Simulation Analysis of Surge Behaviour of Power Transformer Model Winding Represented by Large Number of Sections

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Abstract: **Surge voltage behaviour of HV power transformer windings are of great importance to electrical engineers for design of insulation. Behaviour of HV power transformer winding insulation for fast rising surge voltages such as lightning overvoltages, is dependent upon square root of the ratio of the total ground capacitance to total series capacitance of the winding which is termed as alpha["α"]. Few recent investigations have been reported which have considered HV transformer winding as a model winding consisting of less than ten sections. However an analysis by representing a HV power transformer model winding by large number of sections can provide more accurate results and other technical information also. In the present investigations computer simulation of HV power transformer model winding represented by 8, 16 and 24 sections are analyzed. The different alpha values of winding selected are 5, 10 & 20. Computer simulations have been carried out using software PSPICE version 10.0. Unit step voltage and standard lightning impulse voltage [1.2/50µsec wave shape] have been considered for surge voltage analysis of model winding. The results show that the maximum difference between electrical stress computed for 24 sections representation and 8 sections representation is about 8% for higher α value windings corresponding to zero initial time instant. However there are large differences between voltages appearing across sections of winding at other instants of time.**

I.INTRODUCTION

Surge voltages such as lightning overvoltages are characterized by very steep initial rate of rise of voltage and relatively slow rate of fall of voltage with respect to time. The most important type of transient overvoltages which can cause damage to insulation of HV power transformer winding are surge voltages with fast rise times. This is because the voltage distribution along the length of the HV power transformer winding due to appearance of steep front time voltage surges at line terminal is highly non-uniform. Depending upon the "α" value of winding, magnitude of surge voltage as high as 70% or higher value of the incoming surge voltage magnitude can appear across only 10% of the winding length from the line terminal, close to initial time instant of appearance of surge voltage. In addition, there can be large voltage oscillations of various natural frequencies before the voltage distribution settles down towards steady state behaviour. The transition from initial voltage distribution towards steady state distribution may also result in high voltage stresses across coils of transformer winding at different time instants. The "α" value of a transformer winding can be determined from experiments as reported in literature [9]. Recent investigations has reported the behaviour of HV power transformer model winding consisting of less than 10 sections [6, 7]. It is desirable to investigate the initial surge voltage behaviour of power transformer model winding represented by larger number of sections. From practical considerations we have selected 16 and 24 sections representations for comparing with 8 sections representation for investigating surge voltage behaviour of same model winding. Computer simulations are carried out using software PSPICE version 10.0.

II. ANALYSIS OF MODEL WINDING

For analysis of surge voltage distribution along the length of a HV power transformer winding, the winding can be represented by an equivalent circuit consisting of many similar sections as shown in Fig.1 [1-4]. Each section is same and consists of series inductance ''L'' representing self inductance of winding turns of a section, mutual inductances between sections M_{12},M_{21},…$M_{1,12}$ $M_{12,1}$,…etc, series capacitance C_s representing inter turn insulation and ground capacitance C_g represents insulation between turns to ground. Twelve mutual inductances have been used in analysis for winding represented by 8, 16 and 24 sections [8].

III.SIMULATION RESULTS

The surge voltage distribution for 8,16 and 24 sections representation of the same model winding have been compared for values of 'α' 5, 10 and 20. Figures 2 and 3 show the voltage distribution for "α" value 10 for unit step voltage appearing at line terminal for neutral grounded case for 8 sections and 24 sections representation respectively. Similarly Figures 4 & 5 show the voltage distribution for the same case with 1p.u magnitude standard lightning impulse voltage (1.2/50µsec) appearing at line terminal [5]. We observe from these figures that the voltage distribution waveform for 24 sections has large number of oscillations as

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compared to waveform obtained for 8 sections representation of winding(Figs 3,5).

