ISSN (e) 2520-7393
ISSN (p) 2521-5027
www.estirj.com

SMART HEALTH MONITORING AND PROTECTION SYSTEM FOR DISTRIBUTION TRANSFORMER

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Abstract: The distribution transformer is a crucial device for transferring electrical power from the national grid to consumer premises. A transformer's sudden fault can disrupt the end user's electricity supply due to its constant exposure to diverse environmental conditions throughout the year. Transformer burning incidents result in utility loss, shutdowns, and local impacts due to inadequate monitoring, affecting hundreds of transformers in medium-sized cities. Therefore, proper monitoring system of distribution transformer is needed which must be smart to transfer data to the control room wirelessly and provide protection by isolating the transformer when detects any hazardous abnormality in measured parameters, which serves as indication of incipient faults such as short circuit, inter-turn, insulation failure, etc. in transformer. It will also enable preventive maintenance resulting in decrement of downtime, maintenance charges and increases the life span of transformer. In this paper, we have developed, and simulated a smart health monitoring and protection system of 2 kVA oil immersed distribution transformer along with its prototype, which successfully monitored the parameters such as oil level, oil temperature, load current, voltage, ambient temperature, and humidity. Protection and isolation have also been provided as any one of the parameters exceeded its predetermined value. Different scenarios have been tested and verified such as overload or short circuit, under voltage, low oil level, high oil temperature with quick response.

Keywords: *Smart Monitoring, IOT, Incipient Faults, Distribution Transformer, Protection, Catastrophic Incidents*

1. Introduction

In today's era, Electricity is such a precious commodity that no one can think of a life without electricity. For every industry and commercial activities, the reliability of electrical power is obligatory. [1] because of global population growth, global power consumption is expanding at a 2.3% yearly average growth rate. Hence, all activities required ttransformer devices to change the voltage level by either stepping up or down for transferring electrical power to the consumers. In recent years, the electricity demand has increased drastically, and due to inadequate capacity of transmission and distribution network, Distribution generations has been considered as reliable and feasible solution [2]. Renewable energy sources are unharmful resulting in the reduction of air pollution and can be installed near load centers [3] but required distribution transformer. The usage of distribution transformers is increasing day by day, as renewable energies are intermittent, there is a need of some energy storage system which stores energy when demand exceeds the supply [4] such as battery storge system.

EV is the most technological advancement in recent years resulting in battery storage [5] increasing in the electricity demand. Transformer is needed to be operated at its rated conditions as mentioned on its nameplate for better efficiency and guarantee longer life. Transformers are the main components in making the total capital invest in electrical power system as the cost around few hundred dollars to million dollars. As environmental conditions have severe effect on the operation of distribution transformers which decreases the life performance of the equipment.

Although, transformer have a life of 20-25 years, but it can significantly reduce if it is operated on overload conditions [6]. Transformer is made up of different parts as shown in Fig. 1 including winding, oil, magnetic core, Insulation, Bushing. Abnormality in distribution transformer is accompanied with variation in different parameters like Winding temperature, Oil temperatures, Ambient temperature, Load current, Moisture and dissolved gas in oil, LTC monitoring, Bushing condition [7]. When the fault occurs, it has an adverse effect on the continuity of the electrical power supply and also increases the overall cost of power system as maintenance and repairing or replacement is needed.

Figure.1. Structure of a distribution transformer [8].

There are some health monitoring techniques which are used to overcome the failures in distribution transformers. Some of these are manually test, by which transformer is tested but first removing it from the line, while the other are online techniques using Microcontrollers [9]. However, the improvement is needed so that we must have a real time smart monitoring system using microcontroller, which must be

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capable to monitor the different parameters of the distribution transformer in order to access the information about its health. It will assist operator in a control room to recognize the upcoming fault in the distribution transformer before any hazardous failure occurs. By using such method authorities will have significant saving in a maintenance cost, ensure longer life of distribution transformer and reliability of power supply.

2. Literature Review

Many researchers have done work for the monitoring and protection of distribution transformers by using different techniques.

