Analysing the Faults of a Single-Phase Auto-transformer Coils Using Sweep Frequency Response Analysis Approach

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Abstract

There are many methods that have recently been improved to determine the condition monitoring in most types of single and three-phase transformers. One of these methods is a new method called Sweep Frequency Response Analysis (SFRA), M5300 model. The main concept of such a technique is by adding an amplitude of a wave type of sinusoidal under varied frequencies. The resulting new waveform can be compared with the main waveform. In this paper, there are three types of failures in a 344W single-phase autotransformer consisting of two coils, each containing 100 turns. The first detected failure is the coil movement fault, which is generated by winding deformation through the modeled transformer. The second is the fault caused by a short circuit turn. This type of auto-transformer coil failure gives movement at low, mid, and high frequencies. Finally, a fault is caused by the axial displacement of coils. This type of fault is caused by a short circuit turn across these coils. But in order for the M5300 to generate the necessary results, the Adobe software program has to be attached in order to detect all these kinds of problems. The study of the experienced single-phase auto-transformer coils' frequency, magnitude, impedance, and admittance has been simulated by adding inductors and capacitors to the existing transformer. The 344W autotransformer's results analysis ranged from 100Hz to 2Mz. Furthermore, using both Adobe software and the M5300 device, the tests for 2, 3, and 4 SFRA were planned and simulated.

Keywords: coils; autotransformer; turns; windings; SFRA-M5300; fault; frequency

الملخص:

هناك العديد من الطرق التي تم تحسينها مؤخرًا لتحديد الاعطال التي تحدث في معظم أنواع المحولات أحادية وثلاثية الطور . إحدى هذه الطرق ، هي طريقة جديدة تسمى تحليل استجابة تردد الاجتياح (SFRA) ، نموذج M5300. يتمثل المفهوم الرئيسي لمثل هذه التقنية في إضافة سعة لنوع موجة جيبية تحت ترددات متنوعة. يمكن مقارنة شكل الموجة الناتجة مع شكل الموجة الرئيسي. في هذا البحث، كان هناك ثلاثة أنواع من الاعطال في محول ذاتي أحادي الطور بقوة 344 وات يتكون من ملفين ، كل ملف يحتوي على 100 لفة. أول عطل تم اكتشافه هو عطل حركة الملف ، والذي ينتج عن تشوه اللف من خلال المحول النموذجي. والثاني هو الخطأ الناجم عن دوران ماس كهربائي. يعطي هذا النوع من الاعطال في المحولات حركة بتردد منخفض. أخيرًا، يحدث عطل بسبب الإزاحة المحورية للملفات و السبب الرئيسي لمثل هذا النوع من الاخطاءهو دوران ماس كهربائى بين الملفات. ولكن لكي يتم توليد نتائج جهاز تحليل الاشارة M5300 النتائج الضرورية ، يجب إرفاق برنامج Adobe من أجل اكتشاف كل هذه الأنواع من الاعطال. من خلال إضافة المحاثات والمكثفات إلى المحولات الحالية، تمت محاكاة دراسة تردد لفائف المحولات الآلية أحادية الطور ذات التردد المنخفض والعالي والحجم والمقاومة والمعاوقة. تراوحت نتائج تحليل اعطال المحول الاحادي الطور 344 واط من 100 هرتز إلى 2 ميجا هرتز ، بالإضافة الي انه وباستخدام كل من برنامج Adobe وجهاز M5300، تم تخطيط ومحاكاة اختبارات الثنائية والثلاثية والرباعية للتعرف على شكل العطل وذلك بمقارنته بالموجة الاساسية.

1.Introduction

In the past decades, improvements and optimizations in transmission and distribution energy structures have not been advanced efficaciously. Nonetheless, the capability to attach the transmission traces and generators is similar to the distribution systems, which is the second element that might distribute effective power to the numerous hundreds through this strength gadget. Power transformer faults are difficult to be detected. As a result, the failure of a gadget like an energy transformer is a large hassle, which needs to be analysed. Basically, strength transformers may be broken due to over-voltage levels, overloading, and no longer investigating it for a long time. Consequently, most of these problems can normally affect the electricity transformer operations, leading to instability in energy systems. The SFRA with Adobe software program simulates several faults, including open circuits, and short circuits, while taking high-frequency depending on the generated curve, which the equivalent circuit parameters should be analyzed. Inductance (L), insulating resistance (Rs), and capacitance (C) are the parameters that are suggested to be distributed uniformly. The suggested method simulates the SFRA test to detect faults, which occurred in the coils of a single-phase auto-transformer with a model containing 3 discs only.

Electricity transformer faults can appear at any second. As a result, if there are not any illustrations or powerful techniques used to solve such issues, the electricity transformer is probably broken, hence it must be a new unique method created to detect the windings characteristics of energy transformers. In this paper, a new technical approach called sweep frequency reaction evaluation (SFRA) has been used to detect the winding faults of coils (100 turns each) of a 344W single-phase autotransformer. This method is used to test developments of windings faults regarding their frequency reaction. In addition, identifying the characteristics of used coils (100 turns) such as impedance, admittance, phase angle, and magnitude (dB).