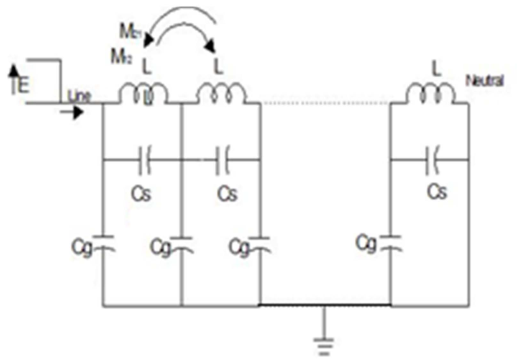
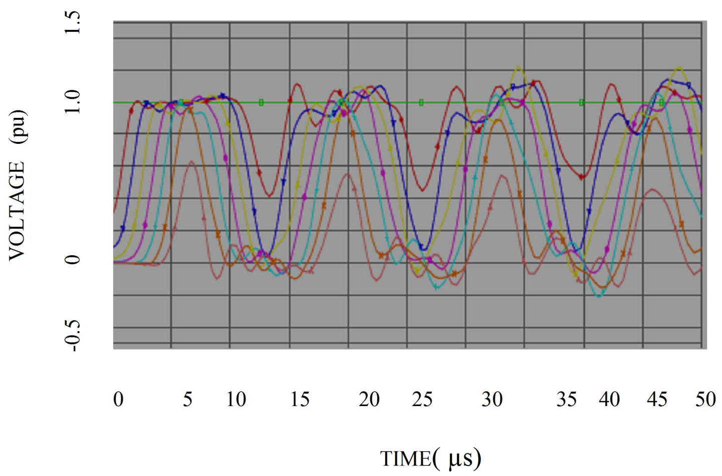
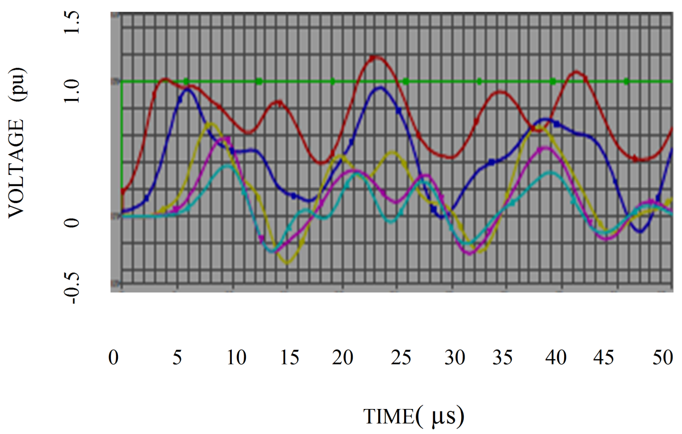


Figure 1: Equivalent circuit of transformer winding for surge voltages.



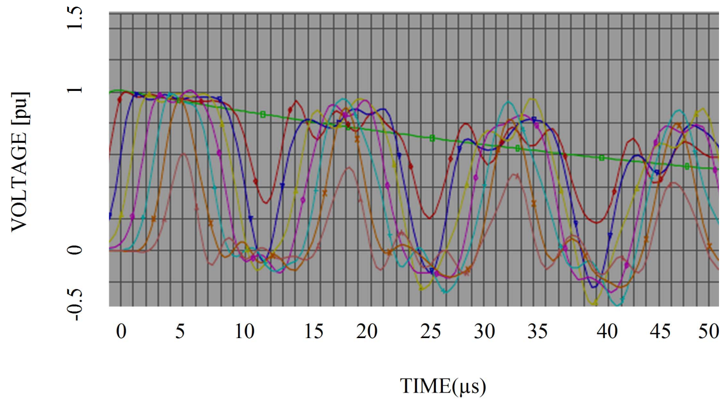
Voltages at nodes :
1-Green, 2- Red, 3-Blue,4-Yellow,5-Pink,6-Sky Blue,7-Orange,8-Light pink.

