ANSYS SOFTWARE APPLICATION TO BUILD TRANSFORMER MODEL AND USE MECHANICAL VIBRATION SIGNAL TO DIAGNOSE FAULT

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ABSTRACT

Fault detection in transformers is an interesting and important technical task since transformers play vital roles in all power systems [1,2,3]. An accurate fault detection helps us not only to quickly repair the transformers but also allow us to isolate (and replace) the transformers before its total breakdown, which in turn will reduce the costs related to power shortage. Most of the fault detection methods base on the electrical signals only, some methods use the sensors measuring the gas components in the oil tank of the transformers, some methods use the sounds generated by partial discharging processes in the transformers' components. But there are faults, which are difficult to be detected using the above mentioned methods. For example, the loose of coils around the magnetic cores, the small deformation of cores,... In this paper we will propose a combined method using the electrical signals and the mechanical vibrations of the transformer to help better detecting the faults. The signals are simulated for a model of transformer in ANSYS software. The numerical results will prove the correctness of the proposed solutions.

Keyword: *fault detection, transformer model, mechanical vibration, ANSYS software*.

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1. INTRODUCTION

Power system is very complex in both structure and operation [1,2,3]. Any failure happens to an element of the system will affect the performance, the quality of power delivery and will cause economics losses [4,5]. Transformers are important elements of the power systems. The fault detection in transformers plays an essential role in keeping the system working conditions properly.

Among the different methods used in transformer fault detections the more popular one is the Frequency Response Analysis method (FRA) due to its effectiveness for many types of faults [6]. In this method, we apply a voltage signal at the input and measure the output signal to calculate the transfer function of the transformer. The measurements are done with various frequencies to have the characteristic transfer function at a number of different frequencies. The output signal can be an electrical one or mechanical one. In this paper, we will consider as the output signal the vibration of the transformer.

When there is a fault inside the transformer, it will cause some changes in the values of the transformer's elements or some changes in the structure of the transformer, which in turn changes the responses from the transformer. In this paper, we will test the fault of wire shortage inside the transformer. The vibration of the transformer will be estimated using the magnetical force fields. The difference in the spectrum of the transfer function will clearly indicate the state of the transformer.

The proposed method is tested using the simulation in ANSYS package and will show the correctness of the approach.

2. METHOD FOR ELETROMAGNETIC FORCE CALCULATION IN ANSYS' MAXWELL PACKAGE

In the software ANSYS' Maxwell 3D, the electromagnetic force is calculated using the effective energy method. In this method, according to the Lorentz' force formula, the Maxwell force tensor is defined as:

$$\sigma = \begin{bmatrix} H_x \cdot B_x - \frac{|B||H|}{2} & H_x \cdot B_y & H_x \cdot B_z \\ H_y \cdot B_y & H_y \cdot B_y - \frac{|B||H|}{2} & H_y \cdot B_z \\ H_z \cdot B_z & H_z \cdot B_y & H_z \cdot B_z - \frac{|B||H|}{2} \end{bmatrix} \quad (1)$$

After that, the electromagnetic force is calculated as:

$$dF = \sigma \cdot dA \quad (2)$$

where: F – the electromagnetic force,

A – the surface area to calculate the force,

σ – Maxwell force tensor from Eq. (1).

The general equation for shifting is given the following equation:

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = \{F^a\} \quad (2)$$

where: [M]: Mass matrix,

{u}: Shift matrix for elements,

[C]: Dynamic interference matrix,

[K]: Stiffness matrix,

[F^a]: External force matrix.

Transform the Eq. (2) into the frequency domain we can get the element shifts calculated using the phasor equation (3):

$$\{U\} = \{U_{\max} e^{i\phi}\} e^{i\Omega t} \quad (3)$$

where U_{max} is the amplitude of the shift.

The corresponding components of the external forces are given in Eq. (4):

$$\{F\} = \{F_{\max} e^{i\psi}\} e^{i\Omega t}$$
$$\{F\} = \{F_{\max} (\cos\psi + i \sin\psi)\} e^{i\Omega t} \quad (4)$$
$$\{F\} = (\{F_1\} + i\{F_2\}) e^{i\Omega t}$$

From the above equation, we can deduct the system of equations for the vibration as in Eq. (5):

$$\left(-\Omega^2 [M] + i\Omega [C] + [K]\right)\left(\{U_1\} + i\{U_2\}\right) e^{i\Omega t}$$
$$= \left(\{F_1\} + i\{F_2\}\right) e^{i\Omega t} \quad (5)$$

3. THE MODEL AND THE SIMULATION OF THE TRANSFORMER IN ANSYS

3.1. 3D model in ANSYS

This paper uses as an example a distribution transformer 400kVA, nominal voltages 22/0.4kV with the structure design as in Fig. 1 [9,10].

