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Understanding SFRA Results Using Transformer Model with Simulated Faults

Sharin Ab Ghani, Mohd Hambali Roslan, Musa Yusup Lada
& Mohd Shahril Ahmad Khiar

ABSTRACT

Sweep Frequency Response Analysis (SFRA) is well known power transformer diagnostics device which capable on detected faults/changes either electrical or mechanical. However the challenges are on understanding the SFRA results for the newcomers' engineers. If wrong, mislead interpretation of SFRA results would arise. Inline of this matter, five transformers model with simulated faults have been developed. The faults are; Core Damage, Shorted Turns, Open Circuit, Radial Deformations (Hoop Buckling) and Axial Displacement. These faults are designed to imitate the actual faults occurred in power transformer. Hence, the SFRA is then applied to the models to visualize the changes of SFRA results. In fact it create a clear understanding of the SFRA results changes with referring to which faults occurred.

Index Terms— Electrical Fault, Frequency Response Analysis (FRA), Mechanical Fault, Transformer.

INTRODUCTION

Power transformer is typically designed to coherent with mechanical forces either from in service events or during transportation, such as lightning and faults [1,2]. Once the power transformer damaged, no matter it is only a small damage, it may affect the power transformer capability to withstand a short circuit fault. The mechanical force depends on the configurations of the winding [3,4]. In the transformer, it is considered to have a complex combination of RLC components. It was contributed by the resistance of the copper winding, inductance winding, and capacitance from the insulation layers between coils, winding, winding and core, core and tank, and vice versa. Fig. 1 illustrates equivalent circuit with RLC components. The basic concept of SFRA measurement is mainly come from the transfer function concept where it is based on the ratio of voltage/current output to voltage/current input. The generated signal is a sinusoidal voltage with sweeping frequency between 20 Hz and 10 MHz [5,6]. The frequency response gain from the measurement is basically representing a whole complex R-L-C network of a transformer as a Device under Test (DUT) and it will be illustrated in bode plot diagrams; consists of magnitude (dB) and phase (deg) [7,8]. Fig. 2 and 3 shows the connection setup of SFRA device and the graphical results from it respectively.

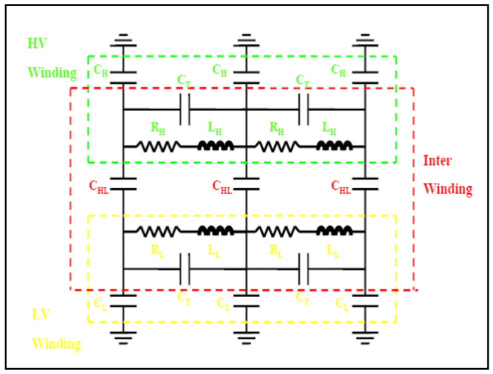

Fig. 1: Equivalent Circuit with Combination RLC Components[6].

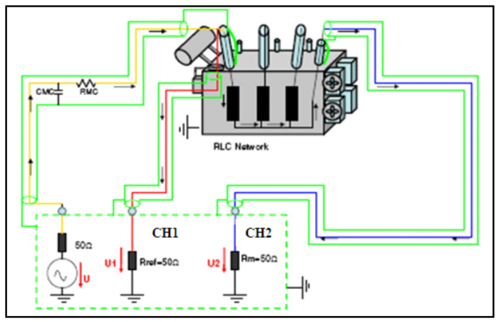

Fig. 2: Connection Setup of SFRA device to the tested transformer [8].

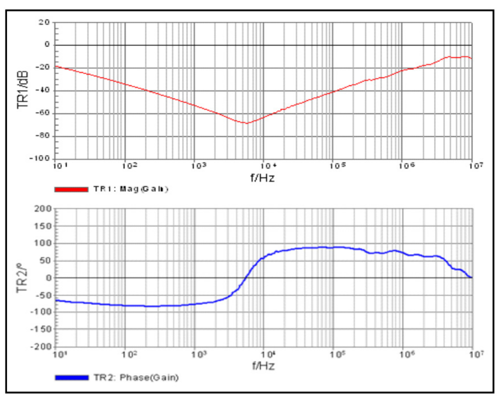

Fig. 3: Graphical Result from SFRA Measurement; upper is magnitude response (dB) and below is phase response (deg).