2.1 Dissolved Gas Analysis

DGA is a diagnostic technique used for analyzing health and making earlier fault detection in electrical oil immersed transformer. There are different thermal, and electrical processes are always going on inside the transformer due to overheating or insulation breakdown, Therefore, [10] explained various types of gases: Hydrogen (H2), Methane (CH4), Ethane (C2H6), Ethylene (C2H4) and Acetylene (C2H2), have been generated in the transformer, by analyzing the concentration and type of each gas present in the transformer utility can detect the incipient fault and its type at the initial stage as shown in Fig. 2.

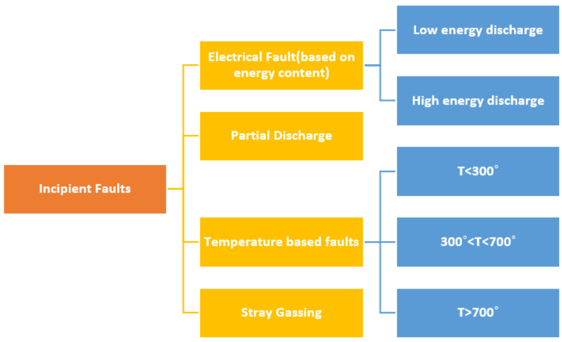

Figure.2. Classification of incipient faults [10].

In Thailand [11], insulation oil of 50 distribution transformers had been tested based on the five different techniques of the DGA. Program of all techniques developed in the MS excel and accessed the condition of oil. Two transformers had also evaluated for the partial discharge and arcing test. The TDCG analysis was also utilized to recommend maintenance measures. Worst case scenario had been analyzed by the DGA technique and isolated the transformer from service.

In [12], different online DGA monitoring equipment had been reviewed, as it enables the predictive maintenance by detecting incipient faults in insulation of transformer. It demonstrated the selection and classifications of online fault detection monitor and fault diagnosis monitor based on the number of valves required, whether installed in closed loop or in valve, number of analogue input and output, and specification of fault diagnosis monitor depending on the importance of transformer.

2.2 Frequency Response Analysis

Transformer frequency response analysis (FRA) is a diagnostic technique used to evaluate the mechanical integrity and insulation condition of transformers. It entails monitoring and analyzing the electrical response of a transformer to a range of frequencies. FRA is especially useful for detecting mechanical and structural faults within the transformer, such as winding deformation, core movement, and other anomalies that can compromise its performance and dependability.

Different methods of FRA had been reviewed in [13] and evaluated by comparing the results. Correlation coefficient and the spectrum deviation are the two indicators modelled and applied on actual implication on power transformer. It is inferred that the spectrum deviation is more likely to prone to error in some occasions and give false results, therefore the other indicator is more accurate in all four case studies.

According to [14], author had tested the impedance of 100 kVA transformer winding at wide range of frequencies, then compared the results with the standard reference values. Results were very much aligned with that of simulation in different cases, hence FRA was proven to be one of the effective tools for fault detection in winding or mechanical structure of the transformer.

[15] had proposed some non-parametric statistical methods to evaluate and interpret the data collected from the FRA of the transformer rather than the convention approach. Proposed model has been applied on the FRA measurements taken from the two transformers, one with interturn fault and other with radial deformation. This study discovered that the non-parametric approaches used may effectively depict the differences between compared FRA data and diagnose the issue.

2.3 Partial Discharge Test

A Partial Discharge (PD) test is a diagnostic procedure that is used to evaluate the insulation state and detect any evidence of partial discharges within the transformer. Partial discharges are electrical discharges that occur locally within the insulation of electrical equipment such as transformers. These discharges can be indicative of insulation flaws or faults, which, if not rectified, can lead to catastrophic failures.

[16] in the research reviewed methods used for evaluating the partial discharge test on transformer. Signal detection-based methods detects wave such as electromagnetic, acoustic signal, electrical, optical signal from the high voltage equipment like power transformer.

2.4 Thermal Imager

Thermal imager technique uses a device known as thermal imager, which can identify the hotspot on the transformer based on temperature. It enables utility to identify the spot or specific part on the transformer which is more likely to be failed due to the high temperature.