Figure 2: Surge voltages at different nodes for 8sections for unit step input (α=10)



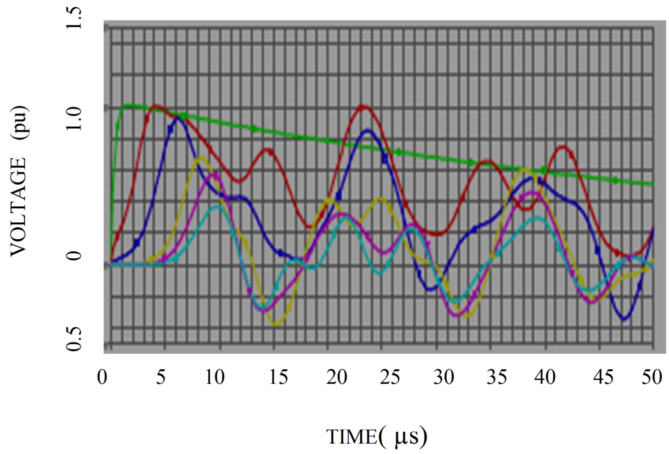
Voltages at nodes :
1-Green, 5- Red, 9-Blue,13-Yellow,17-Pink,21-Sky Blue.

Figure 3: Surge voltages at different nodes for 24 sections for unit step input (α=10)



Voltages at nodes :
1-Green,2- Red,3-Blue,4-Yellow,5-Pink,6-Sky Blue,7-Orange,8-Light pink.

Figure 4: Surge voltages at different nodes for 8 sections for stanard lightning impulse voltage (α=10)



Voltages at nodes :
1-Green, 5- Red, 9-Blue,13-Yellow,17-Pink,21-Sky Blue.

Figure 5: Surge voltages at different nodes for 24 sections one pu stanard lightning impulse voltageinput (α=10)

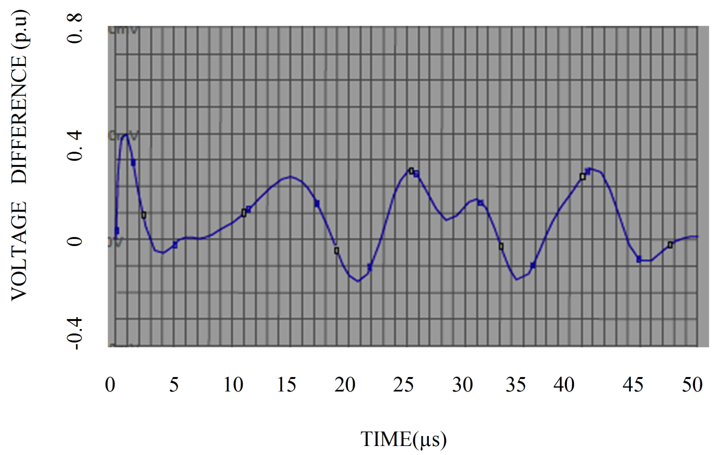


Figure6: Voltage difference between adjacent nodes for 8 sections winding for standard lightning impulse voltage input (α=5).

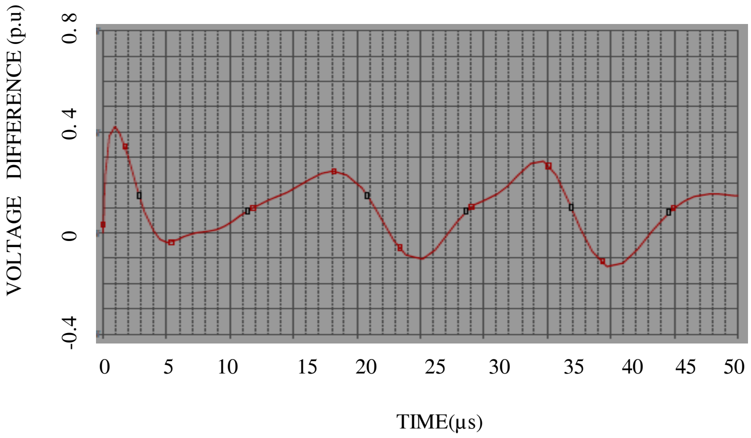


Figure7: Voltage difference between 1st node and 3rd node for 16 sections standard lightning impulse voltage input (α=5)

