On-line Monitoring of Radial Deformation of Transformer Winding Using Scattering Parameters

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Abstract: This paper presents a feasibility study on the on line monitoring of radial deformation in transformer windings. In this paper, the winding and its deformation have been modelled and simulated. It is shown that the proposed method can be used for off-line or on-line applications. The simulation results show that the radial deformation of windings can be detected by the on line monitoring of scattering parameters.

1 INTRODUCTION

Transformers are one of the most important elements of the power system and their failures can result in serious threat on economics of the power system operation. As a result, monitoring methods are very useful for power system engineers. The aim of modern monitoring and diagnostic systems is to ensure the optimal and reliable utilization of transformers. In this regard, several procedures such as thermal monitoring, oil analyzes, partial discharge measurements, transfer function, relaxation current, recovery voltage measurement, etc., are investigated and used. Each method can be suggested for a specific type of problem and has its own merits and demerits [1].

The short circuit currents may result in deformations and displacements of transformer windings due to electromechanical forces [2]. Such deformations do not necessarily lead to an immediate failure of the transformer, but its ability to withstand future mechanical and electrical stresses may be strongly reduced [3].

In recent years, several methods for the detection of winding deformation are proposed such as: Short Circuit test method (SC), Low Voltage Impulse test method (LVI) and Frequency Response Analysis method (FRA), which all these methods are off-line methods [4].

This paper presents an on-line method for radial deformation detection using scattering parameters. The proposed method can be used for off-line or on-line applications. The idea is based on the difference of the reflection of the electromagnetic waves from a sound and deformed windings. Fig.1 shows the procedure of this method. In the first step, data (scattering parameters) should be recorded for the sound winding. In the next step, when a winding deformation takes place, monitoring system can detect it with on line comparison of the new data with the recorded data.

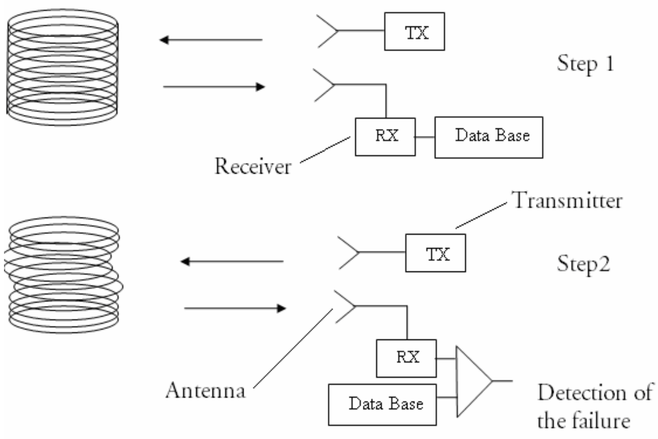

Fig. 1. Procedure of winding deformation detection using scattering parameters

2 SCATTERING PARAMETTERS

An *N*-port microwave network is shown in Fig.2 [5].

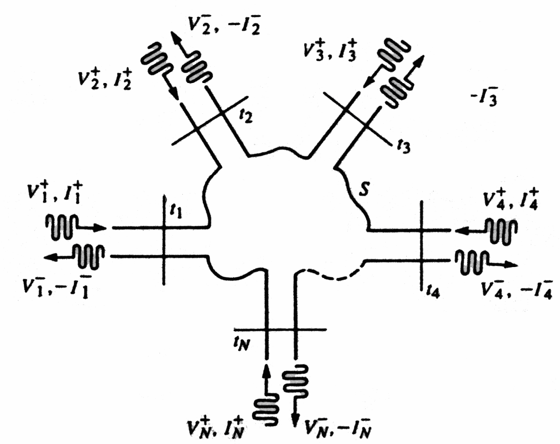

Fig.2: An *N*-port network

The *N*-port network has *N* arms into which power can be fed and from which power can be taken. In general, power can get from any arm (as input) to any other arm (as output). There are thus *N* incoming waves and *N* outgoing waves. We also observe that power can be reflected by a port, so the input power to a single port can partition between all the ports of the network to form outgoing waves. The N incoming and outgoing wave complex amplitudes are usually designated by the N complex quantities V_N^{+} and V_N^{-}, respectively. The incoming wave quantities are assembled into an N-vector V^{+} and the outgoing wave quantities into an n-vector V^{-}. The outgoing waves are expressed in terms of the incoming waves by the following equation.

$$[V^{-}]=[S][V^{+}] \qquad (1)$$

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

In this equation, S is a $N \times N$ matrix of complex numbers called the "scattering matrix". It completely determines the behavior of the network. In general, the elements of this matrix, which are termed "*s*-parameters", are all frequency-dependent.

