Automated Real-Time Transformer Health Monitoring System Using Internet of Things (IoT)

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***Abstract*—The transformer is one of the most crucial components in a power system as its failure may result in significant interruptions to the power transmission line. The power system is prone to many disturbances such as voltage sags, swells and overvoltages. Thus, it is essential to continuously monitor the transformer's health to prevent possible damage due to overheating of the windings and insulations. The transformer health is monitored primarily by tracking the voltage, current, and temperature of the windings. However, in the existing model, an engineer must be on-site to observe the values of the parameters and act on the same. This is not feasible as there is enormous scope for human errors if the engineer is absent on-site. To overcome the flaws mentioned above, a system that uses Internet of Things (IoT) to send real-time data from the transformer to a data center, where the engineer can track the performance and health of the transformer, is proposed. If the engineer is required on-site in case of emergencies, the system still alerts the engineer using a GSM module via SMS. Further, automation is introduced to the transformer cooling mechanism, where the working capacity of the cooler is controlled by a feedback system supported by a microcontroller, hence reducing human dependence by a large margin. Results from experiments and simulations performed are analyzed to predict the performance of the automated IoT-based transformers and compare them with the existing model. The practical hurdles in implementing the proposed model are discussed.**

Keywords—Transformer health; current; voltage; winding temperature; Transformer oil; Internet of Things (IoT); Microcontrollers; GSM (GPRS) module; Automation.

I. INTRODUCTION

The distribution transformer is a vital element in any power transmission system. It steps down the high voltage and delivers power to the industries, houses and other domestic utilities. Hence, if a transformer’s health is not monitored with due importance, it can lead to many quandaries that may cost a lot of time and money. The transformer's health is affected by several factors involving the windings, insulation, core, and transformer oil. However, the most influential parameters that affect the health of a transformer are the voltage, current, and winding temperature of the transformer [1]. Thus, measuring these parameters could give a good analysis of the transformer’s health [2]. The operating conditions are generally determined by the loading of the transformer and the losses involved in the transmission line. This affects the transformer temperature, eventually disturbing the health of the transformer [4]. Since we cannot predict the transients and sudden disturbances (sag, swell or overvoltages) in a power system, we need to continuously monitor the transformer to obtain real-time data and warn the engineer if there is a need for intervention. Presently, monitoring is done by an engineer on-site. This is highly unreliable as the engineer may not always be available, and hence there is a possibility that major faults and surges go undetected [1]. Hence, there is a necessity to build a reliable monitoring system that detect faults quicker than the existing model, analyses real-time data concerning the transformer, and provides adequate reports to the data centre in time so that appropriate precautions are taken to prevent adversities. The lifetime of a transformer is dependent on its health. The healthier the transformer, the longer the transformer can be put into use [6].

This article aims at using Internet of Things to solve this problem. The analysed data is used to alert the engineer if the data is abnormal, and an automated feedback system will sense if the temperature of the transformer is high and accordingly increase the cooling mechanism's capacity. Overall, the IoT-based monitoring system helps identify problems before they occur, allowing us to arrange for methods to reduce the effects of the fault, thus improving the health and performance. This article also compares the proposed model with the existing model and compares the results to reach a reasonable conclusion.

II. GPRS TECHNOLOGY USED

GPRS stands for general packet radio service. The technology uses cellular networks to transfer data via packet-switching technology. The speed of GPRS ranges from 150-300 kbps. GPRS technology is used here to send and receive voice and data simultaneously. The GPRS is synonymous with the internet, offering mobility, reliability, and localization [7].

III. TRANSFORMER HEALTH PARAMETERS

A. *Transformer Voltage:*

The voltage of a transformer is prone to variations in a power system. Harmonics in the power system can cause disturbances to the transformer due to continuously varying voltage. The health of a transformer reduces with frequent swells, sags, and overvoltages.

B. *Transformer Current:*

The current of a transformer is instrumental in determining the losses present. High current can lead to increased losses in the transformer and a reduction in the transformer life and power quality of the power system.

C. Winding Temperature:

The temperature of the windings plays a major role in determining the lifetime of a transformer. An increase in winding temperature for a significantly long time can damage the windings and its insulation, causing the transformer even to fail.

D. Transformer oil level:

The oil of the transformer is used as an insulating material used in the safe functioning of a transformer. It is tested in regular intervals using various chemical tests to ensure that it is fit for use in the transformer. The temperature of the oil also gives a measure of the general health of the transformer and its performance.

IV. LITERATURE REVIEW

Mariprasath et al. [8] suggested a thermal imaging-based technique to monitor the temperature of a transformer. From the thermal images, the major hotspots are found out and are cooled accordingly using the cooling mechanism. However, this method can be expensive and sophisticated.

