# TRANSIENT VOLTAGE DISTRIBUTION IN TRANSFORMER WINDING (EXPERIMENTAL INVESTIGATION)

**Kanchan Rani[1], R. S. Gorayan[2]**

[1] M.tech Student, [2]Professor, Electrical Department IIT (BHU), VARANASI, U.P India,
***kanchan.rani.eee11@itbhu.ac.in, rsgorayan.eee@iitbhu.ac.***

## Abstract

*In this work, the non-liner voltage distribution in transformer winding is investigated that occurs due switching and lightning. Transformer winding is modeled in the alternative transients program (ATP) version of Electromagnetic transients program (EMTP-RV). EMTP software is used to simulate the very fast transient overvoltage. An experimental setup that consist of , Recurrent surge generator, CRO and transformer winding model has been developed and voltages measured at different point along the transformer winding. Simulation results show good agreement with the experimental result.*

***Index Terms:*** *Very fast transient overvoltages, internal resonance, impulse voltage distribution, disc winding*

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## 1. INTRODUCTION

It is well known that switching operation in the Gas insulated switchgears (GIS) produces very fast transient over voltages (VFTO). VFTO have very short rise time of .1µsec or less and its main oscillating frequency range is in between 1MHz to 50MHz [1].

The distribution of these transient over voltages in transformer winding is highly non uniform. It has been observed that 60 Percent of these voltages appears across first 10 percent length of the winding. This non uniform voltage distribution can damage the transformer insulation [2].

This work deals with the voltage distribution in the transformer winding when its terminal is excited with impulse voltage. Study is aimed to analyze the nature of the internal voltage amplification and voltage stress at various points of transformer winding with impulse excitation. A transformer winding model is developed on the EMTP software. Simulation results are compared with the experimental results and a satisfactory result are obtained.

## 2. TRANSFORMER WINDING MODEL

For the study of the transients response of the transformer a high frequency circuit model of 100 KVA transformer model has been developed based on geometry and configuration. While calculating phenomena associated with such high frequencies, the capacitance of transformer winding is important, although it is of no importance at power frequency voltage levels. The most detailed model of the transformer is one in which every turn of the winding is represented and all capacitances and inductances are included. Such a model may be prohibitive in terms of memory and complexity. The details can be reduced, by taking some assumption, to simplify L, C, network without losing much accuracy. A schematic diagram of the developed model is shown as in Figure1

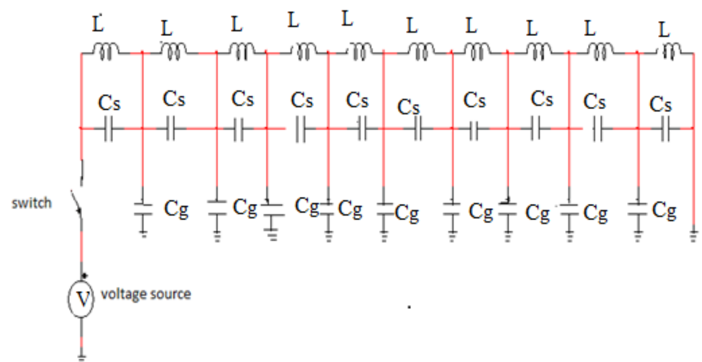


**Fig. 1:** Simplified Equivalent model for Transformer Winding

It is assumed that the winding is uniform i.e. all the series capacitance are equal and all shunt capacitance are equal and all series inductances are equal.

## 3. TEST TRANSFORMER AND CALCULATION OF WINDING PARAMETERS

### 3.1. Test Transformer description

To determine the transient's voltage distribution in the transformer windings, it is necessary to calculate the parameters of the winding i.e. inductance and capacitance. The study has been done on 100 KVA single phase transformer having continuous disk type H.V. winding. The transformer data is given in Table 1.

**Table 1:** Test Transformer data

| | |
|---|---|
| Rating | 100 kVA |
| H.V. voltage | 11 kV |
| L.V. voltage | 433V |
| Frequency | 50Hz |
| Insulation between core and L.V. winding | Bablised Paper |
| Insulation over conductor | Paper |
| Insulation over layer | Paper |
| Insulation over L.V. and H.V. winding | Bablised paper |

Table 2 and 3 present core and windings data for the Test Transformer.

