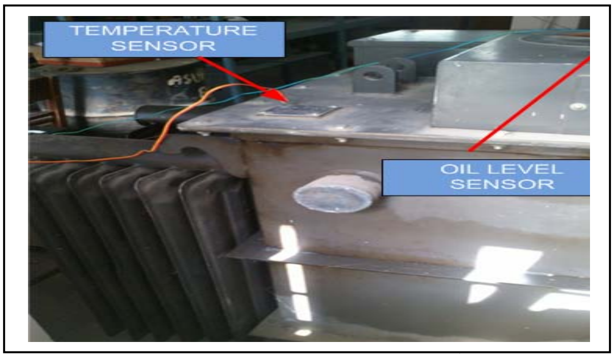
Fig. 1. Functional block diagram of RCMS

A. Data Acquisition System

Temperature, oil level, transformer loading, humming sound are the monitored parameters. There are other important parameters and techniques related to insulation degradation which are used in power transformers like DGA which are not considered here due to economic concerns. The model is designed so that it is economical for distribution transformer according to asset management principles [12].

1) Temperature

Top oil temperature of distribution transformer is monitored using an LM35 thermistor type temperature sensor. Numerous sensors can be placed inside transformer tank for better analysis. The presented experimental system is using single sensor. The analog output of sensor is fed to Analog to Digital Converter (ADC) of a PIC16F877A microcontroller. ADC converts the signal into digital value and transfers the data to the processing system. LM35 is a precision type integrated circuit based sensor so that calibration and interfacing with other devices is easier. It gives 1◦C accuracy



over its operating range of temperature. Some modifications

Fig. 2. Thermal and oil level sensor insertion

are made in this sensor arrangement to keep it in oil bath. Fig. 2 shows the temperature and oil level insertion to the transformer.

2) Oil level

Oil level is measured using a float based sensor. The float moves up and down in transformer tank with changes in oil level. Accordingly, the output analog voltage changes which is measured and interfaced similar to temperature using ADC of microcontroller. The float handle can be modified according to tank size of transformer. Oil level sensor can be fitted in transformer tank or reservoir.

3) Transformer loading

All electrical parameters including loading is monitored using an energy meter. Most of the energy meters are available with RS232 communication port. Energy meter memory data is read continuously using this communication port. Voltages, currents, power factor etc. are monitored which gives a loading profile of transformer.

4) Humming noise

Humming noise is monitored using a microphone attached to the transformer tank. Processing system can directly access the audio data. Hence interfacing is not required. The sound is recorded for 8 seconds in processing system and sent to the HMI. It is recorded in '.wav' format so that data size is less compared to other formats. Processing unit is available with a microphone socket and signal conditioning systems inbuilt in it. This makes the integration easier.

B. Processing System

It consists of an SBC friendly ARM Mini2440 which is shown in Fig. 4. SBC stands for Single Board Computer. These are having all features of a computer in processing level. This ARM based controller is programmed using Visual Studio.NET IDE v2008. It is programmed in C# language to read all parameters mentioned in data acquisition system. Then it communicates this data to the remote operator end through internet using TCP/IP protocol. There will be a specific IP address for each device with which it is identified in the network. Unlike other embedded systems, communication interfacing is easier since SBC runs on Windows CE operating system. Except humming noise, all other parameters are interfaced with serial port using RS232 protocol. This is provided with an auxiliary power supply to operate under power failure.

C. Communication

Public network is used for communication. A separate communication channel cannot be used for this system since distribution transformers are wide spread all over the distribution network. TCP/ IP protocol is used where each remote terminal unit will be identified by their unique IP address. In real time installation, broadband wireless modems can be used. Data transfer rates will depend on network traffic. But it will not harm the performance since data size is also less. This system provides access of information as well as analysis from any remote place using internet. When incorporated in a number of distribution transformers, the transformer can be distinguished by IP address and analysis can be carried out at single or multiple operating ends.

Different communication techniques were considered for this system. A public network use avoids the limitations of distance. Wi-Fi and ZigBee networks can only be used for short ranges. But public telephone lines and mobile network is available even in rural areas.

D. Human Machine Interface (HMI)

This is a Windows form application developed in Visual Studio.NET IDE v.2012. It displays all the parameter values and the algorithm for HI will run simultaneously to show instantaneous health status of transformer. HMI integrates MATLAB and Visual Studio together. Algorithm for HI is written in MATLAB script file. Its result will be shown in application window as shown in Fig. 3.