The authors in [9] and [12] suggested a GSM-based technique. GSM is independent of the distance between the data centre and the transformer; thus, it is more reliable during network interruptions and is also faster than conventional communication methods. Thus, it is fair to employ it in an IoT based system.

In the papers [2]-[3], sensors that track each parameter - voltage, current, and temperature and sends the data to the microcontroller, which sends the data to the data centre via the internet, were used. This system is highly reliable and effective. In [5] and [10], a localized mobile embedded prototype was proposed. This tracks the load current, transformer potential, transformer oil temperature, and levels and displays the parameters' values. The system also employs a GSM module and a microcontroller to carry out the data transfer and alert the engineer using an SMS.

Srivastava et al. [2] had simulated a laboratory model of the proposed IoT-based display system. Another laboratory model was proposed in [11], where an integrated GSM module was also used for data transfer, and the results were claimed to be promising.

Hasan et al. [13] had simulated the working of an IoT-based transformer and recorded the transformer life, comparing it against the present transformer model's lifetime, plotting the obtained results.

V. PROPOSED IOT-BASED MODEL

A. Block Diagram

The block diagram, which is to be used for invigilating the transformer, is represented by Fig. 1. We need to note that the design comprises of two major parts (i) the hardware and (ii) the software sections. The two are integrated to perform seamlessly, complementing each other.

B. Hardware

1) Voltage Sensor: A potential transformer is employed to serve as a voltage sensor. An analog voltage proportional and corresponding to the transformer voltage is recorded and sent to the ADC and then to the microcontroller.

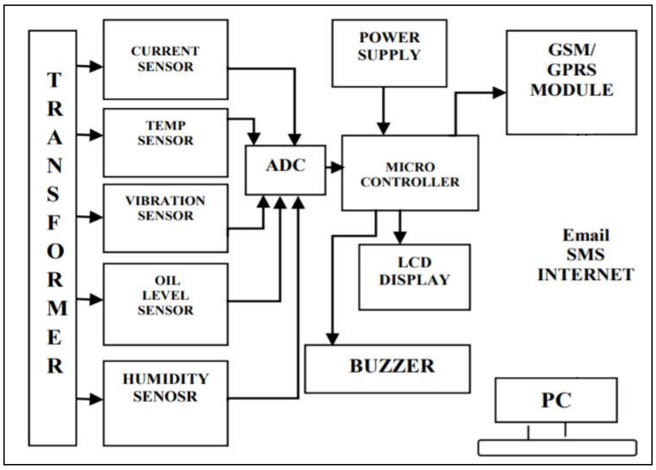

Fig. 1. Block diagram of the proposed real-time health monitoring system

2) Current Sensor: A current transformer is used as a current sensor where it measures the current flowing through the transformer and steps it down to an analog value that can be processed by a microcontroller. The values stored in the database of the current sensors can be later used for different analyses. If the current exceeds a particular value, the circuit trips to prevent permanent damage.

3) Temperature sensors (LM-35): The temperature sensors measure the temperature of the windings, the insulations, and the transformer oil and pass it to the Analog to Digital Converter (ADC), where they are converted to digital data. The LM series temperature sensors are the most reliable and accurate integrated-circuit sensors in the market due to the fact that the output voltage is directly proportional to the Celsius scale. The LM-35 sensors do not require external regulation as they deliver a precision of $\pm 1/4^{\circ}C$ at room temperature.

4) Oil level sensor: The oil levels of a transformer determine the longevity of the transformer. The oil samples are to be regularly taken and analyzed chemically to determine the health of the transformer. The level of oil present in the transformer is critical as it determines the insulating properties of the transformer during its function. So a floating device is used to measure the level of oil in the transformer during its day-to-day functioning [10].

5) NodeMcu: It is an open-source Internet of Things platform consisting of a WiFi development board of 24GHz. The NodeMcu is a combined unit, and all the resources are present on the development board. The main advantage of using NodeMcu is its compatibility with modern tools such as node.js, which helps achieve the best results in the fastest time.

6) GPRS Module: The GSM module has the capability to send an SMS or a message to the engineer who is off-site using mobile data as the means of communication. The module has the capability to receive, delete, store, and write messages simultaneously.

7) Microcontroller: A capable and powerful microcontroller such as the PIC 18F4550, is used as a control mechanism. The microcontroller analyses the digital signals that arrive from the Analog to Digital Converters (ADCs) and accordingly warn the engineer via the GSM/GPRS Module.

C. *Software*

1) NodeMcu Software: NodeMcu software plays a critical role in coding the control unit of the microcontroller. The IDE is preferred due to its speed, reliability, and universal presence.

2) Database Management System: A database that records the transformer data is required for the engineer to refer to the previous data to get an idea about the condition of the transformer. The engineer cannot monitor the transformer constantly. Thus the previous data is stored in the database to be updated on the webpage regularly.

