Transformer Winding Radial Deformation Detection Using Scattering Parameters

Hasan A. Alehoseini
Dep. of Electrical eng.
Amirkabir Uni. of Tech.
Tehran, Iran
ali_alehosseini@yahoo.com

Maryam A. Hejazi
Dept. of Electrical Eng.
Amirkabir Uni. of Tech.
Tehran, Iran
akhavanhejazi@aut.ac.ir

Gevork B. Gharehpetian
Dept. of Electrical Eng.
Amirkabir Uni. of Tech.
Tehran, Iran
grptian@aut.ac.ir

Abstract—**The method of the on-line monitoring of transformer winding radial deformations using scattering parameters has been discussed in this paper. In this method, the signature of the transformer is the scattering parameters, which are calculated using high frequency simulation software and saved for further analysis as a base case. The new simulations can be compared with this case, to detect the radial deformation of transformer winding. Based on simulations of a simplified model of the transformer winding, it is shown that the proposed method can discriminate between the deformed and intact windings.**

***Index Terms*— Winding Radial deformation, On-Line Monitoring, Transformer, Scattering Parameters.**

I. INTRODUCTION

POWER transformers are an expensive and vital component of power system which their condition has a direct influence on the safety and reliability of the power system. Transformer winding failures account for 19 percent of the transformer failures [1]. Due to short circuits, mechanical forces mainly can cause axial displacement and/or radial deformation of transformer windings. These mechanical damages may not result in an immediate failure of the transformer, but the ability of transformer to resist against future dielectric and mechanical stresses may be highly decreased [2, 3].

Condition monitoring of transformers is desirable for increasing their availability, reducing consequential damage or catastrophic failure of power transformer. There are several transformer mechanical damages monitoring and diagnostic methods. Each method has its advantages and disadvantages [4, 5]. In recent years, several off-line methods such as Short Circuit test (SC) [2], Low Voltage Impulse (LVI) [5] and Frequency Response Analysis (FRA) [4] have been proposed for the detection of the winding deformation.

In the short circuit test method, the short circuit reactance is measured while the transformer is disconnected. In this method, the sensitivity of the reactance to the winding deformation is very low, and the type and the location of the mechanical damage in the winding cannot be determined [4].

In the FRA method, experimental approaches of comparison are: time-based, type based and construction-based. The FRA method can be used off-line and on-line [7, 8 and 9].

Compared to the off-line methods, an on-line method has the advantage of stationary installation and hence an improved reproducibility of the test. The merit of on-line monitoring methods over off-line methods is the prediction of the important fault before its occurrence.

In this paper, a new on-line monitoring method has been proposed based on the simulation of scattering parameter of the winding. This method, the same as FRA method, is based on the comparison of results. The simulation results have shown that the scattering parameter of the winding can be used as a fingerprint for the detection of the winding radial deformation.

II. SCATTERING PARAMETERS

The principles of this method are based on the measurement of the magnitude and phase of scattering parameters measured by several high frequency antennas.

The antenna used in the proposed method can be placed inside or outside of the tank. If the antenna is placed outside of the tank, then it has a dielectric window which forms a robust electrical aperture for sending and receiving very high frequency electromagnetic waves. Thus, using the proposed method the dielectric window on the tank of the transformer can be used for both, the partial discharge and winding deformation detection. An *N*-port microwave network is shown in Fig.1.

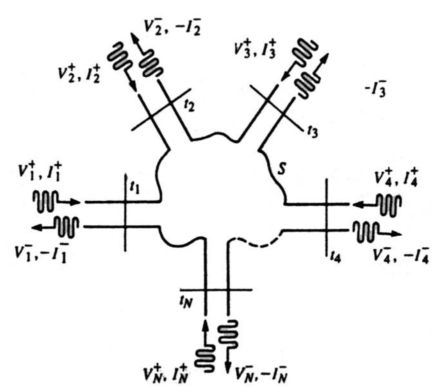

Fig.1: *N*-port network

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The N incoming wave complex amplitudes are usually designated by the N complex quantities V_N^+ and the N outgoing wave complex quantities are designated by the N complex quantities V_N^- .The incoming and outgoing waves are sorted in vectors V^+ and V^-, respectively.

