Experimental Study on Elimination of Partial Discharge Effect on Detection of Radial Deformation of High Voltage Transformer Winding Using Electromagnetic Waves

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***Abstract*—Online detection of defects in power transformers attracts attention of researchers because of its technical and economic advantages. Recently, radial deformation detection has been carried out using ultra-high-frequency (UHF) synthetic-aperture radar (SAR) imaging method. Another defect in the transformer winding is partial discharge (PD). When a PD is occurred, UHF signal is propagated in the transformer environment. Because of same frequency band of UHF SAR imaging method and PD emissions, the stepped frequency approach has been proposed to make the system compatible to eliminate the effects of PD on detection of radial deformation. The feasibility of the mentioned strategies has been simulated using CST software in previous studies. In this paper, a monitoring system is designed and implemented on a real transformer winding to simultaneously detect these defects by the mentioned approaches.**

Keywords—Online partial discharge monitoring; Online radial deformation detection; synthetic aperture radar (SAR) imaging method; stepped-frequency;

I. Introduction

The system reliability of power system can be improved by online condition monitoring of equipment [1-2]. Power transformer is one of the important and expensive equipment in the power system which any defect in it can make a large black out in the system. One of the important issues in the power transformers is radial deformation of transformer winding due to many different events such as short circuit, earthquake or unsuitable transportation. Online protection of power transformer by detecting radial deformation can reduce its unavailability in power system. Recently, the synthetic aperture radar (SAR) imaging method, has been introduced and investigated as a novel method for radial deformation detection in previous studies [3-4].

Detection of partial discharge (PD), as another defect of power transformers, is very important to prevent damage of insulation in transformer winding. PD in the transformer environment propagates ultra-high-frequency (UHF) electromagnetic waves in the range of 0.3 to 3 GHz. This frequency band can be achieved and recorded by UHF antennas [5]. In many previous studies, UHF antennas have been installed in the transformer tank to detect PD occurrence and the applicability of this approach with satisfactory results has been reported [5-6].

In previous studies, the SAR imaging method has been performed by transmitting a short UWB Gaussian wave toward the transformer HV winding and the reflected signal is received to have one-dimensional (1-D) information from the HV winding. The position of antennas is changed along the height of the transformer and 1-D information is gathered for all positions. By using the Kirchhoff's migration algorithm, a two-dimensional (2-D) image of transformer HV winding is generated [3-4] and a comparison of sound and deformed images of winding can show radial deformation. In order to use one set of antennas for detection of two defects, in [7] a simulation in CST software has been performed and it has been proposed to use SAR imaging in UHF band. Therefore, two defects can be detected by only one set of UHF antennas. However, using same frequency band has a major problem which is effect of PD emitted signal on the results of radial deformation detection during SAR imaging procedure. In other words, if during SAR imaging procedure, a PD is occurred, the achieved signal is sum of PD and reflected Gaussian wave from the winding which leads to wrong decision about the winding condition. Therefore, stepped frequency approach has been proposed for SAR imaging method. In this approach, instead of transmitting a Gaussian wave, sinusoidal waves are transmitted and sum of these waves are assumed as the reflected signal from the winding. As discussed in [7], not only the radial deformation has been detected by stepped frequency SAR imaging, but also the PD can be detected by same antennas. In addition, the generalized likelihood ratio test is used to eliminate the effect of PD on the result of radial deformation detection [7]. However, the previous studies were only on simulation environment and practical investigations have not been performed.

In this paper, a monitoring system is designed according to the proposed approach in [7] and the performance of this system is tested on a real transformer winding. This system can operate in two modes to detect PD and radial deformation defects separately or simultaneously using only one set of antennas which results in economic monitoring system for detecting two defects. It should be noted that in previous studies, simultaneous detection of PD and radial deformation has not been investigated.

The contributions of the paper are as follows:

- Designing a monitoring system to detect PD and radial deformation in the transformer winding.
- Eliminating the effect of PD on the results of radial deformation detection using the designed monitoring system on a real transformer winding.
- Investigation of simultaneous detection of PD and radial deformation using the designed monitoring system on a real transformer.

The rest of the paper are as follows:

In the next section, SAR imaging method for detection of radial deformation is explained and then, the designed monitoring system is described. In Section IV, the results of experimental setup is discussed. Finally, the paper is concluded.