3 MODELING OF HV WINDING RADIAL DEFORMATION

From the electromagnetic waves point of view, if the diameter of a hole is less than 0.1 of the wavelength, then the waves can not enter the hole. As a result when the frequency of the electromagnetic waves is, for example 9GHz, then the outer surface of active part of transformer, i.e. HV winding, can be modeled by a metallic cylinder and the effect of the inner parts (core and LV winding) could be neglected.

The model used in HpHFSS software to simulate the winding deformation is shown in Fig. 3. This software has the ability of defining materials with different permittivity and permeability. The model is a metallic cylinder in a metallic box. The space between them is air-filled and all metallic parts are defined ideal. The dimensions of the HV winding model are approximately 0.05 of the dimensions of a real one.

Two X-band waveguide apertures have been modeled on the box for the transmitting and receiving of waves. The software computes the scattering parameters automatically. As presented by equation 2, the scattering matrix is 2x2 because we have two apertures.

$$S=\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \qquad (2)$$

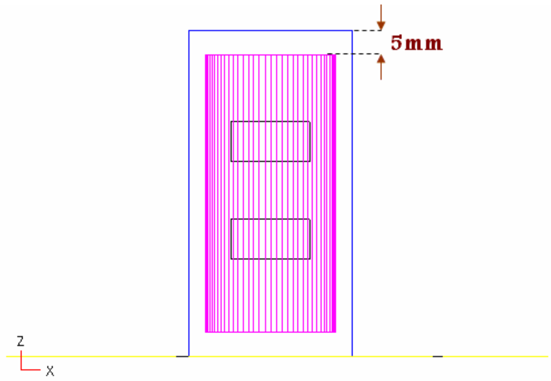

Fig.3: HV winding radial deformation model

To simulate the radial deformation, it is assumed that the radial deformation has been occurred in a specified angle respect to the reference angle (θ), with a specified depth (r), as shown in Fig.4.

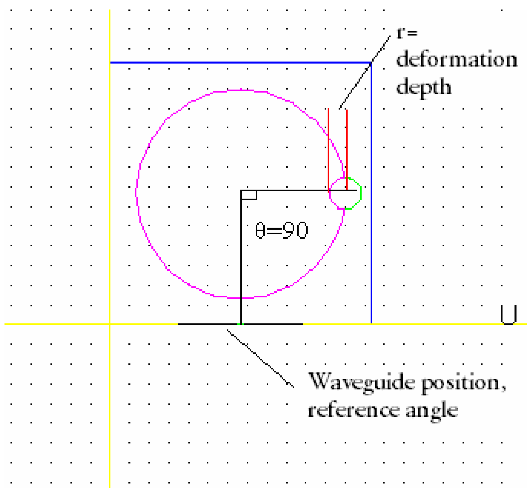

Fig.4: Radial deformation modeled at θ=90

In the software, the curves are approximated by line segments. For example, if the segment angle is 9 degrees for an arc of 180 degrees, there are nine degrees per segment and the arc is made up of 20 segments.

The nodes number is another parameter of the software which is defined as the number of nodes in the wavelength. For example, if the simulation frequency is 9.5GHz, then considering the fallowing equation, the wavelength is equal to 3.157 cm.

$$\lambda=\frac{c}{f}=\frac{3e8(m/s)}{9.5e9(Hz)}=3.157cm$$

In this case, if the node number has been assumed to be equal to 4 then in a cube with the dimensions $3.157_{cm} \times 3.157_{cm} \times 3.157_{cm}$ we have $4 \times 4 \times 4$ nodes.