The relationship between these two vectors can be expressed by the equation (1):

$$\begin{bmatrix} V^-_1 \\ V^-_2 \\ . \\ \\ . \\ V^-_N \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & . & . & . & . & S_{1N} \\ S_{21} & S_{22} & . & . & . & . & S_{2N} \\ . & . & . & . & . & . & . \\ . & . & & . & . & . & . \\ . & . & . & . & . & . & . \\ S_{N1} & S_{N2} & . & . & . & . & S_{NN} \end{bmatrix} \begin{bmatrix} V^+_1 \\ V^+_2 \\ . \\ . \\ . \\ V^+_N \end{bmatrix} \quad (1)$$

In equation (1), S is a $N \times N$ matrix with complex elements called the "scattering matrix". It completely determines the behavior of the network. In general, the elements of this matrix, which are termed “Scattering parameters” or “*S*-parameters”, are frequency-dependent [11].

III. TEST OBJECT AND SIMULATION PROCEDURE

A simplified single-phase model of transformer, used in this paper, is shown in Fig.2. The model is based on ideal metallic cylinder in a metallic tank. The inner metallic cylinder represents the LV winding while the outer metallic cylinder represents the HV winding. The dimensions of the model are approximately 5 percent of a real one and presented in Fig.2. In this research, only one rectangular aperture has been installed. As a result, the *S*-matrix dimension is 1×1 .The single element of the *S*-matrix is easily determined by the following equation:

$$S_{11} = \frac{V_1^-}{V_1^+} \quad (2)$$

which can be written in the following simple form:

$$|S_{11}| = \sqrt{\frac{P_{ref}}{P_{in}}} \quad (3)$$

Where, P_{in} is the transmitting power and P_{ref} is the receiving power of the antenna.

The antenna of the model is a rectangular aperture with the dimensions of a standard X-band waveguide (WR90). The excitation frequency should be between the first and second cut-off frequencies (6.6 and 14.7 GHz for the model) to have a single mode of propagation.

