Monitoring of Radial Deformations on Transformer HV Winding Using Image Processing and UWB Transceivers

Mr. Santosh Vishwakarma
Student M.E (EXTC)
SHREE L.R. TIWARI COLLEGE OF ENGINEERING
Mira Road, Thane, India.

Mrs. Namrata Kulkarni
Asst. Professor
SHREE L.R. TIWARI COLLEGE OF ENGINEERING
Mira Road, Thane, India.

Abstract- This paper presents a new method for detecting the presence and location of mechanical deformation on an actual power transformer winding by using image processing .A vertical imaging setup is used to obtain a two-dimensional (2-D) image of the transformer winding using synthetic aperture radar (SAR) imaging method. The main goal of the image processing method is to detect the location of the radial deformation on the transformer high-voltage (HV) winding. Two different deformations are applied on the winding under the test in this paper. The first one is a modeled bulgy mechanical deformation and the second one is an actual concave buckling made on the actual transformer HV winding.

Index Terms- *fault location, image processing, mechanical deformation, monitoring synthetic aperture radar (SAR) imaging, transformer high-voltage (HV) winding, ultra wideband (UWB) transceivers.*

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I. INTRODUCTION

Recent Years have witnessed the increasing interests, both in research and engineering domains, in the automated fault detection and condition monitoring of electrical equipment with smarter and more efficient approaches. To enhance the reliability of the system, it is necessary to detect, identify, and even predict the faults and failures at early stages as quickly as possible to provide proper remedies. Furthermore, to reduce the amount of unnecessary downtime for maintenance purposes, and consequently reduce important costs in terms of money and time, automated equipment monitoring and fault diagnosis are attracting significant attentions Power transformers are critical equipment in the interconnected power grids which may face electrical or thermal disturbances that cause faults such as arcing, partial discharge, and mechanical deformation. Short circuit currents, unsuitable transportation, and gas explosions are known as the main causes of mechanical defects on transformer windings. They can cause radial deformation or axial displacement, tilting, concave buckling, broken clamping parts, and shortened or open turns on transformer windings. If these mechanical faults remain undiagnosed for a long time, they can initiate more severe failures and disrupt power supplies, inducing huge financial losses or causing worst incidents such as explosions, loss of human lives, or environmental disasters. Therefore, to minimize these problems, early-stage detection of internal deformations prior to problematic failures in a transformer is of vital importance. Traditional offline deformation detection, frequency response analysis, dissolved gas analysis, voltage–current locus, and using ultra wideband (UWB) sensors and synthetic aperture radar (SAR) imaging are some of the recently proposed transformers monitoring methods in the literature. There are substantial advantages in online monitoring methods. They do not affect the transformer operation to get the desired data, leading to save huge outage costs. Furthermore, online monitoring methods are vital in terms of the prognosis of major faults before occurring by detecting their initial signs in early development stages. Therefore, it can prevent possible huge damages during operation and increases system reliability.

1.1 Reasons of transformer deformation

- Power transformers are critical equipment in the interconnected power grids which may face electrical or thermal disturbances that cause faults such as partial discharge, and mechanical deformation.
- Short circuit currents, unsuitable transportation, and gas explosions are known as the main causes of mechanical defects on transformer windings.
- They can cause radial deformation or axial displacement, tilting.
- Concave buckling, broken clamping parts, and shortened or open turns on transformer windings.
- If these mechanical faults remain undiagnosed for a long time, they can initiate more severe failures and disrupt power supplies, inducing huge financial losses or causing worst incidents such as explosions, loss of human lives, or environmental disasters.