4 SIMULATION RESULTS

Table I presents t he simulation results of radial deformation considering different depths (r) and angles (θ). In each row, the position of deformation has been specified by θ. The next columns are scattering parameters and the percent of deviation from the sound case, i.e.:

$$\%\Delta S = \frac{S_{simulation} - S_{sound}}{S_{sound}} \times 100$$

The deformation depth or radius, (r) has also been changed and simulated. As it can be seen, the detection of the radial deformation is possible, if the deformation depth is greater than 0.1 of the wavelength, which is 3.157 cm in the simulations. Fig.5 shows the scattering parameters, *%Δ S11=%Δ S22* and *%Δ S12=%Δ S21*. It is obvious that for the deformation depth of r>3mm the detection of deformation is possible.

TABLE I

Simulation results of radial deformation with different depths and angles

Depth (or radius) of deformations	r =2 mm			
Scattering parameters	S11,S22 (dB)	S12, S21 (dB)	%Δ S11, %Δ S22	%Δ S12, %Δ S21
Sound	-0.156355143	-0.156355143	0	0
θ=0°	-0.156355143	-0.156355143	0	0
θ=90	-0.156355143	-0.156355143	0	0
θ=180°	-0.126426754	-0.126426754	0.345158	-13.0763
θ=270°	-0.156355143	-0.156355143	0	0

Depth (or radius) of deformations	r =3mm			
Scattering parameters	S11,S22 (dB)	S12,S21 (dB)	%Δ S11, %Δ S22	%Δ S12, %Δ S21
Sound	-0.156355143	-14.51453324	0	0
θ=0°	-0.096952462	-16.5765913	0.686243	-21.1327
θ=90	-0.159893328	-14.42904332	-0.04073	0.989099
θ=180°	-0.105740291	-16.21693394	0.584426	-17.7985
θ=270°	-0.159804856	-14.42081459	-0.03971	1.084818

Depth (or radius) of deformations	r =4mm			
Scattering parameters	S11,S22 (dB)	S12,S21 (dB)	%Δ S11,S22	%Δ S12,S21
Sound	-0.156355143	-14.51453324	0	0
0°	-0.074934097	-17.68047141	0.941802	-30.5451
90°	-0.268416614	-12.22270735	-1.28187	30.1941
180°	-0.282582585	-16.22199254	-1.44274	-17.8463
270°	-0.266535534	-12.25255946	-1.26049	29.74741

