Detection of winding inter-turn faults

Detection based on frequency response analysis - Part III

ABSTRACT

This article deals with inter-turn fault detection in the transformer winding, inter-turn fault which occurs due to insulation degradation between one or more sequential turns of the winding. If the fault is not detected at the earliest stage, it propagates to the nearby turns of the winding during certain period of time and it causes irreversible damage to the winding. Therefore, it is necessary to detect inter-turn fault to save the transformer from catastrophic failure.

KEYWORDS

detection, fault factor, inter-turn, SFRA, transformer

Manojmohan SUBRAMANIAN

An inter-turn fault is one of the leading causes of power transformer failures; it can be detected using sweep frequency response analysis

1. Case studies – Detection of fault in layer windings using SFRA

Frequency response analysis can be extended to single and multi-layer windings. At the same time, the fault factor characteristics are obtained for different fault percentages.

1.1. Detection of fault in single-layer winding – measurement results

Sweep frequency response analysis (SFRA) is performed on a single-layer 1000-turn winding from 10 Hz to 25 MHz. This winding has 20 sections where each section consists of 50 turns. Tappings were available at each section end in order to create inter-layer fault. For instance, 5 % fault is created by shortening one section, which corresponds to a short circuit of 50 turns. Fig. 1a and 1b show single-layer winding and a schematic diagram of single-layer winding.

