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IoT-Enabled Smart Condition Monitoring Tool for Oil-filled Transformers

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Abstract: In this digitised world, the Internet of Things (IoT) has drawn people's attention to bond all equipment with the internet. It is understood from several studies that transformers are poorly managed due to their locational disadvantage; therefore, outages are very high, especially in rural India. Due to negligence in routine cleaning and testing of transformer oil, needs a periodical observation to maintain a healthy and reliable electrical system. The application of IoT extended to condition monitoring of insulating oil of transformers in substations to reduce power outages, especially in remote areas where monitoring such substations is complex and expensive. This paper presents an IoT-enabled condition monitoring tool for transformers located in remote substations; it can perform the Breakdown Voltage (BDV) test of insulting oil remotely and help assess the transformer's health with BDV data from a centralised controlled room. The tool can avoid manual intervention and error drastically. It will be a cost-effective and reliable tool for the condition monitoring of transformers by power utilities.

Keywords: *Automation, Breakdown Voltage, Condition Monitoring, IoT, Oil filled transformers*

1. Introduction

In India, millions of distribution transformers are presently in service, and the number of distribution transformers is increasing at an annual rate of approximately 10%. The failure rate of distribution transformers in India is as high as 22%, the highest in the world. Every year failures of distribution transformers worth several Crores cause a tremendous financial loss to the nation[1]. It is observed that the ageing of insulation happens due to the extended operation of transformers and poor maintenance; the degradation of mineral oil results in the ageing of paper insulation also and contributes to significant insulation failure. Hence, monitoring the condition of the transformer is essential to ensure the availability of reliable and quality power in the electrical system. In a transformer, monitoring the dielectric strength of transformer oil is the most important parameter and is also cost-effective [2]. Therefore, most substations are equipped with an oil breakdown voltage measurement set. Due to sampling error and human intervention, most of the available BDV data from substations are either manipulated or not helpful in predicting the transformer's health through an advanced tool like Artificial Intelligence (AI) or Machine Learning (ML). It is a bottleneck to predict the condition of the transformer earlier and leads to the breakdown of the transformer. Hence 16.72% of total transformers are replaced every two years in India. Transformers in remote areas are in danger because they need to be appropriately maintained, and the condition of that transformers remains unknown.

IoT devices are ever-increasing worldwide in every field, which have gathered every sort of data from different areas. These data are highly beneficial for knowing everything around us [3]. This proposed IoT tool is designed to measure the breakdown voltage automatically for a substation where multiple transformers are present by using the existing manually operated breakdown voltage test set. The value of breakdown voltage is fed to the internet cloud through a microprocessor and Wi-Fi module; later, the BDV test data may be used for assessment of the health of the transformer through an available advanced tool like AI and ML by the experts located remotely.

2. Breakdown Voltage Test

The voltage at which the transient or established spark occurs between the electrodes for the first time is the breakdown voltage. The Power-frequency Alternating Current (AC) voltage is applied to the insulating oil through spherical brass electrodes of spacing 2.5mm at the rate of rise of 2kV/s, from zero till the breakdown occurs. The testing circuit will break the voltage within 0.02 seconds after the breakdown. The breakdown voltage can be read through the meter. This test is repeated six times, and the average is displayed for further analysis [4].

The breakdown voltage test kit is generally rated for 0-100kV, 500mA, which contains the following:

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Fig. 1. Breakdown Voltage test kit.

Fig. 3. 250kVA, 50Hz, 11kV delta-star connected distribution transformer

High voltages to the electrodes in test cells are provided by (0-100kV) high voltage testing transformer according to the change in input variac (0-230V). The breakdown voltage of the oil is unpredictable and occurs in a fraction of a second, and a memory option is used to get the value after the breakdown of the oil. Automating a manual breakdown voltage set with cost-effective components are developed earlier [5,6]. The breakdown voltage test kit to perform this experiment is shown in figure 1.