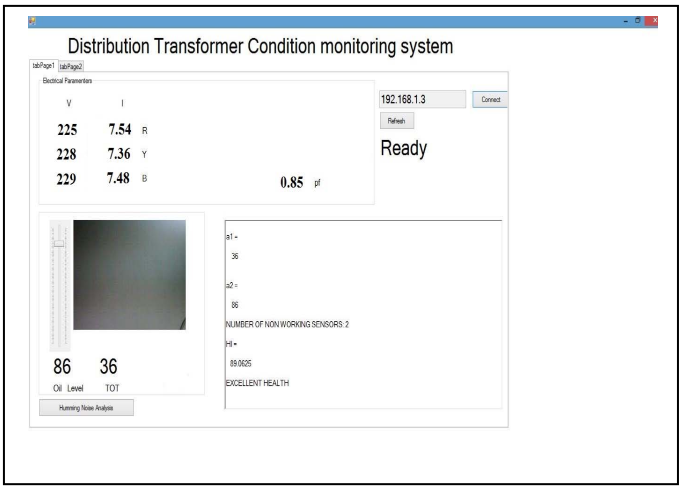


Fig. 3. Application window 1

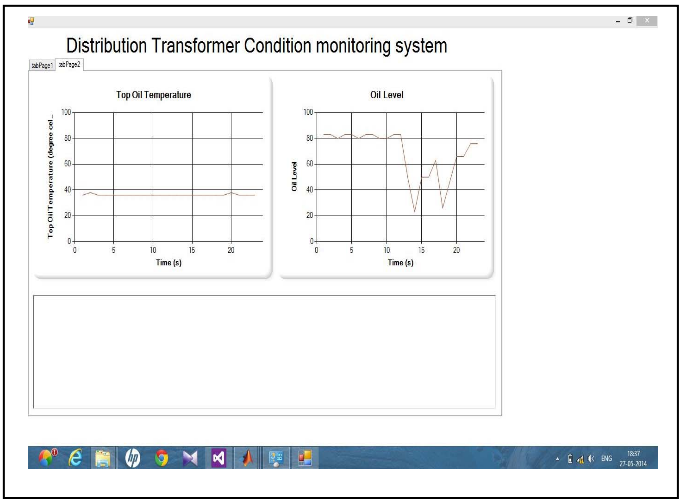


Fig. 4. Application window 2

In another tab of the application, detailed analysis can be done as shown in Fig. 4. Here, temperature as well as oil level are plotted online and humming noise analysis also can be done. The whole analysis tools of MATLAB can be exploited for analysis which makes this HMI a powerful application for condition monitoring. Apart from this, option for report generation is also given.

III. METHODS OF ANALYSIS

After getting the parameters at the remote end, an algorithm is used to predict the health status of transformer. This is based on health index calculation already in use for power transformers as described in [13]. Humming noise is used for HI calculation and a detailed analysis using frequency spectrum is performed.

A. Health Index (HI)

The HI represents a practical tool that combines the results of operating observations, field inspections, and site and laboratory testing into an objective and quantitative index, providing the overall health of the asset. Asset HI is a powerful tool for managing assets and identifying investment needs as well as prioritizing investments in capital and maintenance programs [14], [15]. Priority for different parameters considered in this system is in accordance with the literature given for power transformers.

Four parameters are monitored and has been taken for analysis. Number of parameters available at the user end is checked each time. HI calculation accuracy depends on available parameters [16]. Among these four parameters, which are temperature, oil level, loading and humming noise can be directly used. Nameplate details and test results of a DT gives the rated values as well as allowable maximum limits of these parameters. With respect to its rated values, all parameters are normalized.

The value of each parameter is used to calculate the Health Index Factor (*HIF*) which varies from 0 to 4. Zero corresponds to the most severe condition and 4 corresponds to healthy state. Range of parameters for making this discretion have to be made after testing.

Each parameter is given weightage according to their effect on overall HI. This value varies from 10 to 1 in this algorithm.

Then the following equation is used to calculate HI of DT

$$HI = \frac{\sum_{j=1}^{n} K_j HIF_j}{\sum_{j=1}^{n} 4K_j} \times 100 \quad (1)$$

.

Where,

K_j weightage of i[th] parameter

HIF_j health index factor of i[th] parameter

According to the value of HI, health status is predicted. It is shown in Table. I.

TABLE I. HEALTH STATUS CATEGORIES

Health Index (%)	Health status
100<HI<80	Excellent

Health Index (%)	Health status
80<HI<70	Good
70<HI<60	Alarm state
60<HI<50	Maintenance is required
HI<50	Poor

TABLE II. TRANSFORMER RAITNG

kVA rating	16kVA
Primary voltage	440V
Secondary voltage	400V
Full load current	23A
Winding connection	Dy11

This system is tested on a specially designed transformer whose ratings are given in Table. II.