Figure 1a. Single-layer winding

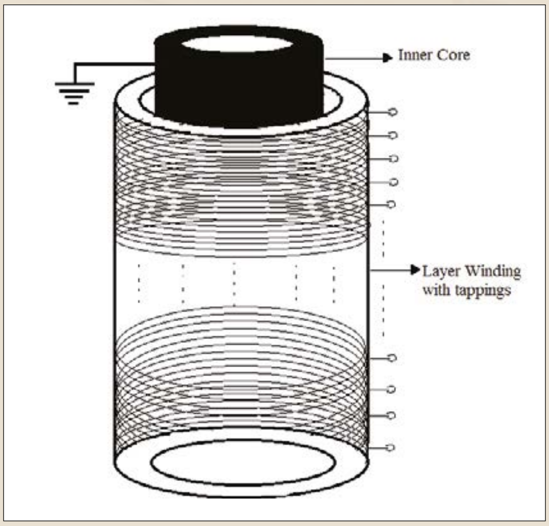


Figure 1b. Schematic diagram

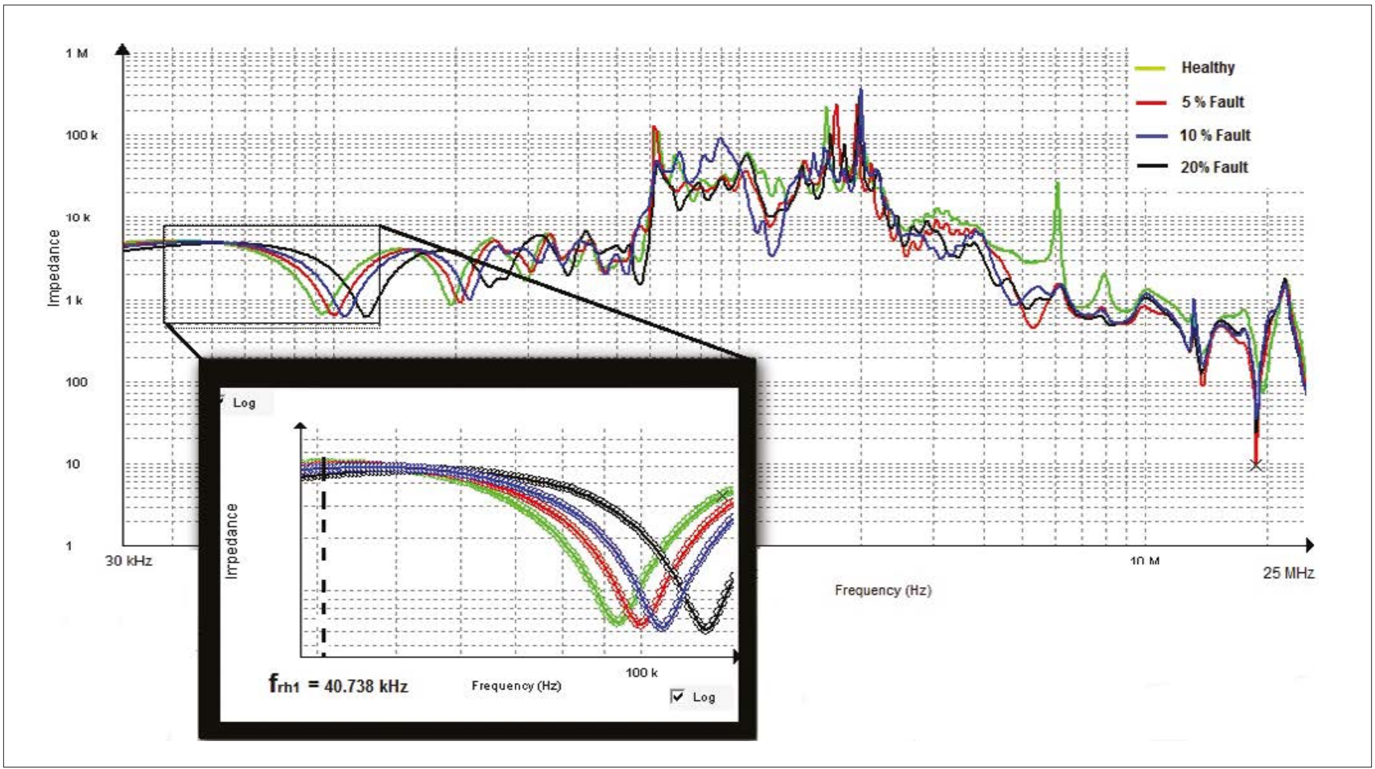


Figure 2. Impedance characteristics for healthy winding and 5 %, 10 % and 20 % faults at different locations along the single-layer winding

Sweep frequency response analysis is performed from 10 Hz to 25 MHz

Fig. 2 shows the measured impedance characteristics for healthy winding and 5 %, 10 % and 20 % faults at different locations along the winding. The first resonant frequency of the healthy winding is f_{rh1}= 40.738 kHz. The impedance characteristic shows a reduction in the impedance at this frequency depending on the location of the fault.

Fig. 3 shows the fault factor characteristics for 5 %, 10 % and 20 % of inter-turn fault in the winding. The curve shifts upwards as the percentage of fault decreases. This curve is symmetrical with respect to the centre of the winding section and provides reliable information about fault detection.

