Case Study and Analysis of Impulse Voltage and its Effect on Transformer Windings

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Abstract— In this work, a comparative study on the variation of maximum voltage to ground and voltage across the coils under different impulse voltages indicated that non-standard impulse voltage waveform develops higher voltage stress in the windings. They draw high risk and are critical to transformer insulation system. [1] Described method can be used by transformer manufactures to estimate voltage wave forms during switching or lightning, and to proves useful information for insulation coordination studies. [2].

Key words: Transformer, Impulse Voltage, Oscillation, Circuit Breaker, Lightning

I. INTRODUCTION

Transformers are an integral part of transmission and distribution networks. When transformer windings are excited by impulse voltages, high amplitude oscillatory voltage stresses induced in the transformer insulation between the winding and the ground and across the windings. [1] The severity of insulation degradation depends on steepness of the wave, instant of chopping, time to collapse, frequency oscillations, overshoot near the peak etc. [2] the positive and negative polarity of oscillating waveforms affects the insulation breakdown in power equipment. High frequency overvoltage is often produced by the re-strikes and pre-strikes during the opening or closing of a switching device like the circuit breakers. Voltage oscillations which proceed toward windings are continuously superposed by new voltage waves from new upcoming surges. Hence, voltage waveforms along the transformer winding within a particular time interval can have very different amplitude and rate of rise. Their oscillations contain a broad frequency range which can be from a few kilohertz up to a few megahertz. [3] These are unwanted phenomena which cause deterioration and failure of the equipment insulation. Sometimes high inter-turn overvoltage can take place which stress the thin insulation and accelerate its failure. The lightning impulse voltages of transformer tests with physically given inductances and capacities shows impulse shapes with superimposed oscillations or overshoots. [4] The distribution of these transient over voltages in transformer winding is highly non-uniform. It has been observed that 60 Percent of these voltages appear across first 10 percent length of the winding. This non-uniform voltage distribution can damage the transformer insulation. This work deals with the voltage distribution in the transformer winding when its terminal is excited with impulse voltage. Distribution of the impulse voltage along the winding depends on the winding capacitive network that is consisting of parallel and series capacitances.

Capacitors between winding turns are known as series and capacitors between turns and core are known as parallel capacitors. [1]

A. *Inductance and Capacitance*

Inductances are calculated by the well-known Maxwell formulas on a turn-to-turn basis. The L matrix is formed in a way that diagonal elements of the matrix correspond to a group of turns. [2]

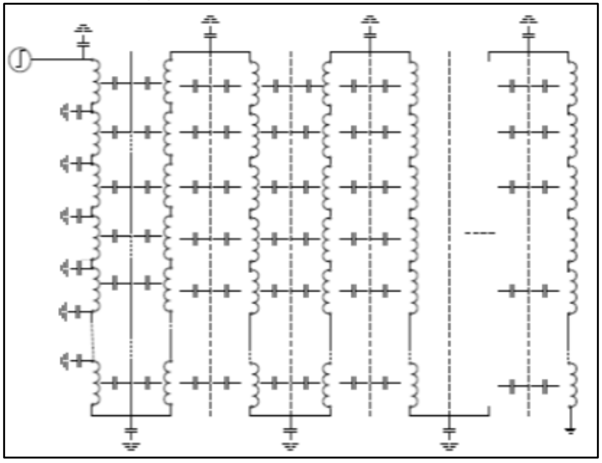

Fig. 1: Inductors and capacitors

The off-diagonal elements are mutual inductances between different groups of turns. For simplicity in this case, the number of turns in a group is kept constant. The studied transformer has 10 layers with approximately 142 turns per layer. Each layer is divided in 10 groups with 14 turns per group. So, we assume that a layer consists of 10 groups. So, the transformer L matrix is of order 100x100. The capacitance matrix is built on a node-to-node basis and because the number of nodes N=B+1 where B is the number of branches represented by inductances, the capacitance matrix is of order 101x101. By making use of the inductance matrix L and the capacitance matrix C, impedance and admittance matrices *Z* and *Y* are determined, [2]

II. IMPULSE VOLTAGE WAVEFORMS

In this study, the transformer windings sections are subjected to six different waveforms including standard and non-standard lightning impulse voltage waveforms. The applied impulse voltage waveforms are generated in MATLAB. [1]

A. Full Lightning Impulse Voltage Waveform

As per IEC 60060-a, a full standard lightning impulse voltage rises to its peak value in 1.2 µs and the tail of the wave decays to a level of 50 percent of the peak in 50 µs.