1.2 THE MAIN MOTIVATIONS

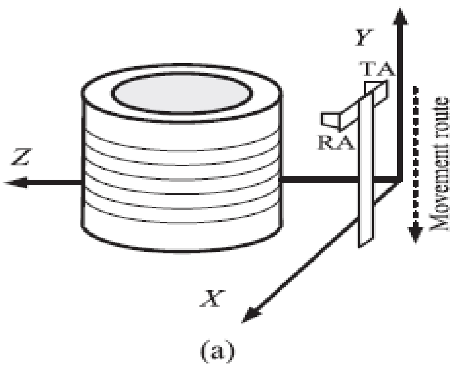
- Modifying the method to detect the presence of the deformation in an analytical and quantitative manner;
- Applying the proposed method on actual deformations in actual transformer windings;
- Locating different bulgy and concave deformations using the proposed quantitative analytical method;
- Discussing the practicability issues of the proposed ideas to be adopted by industry.

2. LITERATURE SURVEY

- A Linear Feature for On-line Monitoring of Mechanical Defects in Transformer Windings". Effective diagnosis and monitoring tool to detect typical mechanical defects, i.e., radial deformation and axial displacement, in power transformers [1].
- "An On-Line Technique to Detect Winding deformation within Power Transformers" New technique to identify mechanical faults within a power transformer [2].
- "A Novel Online Technique to Detect Power Transformer Winding Faults" a novel online technique is introduced to detect the internal faults within a power transformer by constructing the voltage–current locus diagram to provide a current state of the transformer [3].
- "A Simultaneous Method for Detection of Radial Deformation and Axial Displacement in Transformer Winding Using UWB SAR Imaging" In this paper a novel method is presented based on synthetic aperture radar (SAR) imaging to detect the axial displacement and radial deformation simultaneously [4].

3. SAR IMAGING

A two-dimensional (2-D) image of the transformer winding is obtained via SAR imaging procedure using UWB sensors. This method is an accurate way in detecting the location of the deformation.



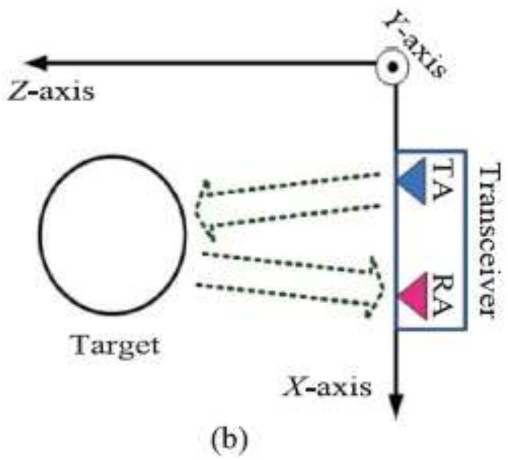


Fig: 3 SAR imaging method. 3 (a). 3-D schemes. 3 (b) Top view. [1]

The schematic figure of the SAR imaging setup is shown in Fig 1. in which a transceiver generates a pulse, and the pulse is transmitted through transmitting antenna (TA) to the environment. When the transmitted pulse meets the target, a portion of it reflects back to the receiving antenna (RA). This is a one dimensional (1-D) signal carrying some information about the target. More impulse responses from other positions thoroughly help to obtain more information from the target. Therefore, the antennas are moved in a specific direction called movement route. The process of transmitting and receiving signals is repeated at predefined points along the movement route to obtain several impulse responses called "scans." For simplicity, the distance between adjacent measuring points or steps is set to be constant. The set of all scans forms a 2-D matrix, which is a function of the time and measuring positions.

The typical UWB pulse of the UWB transceiver, which is used in this paper, is shown in Fig: 3.2. It is a Gaussian pulse modulated by a sinusoidal carrier. after the alignment Fig.3. SAR imaging method. 3. (a) 3-D scheme. 3. (b) Top view.