1.2. Detection of fault in multi-layer winding - measurement results

SFRA is performed on the multi-layer

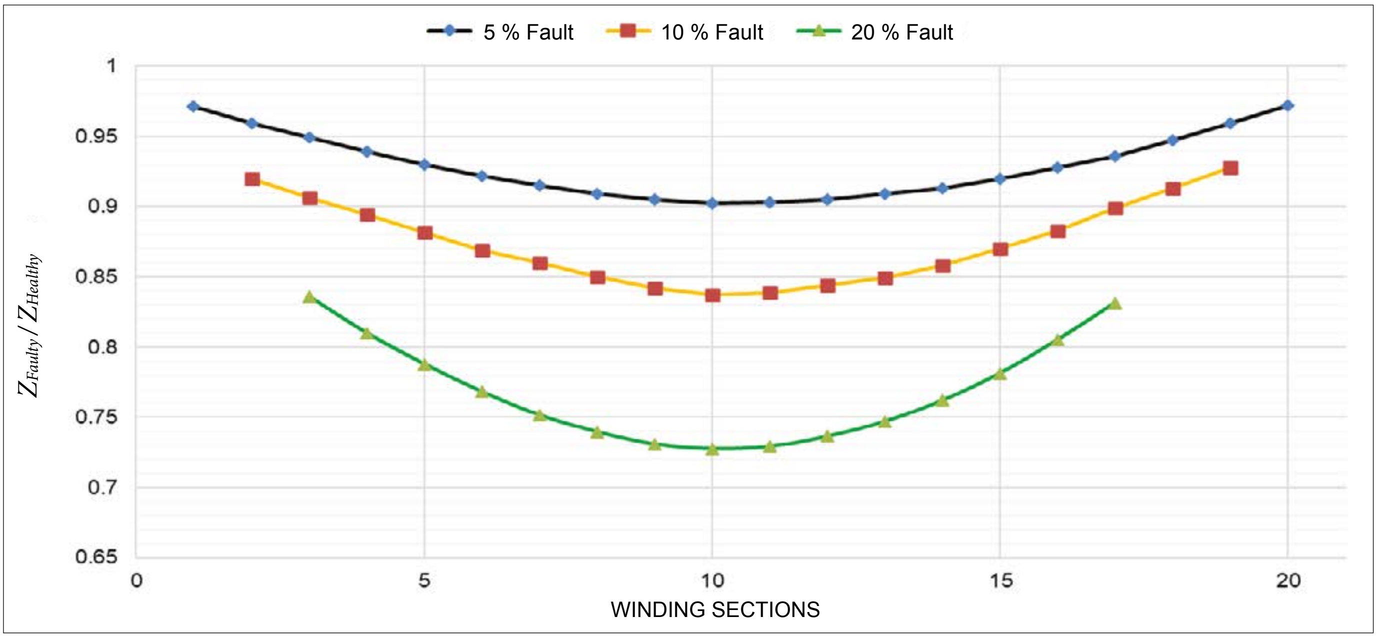


Figure 3. Fault factor for 5 %, 10 %, 20 % faults vs layer sections for different percentage of faults at different locations

Figure 4a. 10 section multi-layer winding

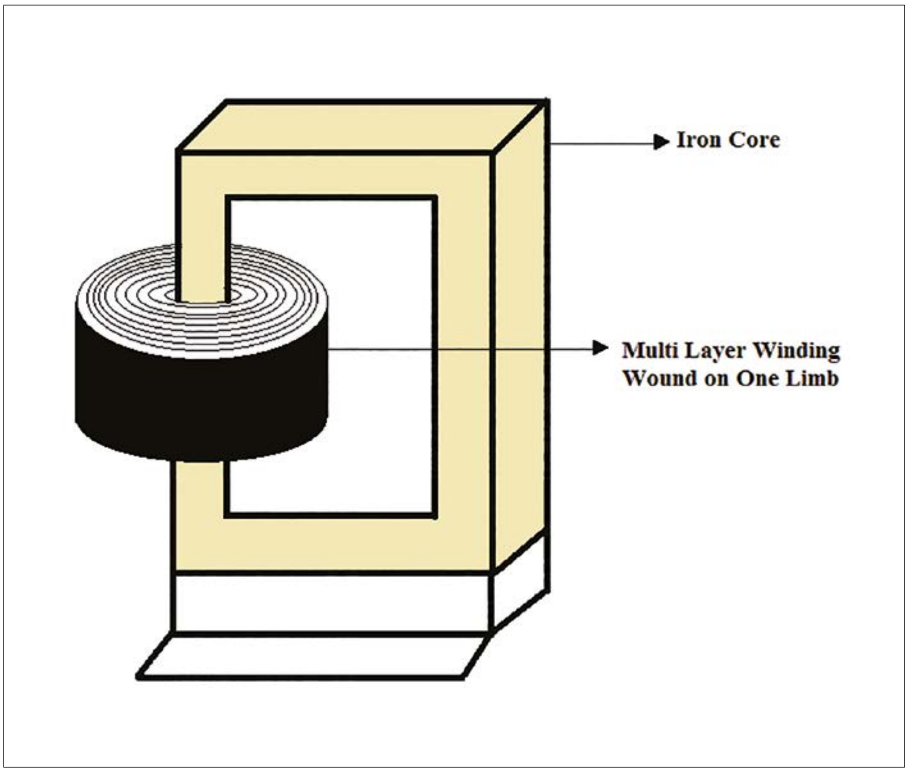


Figure 4b. Multi-layer winding schematic diagram

windings with 10 layers from 10 Hz to 25 MHz. Each layer consists of 200 turns. Tappings were brought out at every section in order to create inter-layer short circuit faults. For instance, 10 % inter-layer fault is created by shortening 2 consecutive layers in a multi-layer winding. Fig. 4a and 4b show the 10 section multi-layer winding and schematic diagram of the 10 section multi-layer winding.

Fault factor is a ratio of the impedances of faulty and healthy winding at the first resonant frequency of the winding; it is a quantity used for the inter-turn fault detection

The sweep frequency response of the winding changes depends on the extent of the fault. Fig. 5 shows the impedance characteristics for healthy and 10 %, 20 % and 30 % inter-layer faults along the first section in the winding.

