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# Modelling of On-line Monitoring of Transformer Winding Radial Deformation Using UWB Sensors

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*Abstract*— **The radial deformation of transformer windings can be caused by mechanical or electromechanical forces. In this paper, a new monitoring method based on Ultra Wide Band (UWB) sensors, to detect the radial deformation of winding of large power transformers, is proposed. The proposed experimental set-up for this method has been modelled using CST (Computer Simulation Technology) software. The results show that the radial deformation of windings can be detected by the on-line monitoring of UWB waves.**

***Keywords-component; Transformer Radial Deformation, On-Line Monitoring, CST Simulation, UWB Waves.***

## I. INTRODUCTION

THE main cause of deformations of transformer windings is the high short-circuit currents. Winding deformation is a mechanical defect that can result in unwanted outage of transformer. Therefore, it is important to detect a mechanical defect before transformer outage [1].

In recent years, several off-line methods such as Short Circuit test method (SC) [1], Low Voltage Impulse method (LVI) [2] and Frequency Response Analysis method (FRA) [3] have been proposed to detect the winding deformation. However, all mentioned methods are offline and the utility engineer should turn off the transformer in order to carry out the measurement. As a result, the engineers need an efficient method that can detect the fault in on-grid connected situation. The advantage of an on-line monitoring method is the prediction of the fault before its occurrence.

This paper presents a feasibility study on on-line monitoring of transformer winding radial deformation using Ultra Wide Band (UWB) waves. The UWB signals used for this method have very high accuracy, because of the excellent spatial resolution of the UWB system. This method can present more information about the type and location of the fault because of special characteristics of UWB signals [4].

This paper starts with the theory of signals used in UWB applications. Then, the simulated structure for the modeling of the winding displacement has been discussed. Finally, the results of the simulation using CST software have been presented.

## II. UWB SIGNALS

A UWB signal is defined to have an absolute bandwidth of at least 500 MHz or a fractional (relative) bandwidth of larger than 20% [5]. Ultra-wideband radars are used for different applications such as subsurface sensing, classification of aircrafts, collision avoidance and detection of humans trapped in buildings on fire, in collapsed buildings and avalanche victims [6]. The penetration capability of a UWB signal is due to its large frequency spectrum that includes low frequency components as well as high frequency ones. This large spectrum also results in high time resolution, which improves ranging (i.e., distance estimation) accuracy.

In this research, the radial deformation of a simulated winding has been detected using ultra-wide band pulses.

## III. MODELING

This section presents the details of the model used for the radial deformation detection. UWB signals have been considered in the form of Gaussian monocycle pulse trains. Fig. 1 shows the transmitted signal that is used in simulations. The parameters of this signal are listed in Table I.

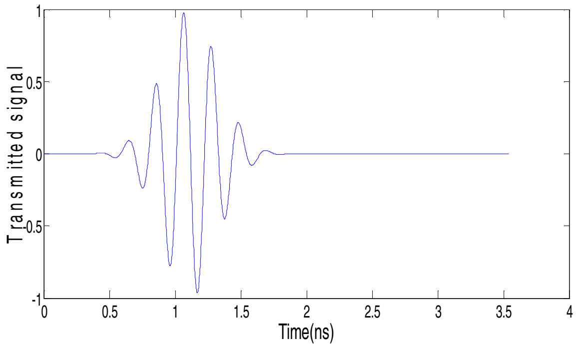

Fig. 1: Transmitted Gaussian UWB signal used for simulation.

TABLE I:
TRANSMITTED PULSE PARAMETERS

| | |
|---|---|
| Center Frequency (radiated) | 4.7GHz |
| Bandwidth (10 dB radiated) | 3.2 GHz |

The set-up which should be modeled has the following parts:

- Transmitting/ Receiving antenna and
- Winding model.

### A. *Transmitting and receiving antenna*

In this paper, a simulated model of Vivaldi antenna [7] has been used for the simulation. The Vivaldi antenna is a UWB antenna with differnet applications. Theoretically, the Vivaldi has an unlimited range of operation frequencies, with constant bandwidth over the entire bandwidth [7]. A Vivaldi antenna, used in this paper, is shown in Fig. 2.