**Table 2:** Transformer Core data

| | |
|---|---|
| Diameter of core | 375 mm |
| Width of window | 375 mm |
| Height of window | 1335 mm |
| CRGO lamination | .33 mm |
| Distance between center of adjacent limb | 685 mm |

**Table 3:** Transformer Winding data

| Winding | L.V. | H.V. |
|---|---|---|
| Type of winding | Helical | Disc |
| Current density | 2.75 A/mm2 | 2.92 A/mm2 |
| Cross area of conductor | 55 mm2 | 8.637 mm2 |
| Number of disc | - | 10 |
| Inside diameter | 405mm | 571mm |
| Outside diameter | 507mm | 649 mm |
| Mean length of turn | 1432mm | 1916mm |

### 3.2 Determination of the transformer winding parameters

**Capacitance calculation:**

Disc to disc capacitance for the winding have been calculated from the principle of electrostatic energy conservation [3].
Net series capacitance is given as:

$$Cs=\frac{\varepsilon_0 \pi D}{N}\left[\frac{(n-1)}{n^2}\frac{\varepsilon_t(h+2\delta_t)}{2\delta_t}+\frac{4(N-1)}{3N}\left(\frac{r+\delta_d}{\frac{2\delta_t}{\varepsilon_t}+\frac{\delta_d}{\varepsilon_d}}\right)\right]$$

Where, D =mean winding diameter
N=number of disc in the transformer
n =number of turn per disc
h=width of copper strip conductor
$\delta_d$= inter –disc space
$\delta_t$ =thickness of insulation

Disc to ground capacitance for winding have been calculated assuming that the coil, core leg and the metal tank form cylindrical electrode system.

Net shunt capacitance is given as: $C_g=\frac{2\pi\varepsilon_0}{\ln\frac{bd}{ac}}\varepsilon_t l$

Where, a = Radius of core
b = Inner radius of L.V. winding
c = Outer radius of H.V. winding
d = Inner radius of H.V. winding
$l$ = Axial length of the H.V. winding

**Inductance calculation [4]:**

We have,

L= .001a$N^2 P_0{}'$

If $\frac{c}{2a}$<.2, then

$$P_0{}'=4\pi\left[\frac{1}{2}\left(1+\frac{1}{6}\left(\frac{c}{2a}\right)^2\right)\ln\frac{8}{\left(\frac{c}{2a}\right)^2}-.8434+.2041\left(\frac{c}{2a}\right)^2\right]$$

## 4. TRANSFORMER WINDING RESPONSE TO IMPULSE VOLTAGES

When analyzing the impulse voltage distribution in the transformer winding a capacitive network is considered. In other words, the presence of series capacitances between winding sections causes the transformer to respond to abrupt impulses as a network of capacitances for all frequencies above its lower natural frequencies of oscillations.

$C_g$ And $C_s$ are the total ground capacitance and series capacitance of the transformer winding respectively. The ratio $\sqrt{C_g/C_s}$ has been denoted by the distribution constant α.

To improve the transients response and to reduce the disc to disc voltage gradient the value of α is as small as possible. One way to reduce the value of α is to increase the value of $C_s$ which can be achieve by interleaving and inter-shielding [5].

### 4.1. Simulation Result

The behavioral response of the high voltage winding of the transformer have been analyzed using EMTP by simulating the circuit shown in Fig-1. An impulse voltage source having peak voltage 40 volt is apply on the excitation terminal and the voltage at various node is measured. The node voltage at 2nd ,3rd and last node is shown in below with isolated neutral. fig -2, fig-3 and fig-4 show the node voltages when α is 10,3.5 and 1 respectively .