Short Frequency Ranges of SFRA

Typically, SFRA will produce a magnitude response for the transformer under test in frequency domain, which is shown the correlation between each ranges of the frequency and the transformer transfer function [9]. The transfer function will act as an indicator for the response from each combination parameter inside the transformer. Basically in this paper, the sweep frequency will be generated between 20 Hz and10 MHz. Therefore according to [10], decided to use three ranges of frequency which are defined to indicate different types of faults. In Table 1 shows the elements that are potentially affected by mechanical and electrical faults and the frequency ranges for each part.

Table 1: Frequency Ranges Used In SFRA Interpretation

Frequency Ranges	Sensitive to Elements
Below to 10 kHz (Low Sub Band)	This range affected with the transformer core and magnetic circuits are found.
5 kHz to 500 kHz (Middle Sub Band)	In this range, affected with radial geometrical movement between windings are detected.
400 kHz and above (High Sub Band)	In this range, axial deformations of each single are detectable.

Transformer Models With Simulated Faults

The simulated faults transformer is a single phase step down transformer with 432 turns at the high voltage transformer winding (primary side) and followed with 86 turns at the low voltage transformer winding (secondary side). The transformer will step down the voltage from 240V (Vp) to 48V (Vs).The simulated faults are applied to the low voltage (LV) winding whilst SFRA are measured on the high voltage (HV) winding. Figure 4 shows all types of simulated faults transformer including the healthy transformer developed for this research.

Research Results and Discussions

In this paper, all the SFRA measurement results obtained from the single phase transformer have been simulated with mechanical and electrical faults and also the healthy transformer (reference) are described. For this measured transformer, Fig. 5 until Fig. 11 illustrates the SFRA results which are related to healthy trans former, electrical faults (shorted turn, core damage, open circuit) and mechanical faults (radial, axial), respectively.

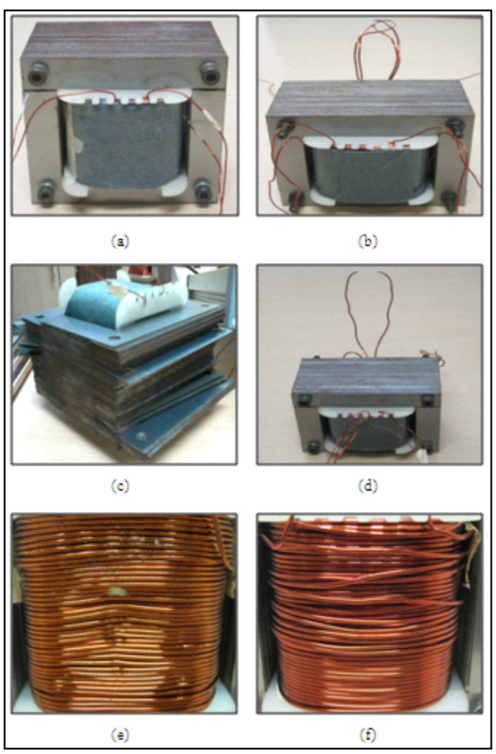

Fig. 4: Transformer Model for each faults (a) Healthy Transformer, (b) Shorted Turns, (c) Core Damage, (d) Open Circuit, (e) Radial Deformations and (f) Axial Displacements Fault.

SFRA Results

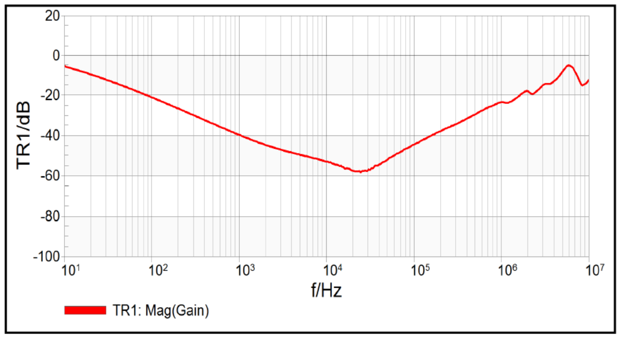

Fig. 5: Healthy Transformer (HV Winding).