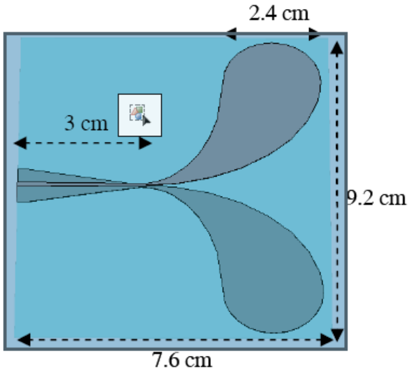

Fig. 2: Vivaldi antenna dimensions [7]

The simulations and characteristics of the Vivaldi antenna have been presented in [7].

### B. *Model of transformer winding*

A simplified model of transformer with the ability of radial deformation has been used in this study. Disks are of plexiglass sheets which are covered by a layer of copper. They are separated with spacers of equal thickness. Fig. 3 shows the model and Table II lists this model dimensions. The upper disk contains 5 segments which can model radial deformation. These segments can be radialy moved, to model the radial deformation in transformer winding. The parameters of segments are listed in Table III.

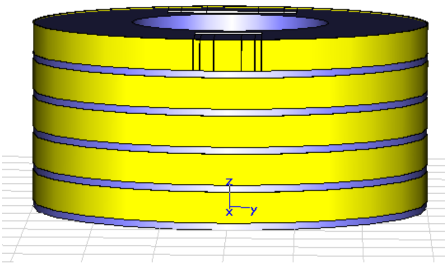

Fig.3: Transformer winding model

TABLE II:
TRANSFORMER WINDING MODEL DIMENSIONS

| | Disk | Spacer |
|---|---|---|
| Diameter | 15 cm | 15 cm |
| Thickness | 2 cm | 0.5 cm |
| Number | 5 | 5 |

TABLE III
SEGMENTS PARAMETERS

| Segment | area |
|---|---|
| $S_1$ | 0.5*2.0 cm$^2$ |
| $S_2$ | 1.0*2.0 cm$^2$ |
| $S_3$ | 1.0*2.0 cm$^2$ |
| $S_4$ | 2.0*2.0 cm$^2$ |
| $S_5$ | 2.0*2.0 cm$^2$ |

## IV. SIMULATION RESULTS

A bi-static configuration is proposed for the measurement set-up. The proposed set-up is simulated as shown in Fig. 4. In this figure, $d_1$ is the distance between the transmitting and receiving antenna, $d_2$ is the distance between the model and the center of the line connecting the antennas, $d_3$ is the distance between the transmitting/receiving antennas from the model. The parameters of the proposed set-up are listed in Table III.

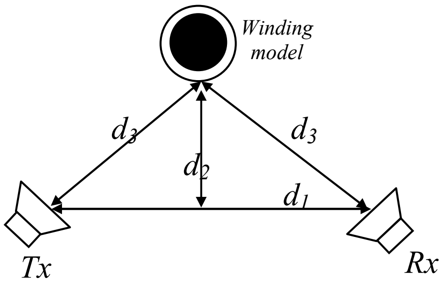

Fig. 4: Proposed set-up for radial deformation measurement

TABLE IV:
PARAMETERS OF PROPOSED SET-UP

| | |
|---|---|
| $d_1$ | 56.56 cm |
| $d_2$ | 49.00 cm |
| $d_3$ | 40.00 cm |

The distance between the antenna and the winding is selected according to the far field limitations of the antenna [7. The proposed set-up, as shown in Fig. 5, has been simulated by CST software.