3) Application Development: Communication between the transformer and the engineer is implemented through the webpage. A basic language like HTML is enough to design a simple webpage that will track all the parameters consistently and display the information in a neat user interface.

VI. IMPACT ON TRANSFORMER LIFE – CASE STUDY

Total transformer failure can impact the power system drastically. Such failures reduce the lifetime of a transformer as the windings and other components are permanently damaged. However, most of these damages can be prevented if the engineer predicts the failure before it happens. With the intervention of IoT, this can be made possible.

Fig. 2 shows the primary causes of failure in a distribution transformer. We can see that the leading causes of failure are insulation failures and winding failures. Insulation failure mainly occurs due to overheating of the windings. Winding failure is primarily due to persistent overvoltages and faults in the transformer, which lead to overheating of the windings.

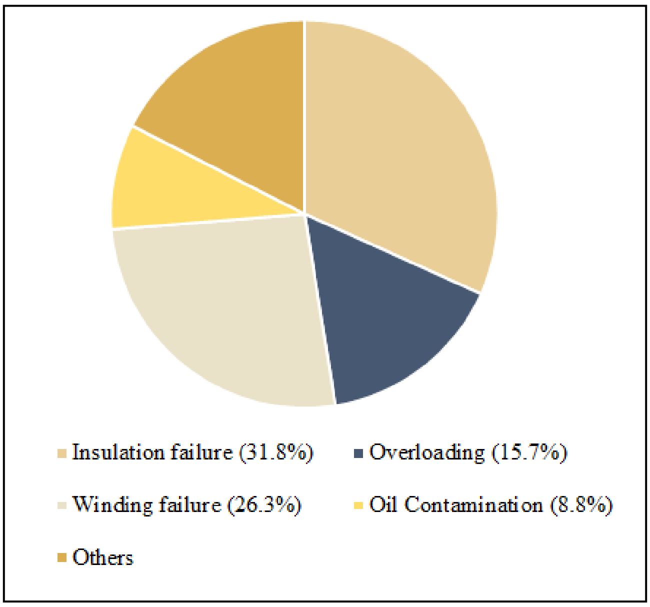

Fig. 2. A pie chart depicting the causes of transformer failure [13].

Using the proposed real-time monitoring system using IoT, the engineer can foresee these errors and failures before they occur, preventing them from happening. Most transformer failures originate from overheating, oil contamination, and overloading. Since oil levels are also monitored in the proposed mechanism, a significant number of failures are reduced.

The health of a transformer is influenced by the number of failures it faces throughout its lifetime. If a transformer encounters many failures, it reduces the lifetime of the transformer by a large amount. Bringing automation into the picture reduces the scope for these failures and thus increases the life and health of the transformer.

The proposed model was tested in a laboratory, and the results obtained were recorded. Over a period, the smart model was successfully able to prevent a large number of unprecedented failures as the engineer was able to identify the root cause of the problem and resolve it in due time.

Bringing automation into the picture has proven to be very useful as the cooling mechanism does not require operating in its maximum capacity when there is a significantly low load. This saves energy and cost of operation. The elimination of human errors in the equation has resulted in a more reliable system, as the feedback system operates itself to nullify the disturbances caused. The proposed model's results are shown from MPLAB in Fig. 3, where the existing cumulative lifetime of a transformer is compared to that of the proposed model, with results obtained from [12].

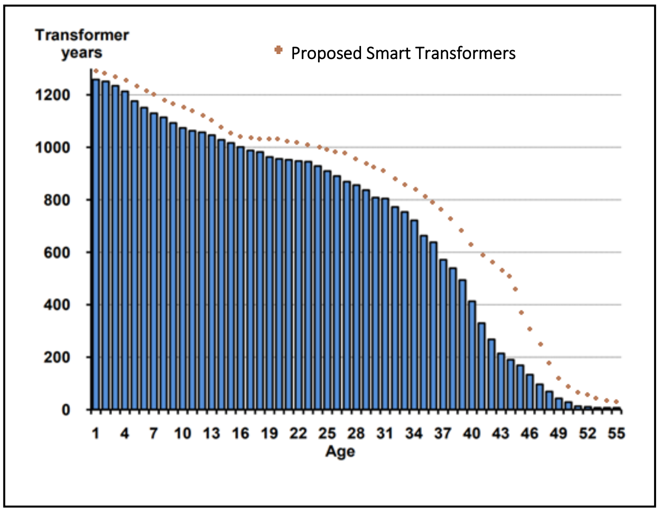

Fig. 3. Graph comparing the lifetime of existing transformer [12] with the proposed model obtained by simulating the same.

The average lifespan of a transformer is increased considerably by 5 to 6 years, as observed from the graph plotted above. Moreover, a significant amount of energy, effort, and cost is saved by employing automated mechanisms to control the transformer parameters.