In [17], Author had reviewed different health monitoring techniques of transformer and monitored six different distribution transformers, in which the hotspot was the bushings of the transformer, as in one of the case operating at a temperature of about 327˚C in Fig. 3. The main cause of transformer failure was the insulation degradation because of about 327˚C in Fig. 3. The main cause of transformer failure was the insulation degradation because of continuously subjected to high temperature results in short circuit.

Figure.3. Hot spot on line joint and transformer [17].

Based on image processing [18], graph-based semi-supervised learning, and GAN (Generative adversarial network), a failure diagnosis model for transformers is developed. The important feature parameters from the infrared images are retrieved, including temperature characteristics, texture features, and form features.

2.5 IOT Based Real Time Monitoring

IOT refers to any device or equipment which is connected to the internet, make it easier for the operator to monitor and control it through smart devices while sitting anywhere in the world.

Authors in [19] have taken step to overcome the manual monitoring of distribution transformer, by implementing the online health monitoring system of transformer while using GSM module to notify the operator, in case of increment of any parameter value from the threshold. Data taken from the proposed model had been compared with the readings taken with the help of multimeter.

In [20], the GPRS module used to analyze the monitoring of the transformer via smart mobile device and the monitoring node in the substation. Sensors were deployed on the transformer to measure the different parameters such as vibration, current, temperature, humidity, and oil level. The proposed model has also been simulated in the Proteus ISIS software to check the validation of the model.

[21] in research used three phase transformers for the detection of health index (HI) of substation transformer, they have used OCMS (online condition monitoring system) technique. Discussed Capabilities and practical usefulness of the proposed OCMS in utilities and industries.

All these papers have done work in their respective areas by using the most efficient tool, IoT. Through the thorough literature review, it has been found that for the health condition monitoring system for distribution transformers, using the Internet of Things (IoT) is the most appropriate, efficient, and reliable tool than manual monitoring. It saves time as well as provides accuracy in our work. In our study, we are going to work on the IoT technique with a few modifications. In order to prevent a systemic failure that would be catastrophic, we will identify every transformer issue in this endeavor. This work also focuses on wireless communication, which replaces the need for bulky wires, which are expensive, unreliable, and maintenance intensive.

2. Methodology

There are hundreds of Distribution transformer in each city, which are always subjected to various environmental conditions 24/7 along with continuous varying load. These conditions increase the chances of fault in transformers, which may lead to the shutdown of electrical power in that region for a whole day or more depending on the nature of fault that the transformer encountered. Therefore, there is a high desire to design and develop a system which can detect the incipient faults and enables the utility to do preventive maintenance. The entire process is depicted in the Fig. 4.

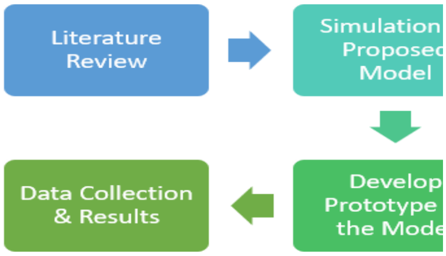

Figure.4. Methodology framework

We had employed different types of sensors inside and outside the distribution transformer to make it more comprehensive to acquire data which would be further processed. The word smart can refer to any system that could provide an ease to the operator to control and monitor the device remotely. The operator would be aware of the health of a transformer without its manual inspection or isolating it from the feeder. In this study, smart system had been developed that can monitor the health of distribution transformer by monitoring its parameters such as its oil level, load current, voltage, oil temperature. Its general layout is depicted in Fig. 5.

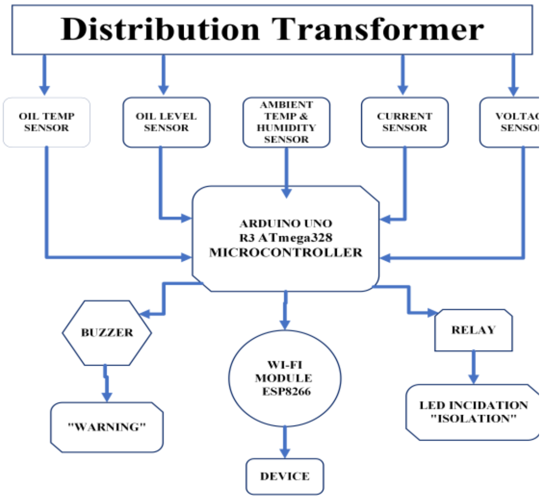

Figure.5. General layout of the proposed model.