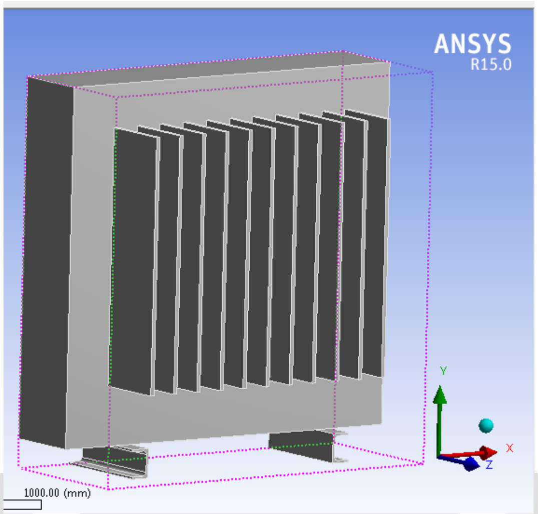

Fig. 1: *The model of a distribution transformer 400kVA, 22/0.4kV*

The shell of the transformer is made from steel of 8mm thickness. The shell has also some tails for heat dissipation. The bottom of the transformer is fixed by two C-sharp steel plates to the earth.

3.2. Finite elements grid generation

In order to simulate the behavior and performance of the transformer, we use the finite element method and the ANSYS software. The grid used by the finite elements method is generated automatically using the standard tetrahedral elements as show in the figure below [7,8].

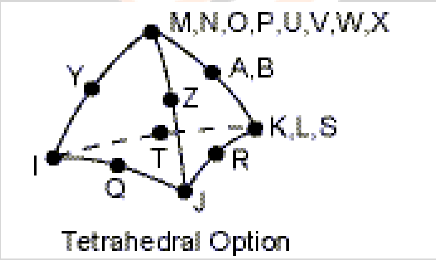

Fig. 2*: The tetrahedral finite element*

As the results, the transformer is divided into a grid of 41743 tetrahedral elements with 111021 nodes as seen in Fig. 3.

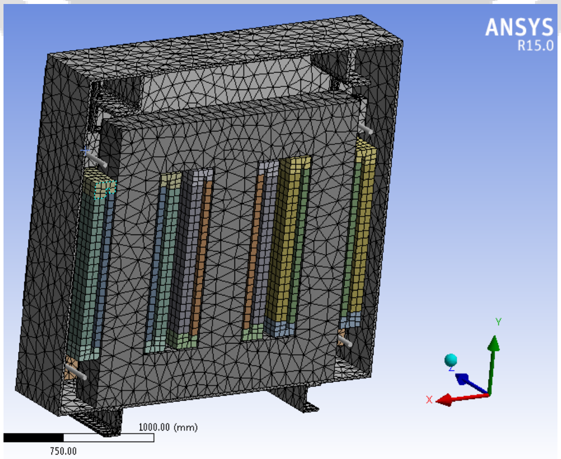

Fig. 3: *The grid generated for the selected distribution transformer*

3.3. The border conditions

- Symmetrical borders:

Due to the symmetry of transformer designs, we have applied the symmetrical borders setting to reduce the calculation time.

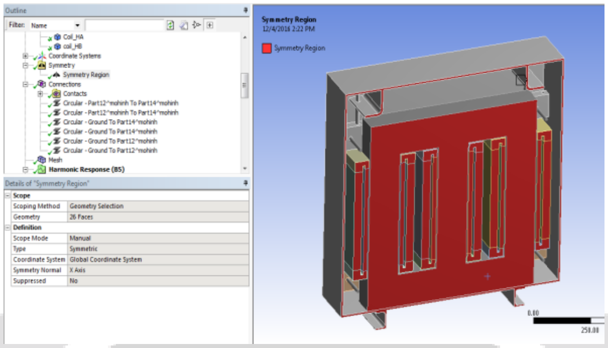

***Fig. 4**: Setting the symmetrical conditions for the simulation*

4. SIMULATION RESULTS

4.1. Simulation results in normal working conditions

The frequency based movement in the x direction of the shelter is presented in Fig. 5. The maximum shift is $2.88 \cdot 10^{-5}$ mm corresponding to the frequency 125Hz.

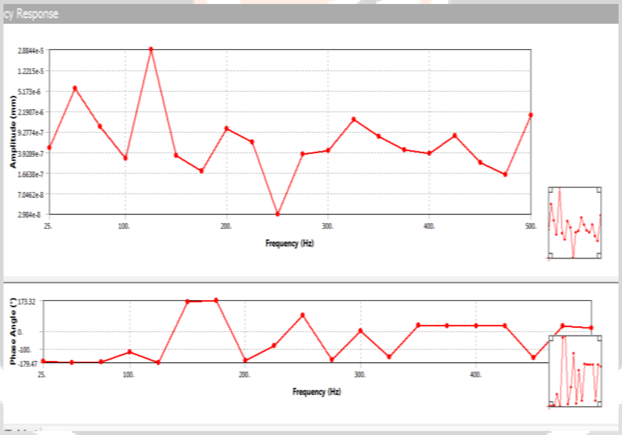

***Fig. 5:** The frequency characteristic of the shelter's movement in the x direction*

The frequency based movement in the y direction of the shelter is presented in Fig. 6. The maximum shift is $7.339 \cdot 10^{-4} mm$ corresponding to the frequency 50Hz.