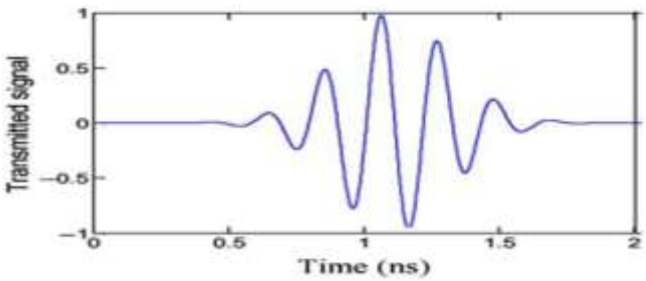


Fig: 3.2 UWB pulse. [1]

Procedure of scans, undesired parts can be removed from the raw impulse response. For this three-dimensional (3-D) target, there are several paths through TA-target-RA. The closest point of the target to the antennas provides the shortest path with minimum transmission time (Tmin) and the farthest point makes the longest path (Tmax). Therefore, the time delay of the target reflection is t as Tmin $\leq t \leq$ Tmax. After pre-processing steps, the scans are ready to be used by the migration algorithm to form a 2-D image.

4. VERTICAL IMAGING SETUP

It should be mentioned that the horizontal setup presented in is not practically installable on a transformer tank due to its required length which is almost twice the required length of vertical setup and almost three times bigger than the available width on the tank of the transformer in this paper, as shown in Fig. 4 However, the required length for the vertical imaging setup can be as low as the height of the tank as also illustrated in Fig. 4. Therefore, the vertical setup is generally more practical from the point of view of transformer manufacturers. In this setup, the imaging route in front of the transformer winding is vertical as demonstrated in Fig:4(a). In this setup, the measurement steps are 24 points. The mechanical deformation model is made up of copper strips with the dimensions illustrated in Fig:4(b)

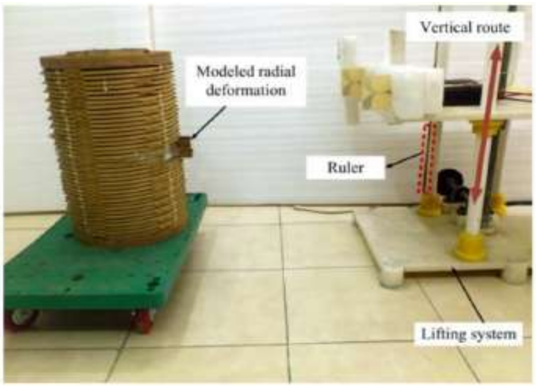


Fig: 4.1(a) Experimental setup[1].

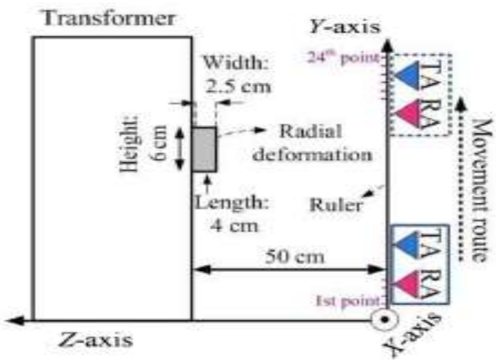


Fig: 4.1(b) Side view [1]

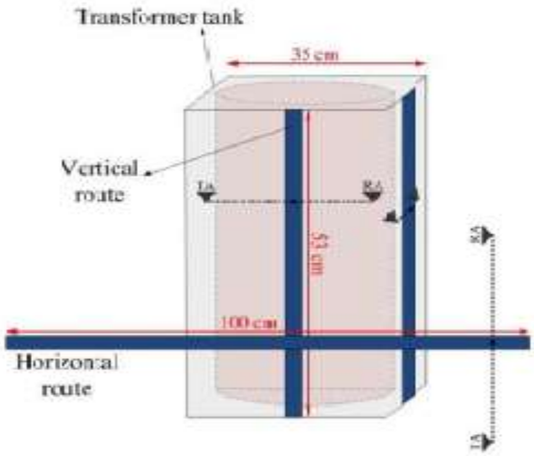


Fig: 4.1(c) Horizontal imaging setup versus vertical setup [1]

In different test cases, the radial deformation model is placed in three different heights of the transformer winding as shown in Fig. 5. The length of this deformation is 6 cm and it covers six winding discs in each position. The radial deformation is placed at the "bottom part" (located 7 cm from the bottom of the transformer winding), "middle part" (25 cm from the bottom of the winding), and "top part" (40 cm from the bottom of the transformer winding).