IV. TEST RESULTS

The results are discussed in two sections. First, health index based test results are given. Then a detailed analysis on humming noise is explained.

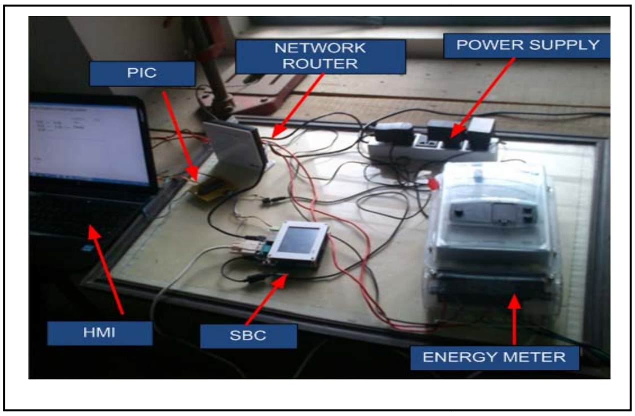


Fig. 5. Experimental set up

Different conditions were applied over distribution transformer for getting the health index variations. All four parameters are changed to imitate real time operation. The results are shown in Table. III. Temperature variation is in accordance with the loading variations. Oil level is varied using a drain valve on the tank of transformer. Humming noise is changed by loosening the bolts of the core.

HI decrease as loading and thereby temperature increases in a normal operating system. When there is oil leakage in a transformer, there is a cumulative increase in temperature which again makes the condition more severe. Transformer oil level decrease causes the humming noise to increase. When oil level decrease to an extend of core level or below, temperature increase is very high and in real distribution transformer operation this causes core deformation and bushing connector overheating. Usually, bushing connector will get burnt in this case.

HI estimation and health status prediction makes it possible to avoid transformer replacement and enables condition based maintenance. Such a maintenance practice is a need for asset management in the current scenario. MATLAB can be used to estimate the hot spot temperature and life expectancy of transformer according to therrmal model based on IEEE standards [17]. The environment provided by MATLAB and Visual Studio is equivalent to a LabView platform for monitoring. But this application is specific for transformer condition monitoring.

Humming noise analysis is also done for two conditions as shown in Fig. 6,7. Humming noise for a transformer under normal condition is lesser for noise frequency components. Whenever core vibrations are more, magnitude of corresponding frequency components increases. In test set up, this is made possible by loosening the bolts of the core. This happends in real time due to different mechanical effects

TABLE III. TEST RESULTS

Case	Temperature	Oil level (%)	Loading (%)	Hummin g noise	Health status
1	Low	95	70	Low	Good
2	High	95	110	High	Alarm state
3	Low	90	70	Low	Good
4	Medium	70	70	Medium	Alarm state
5	High	70	100	High	Poor

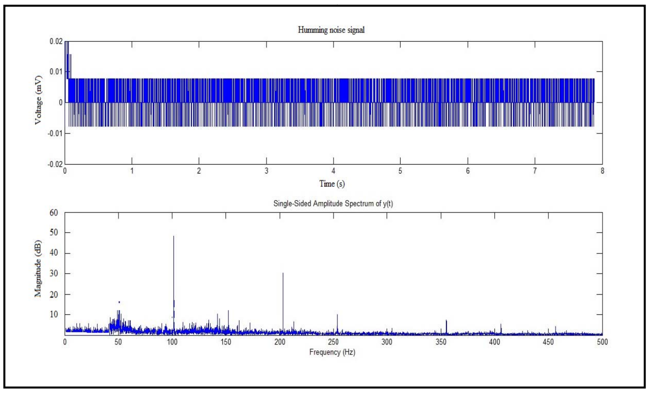


Fig. 6. Humming noise under abnormal condition of core

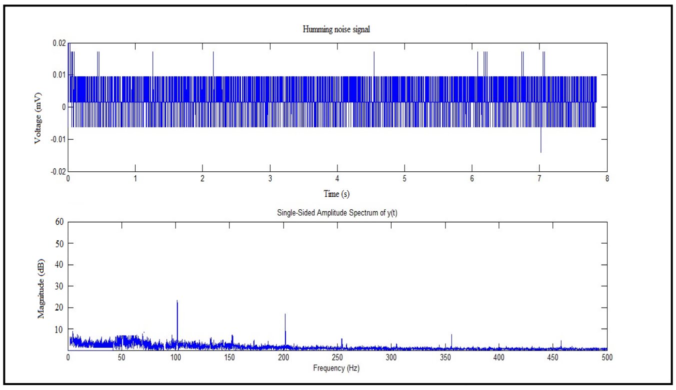


Fig. 7. Humming noise under normal condition of core

The analysis can be extended to different types of mechnaical as well as electrical faults. Whenever there are some unbalances in the mechanical forces, significant changes will be there in humming noise frequency spectrum.