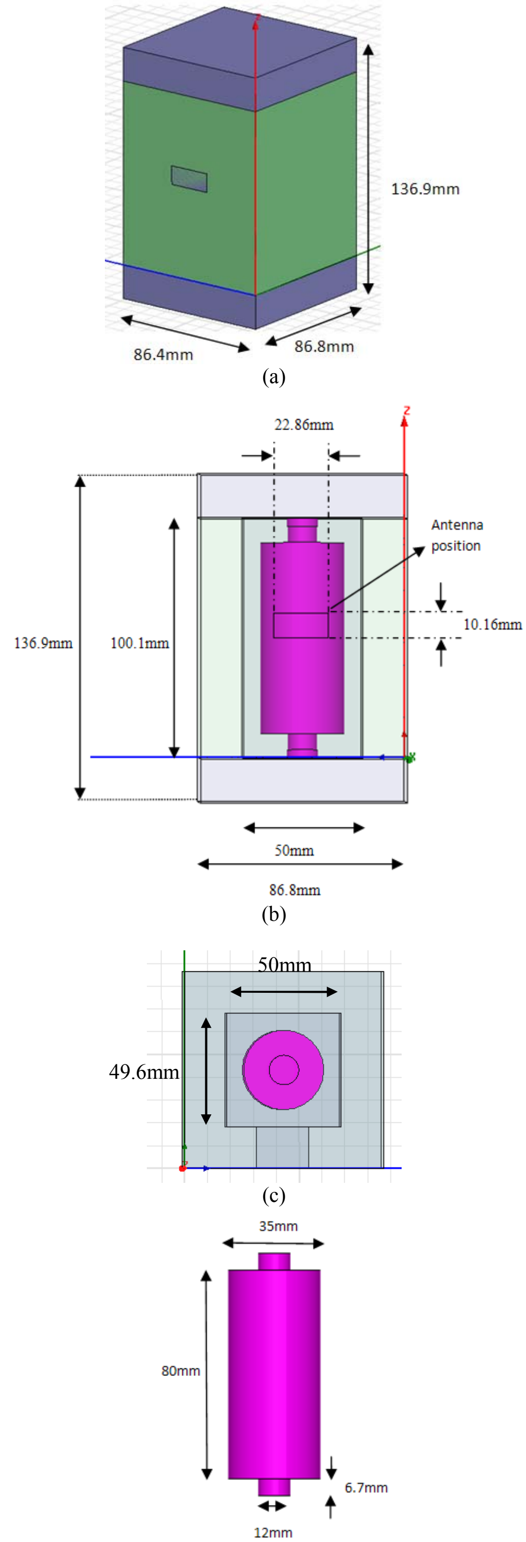

Fig. 2: Simplified model of transformer a) Three dimensional view, b) Side view of transformer model, c) Top view of transformer model and d) Side view of winding model

From the electromagnetic waves point of view, if the diameter of a hole is less than 0.1 of the wavelength, then the wave cannot enter the hole. The wavelength at the middle of the band is 31mm which is greater than one tenth of the distance between the high voltage winding disks in the reduced scales (i.e., 6mm×0.05=0.3mm). As a result, considering the dimensions of the HV winding of a power transformer and the frequency of the electromagnetic wave, the inner parts (core and LV winding) can be neglected and only the outer surface of HV winding should be modeled.

The scattering parameters of the intact winding model are calculated by using the high frequency simulation software in the range of 7-12 GHz and stored as a fingerprint of the transformer winding.

Fig.3 shows different radial deformation types of the winding model.The deformation in the model No.1 is only on one side of the winding model. In the same way, the deformation on other sides or the extent of the deformations have been modeled.

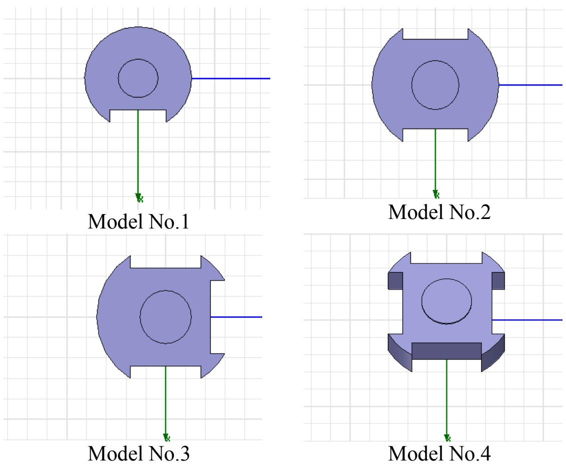

Fig.3: Different radial deformation types

The deformation is modeled to the cylinder by subtracting a cube with the width of a=6mm , length of b=18mm and height of 80mm (Fig.4).

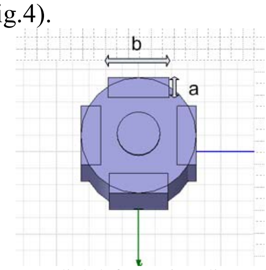

Fig4: Radial deformation dimensions

In this research, the effect of radial deformation extent and its location have been simulated by High Frequency Simulation Software (HFSS). The radial deformation can happen in different sides of the winding. Fig. 5 and Fig. 6 shows the simulated winding models in different positions respect to the antenna position.

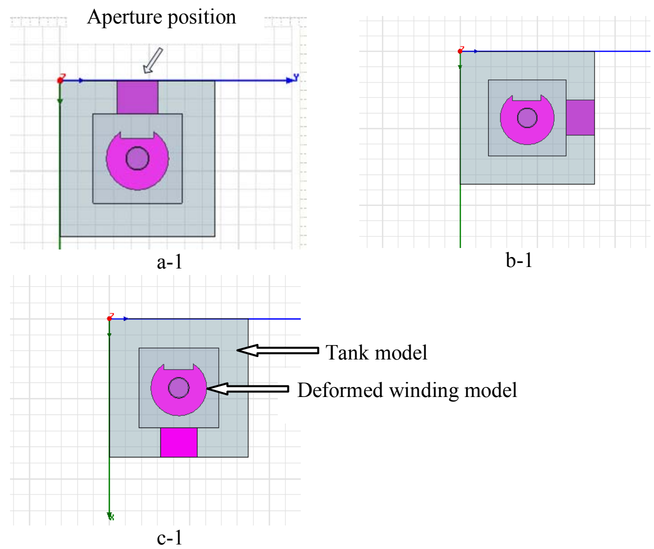

Fig. 5: Model No.1in different positions respect to antenna.