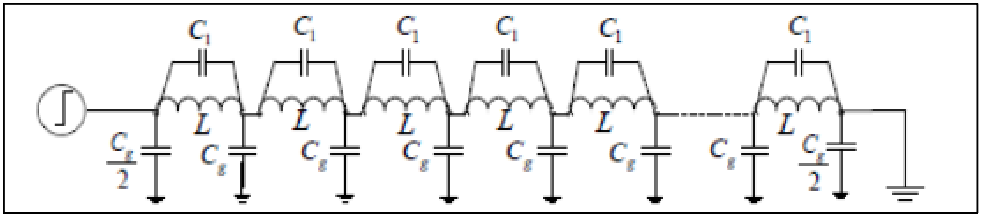

Fig. 2: lumped-parameter model for transformer voltage distribution

$$Z = \left(j\omega + \sqrt{\frac{2\omega}{\sigma\mu_0 d^2}} \right) L$$

$$Y = (j\omega + \omega \tan\delta)C$$

Where,
d - is the distance between layers,
σ - is the conductor conductivity,
tan δ - is the loss tangent of the insulation

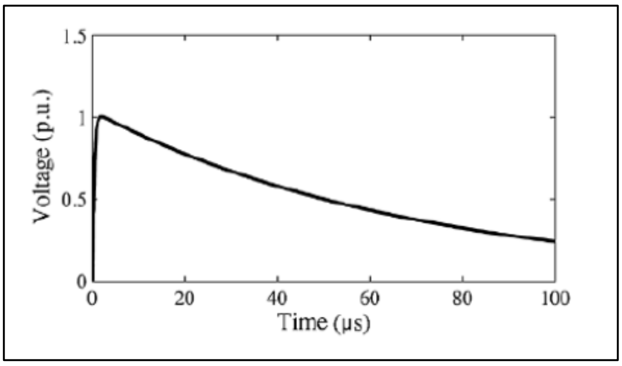

Fig. 3: Full lightning impulse voltage waveform

B. Chopped Lightning Impulse Voltage

A chopped wave is developed during flashover. The standard lightning impulse voltage waveform can be chopped on the tail, peak or front. The crest value of the standard tail chopped wave is 10% greater than that of full impulse wave and chopped at 2-6 µs. [1] Such impulse has a rapid voltage collapse on the tail with a small portion of negative overshoot. In this work, impulses with chopping time 3µs, 8µs and 15µs on tails are used to investigate the voltage distribution on the windings. The tail chopped impulse at 8µs and 15µs represent the non-standard chopped impulses. [1]

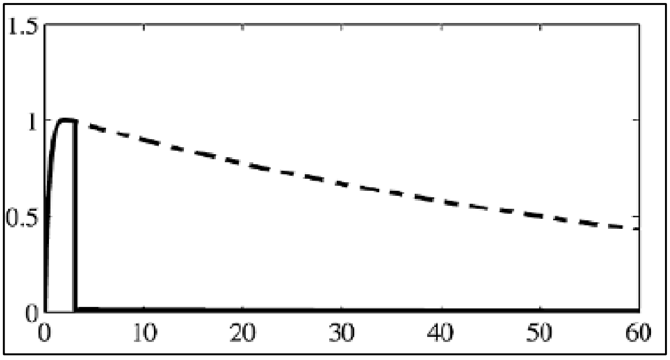

Fig. 4: Standard chopped impulses (3µs)

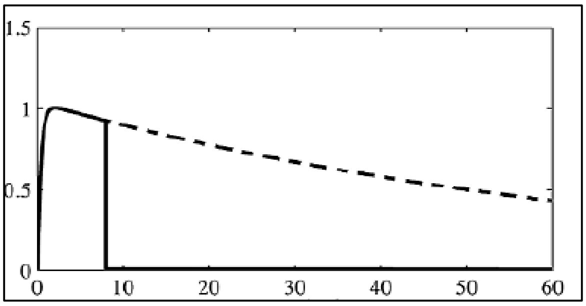

Fig. 5: Non-standard chopped impulse waveform (8µs)