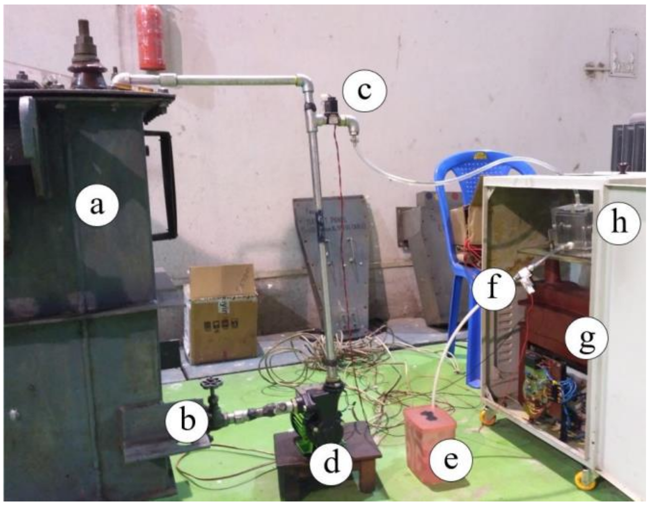


Fig 2. Automatic sampling of oil from the transformer. (a)Transformer (b)Drain valve (c)Feeder solenoid valve (d)Motor pump (e)Waste oil collector (f)Drain solenoid valve (g)High voltage testing transformer (h)Modified test cell

3. Transformer oil sampling

- Single phase variable auto-transformer of 0-230Vac
- Stepper motor to control the position of the variac
- Dry-type High-Voltage testing transformer
- 400mL test cell with spherical/mushroom brass electrodes
- Digital/Analog Voltmeter
- Control switches
- Safety relays
- Door lock relay,
- Zero interlocks relay,
- Primary and Secondary overcurrent protections.

Mineral oil, a non-biodegradable petroleum bi-product is used in transformers for electrical insulation and cooling purposes. The sampling device is made of glass or aluminium and rinsed with the sampling oil. According to the standards, sampling cannot be done during rain, fog, or high wind. The specific quantity of oil, along with transformer contaminations, if any, was taken out from the drain valve of the transformer and sealed with cork stoppers wrapped in aluminium [7]. After the breakdown voltage test, the oil will be poured into the trash, which may create environmental issues.

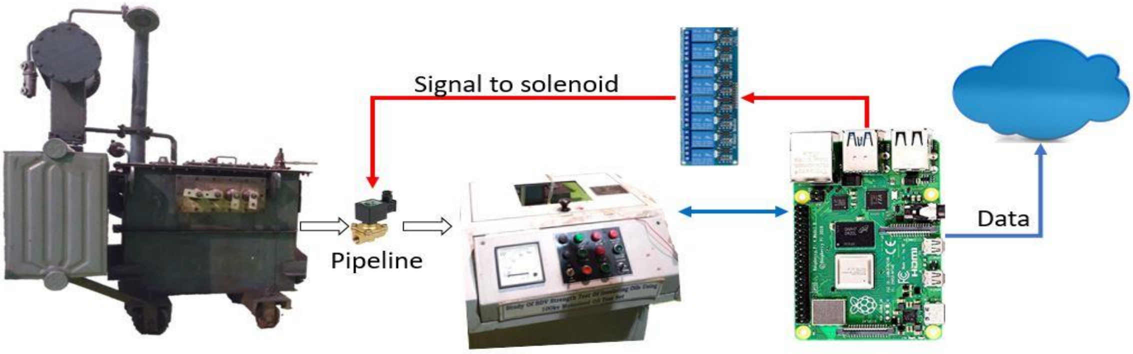
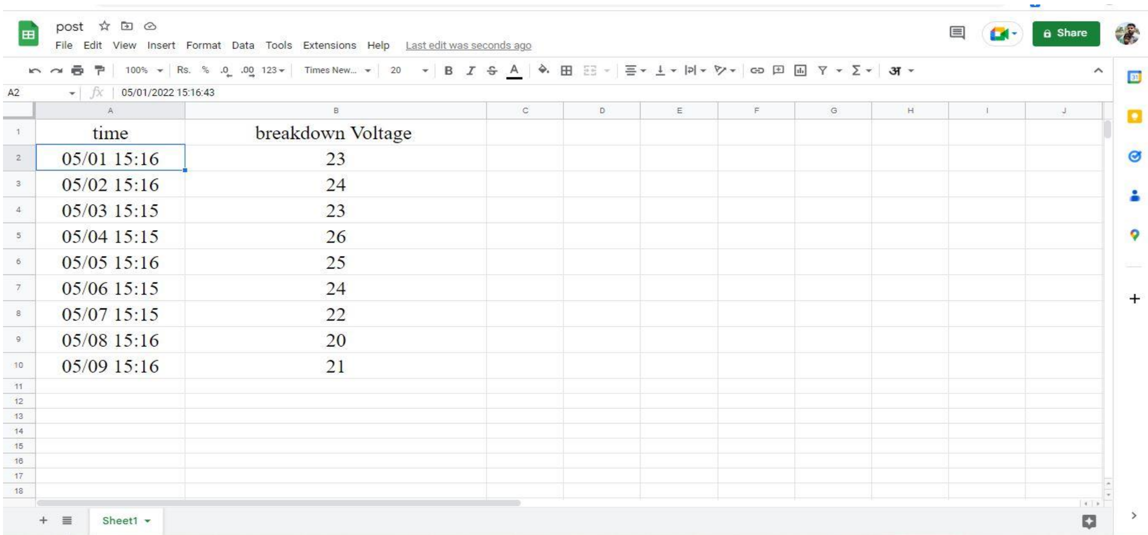