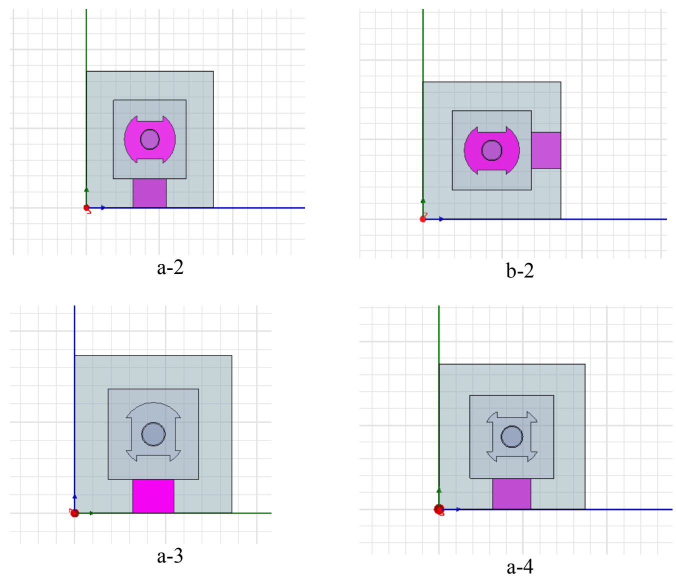

Fig. 6: Model No.2, 3 and 4 in different positions respect to the antenna.

The scattering parameters have been calculated from7-12 GHz for different radial deformation extents in different positions of the winding model respect to the aperture antenna as shown in Fig.5 and Fig.6. Simulation results of the magnitude and phase of scattering parameter for the different cases of Fig. 5 and Fig. 6 are shown in Fig. 7 to Fig.14.

The results show the sensitivity of the method to the extent and position of the radial deformation. The following activities will remain for our future work:

- The simulations should be extended to all of possible positions of the radial deformation.
- The simulation results should be compared with the measurement.
- The results can be used for training of an expert system to estimate the extent and position of the radial deformation.

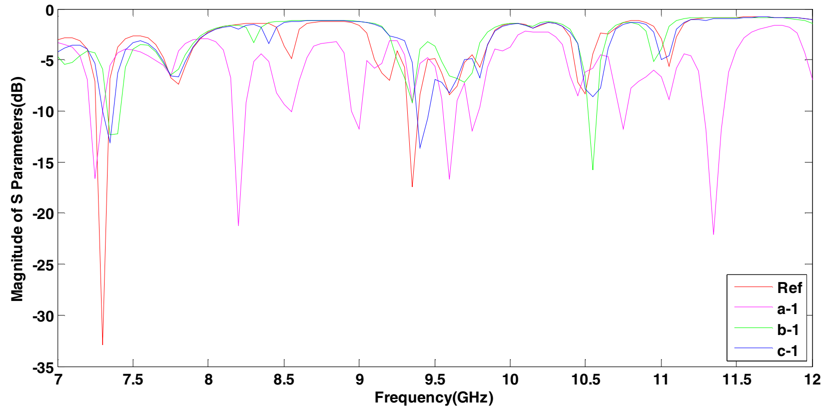

Fig. 7 : Magnitude of scattering parameter for reference position and positions a-1, b-1 and c-1 shown in Fig.5

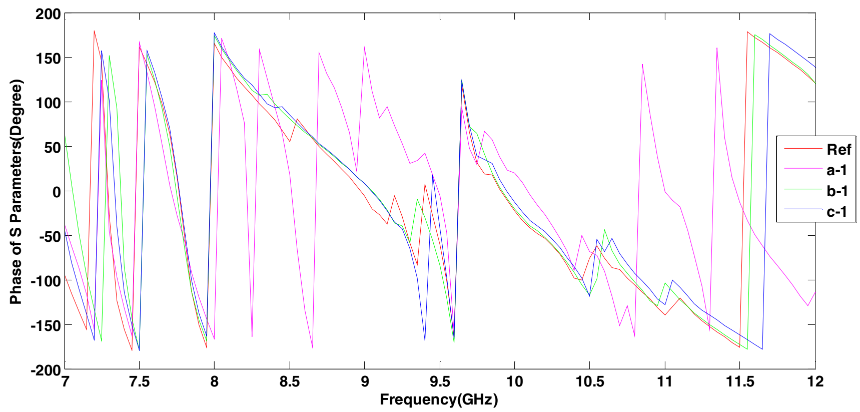

Fig. 8 : Phase of scattering parameter for reference position and positions a-1, b-1 and c-1 shown in Fig.5