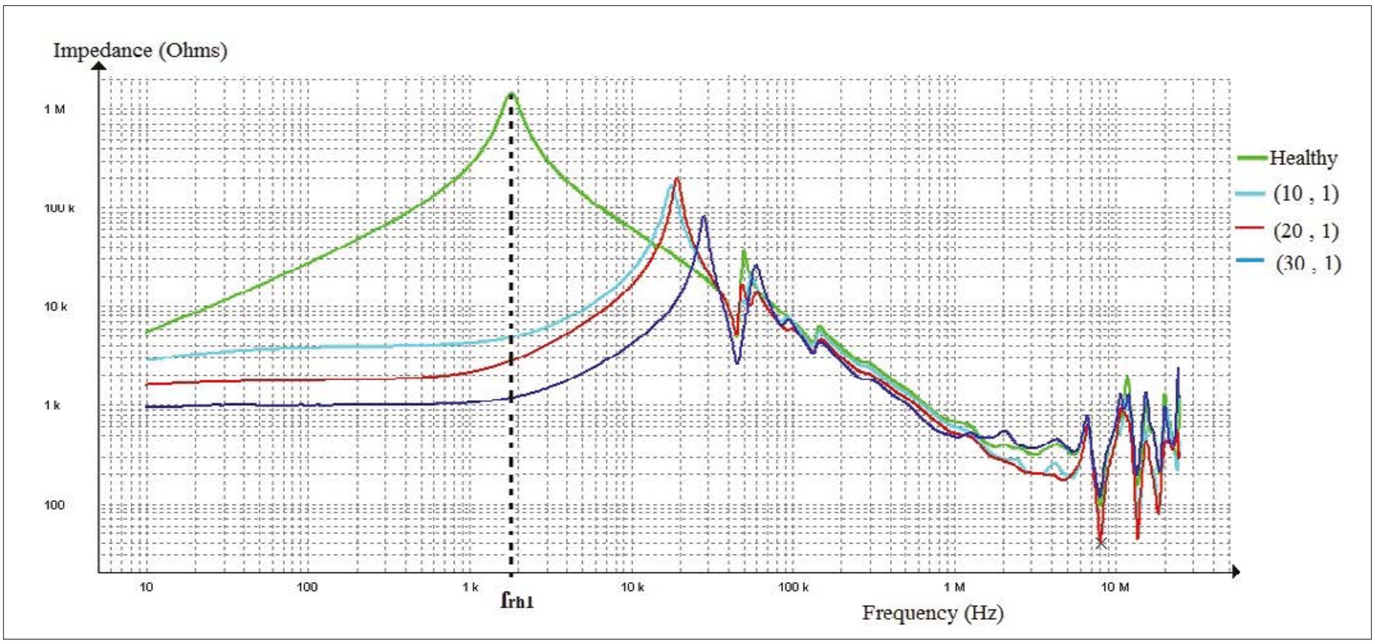
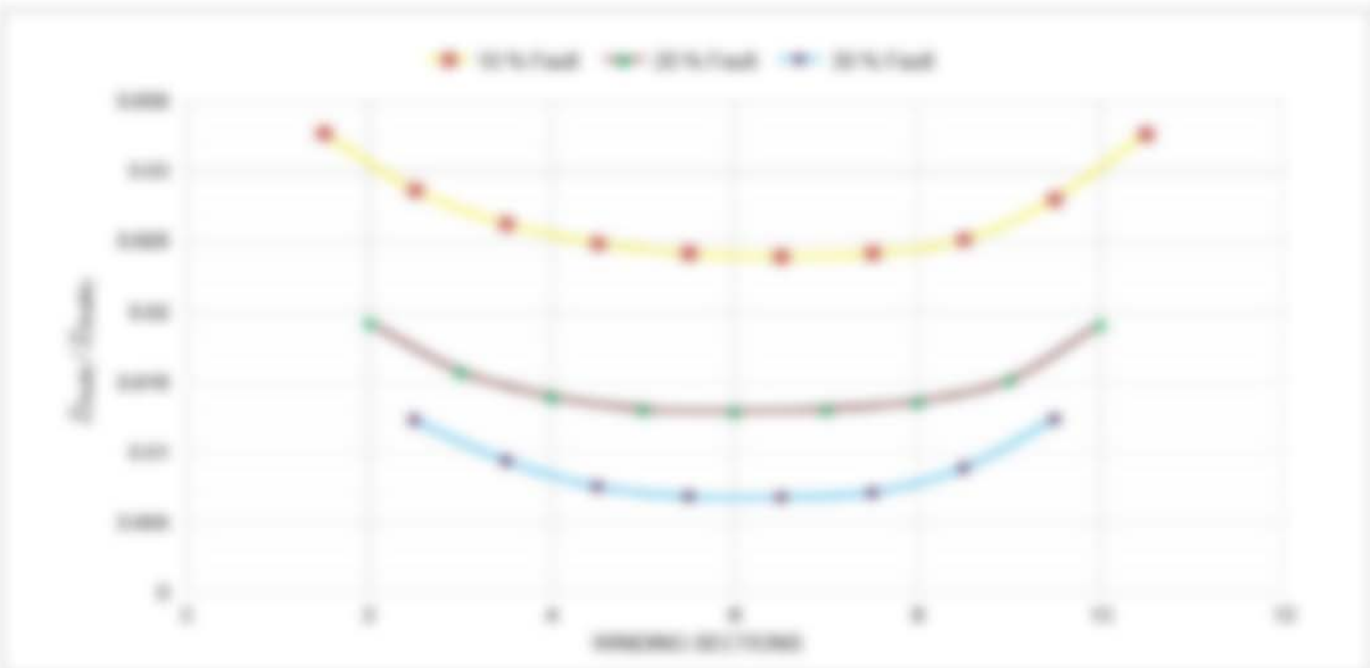