2.Sweep frequency response analysis features and applications

Sweep Frequency Response Analysis (SFRA) is a technique used to monitor the condition of high-priced power equipment. The M5300 SFRA is used to measure the passive element (RLC) frequency response. For example, the transformer winding impedance over a large range of frequencies can be measured easily using SFRA equipment as shown in figure (1). This experiment is primarily designed in order to diagnose transformer incipient faults. The results obtained are matched against a reference data set and differences can be used to determine the type of fault and its location as well [1-3].

Fig.1. M5300 SFRA device [8].

SFRA is a non-intrusive electric test that keeps away from beginning a transformer tank to assess its electrical and mechanical situation. Starting the tank will purpose oil degasification and dehydration, which can reduce the effect on device operation and loss of delivery to clients. Therefore, using M5300 SFRA can save tens of millions of ringgits in timely upkeep. It could deliver valuable statistics concerning the mechanical and electrical situations of the transformer [4]. Essentially, short circuits in winding reasons the electrical length of the winding to be decreased. Consequently, the winding herbal frequencies shall be modified or remain nearly unchanged if the short circuit fault occurs. However, this operation is a critical asset that can be used as the principal sign of the winding short circuit fault. In the case of core-typed three-section transformers, the internal short circuit fault will cause an in-depth growth of the first antiresonance in the low frequency (LF) reaction. The primary antiresonance frequency is generally from hundreds of Hz up to a few kHz. However, it is able to increase notably depending on the severity of the short circuit faults as proven determined in figure (2) below. Although the growth of the frequency isn't always totally a demonstration of a short circuit happened just in the winding beneath dimension. However, this is because the scenario impacts all first antiresonance responses of windings on the same core as illustrated in figure (2) below [4].

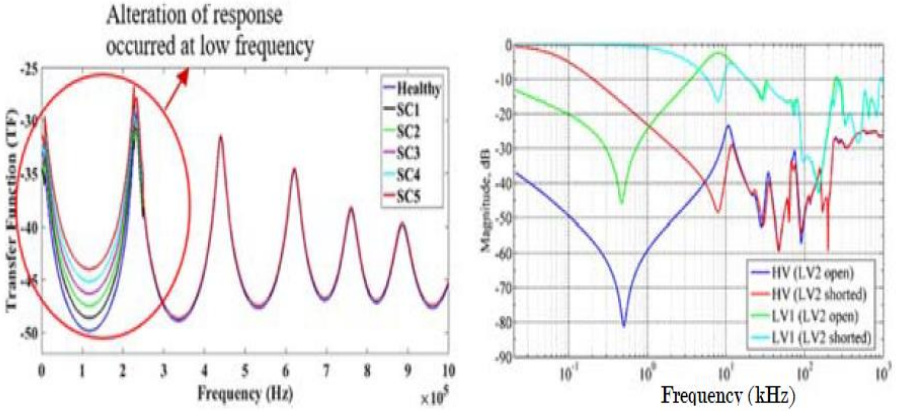

Figure.2. Impact of short circuit fault on the SFRA signature [4].

One of the maximum comprehensive measurements of transformer deformation is Sweep Frequency response analysis (SFRA), that is detecting the deformation mechanic shape within the transformer. SFRA is an effective tool, it can deliver complete information on the winding mechanical structure and additionally the center and clamping structure. In addition, these operations are critical as even a little winding and core deformation within the winding and core can spread right into a failure of the transformer below fault circumstance. Center harm may be caused by shrinking from a thin transformer, while harm's middle is due to the quick circuit. SFRA approach discusses approximately detecting the deformation mechanic transformer. It is a diagnostic gear that may get a demonstration from a mechanic fault like a core or winding motion, transformer, and electric-powered fault. For instance, short–circuits and partial discharge. Based on the injected enter sign, there are different kinds of SFRA such as impulse voltage-primarily based evaluation response frequency, sinusoidal sweep frequency reaction evaluation, and many others [5].

3.SFRA Measurement

There are two incredible environments for the application of the sweep frequency response method within the production unit and in the discipline. The techniques and precautions used to generate a superb length are the same in each case. However, there can be a distinction in motivation for the checks in every category. Motives to apply SFRA in manufacturing facility surroundings encompass first-rate guarantee, baseline reference, relocation, and commissioning coaching. Motives to use SFRA in a place surrounding consist of relocation and commissioning validation and post-incident such as lightning, fault, short circuit, seismic event, and many others [5].

Frequency response analysis is the quantitative method of the output spectrum of a gadget or tool in response to a stimulus. It can be used to measure values and segments of the output as a function of frequency, in the evaluation of the transformer entry. The ordinary implementation of this operation is based on introducing a variable frequency sinusoidal sign and measuring the value and phase at the alternative side of the element measured. A transformer can be considered a complicated network of inductances and capacitances. This network is predicated totally on mechanical/electric parameters; hence the frequency response of a particular transformer acts as a fingerprint of this transformer and ought to stay equal inside the direction of its life. The SFRA effects are primarily based completely on the assessment of the fingerprint through the years, and therefore, any parameter that could have an effect within the curve needs to be averted as the ones may need to inadvertently be understood as a transformer hassle. As a preferred guiding principle, shorted turns, magnetization, and other troubles associated with the modified form of the curve inside the lowest frequencies. Medium frequencies constitute axial or radial movements inside the windings and excessive frequencies imply troubles concerning the cables from the windings to the bushings. Figure (3) illustrates an instance of low, medium, and high frequency generated by SFRA, in addition to SFRA (M5300) equipment. Furthermore, the use of M5300 for creating the coil movement is shown in figure (4) [5,6,9].