Fig. 4. System components.



time	breakdown Voltage
05/01 15:16	23
05/02 15:16	24
05/03 15:15	23
05/04 15:15	26
05/05 15:16	25
05/06 15:15	24
05/07 15:15	22
05/08 15:16	20
05/09 15:16	21

Fig. 5. Google sheets stores the breakdown voltage of the transformer with date and time.

The proposed automatic sampling of mineral oil from the transformer is shown in figure 2. An external aluminium structure is assembled between the drain valve and the top connector, ensuring the oil flow through the pipe while in operation. The proposed IoT-enabled tool is fixed with Kirloskar Electrics 250kVA, 50Hz, 11kV delta-star connected distribution transformer, which has been removed from service in the National Institute of Technology Durgapur substation, as shown in figure 3. Two solenoid valves sample the oil from the transformer to the break-voltage test cell. Generally, low viscous mineral oil will be circulating inside the tank and the cooling fins. Since the transformer was removed from the service, there is no oil circulation in the transformer tank. Therefore, a motor pump is fixed to ensure oil flow in the external aluminium structure.

On a regular period, the oil will be extracted from the transformer and poured into the breakdown voltage test cell. After obtaining the values, the oil will be poured into the waste oil collector. This waste mineral oil can be recycled to the transformer after filtration. During the filtration process, moisture, dissolved gases, and contaminations were removed to ensure the oil quality and performance.

4. System Components and process

The system components have been made with accessible installation features and cost-effective components. Figure 4 shows the essential components used for this work. Raspberry pi is the heart of this IoT enable condition monitoring tool, which interfaces the hardware and software communication modules. For a specified regular interval of time, this microcontroller performs the breakdown voltage test by extracting oil from the transformer using solenoid valves and sending the data to the cloud database. For this work, we used the Google database to store the values shown in Figure 5. With the help of remote monitoring software, we can know the current status of the breakdown voltage test while performing the experiments shown in Figure 6.