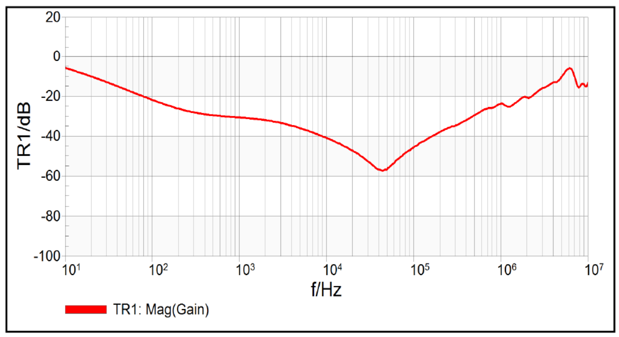

Fig. 6: Shorted Turn Fault (HV Winding).

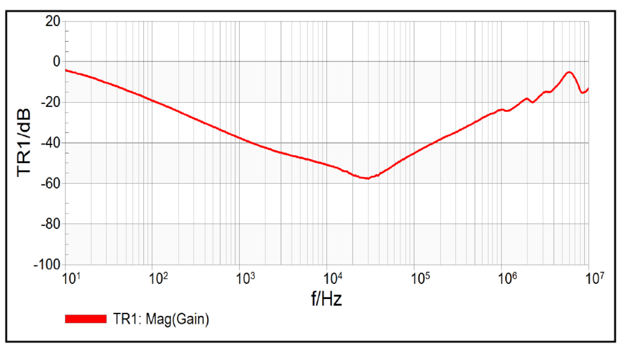

Fig. 7: Core Damage Fault (HV Winding).

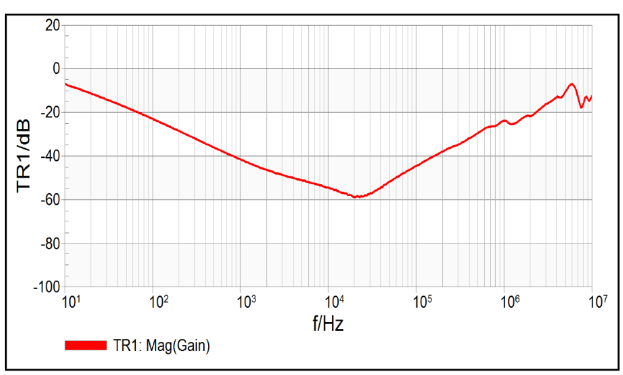

Fig. 8: Open Circuit Fault (HV Winding).

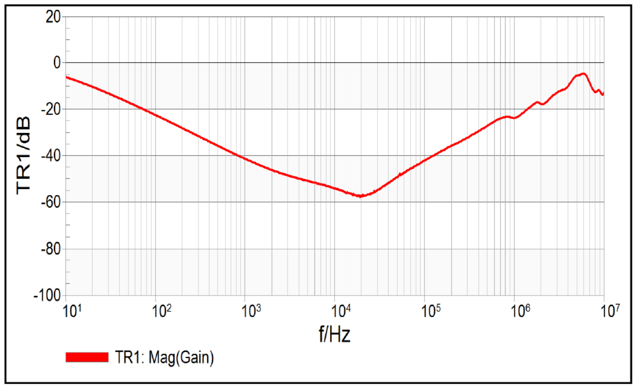

Fig. 9: Radial Deformation (HV Winding).

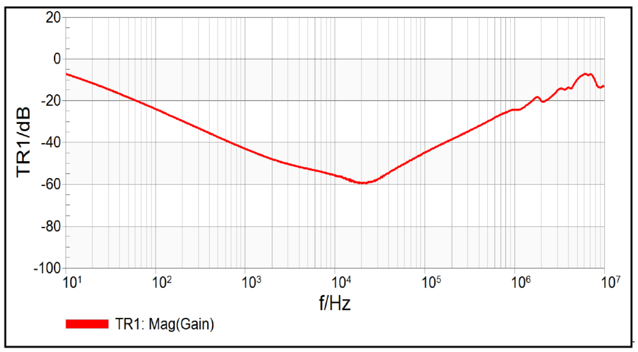

Fig. 10: Axial Displacement (HV Winding).