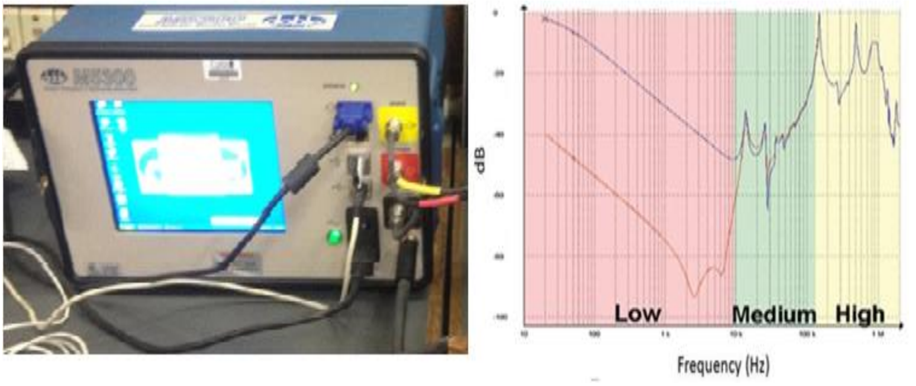

Fig.3. M5300 SFRA analyzer & an example of low, medium, and high frequency [7].

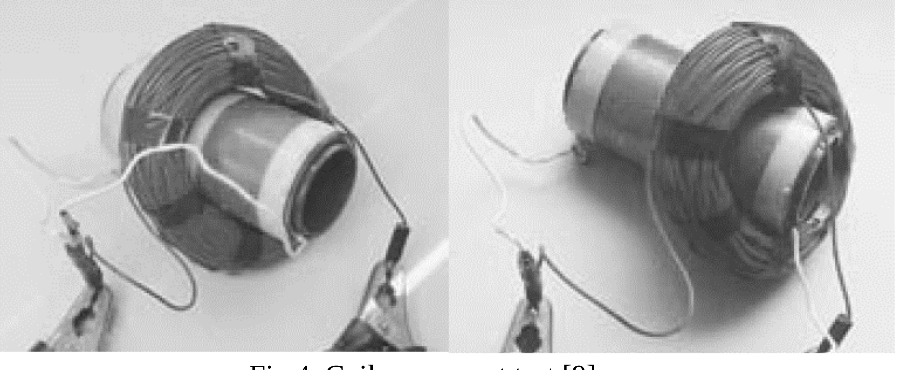

Fig.4. Coil movement test [9].

4.344W Autotransformer Model

Recently, there are several methods to come up with a transformer model. In this paper, the transformer is analyzed using assumed parameters. Figure (5) below illustrates the components of the transformer model, which are $(R_1\&R_2), (L_1\&L_4)\ and\ (C_1\&C_3)$.

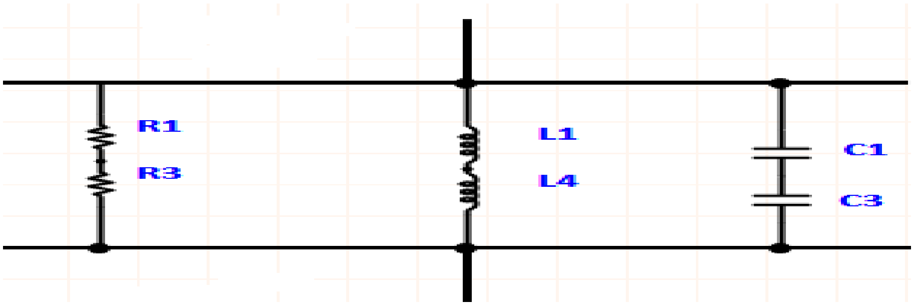

Fig.5. 344W autotransformer model.

5. Fault analysis experiments

The M5300 SFRA device become utilized to generate alerts among 20HZ and 2MHZ in this test. The experiment's essential intention is to determine the 1-phase autotransformer's fault types, which appear as waveforms of the value of the transformer such as impedance, attenuation, and voltage degree. The SFRA approach will be used to emulate all of these parameters' waveforms.

Figure (6) below illustrate how to examine coil faults of a 344W - 1-ph autotransformer using the SFRA type of M5300. The 1-phase autotransformer is linked to the SFRA tool, which is then connected to the computer for viewing waveforms and findings of any types of faults. In fashionable, the SFRA analyser has input and output channels that can be coupled to both primary and secondary windings of a single-phase autotransformer, with the transformer being examined whilst it's far out of service.