II. SAR Imaging Method for Detection of Radial Deformation

Different views of SAR imaging set-up can be seen in Fig. 1. A pulse is transmitted from the transmitting antenna (TX) and its reflected signal from the target, which is transformer winding in this study, is recorded by the receiving antenna (RX). This procedure can prepare 1-D information of the target. By moving the antennas along the height of the transformer and repeating the procedure of sending and receiving the signals, 2-D information of the winding is gathered.

It should be noted that the received signal is not only from the direct path through transmitting antenna to target and from target to receiving antenna. Several undesired paths are exist between transmitting antenna and winding or between winding and receiving antenna, which lead to undesired parts in the recorded signal. In order to overcome this issue, the shortest and longest paths through TX-target-RX is calculated. It is defined that desired information of the received signal is between the desired duration of signal between T_{min} and T_{max}, which are the longest and shortest time delays, respectively. In other words, the desired signal is in the time duration of t as $T_{min} \leq t \leq T_{max}$.

The 2-D image of the winding can be generated by calculating the magnitude of the reflected waves at every position of antennas. The detailed description has been stated in [8]. The following equation show the final formulation of generating a 2-D image of transformer winding (Fig. 2):

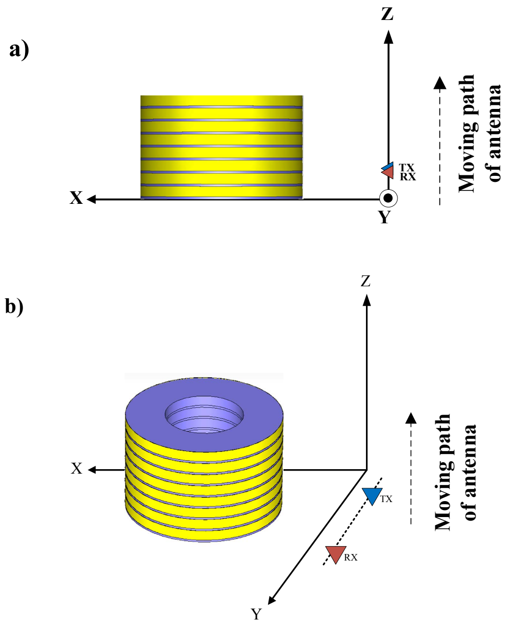

Fig. 1. Setup of SAR imaging method, (a) X-Z side view, (b) 3-D view

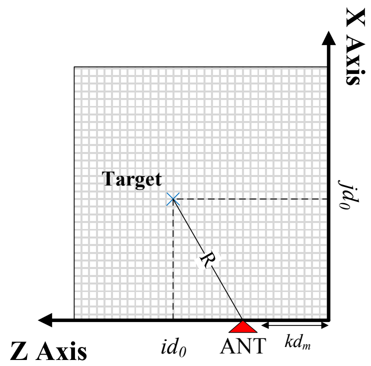

Fig. 2. Schematic of applying Kirchhoff's migration method according to Eq. (1)

$$U(id_0, jd_0) = U(id_0, jd_0) + \frac{d_M . jd_0}{2\pi . R^2 . v . T_s} \times \sum_k [f(kd_M, (n+1)T_s) - f(kd_M, nT_s)]\Big|_{nT_s = 2R/v} \quad (1)$$

$$i, j, k \in Z \quad and \quad 0 \leq k < K \ , 0 \leq j < N \ , 0 \leq i < M$$

where, d_M is the distance between two neighboring measured points, $f(.)$ is the boundary field value, T_s is the sampling time of scanning, kd_M is the k-th measured point on the Y- axis, N and M show the number of image pixels on the X- and Y-axes, c is the wave speed, d_0 is the special point (position) and K is the total number of measured points.

In order to detect radial deformation, it is enough to compare the image of transformer winding in sound condition (when there is no radial deformation) and its image in defected condition. If there is any difference in images, it means that there is a radial deformation in the winding. The procedure of comparison can be found in details in [8].