RESULTS DISCUSSION

To have a clear view on defining the SFRA results characteristics, correlation coefficient function (CCF)equation is used stated in Eq. (1). It is a well-known statistical indicator that indicated relationship between two data sets [11,12]. In this section, the faulty SFRA results data are compared with healthy SFRA results. Table 2 indicates deviation of SFRA results from healthy to the defected transformer. Description of the CCF results in Table 2 is based on selected frequency sub-bands stated in Table 1. In frequency range between 10 Hz – 10 kHz merely for electrical faults (core, shorted and open faults). Meanwhile 5 kHz to 500 kHz is for mechanical faults (radial deformation) and 400 kHz to 10 MHz is for (axial deformation).

Table 2: CCF Results from Comparison Between Healthy and Damage Transformers for Selected Sub Bands

Type of Faults	Measured side of winding	Selected Frequency Sub-Bands		
		10 Hz to 10 kHz	5kHz to 500kHz	400kHz to 10MHz
Core	HV	0.9999	0.9895	0.9997
Shorted		0.9757	0.7072	0.9927
Open		0.9999	0.9976	0.9801
Radial		0.9999	0.9891	0.9920
Axial		0.9998	0.9934	0.9812

Core fault: This experimental study concerns a fault that was simulated on the single phase transformer which has been simulated with core damage faults. The fault is simulated by rearrange the E-I iron core and displace the core in a wrong direction and place. This is intended in order to simulate the real core damage that might determine from the real life transformer fault. The CCF numerical value is 0.9999 in frequency 10 Hz to 10 kHz. From this, it shows that HV winding has a low deviation with 0.01%.

Shorted turn fault: This experimental study concerns a fault that was simulated on the single phase transformer which have been simulated with shorted turn faults. The fault is simulated by shorting the 79^{th} and 80^{th} turn of the LV transformer winding. This is intended in order to simulate the real shorted turn fault that might determine from the real life transformer fault. The CCF numerical value is 0.9757in frequency 10 Hz to 10 kHz. From this, it shows that HV winding has a deviation with 2.43%.

Open winding fault: This experimental study concerns a fault that was simulated on the single phase transformer which has been simulated with open circuit faults. The fault is simulated by cutting one of the turns of LV transformer winding. This is intended in order to simulate the real open circuit fault that might be determined from the real life transformer fault. The CCF numerical value is 0.9999in frequency 10 Hz to 10 kHz. From this, it shows that HV winding has a deviation with 0.01%.

Radial deformation fault: This experimental study concerns a fault that was simulated on the single phase transformer which have been simulated with radial deformations (hoop buckling) faults. The fault is simulated by compressing the LV transformer winding by using a clamp. This is intended in order to simulate the real radial deformations fault that might be determined from the real life transformer fault. The CCF numerical value is 0.9891in frequency 5kHz to 500 kHz. From this, it shows that HV winding has a deviation with 1.09%.

Axial deformation fault: This experimental study concerns a fault that was simulated on the single phase transformer which have been simulated with axial displacement faults. The fault is simulated by making the LV transformer winding to shift each other and displaced from its original place. This is intended in order to simulate the real axial displacement fault that might be determined from the real life transformer fault. The CCF numerical value is 0.9812in frequency 400kHz to 10 MHz From this, it shows that HV winding has a deviation with 1.88%.

CONCLUSIONS

In this paper, SFRA that being used in this experimental study has proven to be valuable diagnostic tools in order to detect core and winding movements and also other faults which affect the impedance of the transformer. It has been used in this SFRA measurement test setup which started in low frequency sub band until high frequency sub band. As the bandwidths of the frequency have been divided into three parts of sub bands, each of the parts has their valuable meanings.

After performing the experimental work, it is proven that the proposed sub bands and the real transformer with simulated faults have related to each other. The single phase transformers models are proved to have an ability to simulate the electrical and mechanical faults. In conclusion, the single phase transformers modelled with simulated mechanical and electrical faults are design completely. Finally, the objective for this project is carrying out successfully.

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Sharin Ab Ghani
Mohd Hambali Roslan
Musa Yusup Lada
Mohd Shahril Ahmad Khiar
Faculty of Electrical Engineering,
Universiti Teknikal Malaysia Melaka (UTeM),
Hang Tuah Jaya,76100, Durian Tunggal, Melaka, Malaysia