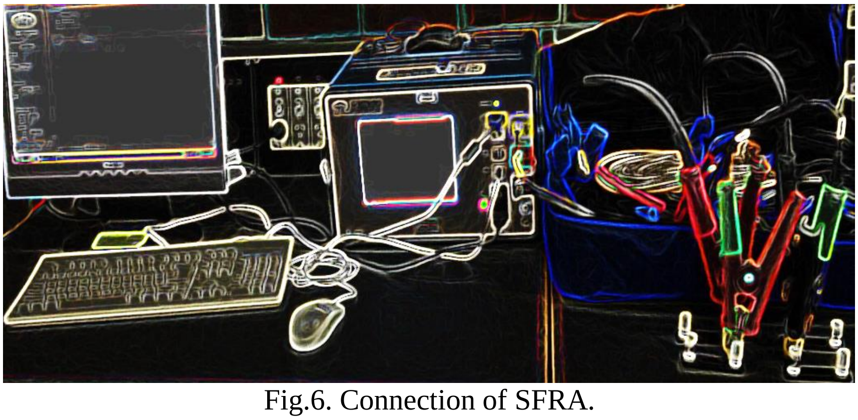

Fig.6. Connection of SFRA.

This test is generated to look at the faults of the autotransformer coils. Essentially, a one-phase autotransformer becomes tested with an SFRA M5300 connected to a computer through the Adobe software program to determine winding parameters and also the fault types.

5.1 Experiment.1 Two SFRA of two coils (100 turns each)

Figure (7) below illustrates the SFRA laboratory test used for checking out graphically the traits of two coils A and B. There were additional components, which are 1.66μFcapacitor and 5.3H inductor used for the test to get various waveforms outcomes. In this experiment, SFRA M5300 channels are connected with the coils. In addition, a PC is connected via an Adobe application to reveal the coil waveforms characteristics. The test is performed twice to compare the generated waveforms by the M5300. The expected fault is a type of coil movement due to the connected elements as illustrated in figure (4).

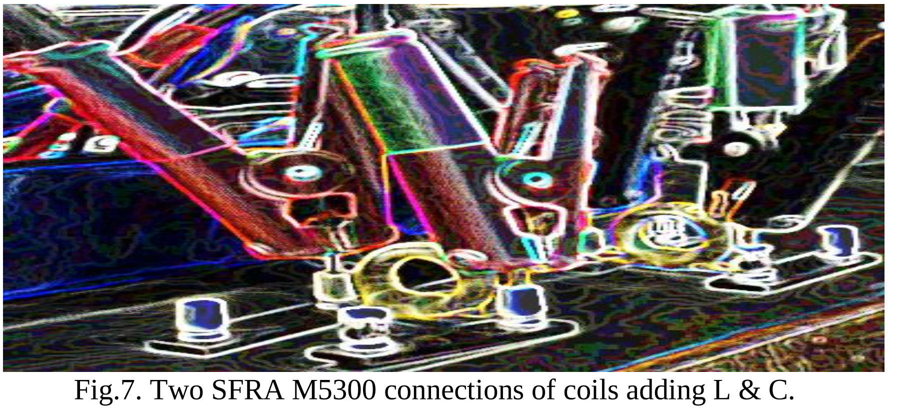

Fig.7. Two SFRA M5300 connections of coils adding L & C.

5.2 Experiment.2 Three SFRA of two coils (100 turns each)

figure (8) below shows the SFRA laboratory test used for generating the fault waveforms using three responses. In this experiment, there were 1.33μFcapacitor attached to the coils for getting different results. In addition, the expected fault is a type of short circuit fault. The test is performed three times to compare the generated waveforms by the M5300.

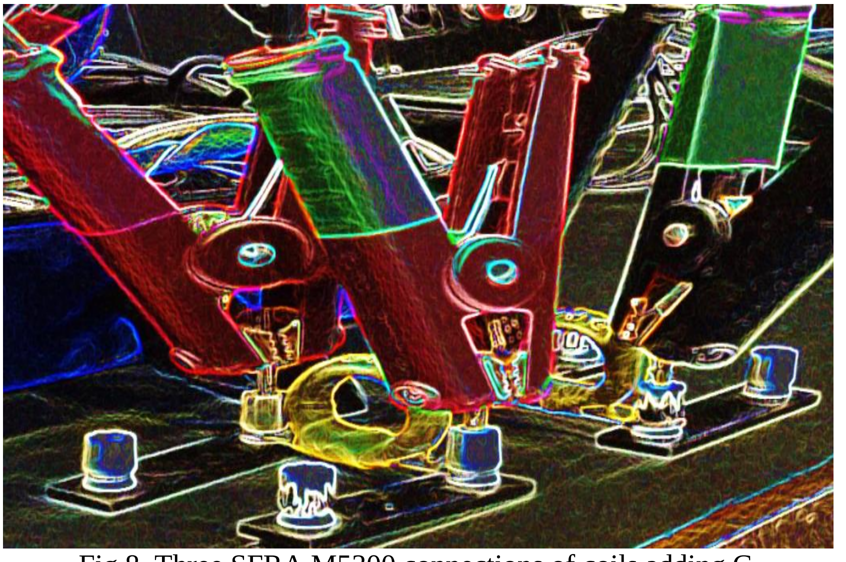

Fig.8. Three SFRA M5300 connections of coils adding C.

5.3 Experiment.3 Four SFRA of two coils (100 turns each)

Figure (9) below indicates that the SFRA laboratory experiment was used for determining the coil axial displacement fault. There an inductor of 3H is connected through the coils of the used autotransformer to get varied results. In this experiment, four SFRA using M5300 to determine the faults, which can be generated through impedances and admittances of the autotransformer coils.