It enabled the system self-monitored and provided protection by isolating the transformer in case of the fault.

3.1 Flow Diagram

Hardware and Simulation model both are working according to the flow chart depicted in Fig. 6.

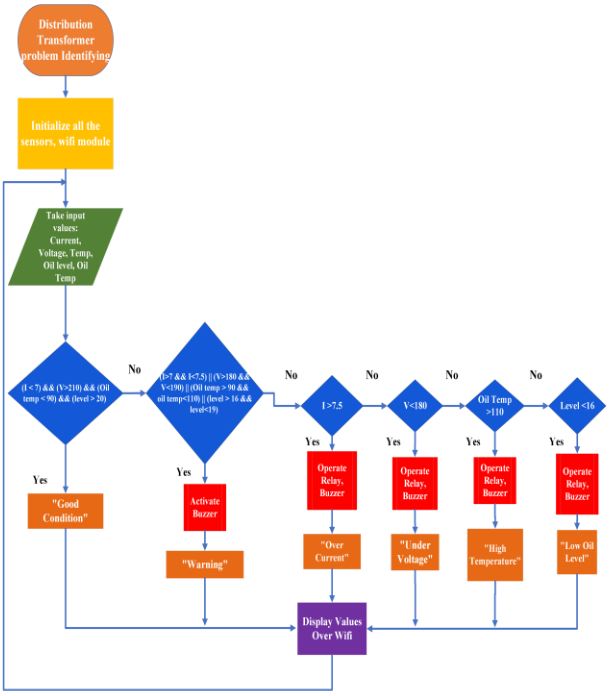

Figure.6. Flow chart of the smart monitoring and protection of distribution transformer.

3.2 Simulation

The simulation of proposed model is done on ISIS Proteus 8 Professional software as shown in Fig. 7. This software is essential for testing and debugging circuits, as well as lowering development time and cost and verifying the operation and dependability of electronic systems prior to physical manufacturing. The distribution transformer with output 220V and 110V is used and due to unavailability of ZMPT101B voltage sensor in the proteus library, Potential divider voltage sensor is used to measure the voltage at the secondary of transformer. Terminal box is used just as serial monitor to display the output data. These could also be monitored on smart devices such as mobile phone via Wi-Fi module. When any of the parameters exceeds the specified values established in the programming, a pulse signal is created and sent to the DC relay, which activates and disconnects the load from the transformer and also allows the buzzer to warn the operator along with the LED indicator.

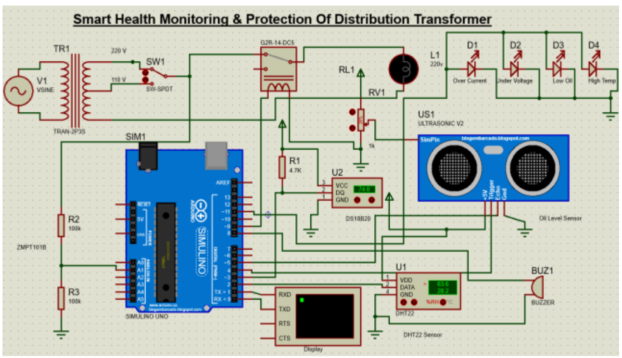

Figure.7. Simulation of proposed model

3.3 Experimental Setup

A 2 kVA oil-immersed distribution transformer is used in this project. It is made up of a ferromagnetic core and coils that are immersed in insulating oil as evident in Fig. 8. The specification of the transformer is presented in Table I.

Figure.8. 2 kVA oil immersed transformer

Table.1. Specifications of 2 kVA transformer

Category	Specification
Rating	2 kVA
Input Voltage	220 V
Output Voltage	110, 220 V
Sec Current	8.5 A
Frequency	50 Hz
Cooling Type	ONAN
Weight	24 Kg

Various sensors have employed to collect different parameters, these are as follows.