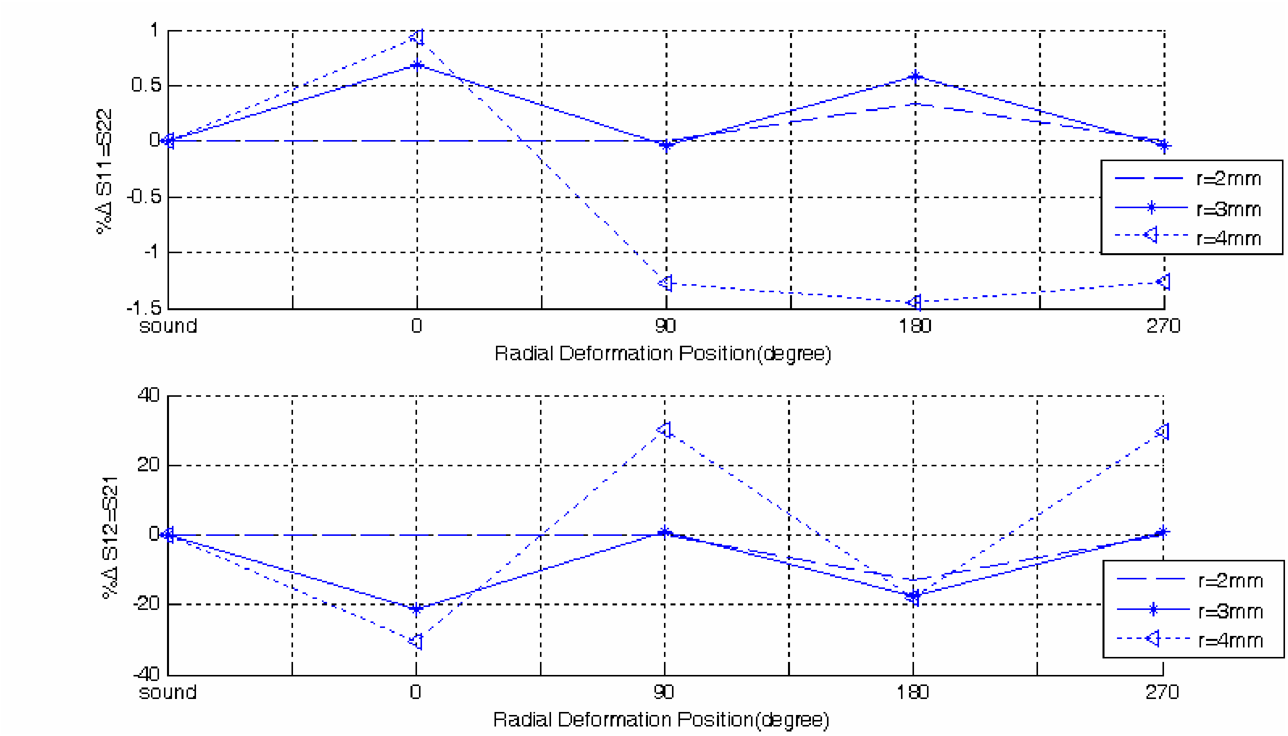

Fig.5: Simulation results of radial deformation with different depths and angles (Segment No.=15 and Node No.=4)

The case of 3mm radial deformation has been studied in more details. The simulation results have been given in Table II and Fig.6. The results show the possibility of the radial deformation detection using scattering parameters.

TABLE II

Simulation results of 3mm radial deformation in HV winding (Segment No. =15 and Node No. =4)

Scattering parameter	**S11,S22**	**S12,S21**	**S11,S22 (dB)**	**S12,S21 (dB)**	**%ΔS11, %ΔS22**	**%ΔS12, %ΔS21**
sound	**0.98216**	**0.18805**	**-0.156355143**	**-14.51453324**	**0**	**0**
θ=0°	0.9889	0.14831	-0.096952462	-16.5765913	0.686243	-21.1327
θ=5°	0.98271	0.18514	-0.151492491	-14.64999481	0.055999	-1.54746
θ=10	0.98645	0.16405	-0.118498457	-15.70047531	0.436792	-12.7626
θ=20	0.9846	0.17485	-0.134803371	-15.14668727	0.248432	-7.01941
θ=30	0.98491	0.17307	-0.132069061	-15.23556413	0.279995	-7.96597
θ=45	0.9822	0.18772	-0.156001404	-14.52978909	0.004073	-0.17549
θ=90	0.98176	0.18991	-0.159893328	-14.42904332	-0.04073	0.989099
θ=180°	0.9879	0.15458	-0.105740291	-16.21693394	0.584426	-17.7985
θ=270°	0.98177	0.19009	-0.159804856	-14.42081459	-0.03971	1.084818