III. Design of Monitoring System

The designed monitoring system for detection of radial deformation using UHF stepped frequency SAR imaging approach and detection of PD event in the transformer winding is shown in Fig. 1. The designed system has two main parts: transceiver and sampling board. The transceiver has three parts including transmitter, receiver and local oscillator. The system has two operation modes: active mode for detection of radial deformation and passive mode for PD detection. The transmission section is tuned with 10MHz steps and the frequency can start from 800MHz up to 3GHz. The receiver section can be tuned from 100MHz to 3GHz in which the 100MHz to 800MHz is solely for passive mode (i.e. PD detection), while 800MHz to 3GHz is used both for passive and active modes. A graphical user interface is designed to determine power of transmitted signal and frequency band of SF approach (lower and upper frequencies). The role of software part in desktop computer is sending control commands according to the user defined parameters, such as frequency band or power of the transmitted signal, from RS232 port. Then, FPGA starts to sample the IF signals using external trigger pulses. These sampled values are send to desktop computer to be saved and used for Kirchhoff's migration method. The schematic of designed system is shown in Fig. 3.

In the active mode, as described before, sinusoidal signals in UHF band is transmitted to the winding, step by step. The power of transmitted signal in this system can be determined from 0dB to 10dB. In this mode, three parts of transceiver are in circuit.

In the passive mode, the aim is the detection of PD when transceiver is off. In this mode, the system only receives signals from environment.

IV. Experimental Set-up and Results

In this paper, the designed monitoring system is tested on a real transformer winding to detect its radial deformation and PD defects as shown in Fig. 4. The detail specifications of this winding can be found in [4]. The transmitting and receiving antennas with wide range of frequencies, especially in UHF band, are used which detail specifications of antennas can be found in [9]. The moving path of antennas has 16 predetermined positions to perform procedure of sending and receiving the signals according to the UHF SAR imaging method. The distance between the antennas and winding is about 70cm.

In this section, at first the radial deformation is detected using SAR imaging method when there is no PD in the winding. Then, PD is solely detected on the winding. Finally, possibility of simultaneous detection of PD and radial deformation using designed monitoring system is investigated.

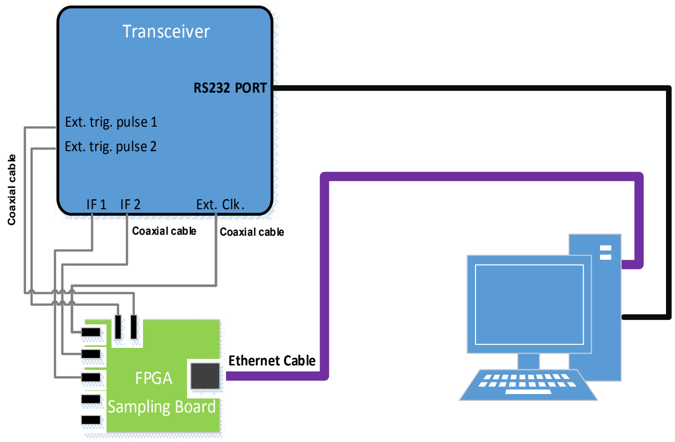

Fig. 3. Designed monitoring system for PD and radial deformation detection

Fig. 4. Set-up of winding and antennas

A. Radial deformation detection

The procedure of SAR imaging in UHF band using stepped frequency approach is performed in this subsection using the designed monitoring system on a real transformer winding. In each position, according to the stepped frequency approach, sinusoidal signals in about 220 frequency steps are transmitted to the target from the frequency of 0.8GHz to the frequency of 0.8GHz. By applying Kirchhoff's migration algorithm on the received signals, the image of winding in sound condition can be generated which is shown in Fig. 5. Then, in one part of winding, a radial deformation is created and the procedure of imaging is repeated to generate the defected image of transformer winding by applying Kirchhoff's migration algorithm on the received signals as shown in Fig. 6.

As described in [7], each color can be represented by a number between 0 and 1. This definition is shown in Fig. 7. For example in this figure, number 0.4 is defined as separator for hot and cold colors. It means that a point in the image which its color number is greater than 0.4, is named as a point with hot color. As described in [7], the number of hot colors is used as the comparative parameter to detect radial deformation. In this study, the number of hot colors in sound image is 294 and the number of them in deformed image is 936, which show the existence of radial deformation in the winding.

B. PD detection

In this subsection, passive mode of the monitoring system is used to detect possible occurrence of a PD in winding. Using two needles, a PD is generated near the winding. While there is not any PD in the winding, the monitoring system receives noise of environment that usually have not significant amplitude as shown in Fig. 8-a. But if a PD occurs in the winding, its signal propagates and received by the monitoring system which has remarkable amplitude in a few samples which is shown in Fig. 8-b. This burst like and strong signal can be used to detect PD.