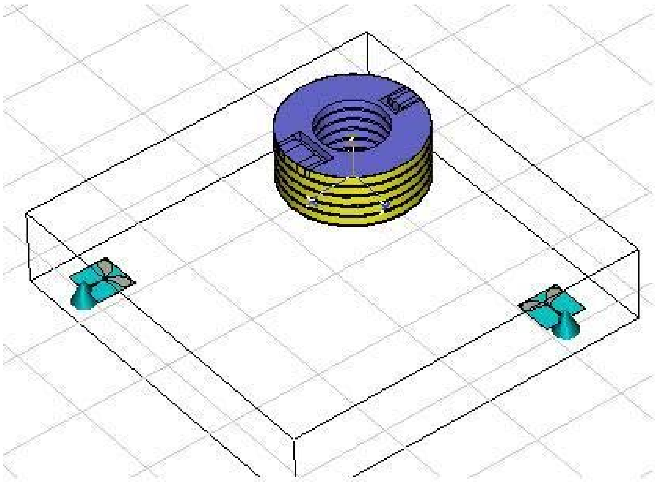

Fig. 5: Simulated set-up by CST software

In this simulation, the propagation medium is considered to be air and the transformer tank is not modeled.

The simulations have been carried out for two cases, as follows:

- The reference case, in which the winding is in its reference position and
- The deformed cases, in which the radial deformation has been occurred as listed in Table V.

In both cases , i.e , the reference and the deformed cases, a Gaussian signal has been transmitted to the winding model by using the transmitting antenna and the receiver receives the reflected signal.

For the deformed cases, the radial deformation has been modeled by moving the segments inward or outward and then, the received signal has been recorded by the receiving antenna.

The amount of the radial deformation for each segment is summarized in Table V. For all segments the amounts of the radial deformation are the same.

Table V

RADIAL DEFORMATION TESTS

| Test No. | Amount of radial deformation |
|---|---|
| 1 | 0mm |
| 2 | +1mm |
| 3 | +2mm |
| 4 | +3mm |
| 5 | +4mm |

Fig. 6, 7 and 8, show the received signals of deformation in segments $S_1$, $S_2$ and $S_4$ in comparison with the reference case.

By using the Mean Absolute Distance (MAD) index, the signals received in different deformation tests can be compared with the signal of the reference case, as follows:

$$MAD = \frac{1}{N}\sum_{j=T_1}^{T_2}\left|\frac{a_j - a_1}{a_1}\right| \qquad (1)$$

Where, $T_1$ is the beginning time of the window, $T_2$ is the end instant of the window and $N$ is defined, as follows:

$$N = \frac{T_2 - T_1}{T_S} \qquad (2)$$

Where, $T_S$ is the sampling time.

Table VII lists the calculated *MAD* index for the radial deformation measurements.

The results show the sensitivity of the method to the radial deformation.