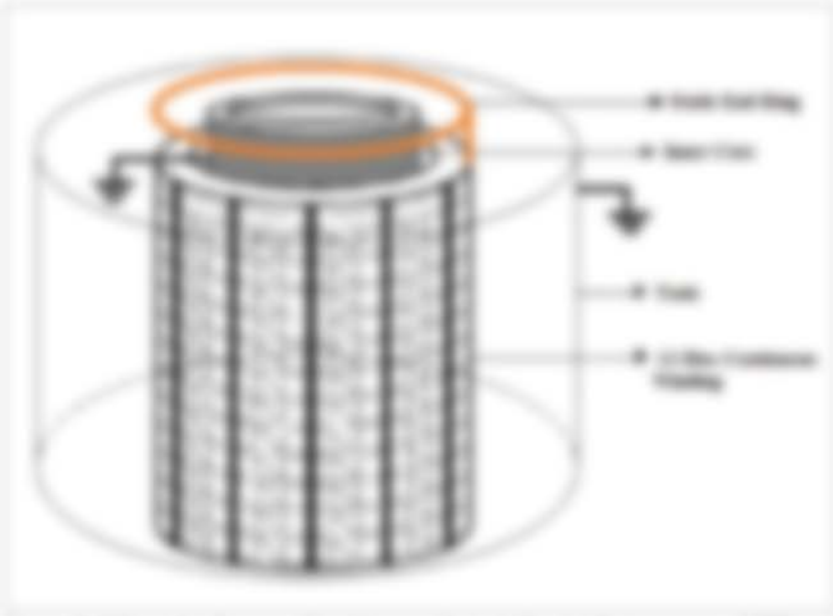