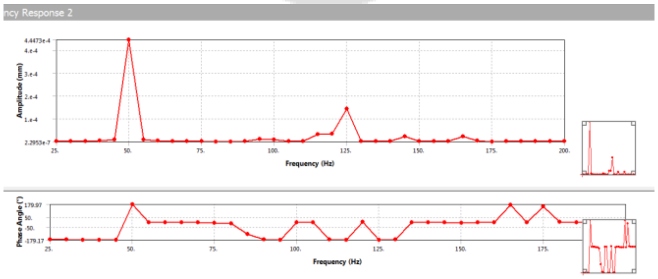

***Fig.6**: The frequency characteristic of the shelter's movement in the y direction*

The frequency based movement in the z direction of the shelter is presented in Fig. 7. The maximum shift is $1.01 \cdot 10^{-4} mm$ corresponding to the frequency 50Hz.

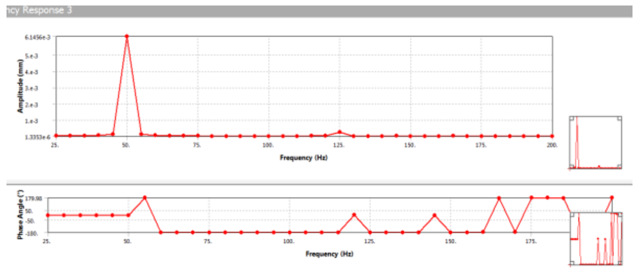

Fig. 7: *The frequency characteristic of the shelter's movement in the y direction*

4.2. Simulation results in faulty working conditions (wire shortage)

The frequency based movement in the x direction of the shelter is presented in Fig. 8. The maximum shift is $1.46 \cdot 10^{-3} mm$ corresponding to the frequency 120Hz.

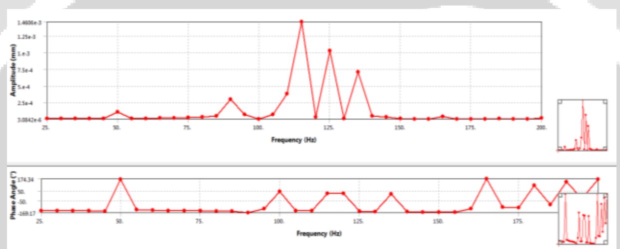

Fig.8: *The frequency characteristic of the shelter's movement in the x direction*

The frequency based movement in the y direction of the shelter is presented in Fig. 9. The maximum shift is $1.34 \cdot 10^{-2} mm$ corresponding to the frequency 50Hz.

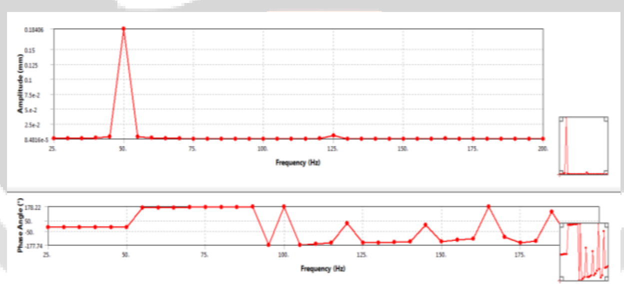

Fig. 9: *The frequency characteristic of the shelter's movement in the y direction*

The frequency based movement in the z direction of the shelter is presented in Fig. 10. The maximum shift is $0.186 mm$ corresponding to the frequency 50Hz.

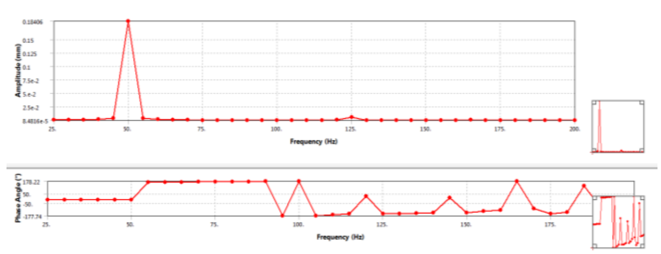

Fig. 10: *The frequency characteristic of the shelter's movement in the z direction*

The results showed that there is a clear difference between the two cases when the transformer is in normal condition and when there is a wire shortage inside the coils of the transformer. It indicates that we may use some simple model with linear thresholding comparison to classify the state of the transformer.

5. CONCLUSIONS

This paper considered the model of distribution transformer of 400kVA, 22-0.4kV in ANSYS software. The model was used to simulate the transformer in normal condition and in wire shortage condition. The numerical results showed that the transformer shelter shift in two cases are clearly different, which helps to build a model to classify the state of the transformer.

In the future, we will include more simulation data to enhance the quality of the classification and to improve the reliability of the results.

6. ACKNOWLEDGEMENT

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