- DS18B20 temperature sensor is floating in transformer oil to monitor oil temperature.
- The DHT22 temperature and humidity sensor is a digital sensor used to read the ambient temperature and humidity in the surroundings of transformer.
- An ultrasonic sensor HC-SR04 detects distance by producing high-frequency sound waves, used to measure the oil level within an oil-immersed transformer as shown in Fig. 8.
- The SCT-013-015 is a current transformer (CT) sensor that measures load current.
- The ZMPT101B is a voltage sensor module that primarily measures alternating voltage at secondary.

The entire hardware setup is depicted in Fig. 9. Arduino Uno R3 is a popular open-source microcontroller board used to process data from different sensors. Its components are Microcontroller (ATmega328P), Digital I/O Pins, Analog Input Pins, USB Interface, Power Supply Connector, Voltage Regulator, Crystal Oscillator. ESP8266 is a flexible Wi-Fi module, provides low-cost, low-power, and small hardware that can connect to Wi-Fi networks, making it suited for applications such as remote monitoring, sensor data transmission, and IoT management. A 5V DC relay module is a low-voltage electrical switch that may be controlled by a microcontroller or Arduino, to isolate the circuit by receiving input signal from the microcontroller, whenever any one of the parameters goes beyond the predetermined value. A 5V rectifier circuit is intended to convert alternating current (AC) to direct current (DC) with a constant output used to provide a regulated dc power supply to the sensors that require a 5V supply. An electroacoustic transducer used to notify the operator when the fault is at its initial stages and begins to uptick at dangerous level. Devices used as a load are 200W incandescent lamp, 12V LED bulb, Iron, Mobile charger etc.

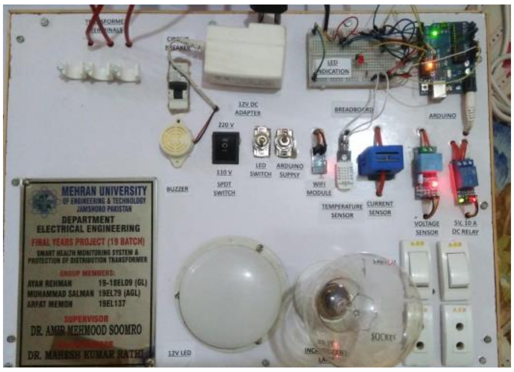

Figure.9. Hardware setup of proposed model

4. Results And Discussion

The proposed hardware model had tested at different condition while varying load, changing oil level by using syringe and a pipe system, changing voltage by using 110v terminal of the transformer's secondary, hence the undervoltage, overcurrent, high oil temperature, and low oil level had been detected accurately while comparing with the predetermined values set in the program.

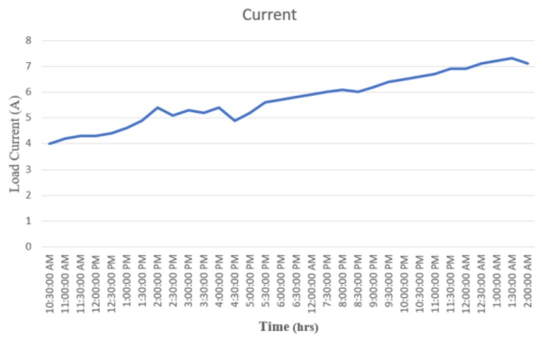

Figure.10. Load current monitoring

Transformer had energized for a long period to analyze and monitor its different parameters. For load current in Fig. 10, connected load varied and analyzed the different reading of load current. When the current surpasses 7A, the warning buzzer activates and acts as an overload alarm. In Fig. 11, Oil Level monitoring had been shown. For varying the transformer oil level for testing, syringe pipe system had been used and as the oil level fell below the 19 cm, the buzzer activated.

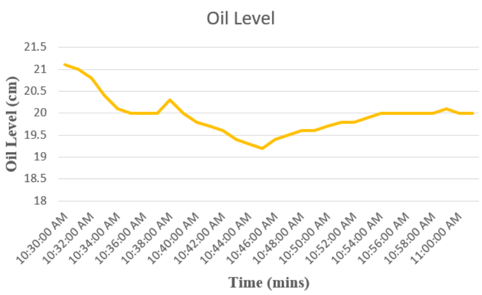

Figure.11. Oil level monitoring

Oil temperature and voltage have also been monitored and recorded as shown in Fig. 12 and Fig. 13. However, the voltage is changed to 110V to activate undervoltage protection via relay.