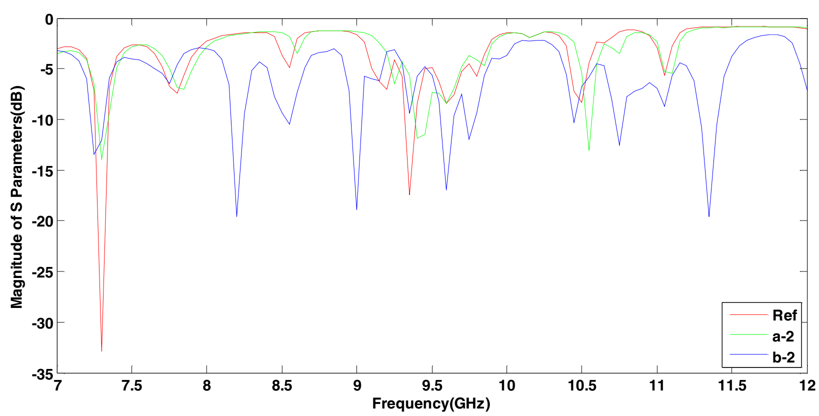

Fig. 9: Magnitude of scattering parameter for reference position and positions a-2 and b-2 shown in Fig.6

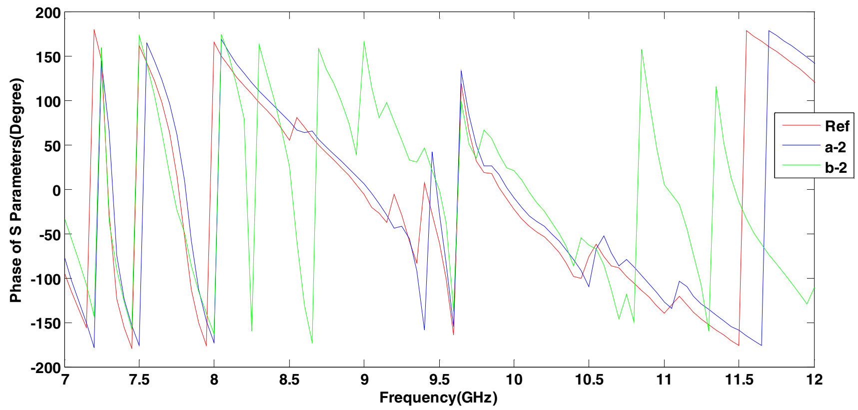

Fig. 10 : Phase of scattering parameter for reference position and position a-2 and b-2 shown in Fig.6

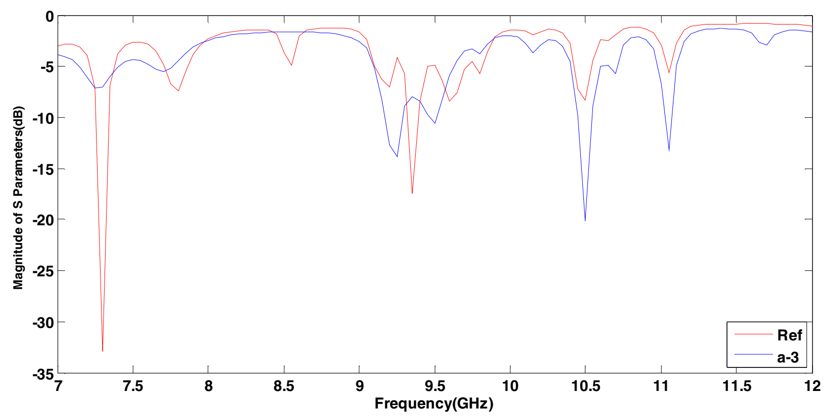

Fig. 11: Magnitude of scattering parameter for reference position and position a-3 shown in Fig.6