C. Detection of PD occurrence during SAR imaging procedure

As described in [7], occurrence of a PD during SAR imaging procedure may lead to wrong decision about the transformer condition due to unreliable results of SAR imaging. The received signal of SAR imaging method when a PD is occurred during SAR imaging procedure is shown in Fig. 9.

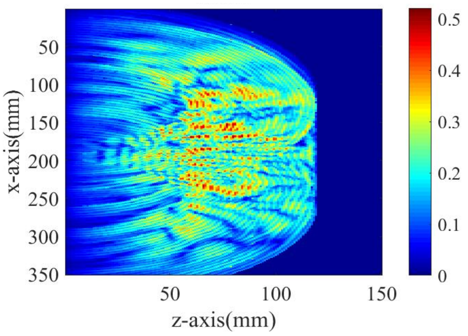

Fig. 5. Image of sound winding using UHF stepped-frequency SAR method

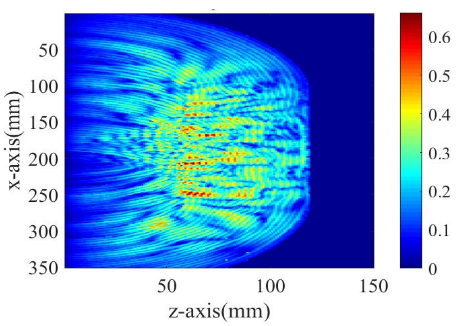

Fig. 6. Image of defected winding using UHF stepped-frequency SAR method

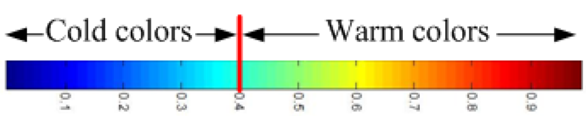

Fig. 7. Quantifying of hot and cold colors to make images comparable

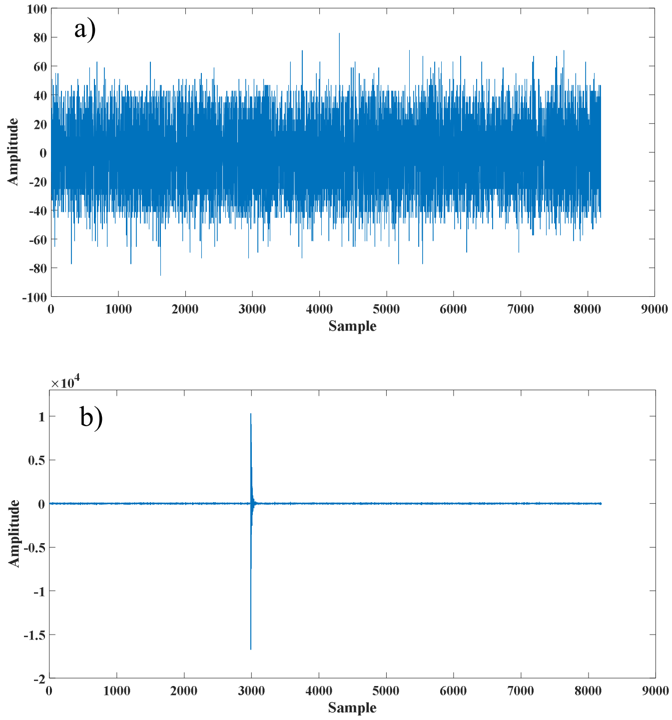

Fig. 8. Recorded signal by the monitoring system in passive mode, a) noise of environment since there is no PD and b) PD signal.

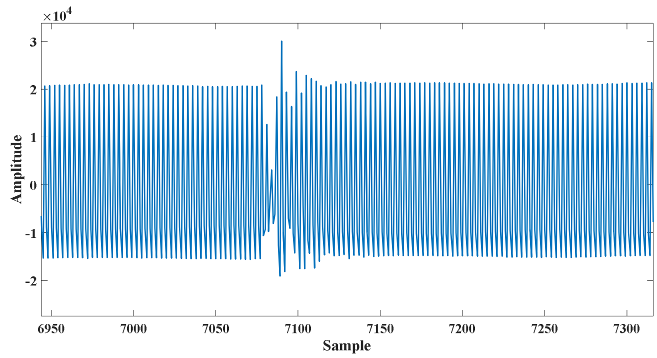

Fig. 9. The received signal of UHF stepped-frequency SAR imaging procedure disturbed by a PD

As described in [7], in no PD condition, the fast Fourier transform (FFT) of the received signal has noisy behavior in all frequencies except in the frequency of the transmitted sinusoidal signal. But if a PD is occurred during SAR imaging procedure, because of wide range of frequency content of PD, the FFT of the received signal, not only have remarkable value in the frequency of the transmitted sinusoidal signal, but also has remarkable value in wide range of frequencies. In other words, if only the amplitude and phase of the received signal is differed compared with the transmitted signal, there is no PD in this condition. Otherwise, a PD is occurred during SAR imaging procedure and the process should be repeated on the disturbed frequency.