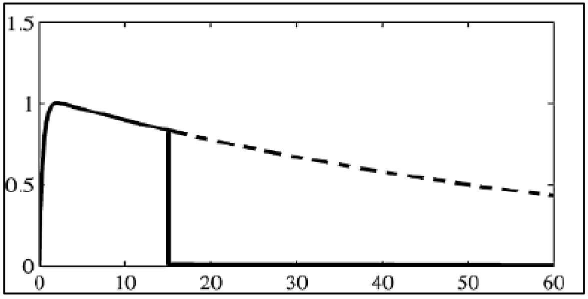

Fig. 6: Non-standard chopped impulse waveform (15µs)

C. Non-Standard Single-Pulse Impulse Voltage Waveform

Single pulse non-standard impulse voltage waveform has been used in this work to study the winding response against non-standard lightning impulse waveforms without oscillations. [1] These impulses have a steeper wave front and short, non-oscillating tail compared to the standard lightning impulse waveform. The wave shape of a typical single pulse impulse voltage waveform is shown in the figure 7.the wave front time of the impulse is 0.8µs.

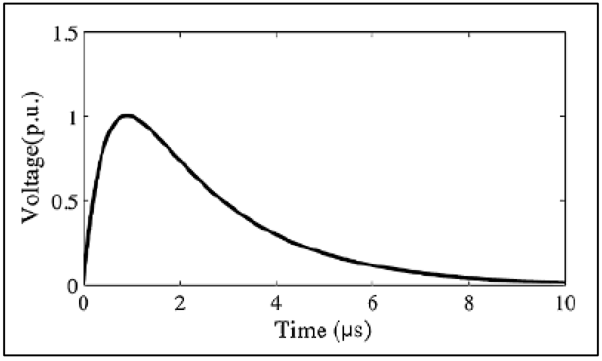

Fig. 7: Single pulse impulse voltage waveform

D. Non-Standard Damped Oscillating Impulse Voltage Waveform

Oscillations can occur in impulse waveforms due to series and parallel resonance. The wave shape of a typical damped oscillating impulse waveform is shown in figure 8. The voltage rise time is 1.9µs.

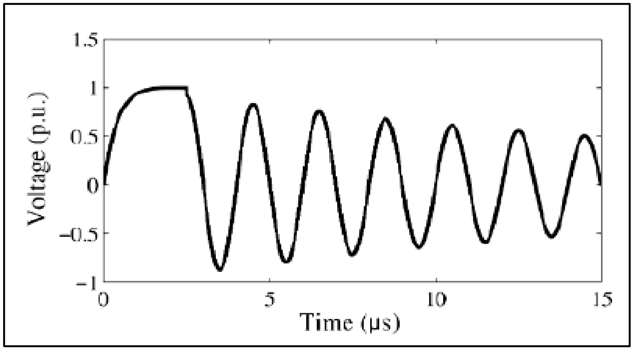

Fig. 8: Damped oscillating impulse voltage waveform

III. CONCLUSION

In this work, the standard and non-standard impulse voltages along with different chopping times, non-oscillating single pulsed wave and non-standard sampled oscillating impulse voltage were studied using and simulated transformer model. The simulations are performed using MATLAB Simulink. Test result showed that non-standard impulse voltage waveforms develop high voltage stress posing highest risk to the equipment's insulation.

REFERENCES

[1] Kaveri Bhuyan, Saibal Chatterjee: "Electric Stresses on Transformer Winding Insulation Under Standard and Non-Standard Impulse Voltages".
[2] M. Popov, R.p.p. Smeets, L. van der Sluis, H. de Herdt, J. Declercq: "Analysis of Voltage Distribution in Transformer Windings During Circuit Breaker Prestrike".
[3] Kanchan Rani, R. S. Gorayan: "Transient Voltage Distribution in Transformer Winding", IJRET, ISSN: 2319-1163.
[4] M. Heidarzadeh, M. R. Besmi: "Influence of the Parameters of Disk Winding on the Impulse Voltage Distribution in Power Transformers".
[5] Devrajan. M, Premi. V: "Simulation of Characteristics of Impulse Voltage Generator for Testing of Equipment Using MATLAB Simulink".
[6] Daniel McDermit, David D. Shipp, Thomas J. Dionise, Visuth Lorch: "Medium Voltage Switching Transient Induced Potential Transformer Failures".
[7] Tamer Abdelazim, Thomas J. Dionise, Robert Yanniello: "A Case Study of Voltage Transformer Failures in a Modern Data Center"