5. IMAGE PROCESSING METHOD

The goal of applying image processing methods on the resulted images is to quantitatively detect the presence and the location of the radial deformations on different heights. Fig. 5(a) Actual transformer winding. (b) Three studied parts for applying mechanical deformation. Fig. 6 Colour bar and areas of warm and cold colours. First, the imaging process is applied on the sound transformer winding, which does not have any defect. This image gives a reference as the sound winding image (SWI) for later comparisons. The images reveal a top view of the transformer winding. The warm colors in each image present a high reflection and the cold ones illustrate a moderate reflection from the target.

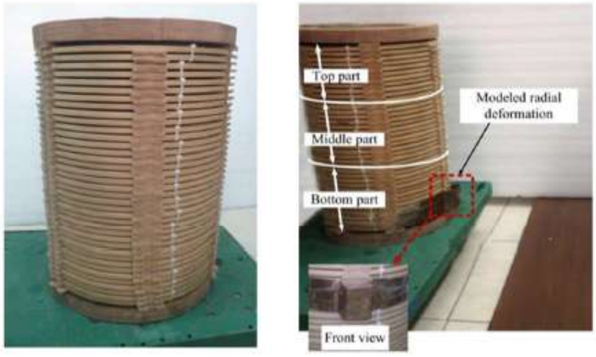


Fig: 5. (a) Actual transformer winding. Fig: 5. (b) Mechanical radial deformation [1]

Therefore, the highest reflection occurs from the most front part of the transformer winding because it has the shortest distance from the antennas. Since this method works based on the imaging data received from different heights of the transformer winding, just the vertical imaging setup results are useful for the mentioned purposes.

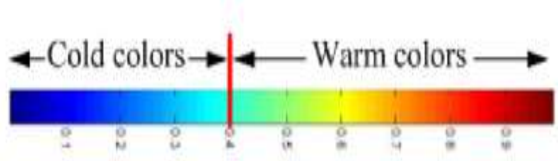


Fig. 5. (c) Color bar and areas of warm and cold colors [1]

In this paper, the value of the image pixels is used. The colour bar graph in Fig. 5. (c) Shows the mapping basis used in this paper which maps each colour to a normalized image value between 0 and 1. Hereinafter, these values will be called colour number (CN). A simple way to distinguish between warmer and colder colors is to assign a user-defined distinguishing CN (DCN). For a desired accuracy, this DCN should be neither too high (close to 1) nor too low (close to 0). A suitable range for the DCN is between 0.3 and 0.5 as it has been concluded by a trial and error procedure.
as a simple correlation method to monitor the deformation. The result of the correlation represents differences between DWI and SWI including the difference in color or in the shape of their image since the mechanical deformation causes some disorders in DWIs compared to the SWI. Different tests have

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been examined with different modeled deformations in different locations.

5.1. First Stage: Detecting the Presence of the Deformation

1) Quantitatively interpret the qualitative images.
2) Distinguish between the sound and defected situations; and more importantly.
3) Find the location of the deformation. Since the proposed image processing methods are based on the comparison between the images of the sound and deformed windings, these methods can be applied to any other setting. It means that, for each specific setting, reference images for each side of the windings as SWIs can be obtained. These SWIs are used as signatures or references for that specific transformer. To reduce measurement errors, the average of *N*warm values for different SWIs can be computed to obtain *N*warm-ref. The same averaging can be computed for *S*warm values of different SWIs to obtain *S*warm-ref. Then, these reference values will be compared to the values of images obtained for other situations. If there is no deformation in *k*th image, the *N*warm-k and *S*warm-k values will be very close to their values for the SWIs (i.e., *N*warm-ref and *S*warm-ref). However, for any deformation in any location, *i*th image will be different from the reference SWIs.