D. Simultaneous detection

In previous subsections it has been shown that the monitoring system can:

- Detect radial deformation in no PD condition as mentioned in Section IV.A.
- Detect PD occurrence while the transceiver is off as mentioned in Section IV.B.
- Detect PD occurrence during SAR imaging procedure while the transceiver is on as mentioned in Section IV.C.
- Eliminate PD effect on radial deformation detection as mentioned in Section IV.C. From Sections IV.B and IV.C, it can be concluded that PD can be detected whether there is radial deformation or not.

Therefore, it can be said that the designed monitoring system, can detect all possible condition of occurrence of radial deformation and PD defects in power transformers.

V. CONCLUSION

In this paper, experimental study of detection of two important defects, PD and radial deformation of HV winding, in power transformers using only one set of antennas is investigated. A monitoring system is designed and implemented to detect radial deformation using SAR imaging method and PD using the UHF antennas. This monitoring system is tested on a real transformer winding and results show that it can detect both defects whether occur simultaneously or not. Therefore, it can lead to economic usage of only one set of antennas in the power transformer tank for detection of two defects (dual-purpose application) and achieving more complete online information of transformer condition.

REFERENCES

[1] Rahbarimagham, H., Porzani, H. K., Hejazi, M. S. A., Naderi, M. S., & Gharehpetian, G. B. Determination of transformer winding radial deformation using UWB system and hyperboloid method. IEEE Sensors Journal, 15(8), 2015, pp. 4194-4202..

[2] Karimifard, P., Gharehpetian, G. B., & Tenbohlen, S. Localization of winding radial deformation and determination of deformation extent using vector fitting□based estimated transfer function. International Transactions on Electrical Energy Systems, 19(5), 2009, pp. 749-762.

[3] M. S. Golsorkhi, G. B. Gharepetian, M. Dehmollaian, M. A. Hejazi, "A Feasibility Study on Application of Radar Imaging for Detection of Transformer Winding Radial Deformation", IEEE Transactions on Power Delivery, Vol. 27, No. 4, Oct. 2012, pp. 2113-2121.

[4] Mortazavian, S., Shabestary, M. M., Mohamed, Y. A. R. I., & Gharehpetian, G. B. Experimental Studies on Monitoring and Metering of Radial Deformations on Transformer HV Winding Using Image Processing and UWB Transceivers. Industrial Informatics, IEEE Transactions on, Vol. 11, Issue 6, 2015, pp. 1334-1345.

[5] H. R. Mirzaei, A. Akbari, E. Gockenbach and K. Miralikhani, "Advancing New Techniques for UHF PD Detection and Localization in the Power Transformers in the Factory Tests", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 22, No. 1, 2015, pp. 448-455.

[6] H. Karami, M.S.A. Hejazi, M.S. Naderi, G.B. Gharehpetian, S. Mortazavian, “Three-dimensional Simulation of PD Source Allocation Through TDOA Method”, 4th Conference on Thermal Power Plants (Gas, Combined Cycle, and Steam), Dec. 18-19, 2012, Tehran, Iran.

[7] Karami, H., Gharehpetian, G. B., Norouzi, Y., & Hejazi, M. A. GLRT-based mitigation of partial discharge effect on detection of radial deformation of transformer HV winding using SAR imaging method. IEEE Sensors Journal, 16(19), 2016, 7234-7241.

[8] S. Mortazavian, G. B. Gharehpetian, M. Akhavan Hejazi, M. S. Golsorkhi, and H. Karami, “A Simultaneous Method for Detection of Radial Deformation and Axial Displacement in Transformer Winding Using UWB SAR Imaging”, 4th Conference on Thermal Power Plants (Gas, Combined Cycle, and Steam), Dec. 18-19, 2012, Tehran, Iran

[9] http://www.taoglas.com/wp-content/uploads/2015/04/TG.35.8113W.pdf