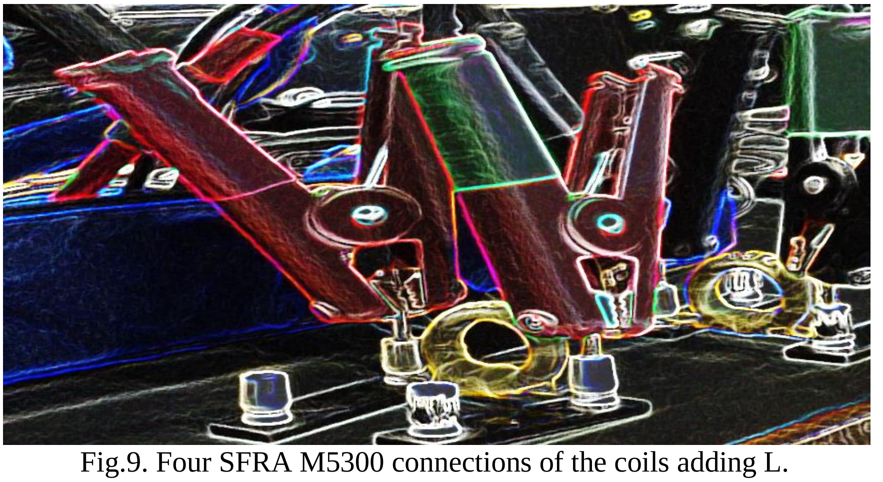

Fig.9. Four SFRA M5300 connections of the coils adding L.

6. Simulated Results & Discussion

6.1 Results and Discussion of Experiment (1)

Fig.10. Two SFRA on two-coil (100 turns each) result shows no significant windings variation between the frequency and magnitude.

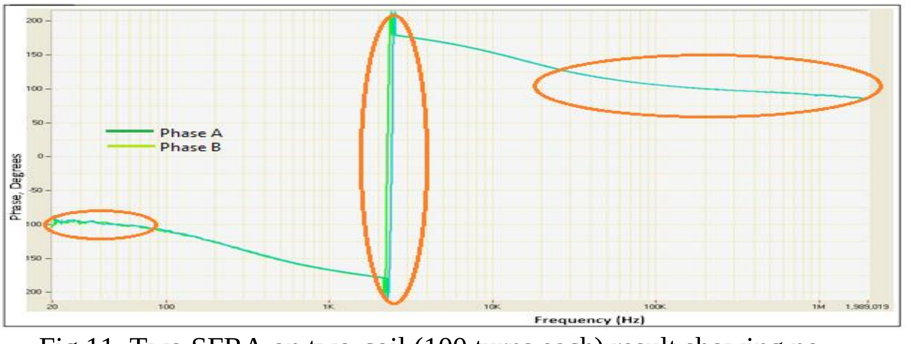

Fig.11. Two SFRA on two-coil (100 turns each) result showing no significant variation of windings between the frequency and phase.

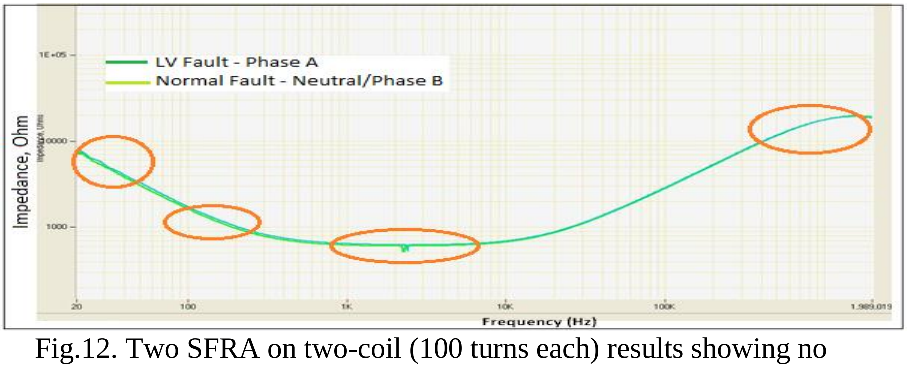

Fig.12. Two SFRA on two-coil (100 turns each) results showing no significant variation of windings between the frequency and impedance.

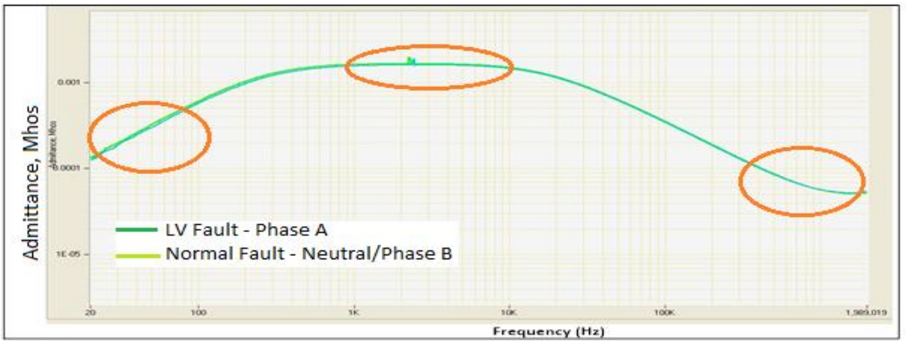

Fig.13. Two SFRA on two-coil (100 turns each) result shows no significant windings variation between the frequency and admittance.