Figure 5. Impedance characteristics for healthy and percentage of faults along the multi-layer winding

SFRA method can be used for detecting the inter-turn faults for both single-layer and multi-layer winding





Presence of the static end ring has an influence on the resonant frequencies in the frequency response trace which comes

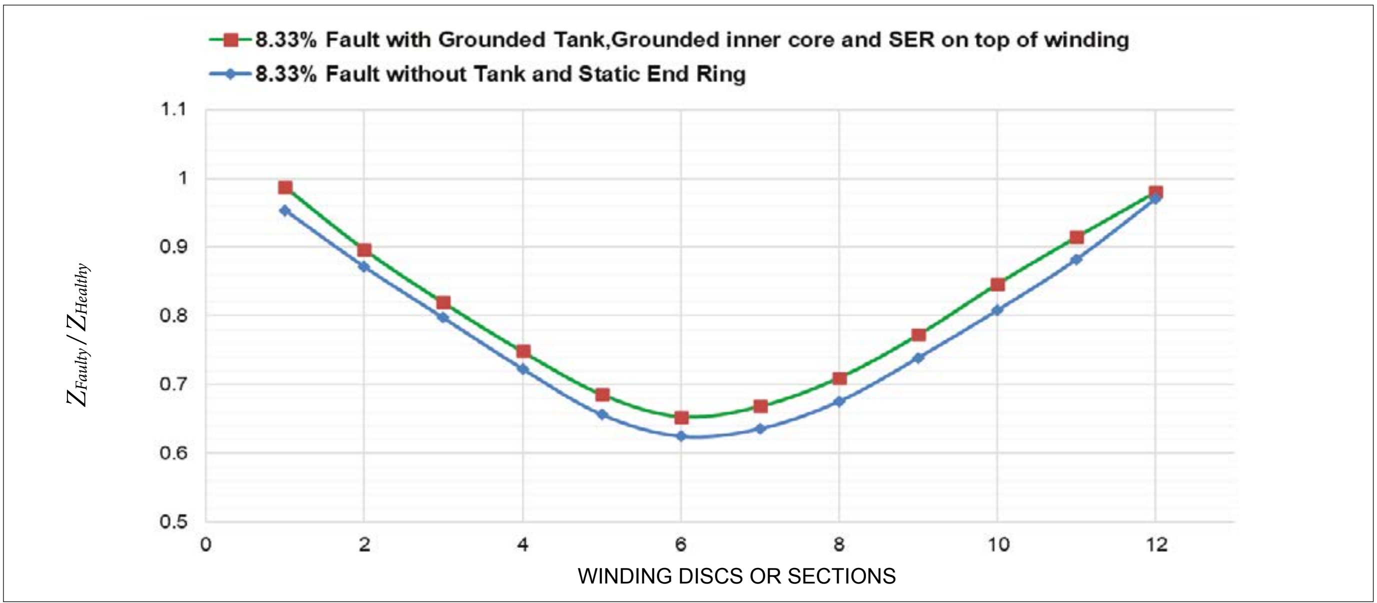


Figure 8. Fault factor vs winding disc or sections for 8.33 % inter-turn fault in continuous disc winding in the presence and absence of SER and tank

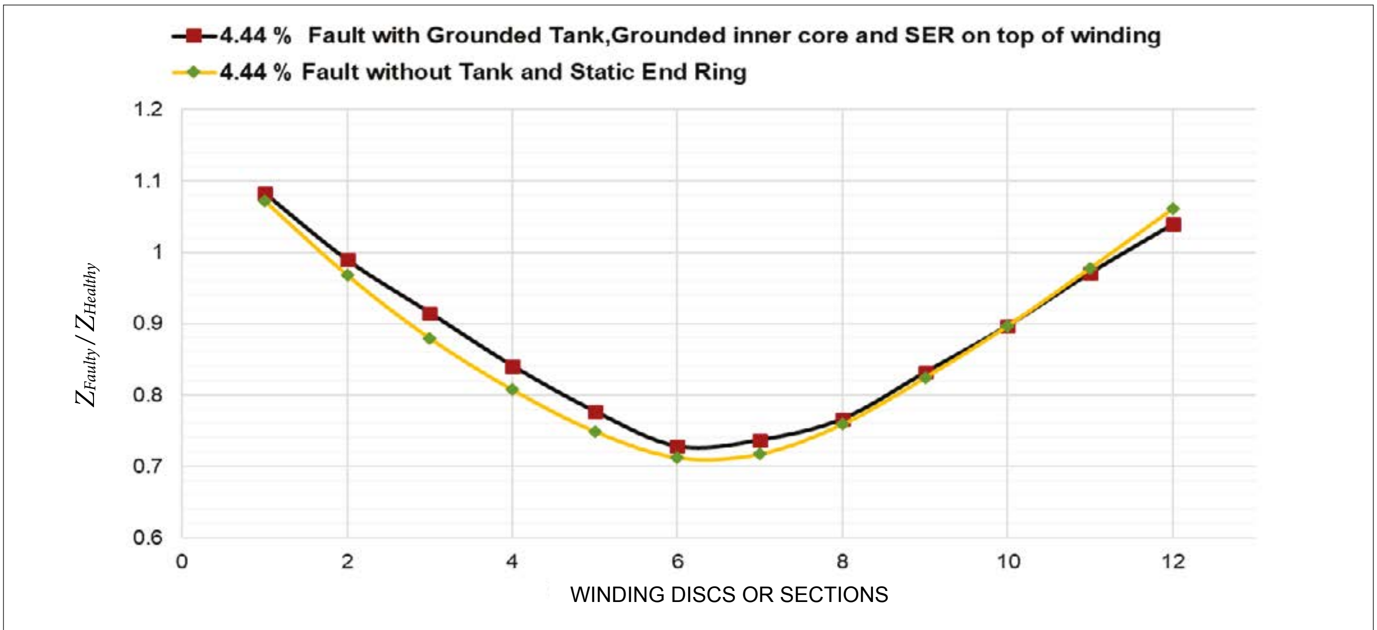


Figure 9. Fault factor vs winding disc or sections for 4.44 % inter-turn fault in continuous disc winding in the presence and absence of SER and tank

To improve the transient voltage distribution along the winding, it is necessary to make the initial voltage distribution constant (α) as low as possible; one way of accomplishing this is to increase the series capacitance by providing SER at the line terminal of the transformer winding

- From the fault factor characteristics, it is inferred that the characteristics move downwards as the percentage of inter-turn faults increases.
- An effect of the SER and tank on the detection of fault is introduced and the fault factor characteristics are obtained in the presence and absence of a SER and grounded tank.
- The absolute difference between the fault factor characteristics in the presence and absence of the SER and tank is around 0.013 for different percentage of faults.