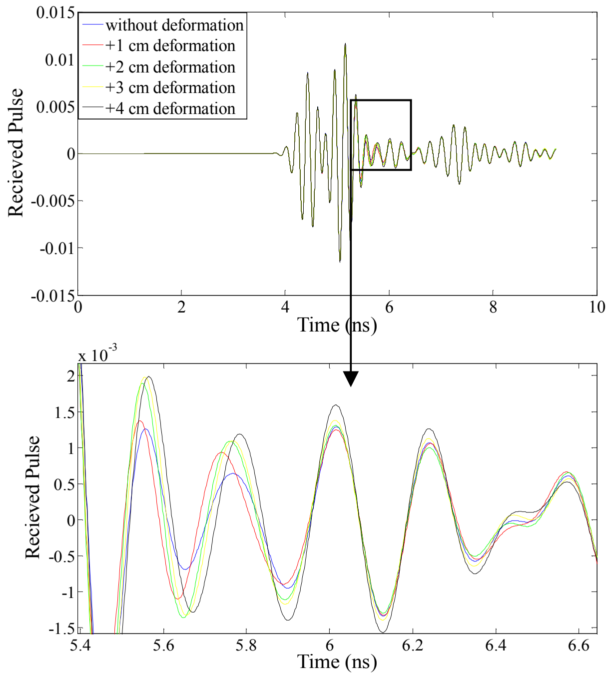

Fig. 6: Comparison of received signals for $S_1$

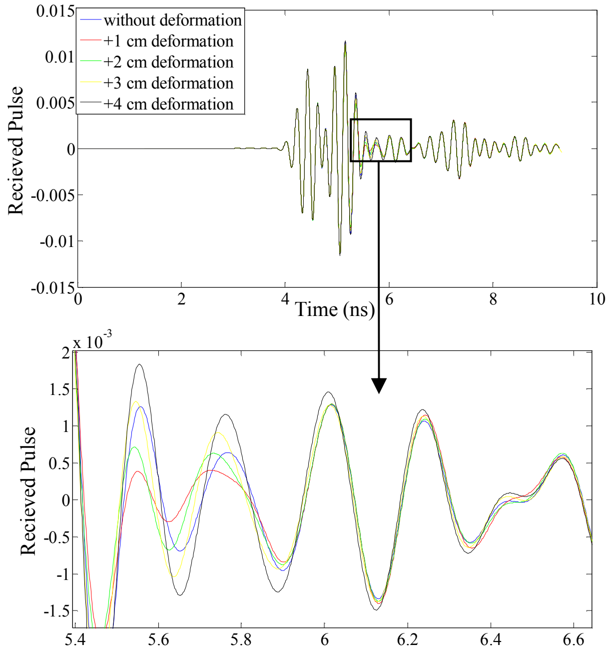

Fig. 7: Comparison of received signals for $S_2$

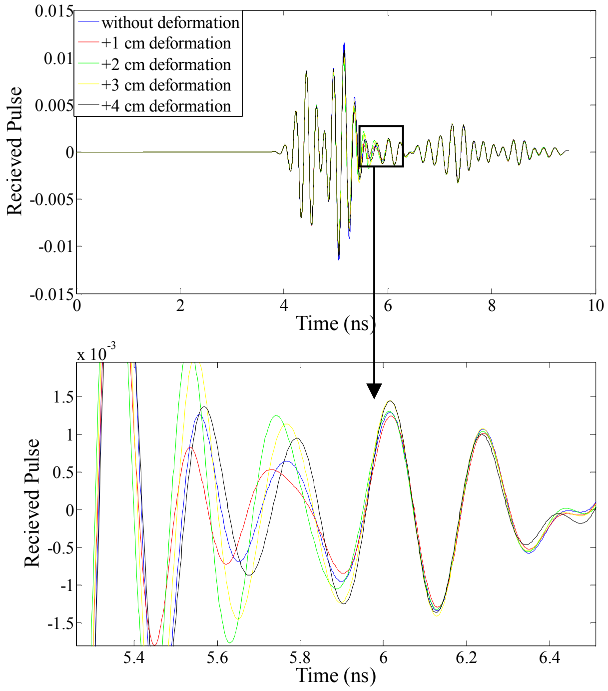

Fig. 8: Comparison of received signals for $S_4$

TABLE VI:
*MAD* INDEX OF RADIAL DEFORMATION

| Deformation Area (cm$^2$) | Deformation length (cm) | *MAD* |
|---|---|---|
| $S_1$ | 1 | $6.53*10^{-5}$ |
| $S_1$ | 2 | $1.73*10^{-5}$ |
| $S_1$ | 3 | $7.00*10^{-5}$ |
| $S_1$ | 4 | $1.31*10^{-4}$ |
| $S_2$ | 1 | $1.72*10^{-4}$ |
| $S_2$ | 2 | $1.95*10^{-4}$ |
| $S_2$ | 3 | $6.78*10^{-5}$ |
| $S_2$ | 4 | $7.74*10^{-5}$ |
| $S_4$ | 1 | $2.57*10^{-4}$ |
| $S_4$ | 2 | $1.24*10^{-4}$ |
| $S_4$ | 3 | $12.00*10^{-4}$ |
| $S_4$ | 4 | $9.88*10^{-4}$ |

## V. CONCLUSION

In this paper, a new method based on UWB waves for the detection of the radial deformation of the transformer winding has been proposed. This method can be used for off-line or on-line applications. Simulations on a simplified model of the transformer winding show the sensitivity of the proposed method to the winding radial deformation.

## VI. ACKNOWLEDGMENT

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