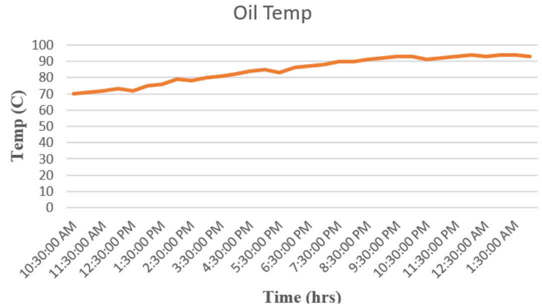

Figure.12. Oil temperature graph

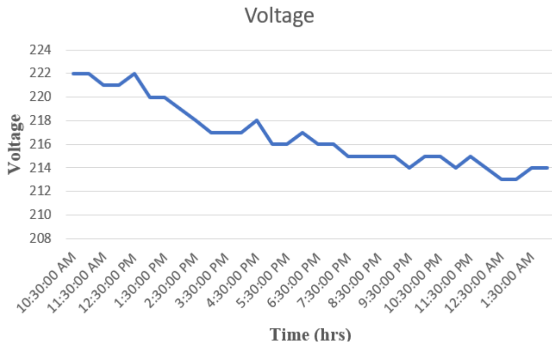

Figure.13. Output voltage graph of 2 KVA transformer

Transformer has tested and evaluated at various loading condition and monitored data had shown in table II. Through the incorporation of a Wi-Fi module, the suggested model successfully proved its ability to monitor and transfer data to a smartphone. Furthermore, it demonstrated its capacity to quickly activate protection systems in reaction to any identified irregularities throughout the rigorous testing phase, assuring increased security and safety measures.

Table.2. Various parameters monitoring values using proposed model

Oil Temp (˚C)	Humidity (%)	Ambient Temp (˚C)	Current (A)	Voltage (V)	Oil Level (cm)
60	45	28	0.3	222	21
70	45	28	0.9	222	21
75	45	28	2.1	221	**17**
72	45	28	0	**111**	21
92	45	28	6.4	214	21
83	46	26	**7.6**	23	21

5. Conclusion

The distribution transformer holds significant importance in the process of transferring electrical power from the national grid to individual consumer premises. However, the constant exposure of transformers to various environmental conditions throughout the year puts them at risk of sudden faults. These faults can lead to disruptions in the electricity supply to end users and cause significant inconvenience. Incidents of transformer burning not only result in utility loss and shutdowns but also have local impacts, particularly in medium-sized cities where hundreds of transformers are affected. To address this issue, there is a strong need for an efficient monitoring system for distribution transformers. This monitoring system should not only be smart but also capable of wirelessly transmitting data to a central control room. By doing so, it can provide real-time information on the transformer's condition and ensure timely and appropriate actions can be taken in case of any hazardous abnormalities detected in the measured parameters. These abnormalities serve as indicators of potential incipient faults, such as short circuits, inter-turn issues, insulation failures, and so on, within the transformer. Implementing such a monitoring system would not only mitigate the risks associated with transformer faults but also enable preventive maintenance. This, in turn, would lead to a decrease in downtime and maintenance charges, while significantly increasing the overall lifespan of the transformers. Therefore, a comprehensive and reliable monitoring system for distribution transformers is crucial to ensure uninterrupted electricity supply and optimize the performance and longevity of these essential power distribution assets. In this paper, we have comprehensively developed and simulated a sophisticated smart health monitoring and protection system for a 2 KVA oil immersed distribution transformer. Additionally, we have also created a functional prototype of this system, which has proven to be highly effective in monitoring and controlling various crucial parameters. These parameters include oil level, oil temperature, load current, voltage, ambient temperature, and humidity. Our primary objective was to create a system that not only monitors but also ensures the protection of the transformer. In order to achieve this, we have implemented mechanisms that act swiftly if any of these parameters surpass their predetermined thresholds. This ensures the longevity and optimal performance of the transformer, safeguarding it from potential damage. Throughout the course of our research, we conducted rigorous testing and verification to examine different real-world scenarios.