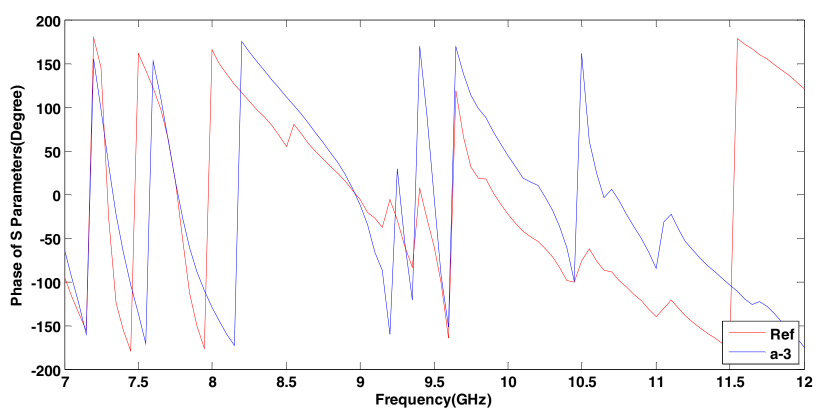

Fig. 12: Phase of scattering parameter for reference position and position a-3 shown in Fig.6

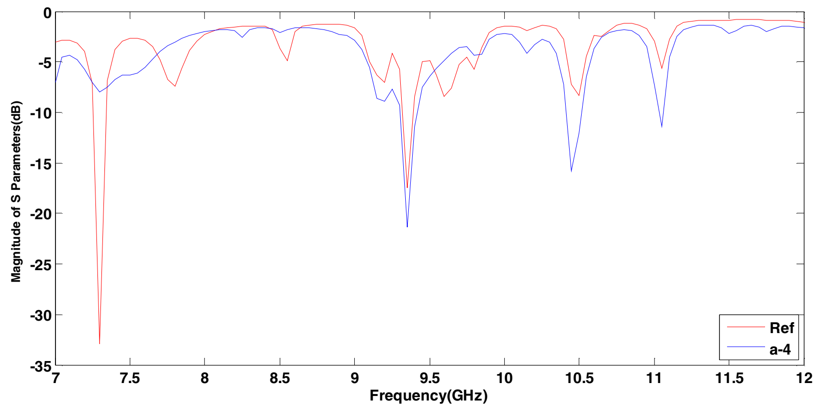

Fig. 13: Magnitude of scattering parameter for reference position and position a-4 shown in fig.6

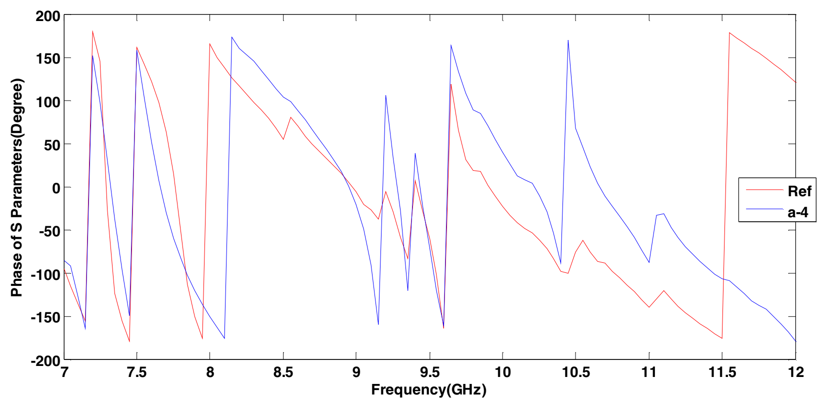

Fig. 14: Phase of scattering parameter for reference position and position a-4 shown in Fig.6

IV. Conclusion

In this paper, the on-line monitoring of the transformer winding has been investigated using scattering parameters. To show the capability of the method, the scattering parameters of a simplified model of transformer have been simulated using high frequency software in different radial deformation extent and positions. The results show the capability of the method in the detection of radial deformations.

V. ACKNOWLEDGMENT

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