Efficacy of the developed methodology is validated under practical cases which involve the SER, grounded inner core and grounded tank.

Frequency response analysis of a healthy winding and faulty winding at first resonance frequency is required to detect the inter-turn fault in the winding by measuring impedance over the wide frequency range. Also, the presence of SER, grounded tank housing and grounded inner core is included in the measurement to check

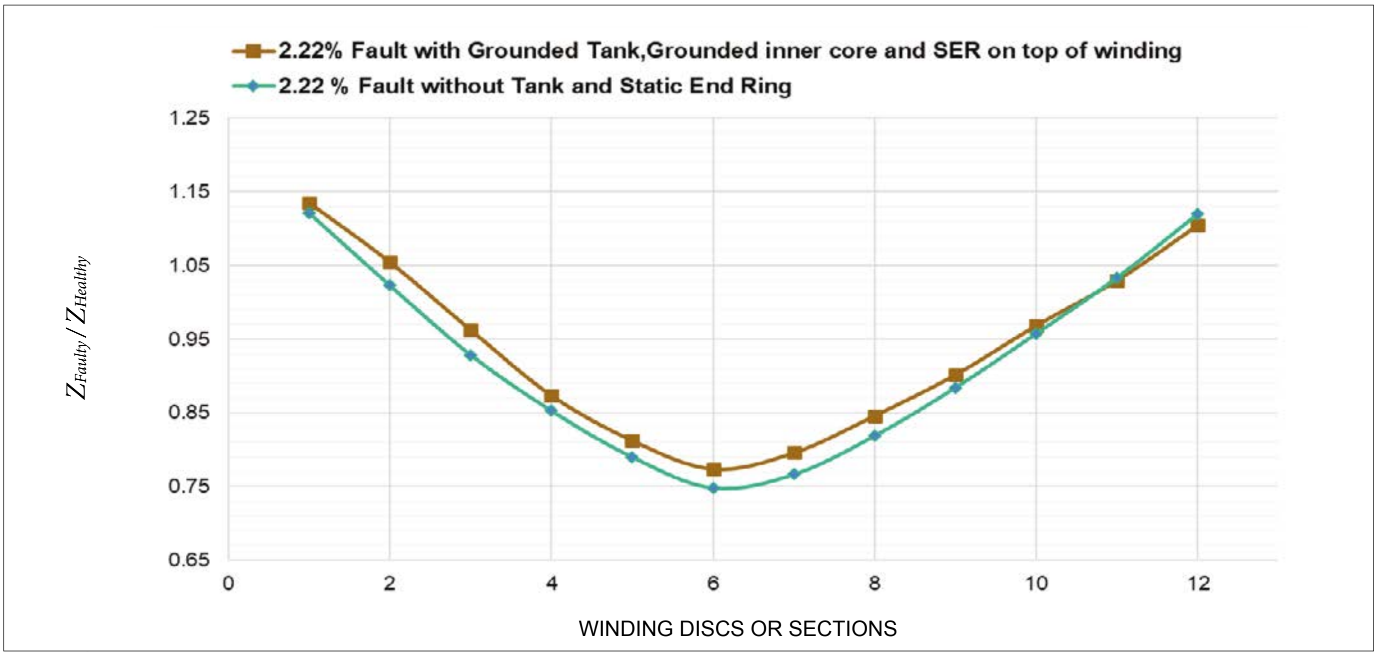


Figure 10. Fault factor vs winding disc or sections for 2.22 % inter-turn fault in continuous disc winding in the presence and absence of SER and tank

the influence of the winding distributed parameters on the detection of the fault. The corresponding flow chart for detection of fault is shown in Fig. 11.

Conclusion

The methods for the detection of the inter-turn fault in a continuous disc winding and layer windings are developed by using sweep frequency response analysis through the transformer winding circuit modelling and impedance mea-