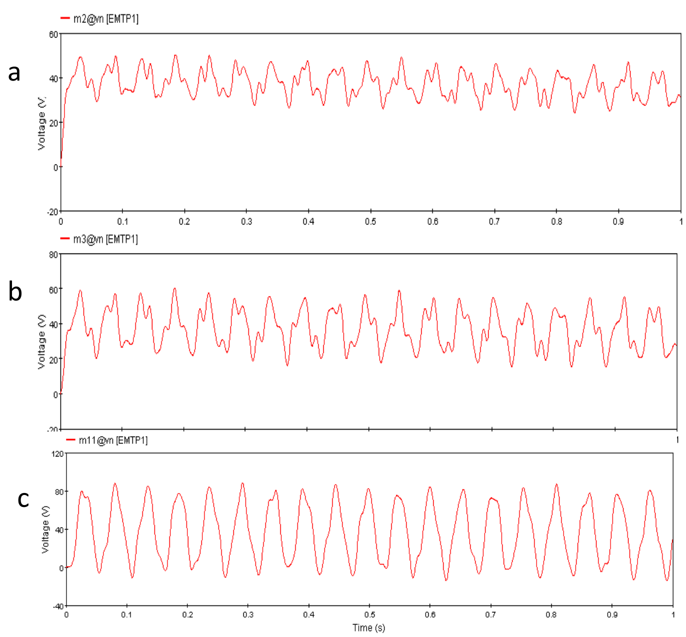


**Fig2** : node voltage when α =10 at a- 2nd node b- 3rd node c- last node

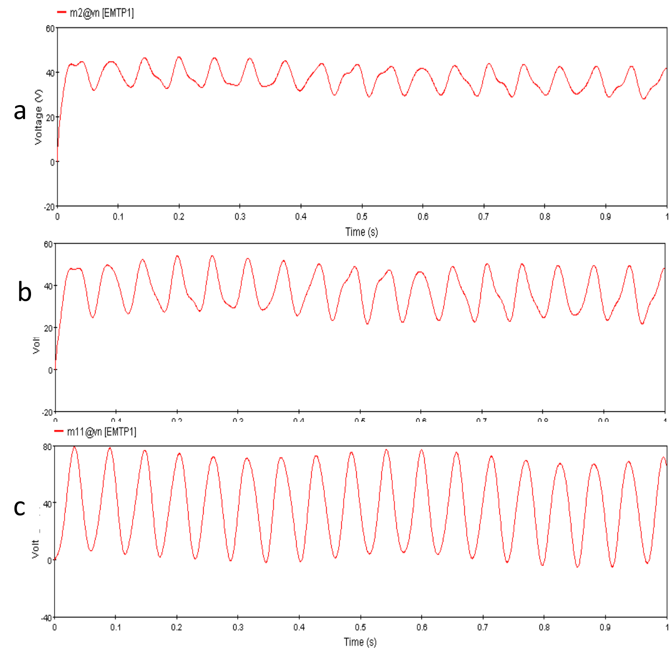


**Fig3**: node voltage when α =3.5 at a. 2nd node b.3rd node c. last node

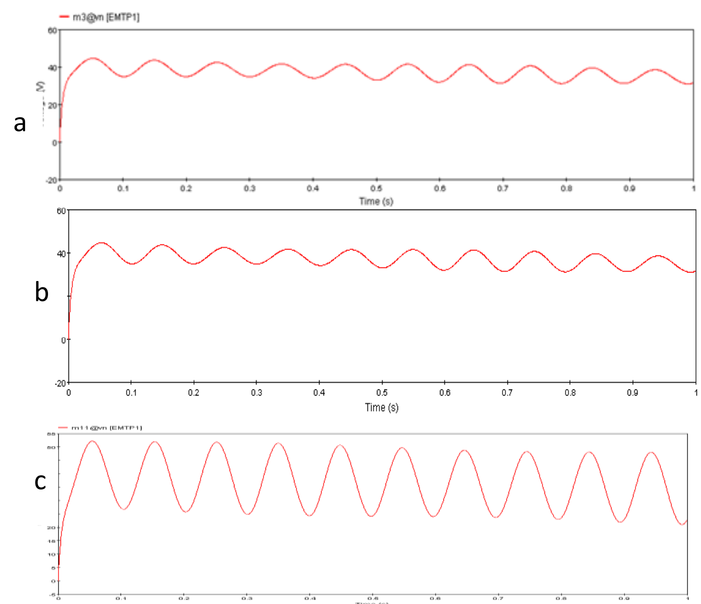


**Fig4**: node voltage when α = 1 at a. 2nd node b. 3rd node c. last node

### 4.2 Experimental results

The transient response of the transformer winding is investigated using experimental set up as shown in Fig 5

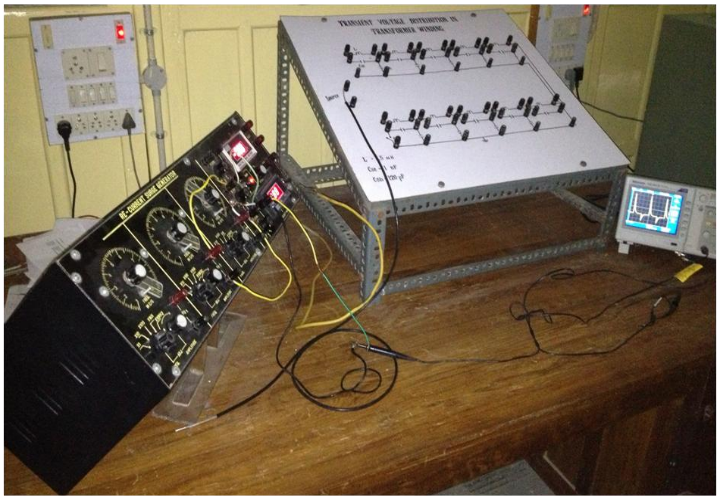

**Fig 5** : Experiment set-up

In the experiment the same impulse voltage as in simulation was injected to the transformer winding model using the recurrent surge generator and the voltage at various node is observed using CRO.