V. CONCLUSION

A condition monitoring system is an important tool for asset management. RCMS described here is different from power transformer condition monitoring systems. This system serves the purpose of predicting the health status of a distribution transformer precisely. Health index of a distribution transformer is calculated using algorithm and those test results are found to be satisfactory. RCMS can be incorporated in the distribution network for efficient control and monitoring. Condition based maintenance will become relevant only under such an online monitoring system. RCMS implementation in distribution network can reduce failure and ageing rate of distribution transformers.

REFERENCES

[1] A.J.Vandermaar, K.D. Srivastava, M. Wang, “Review of Condition Assessment of Power Transformers in Service”, IEEE Electrical Insulation Magazine November/December 2002. Vol. 18, No. 6, pages: 12-25

[2] Y. Han, Y. H. Song, “Condition Monitoring Techniques for Electrical Equipment—A Literature Survey”, IEEE Transactions on Power Delivery, vol. 18, no. 1, January 2003, pages: 4-13

[3] Poza, F. , Marino, P. Otero, S. Machado, “Programmable electronic instrument for condition monitoring of in-service power transformers”, IEEE Transactions on Instrumentation and Measurement, Volume: 55 , Issue: 2, April 2006, pp: 625 – 634

[4] Chatterjee, B., Dey, D., Chakravorti, S. , “Implementation of an Integrated, Portable Transformer Condition Monitoring Instrument in the Classroom and On-Site”, IEEE Transactions on Education Aug. 2010, Volume: 53, Issue: 3, pp: 484 – 489

[5] Weranga, K.S.K., Chandima, D.P., Kumarawadu, S.P, Smart metering for next generation energy efficiency & conservation , Innovative Smart Grid Technologies - Asia (ISGT Asia), April 2012 IEEE, pp: 1 – 8

[6] Pylvanainen J.K., Nousiainen K., Verho P., Studies to Utilize Loading Guides and ANN for Oil-Immersed Distribution Transformer Condition Monitoring, IEEE Transactions on Power Delivery Jan. 2007, Volume: 22 , Issue: 1, pp: 201 – 207

[7] Russell B.D., Benner C.L., Intelligent Systems for Improved Reliability and Failure Diagnosis in Distribution Systems, IEEE Transactions on Smart Grid June 2010, Volume: 1, Issue: 1, pp: 48 – 56

[8] Swift, G., Molinski, T.S., Lehn, W. , A fundamental approach to transformer thermal modeling. I. Theory and equivalent circuit, IEEE Transactions on Power Delivery Apr 2001, Volume: 16, Issue: 2, pp: 171 – 175

[9] Swift, G., Molinski, T.S., Bray, R., Menzies, R. , A fundamental approach to transformer thermal modeling. II. Field verification, IEEE Transactions on Power Delivery Apr 2001, Volume: 16, Issue: 2, pp: 176 – 180

[10] Lopez-Fernandez X.M, Penabad-Duran P, Turowski J, Three-Dimensional Methodology for the Overheating Hazard Assessment on Transformer Covers, IEEE Transactions on Industry Applications Sept.-Oct. 2012, Volume: 48, Issue: 5, pp: 1549 – 1555

[11] Nordman, H. , Rafsback, N. , Susa, D. , Temperature responses to step changes in the load current of power transformers, , IEEE Transactions on Power Delivery Oct. 2003, Volume:18, Issue: 4, pp: 1110 – 1117

[12] Susa, D. , Lehtonen, M. , Nordman, H. , Dynamic thermal modeling of distribution transformers, IEEE Transactions on Power Delivery July 2005, Volume: 20, Issue: 3, pp: 1919 – 1929

[13] Radakovic, Z. , Feser, K. , A new method for the calculation of the hot-spot temperature in power transformers with ONAN cooling, Power Engineering Society General Meeting, 2003, IEEE Volume: 4, July 2003

[14] Jahromi A, Piercy R, Cress S, Service J,” An Approach To Power Transformer Asset Management Using Health Index”, IEEE Electrical Insulation Magazine, April 2009, Volume:25, Issue: 2, pp: 20-34.

[15] Dominelli N, “Equipment health rating of power transformers”, IEEE International Symposium on Electrical Insulation, 19-22 Sept. 2004, pp: 163 – 168.

[16] Abu-Elanien, Salama, Ibrahim M, “Determination of transformer health condition using artificial neural networks”, International symposium on Innovations in Intelligent Systems and Applications (INISTA), 15-18 June 2011, pp: 1 – 5.

[17] IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid-Filled Transformers, IEEE Std 1538-2000, IEEE Power & Energy Society.