5.2. Second Stage: Detecting the Type of the Deformation

After detecting the presence of the deformation in the first stage, the type of the deformation can be determined in the second stage. If the *N*warm-i value is greater than the *N*warm-ref value, it shows that a bulgy deformation has occurred.

As stated in Section III, this is due to the fact that the highest reflection occurs from the closest part of the transformer winding, and it consequently causes the images of the bulgy deformation to have more warm colors

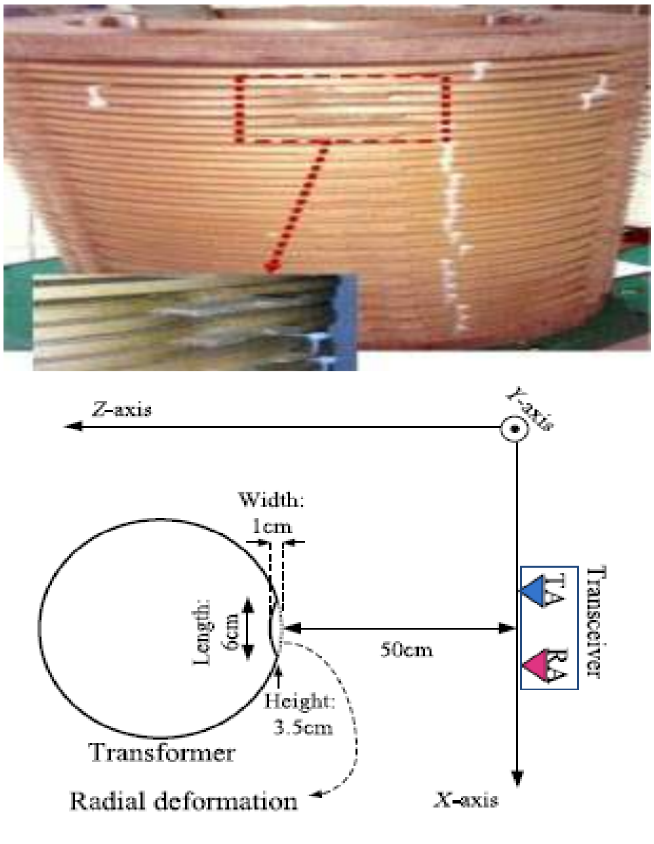
5.3. Third Stage: Detecting the Location of the Deformation

In the third stage, the information from the antenna (which has been obtained from 24 points in this paper) is divided into *n* sections where *n* can be 2, 3, 4, 6, 8, 12, or 24. Depending on the required accuracy, the operator can choose either two section comparison (to simply detect that the deformation is on the upper or lower sections of the winding) or 24-section comparison (for higher accuracy). After dividing the information of the defected winding into *n* sections, the information of each section of the deformed winding is investigated to find the deformation location which will be discussed more in experimental results.

6. ACTUAL RADIAL DEFORMATION DETECTION

In the previous sections, the ability of the proposed method in locating modeled radial deformations on the actual transformer winding was investigated. The modeled deformation had a bulgy form, as shown in Fig. 5. However, the actual mechanical defects on power transformer windings may have different shapes and dimensions. First, these defects may occur in the shape of some concave buckling on the transformer winding. Second, the width of these defects can be less than that of the modeled deformation. Hence, to obtain more realistic results, a radial concave buckling is made on the winding .

(a)



(b)

Fig: 6.1 Concave radial deformation (a) image and (b) top view scheme [1]

7. CONCLUSION

In this paper, the application of image processing methods for detecting the presence and location of mechanical deformations on an actual transformer winding has been studied. The winding images have been obtained using the SAR imaging method. Three-stage image processing strategies have been proposed and applied on the experimental setup.

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