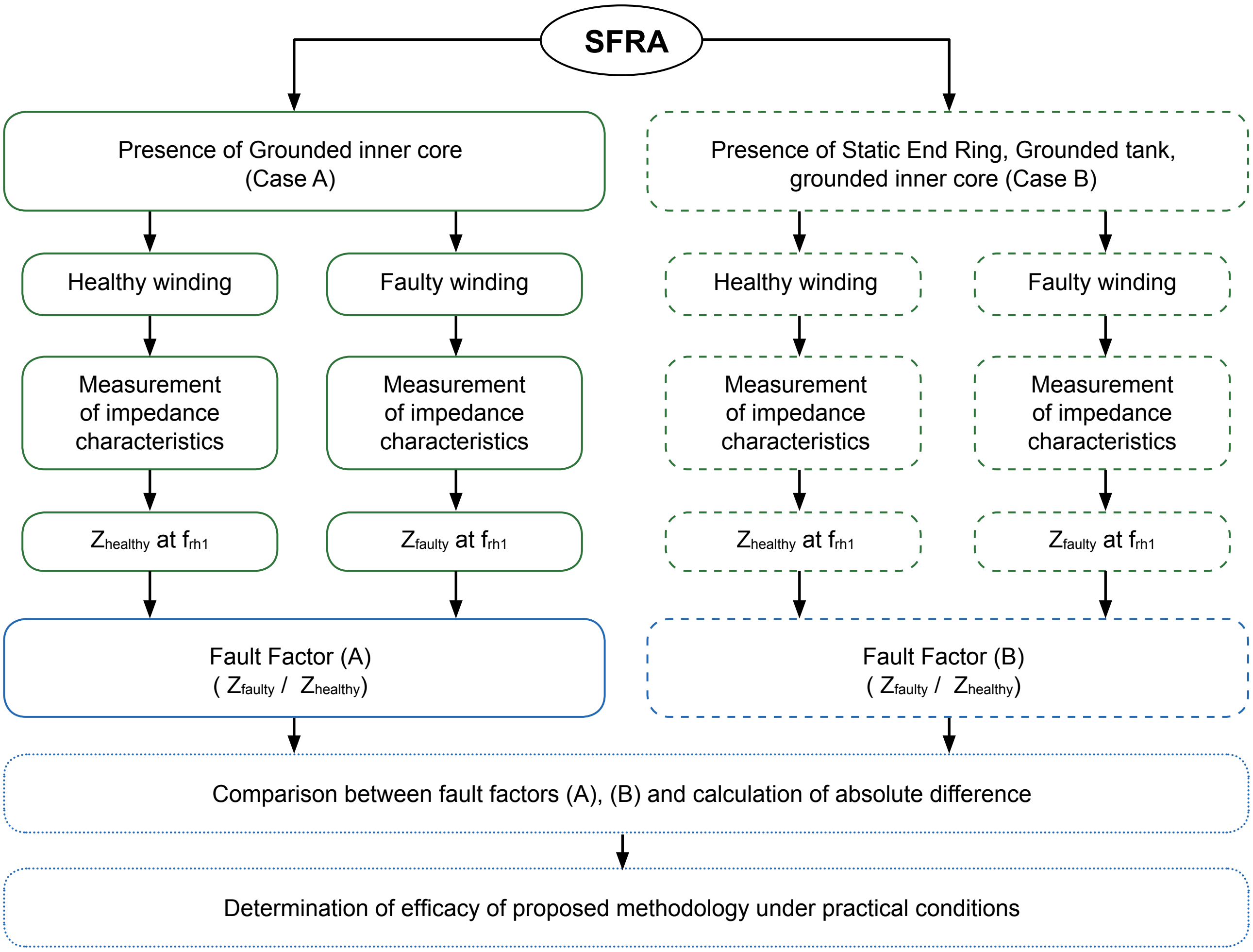


Figure 11. Flow chart for detection of a fault in the presence and absence of grounded tank grounded inner core and SER

Efficacy of the SFRA methodology is validated under practical cases which involve the SER, grounded inner core and grounded tank for different types of transformer windings

surement over a wide frequency range.

The proposed methodology provides a better insight into the detection of the fault in the winding through fault factor characteristics. Also, the effect of the grounded inner core, grounded tank and SER on top of the winding is included in the existing measurement setup to check the influence of the winding distributed parameters, such as shunt and series capacitances, on the detection of the fault.

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Author

Manojmohan Subramanian completed M.Eng. in High Voltage Engineering from College of Engineering Guindy, Anna University Chennai, India, B.Eng. in Electrical and Electronics Engineering from Thiagarajar College of Engineering, Madurai, and Diploma in Electronics and Communication Engineering. Presently he is working as an Energy and Utilities Consultant. He has also been working as a Systems Engineer at Tata Consultancy Services and British Telecommunication, UK. Today he is an active member of IAENG Hong Kong, IRED NewYork, ITEEA, and NASSCOM. His research interests include transformer fault diagnosis and condition monitoring, frequency response analysis of transformers, characterization of transformer insulation, power transmission and distribution, smart grid, deregulated energy market, advanced metering infrastructure, energy data management, applications of artificial intelligence, and data analytics for utilities.