5. Condition Monitoring of transformers in a substation

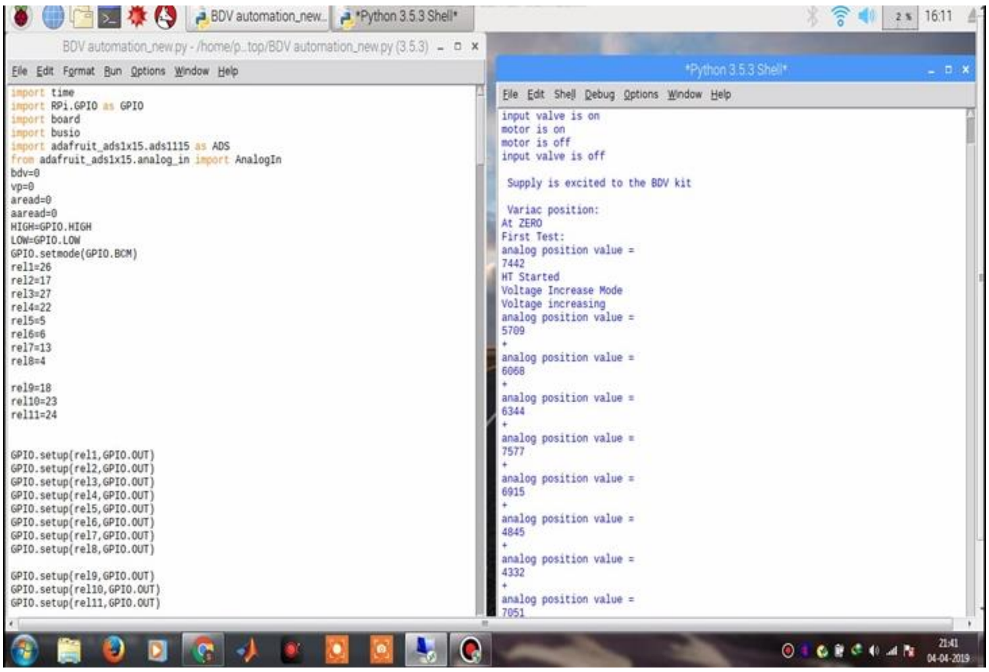


Fig. 6. Microcontroller performing automatic breakdown voltage test on the transformer.

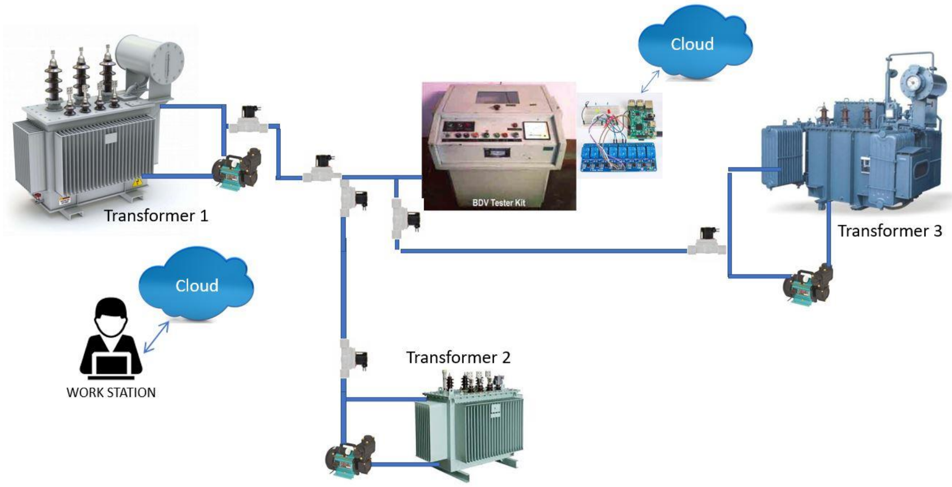


Fig. 7. A IoT enabled smart condition monitoring tool for a substation with three transformers.

For a substation with several numbers of transformers, this system will be beneficial in finding the condition of insulting oil. The breakdown voltage test kit can be placed in a common place connected to each transformer's drain valve using aluminium or stainless-steel pipelines. The same microcontroller can perform the breakdown voltage test and post the data to the cloud. Figure 7 shows the model connection of this IoT condition monitoring tool for three transformers in a substation.

6. Conclusion

In India, almost all substations are equipped with manual breakdown voltage test sets. This proposed automated breakdown voltage test tool will enable the quality of testing without human interference and enhance the transformer and its component life by monitoring the condition of oil at regular intervals of time. Using these tools, tested mineral oils can be recycled after filtration, which improves transformers' environmentally-friendly operation. This tool helps the engineers perform the breakdown voltage test throughout the years when needed, including on rainy days. The implementation cost of this tool in substations or transformers is less compared to the financial loss made by the failures of transformers.

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Author contributions

Jasper D:, Investigation, Writing-Original draft preparation, Field study, Data curation.

Sujit Khandai: , Software, Validation, Field study, Writing-Reviewing and Editing

Nirmal Kumar Roy: Conceptualization, Methodology, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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