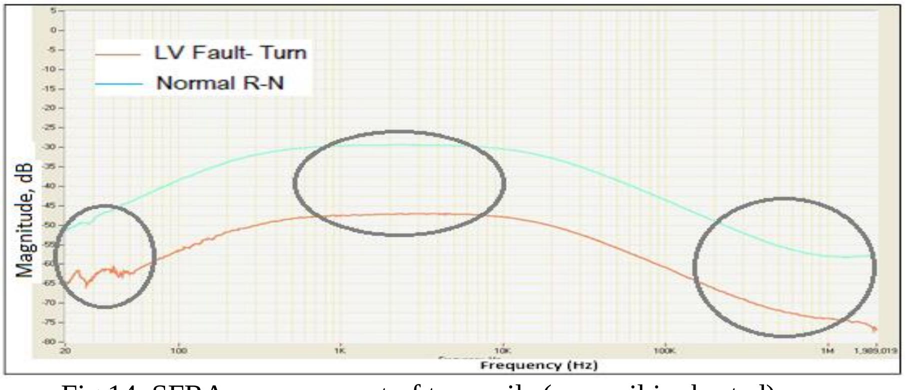

Fig.14. SFRA measurement of two coils (one coil is shorted) – magnitude Vs. frequency.

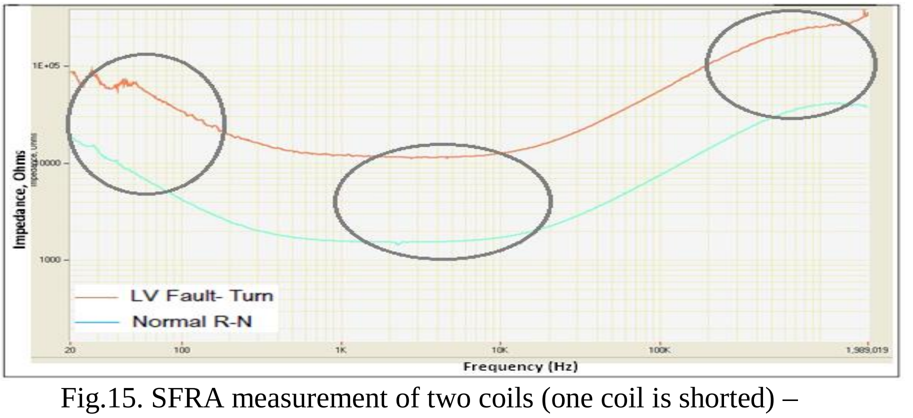

Fig.15. SFRA measurement of two coils (one coil is shorted) – impedance Vs. frequency.

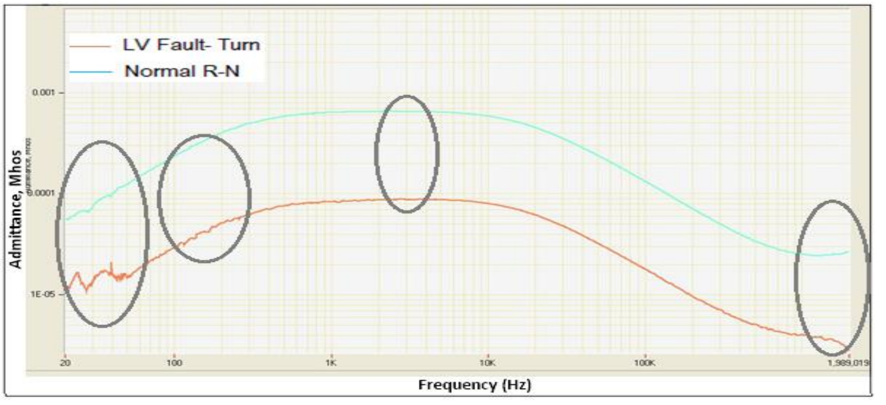

Fig.16. SFRA measurement of two coils (one coil is shorted) – admittance Vs. frequency.

This case can be divided into two parts which can be explained as follows.

Case1. According to figure (10), it can be clearly seen that the fault of coils is coil movement in both phase A and phase B are good phases and there is no change in the waveforms of both phases. The waveforms of both phases according to the relation between the magnitude and frequencies from Zero Herts up to about 2MHz is constant and has the same shape. In figure (11) both phases are almost similar to each other, but there is a very small change at low frequencies from (20Hz to 100Hz) due to adding a shunt capacitor through the coils. In addition, figures (12 & 13) illustrate the impedance and admittance Vs. frequency observing that the two coils are the same having the same waveform, hence these phases are both good phases.

Case.2 According to figure (14), it can be clearly seen that the fault of coils is coil movement in both phase A and phase B. These generated phases are bad phases because there is a big change in the waveforms of phase B. The waveforms of both phases according to the relation between the magnitude and frequencies from 20Hz to 2MHz were varied and had different shapes. In addition, figures (15 & 16) above, illustrate the impedance and admittance Vs. frequency observing that the two coils are having different waveforms, hence these phases are both bad phases.