References

[1] Memon, O., et al., Implementation of microgrid with integration of hybrid renewable sources using different backup techniques. Indian Journal of Science and Technology, 2020. 13(33): p. 3457-3466.

[2] Kumar, M., et al., Optimal Multi-Objective Placement and Sizing of Distributed Generation in Distribution System: A Comprehensive Review. Energies, 2022. 15(21): p. 7850.

[3] Memon, F.L., M.K. Rathi, and A.M. Soomro, Optimal Integration of Distributed Generation in Distribution System to Improve Short Circuit Current Level. International Journal of Electrical Engineering & Emerging Technology, 2020. 3(2): p. 79-85.

[4] Shaikh, A., et al., Assessment of a Stand-alone Hybrid PV-Hydrogen Based Electric Vehicle Charging Station Model Using HOMER. Journal of Applied Engineering & Technology (JAET), 2022. 6(1): p. 11-20.

[5] Sheikh, H.I., M.K. Rathi, and A.M. Soomro, Optimal integration of battery energy-storage system with high penetration of renewable energy in radial distribution network. Clean Energy, 2022. 6(3): p. 404-411.

[6] Rengaraj, R., et al., Transformer Oil Health Monitoring Techniques—An Overview. Advances in Smart System Technologies: Select Proceedings of ICFSST 2019, 2021: p. 135-154.

[7] Hazarika, K., G. Katiyar, and N. Islam. IOT based transformer health monitoring system: a survey. in 2021 international conference on advance computing and innovative technologies in engineering (ICACITE). 2021. IEEE.

[8] Tran, Q.T., et al., A review of health assessment techniques for distribution transformers in smart distribution grids. Applied Sciences, 2020. 10(22): p. 8115.

[9] Suja, K. and T. Yuvaraj. Transformer Health Monitoring System Using Android Device. in 2021 7th International Conference on Electrical Energy Systems (ICEES). 2021. IEEE.

[10] Wani, S.A., et al., Advances in DGA based condition monitoring of transformers: A review. Renewable and Sustainable Energy Reviews, 2021. 149: p. 111347.

[11] Wannapring, E., C. Suwanasri, and T. Suwanasri. Dissolved Gas Analysis methods for distribution transformers. in 2016 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON). 2016. IEEE.

[12] Bustamante, S., et al., Dissolved Gas Analysis Equipment for Online Monitoring of Transformer Oil: A Review. Sensors, 2019. 19(19): p. 4057.

[13] Ryder, S.A. Methods for comparing frequency response analysis measurements. in Conference Record of the the 2002 IEEE International Symposium on Electrical Insulation (Cat. No. 02CH37316). 2002. IEEE.

[14] Ryder, S.A., Diagnosing transformer faults using frequency response analysis. IEEE electrical insulation magazine, 2003. 19(2): p. 16-22.

[15] Behjat, V., M. Mahvi, and E. Rahimpour, New statistical approach to interpret power transformer frequency response analysis: non-parametric statistical methods. IET Science, Measurement & Technology, 2016. 10(4): p. 364-369.

[16] Faizol, Z., et al., Detection Method of Partial Discharge on Transformer and Gas-Insulated Switchgear: A Review. Applied Sciences, 2023. 13(17): p. 9605.

[17] Mariprasath, T. and V. Kirubakaran, A real time study on condition monitoring of distribution transformer using thermal imager. Infrared Physics & Technology, 2018. 90: p. 78-86.

[18] Fang, J., et al., Fault diagnosis of electric transformers based on infrared image processing and semi-supervised learning. Global Energy Interconnection, 2021. 4(6): p. 596-607.

[19] Rahman, S., et al. Design and implementation of real time transformer health monitoring system using GSM technology. in 2017 International Conference on Electrical, Computer and Communication Engineering (ECCE). 2017. IEEE.

[20] Pawar, R.R. and S. Deosarkar. Health condition monitoring system for distribution transformer using Internet of Things (IoT). in 2017 international conference on computing methodologies and communication (ICCMC). 2017. IEEE.

[21] Ballal, M.S., et al., Online condition monitoring system for substation and service transformers. IET Electric Power Applications, 2017. 11(7): p. 1187-1195.

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