VII. CONCLUSIONS

The real-time health monitoring system using Internet of Things proposed by this article is designated as the energy-efficient and cost-effective alternative to the existing model, where the monitoring is done manually. The model eliminates the scope for human error and automates the process, thereby making the system more reliable and free from faults and errors. By tracking critical transformer health parameters such as the voltage, current, temperature, and oil level continuously with time, we can prevent the transformer from encountering frequent failures, thus improving the transformer's overall health, subsequently, its lifetime. The parameters are tracked using appropriate sensors that transmit real-time data to the microcontroller, which sends an alert to the engineer who is not on-site via GSM as an SMS or as a message through the internet, thus incorporating the concept of the Internet of Things.

Although the proposed system poses certain risks, such as cyber-attacks, establishing a secure cyber-security system to implement the model will prove very useful in the long run, helping in cutting costs and saving energy. The system uses a cloud-based database management system and displays the real-time health parameters through a web-based application; thus, the data is accessible remotely to the engineer. The system is a breakthrough in integrating the transformer with new technologies that incorporate the internet and seamless microcontroller systems. In future models of the same, the system can also use GPS and other technologies to automate tasks based on the weather, temperature, and condition of the location. The security in such cases must be of a very high standard and must be tested in frequent intervals of time.

VIII. Future Scope

It is impractical to replace all the existing transformer systems with the new IoT-based Transformers as it will incur huge costs and may cause significant interruptions in the respective power systems. Hence the proposed model can be implemented in the transformers that are constructed in the future. With the implementation of smart grids and microgrids gaining popularity in the energy sector, Smart transformers are the next breakthrough in the field of power systems research [5].

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References

[1] C. Bengtsson, “Status and Trends in Transformer Monitoring” IEEE Transactions on Power Delivery, Vol. 11, No. 3, July 1996.

[2] D. Srivastava and M. M. Tripathi, "Transformer Health Monitoring System Using Internet of Things," 2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 2018, pp. 903-908, doi: 10.1109/ICPEICES.2018.88

[3] W. L. Chan, A. T. P. So and L. L. Lai, "Internet based transmission substation monitoring," in *IEEE Transactions on Power Systems*, vol. 14, no. 1, pp. 293-298, Feb. 1999, doi: 10.1109/59.744546.

[4] A. P. Marques, C. de Jesus Ribeiro, C. H. B. Azevedo et al, "Power transformer disruptions- a case study," in IEEE Electrical Insulation Magazine, vol. 30, no. 2, pp. 17-21, March-April 2014

[5] M. Couto, J.A. Peças Lopes, C.L. Moreira, Control strategies for Multi-Microgrids islanding operation through Smart Transformers, Electric Power Systems Research, Volume 174, 2019, 105866, ISSN 0378-7796, https://doi.org/10.1016/j.epsr.2019.105866.

[6] Liebfried, T., "Online Monitors Keep Transformers in Service", IEEE Computer Applications in Power, July 1998. p.36-42’

[7] Hongyan Mao, “Research of Wireless Monitoring System in Power Distribution Transformer Station Based on GPRS”, Volume 5, C 2010 IEEE, 978-1-4244-5586-7/10/$26.00

[8] Mariprasath, T., & Kirubakaran, V. (2018). A real time study on condition monitoring of distribution transformer using thermal imager. Infrared Physics & Technology, 90, 78–86. doi:10.1016/j.infrared.2018.02.009

[9] M. S. Sujatha., M. V. Kumar, “On-Line Monitoring and Analysis of Faults in Transmission and Distribution Lines Using GSM Technique”, Journal of Theoretical and Applied Information Technology, ISSN: 1992- 8645, E-ISSN: 1817-3195, 30th November 2011, Vol. 33 No.2.

[10] Hussain, M., Salman, M., Rohit, Subhan, A., Khalid, H., & Zaidi, S. S. H. (2018). Condition based health monitoring of transformers. 2018 "International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)". doi:10.1109

[11] Avinash Nelson A, Gajanan C Jaiswal, Makarand S Ballal, and D. R Tutakne,” Remote Condition Monitoring System for Distribution Transformer”, 978-1-4799-5141-3/14/$31.00 ©2014 IEEE.

[12] W. K. A. Hasan, A. Alraddad, A. Ashour, Y. Ran, M. A. Alkelsh and R. A. M. Ajele, "Design and Implementation Smart Transformer based on IoT," 2019 International Conference on Computing, Electronics & Communications Engineering (iCCECE), London, United Kingdom, 2019, pp. 16-21, doi: 10.1109/iCCECE46942.2019.8941980

[13] Jaspreet Singh, Sanjeev Singh, “Transformer Failure Analysis: Reasons and Methods”, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181