6.2 Results and Discussion of Experiment (2)

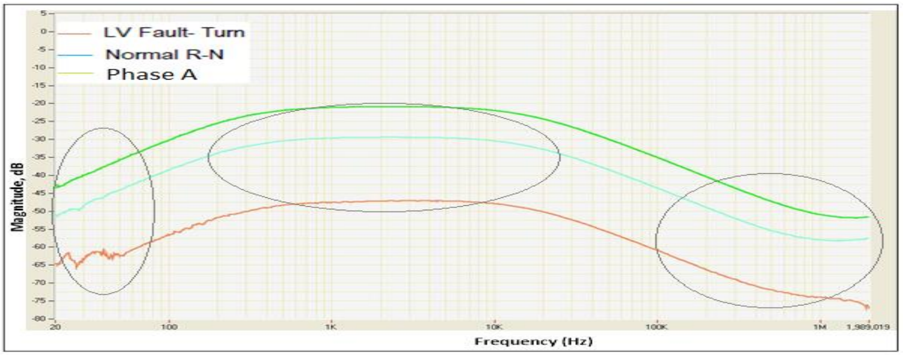

Fig.17. Three SFRA measurement magnitude Vs. frequency – phase A shorted.

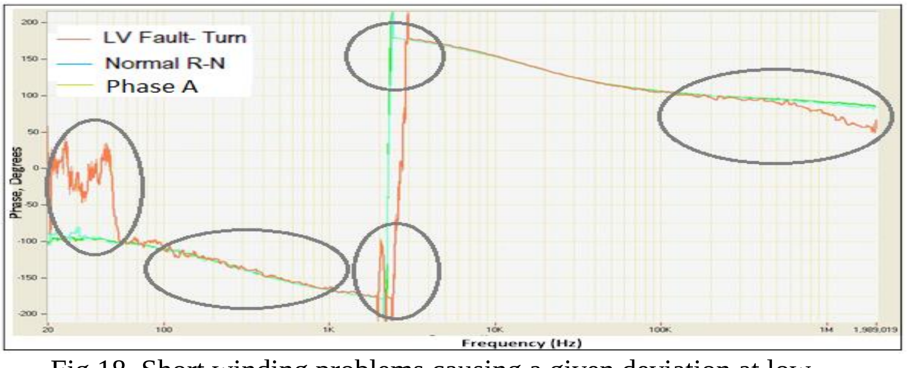

Fig.18. Short winding problems causing a given deviation at low frequencies.

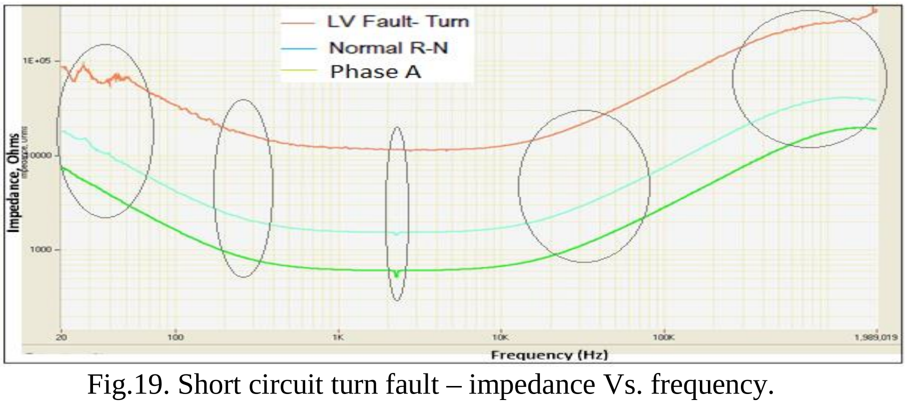

Fig.19. Short circuit turn fault – impedance Vs. frequency.

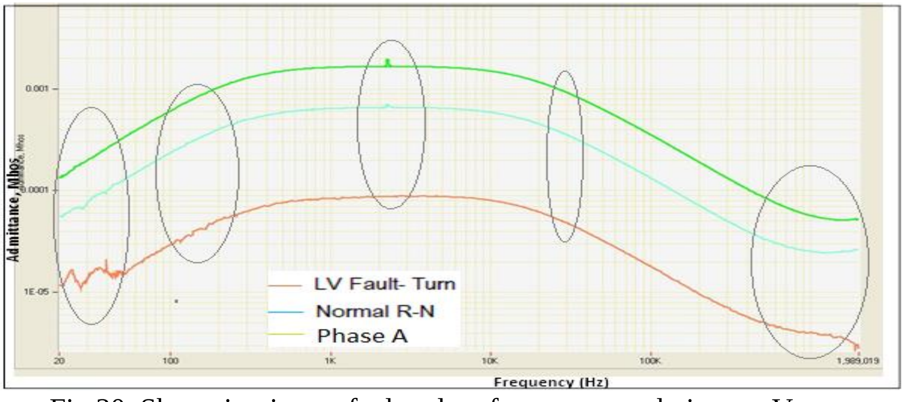

Fig.20. Short circuit turn fault at low frequency – admittance Vs. frequency.

Figure (17) above, shows that the short circuit (SC) caused a big change in the curves at low frequencies which was identified from 20Hz up to 100Hz. The short circuit fault created coil movement. Furthermore, the second resonance caused a minor change in the first resonance curve due to a short circuit turn fault. Based on figures (18 to 20) above, can be seen the short circuit is caused due to changes in the parameters of the coil by adding a capacitor element, which leads to an increase in the capacitance of the core of the transformer.