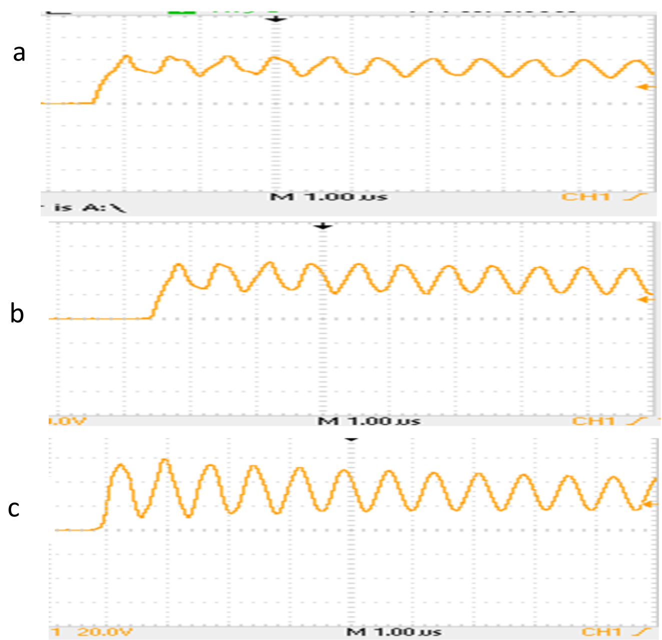


**Fig 6**: node voltage when α = 10 at a. 2nd node b. 3rd node c. last node

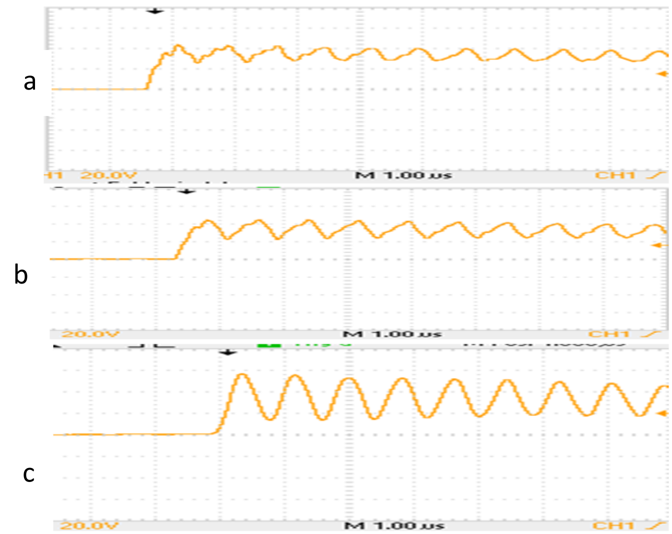


**Fig 7**: node voltage when α =3.5 at a. 2nd node b. 3rd node c. last node

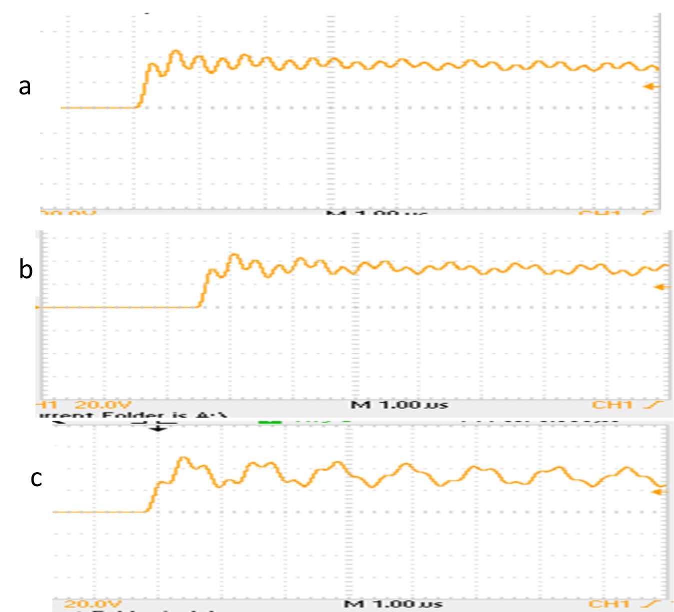


**Fig 8** : node voltage when α =1 at a. 2nd node b. 3rd node c. last node

## CONCLUSIONS

The result obtained from the EMTP simulation closely agrees with the experimental results. Impulse response of transformer winding is oscillatory. If the oscillation frequency equals the transformer natural frequency, then oscillatory transients response can trigger internal resonance. Voltage at different node shows that oscillation is reduced as the value of α is decreases.

Results also indicate that voltage distribution in the transformer is highly non uniform with larger value of α as compare to when value of α is low.

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## BIOGRAPHIES:

Obtained the Under Graduate degree from B.B.D. National Institute of Technology & Management, Lucknow. Presently doing Post Graduation from Indian Institute of Technology, BHU, Varanasi

Obtained the Under Graduate and Masters degree from University College of Engg. Burla, Sambalpur University, Odissa, and Ph.D. from Institute of Technology, BHU, Varanasi. Presently, working as Professor in IIT (BHU) Varanasi.