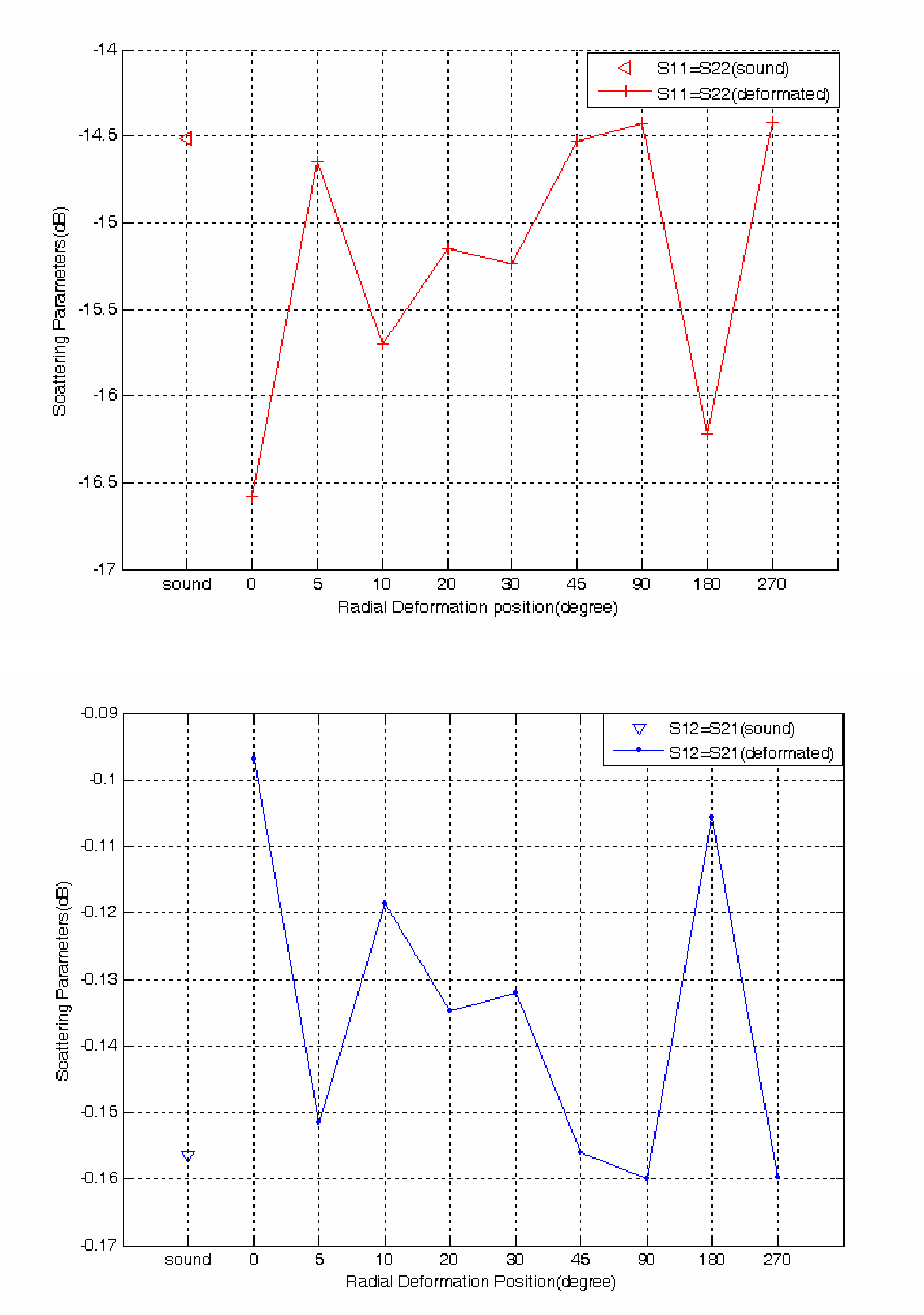

Fig.6: Scattering parameter vs. radial deformation position

5CONCLUSIONS

In this paper a feasibility study on using electromagnetic waves for the on-line detection of transformer winding radial deformation has been presented.

The proposed method can be used for off-line or on-line applications. According to simulation results carried out by HpHFSS software, radial deformation of the winding can be detected by the on-line monitoring of scattering parameters.

6 ACKNOWLEDGMENT

The financial support of Iranian Research Organization for Science and Technology (IROST) towards this research is hereby acknowledged.

7 REFERENCES

[1] E. Rahimpour, J. Christian, K. Feser and H. Mohseni, “Transfer Function Method to Diagnose Axial Displacement and Radial Deformation of Transformer Windings” IEEE Transactions on Power Delivery, Vol. 18, No. 2, April 2003

[2] J. Christian and K. Feser, “Procedures for Detecting Winding Displacements in Power Transformers by the Transfer Function Method” IEEE Transactions on Power Delivery, Vol. 19, No. 1, Jan. 2004

[3] D. K. Xu, J. H. Huang “On-line Monitoring of Winding Deformation of Power Transformer” IEEE conference on Electrical Insulating Material, 2001, pp. 853-856

[4] D. K. Xu and Y. M. Li, “A Simulating Research on Monitoring of Winding Deformation of Power Transformer by On-line Measurement of Short-Circuit Reactance”, IEEE 1998, pp. 167-171

[5] David M. Pozar “Microwave Engineering” Addison-Wesley, 1990