6.3 Results and Discussion of Experiment (3)

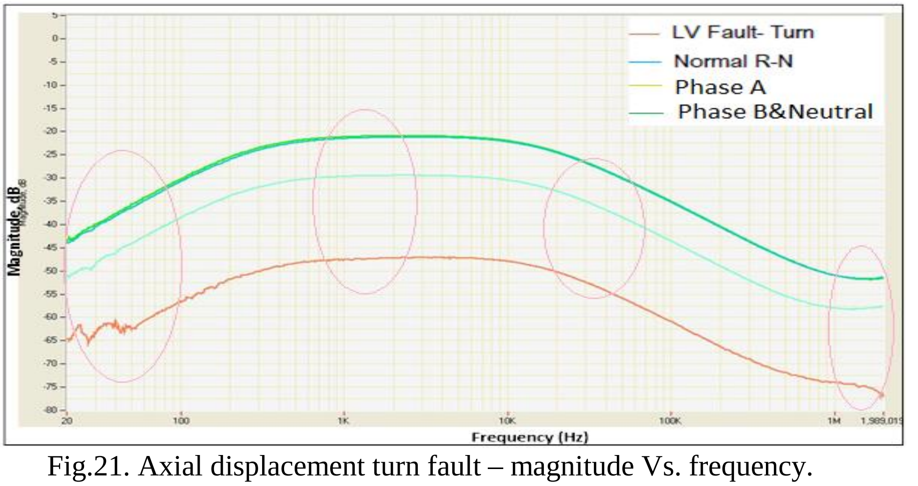

Fig.21. Axial displacement turn fault – magnitude Vs. frequency.

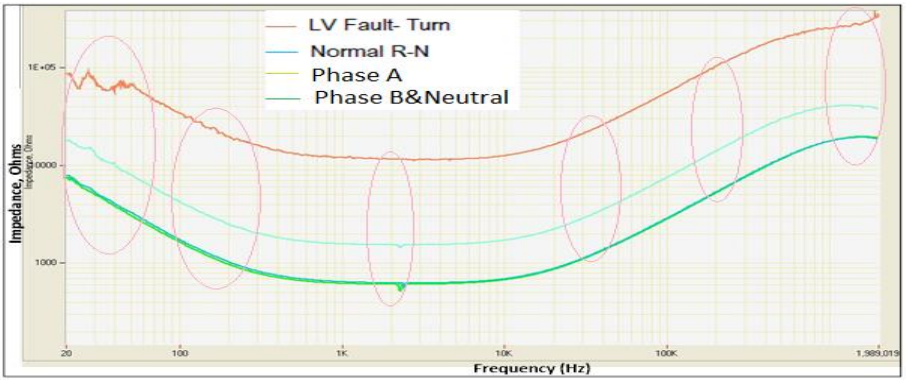

Fig.22. Axial displacement turn fault at phase A – Impedance Vs. Frequency.

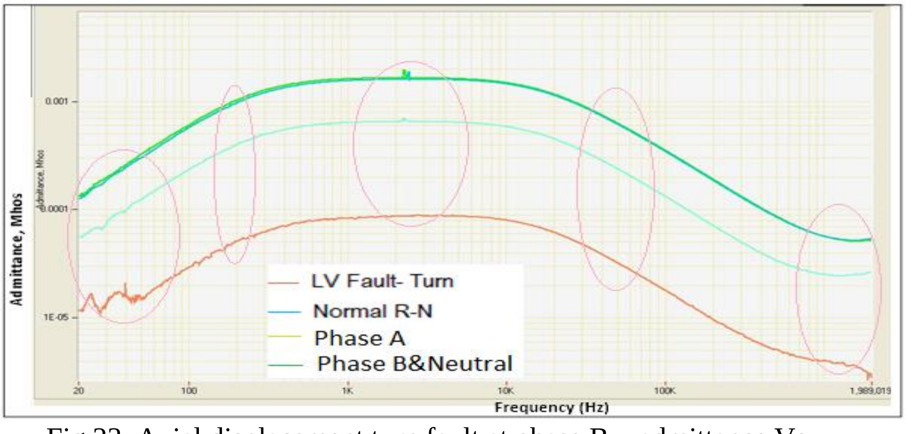

Fig.23. Axial displacement turn fault at phase B – admittance Vs. frequency.

Figure (21) illustrated above, illustrates the axial displacement at low voltage fault–turn means that disk3 and disk4 are moved axially at low frequencies from 20Hz to 125Hz. On the other hand, the displacement waveform cannot be seen at high frequencies.
From figures (22 & 23) illustrated above, it can be seen that the transformer equivalent circuit is more inductive, and the displacement appears at low and mid frequencies only due to coils displacement which is caused by the first and second resonance in transformer windings.

7.Conclusion

Sweep Frequency Response Analysis is one of the best methods for measuring the transformer's characteristics. It can be used to identify the components of failures on the transformer and also the failures that are caused by core movement and internal displacement. For the failure caused by coil movement, there was a bad and good phase in the analysed transformer. The failures caused by short circuit turns are due to the second resonance according to the resulting waveform. It is observed that the experiment done in the lab was very helpful to analyse all sorts of autotransformer failures.

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