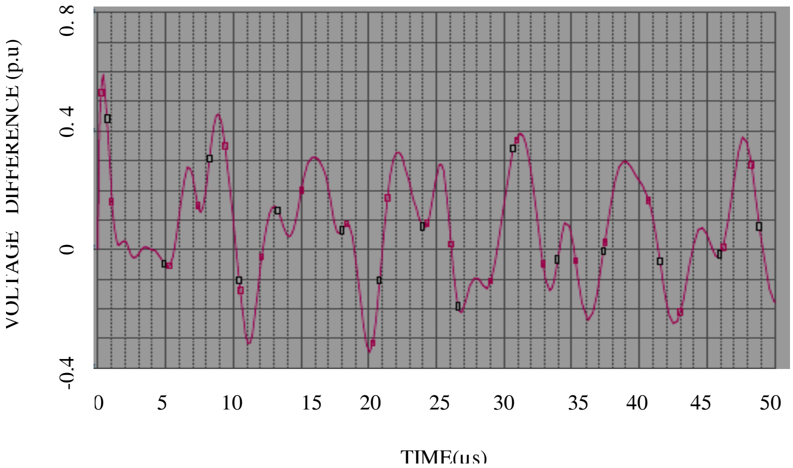


Figure8: Voltage difference between 1st node and 3rd node for 16 sections standard lightning impulse voltage input (α=10)

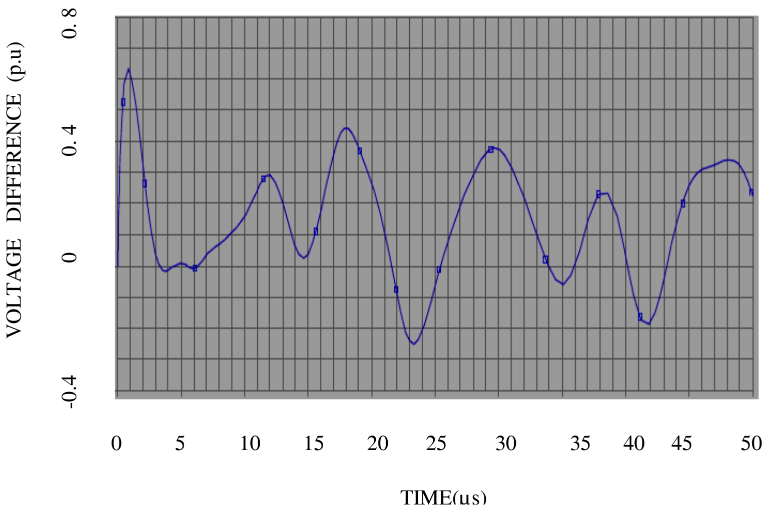


Figure9: Voltage difference between 1st node and 4th node for 24 sections standard lightning impulse voltage input (α=10)

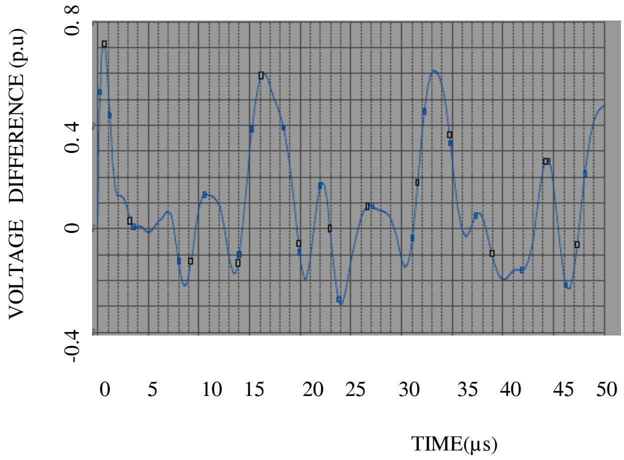


Figure10: Voltage difference between 1st node and 3rd node for 16 sections standard lightning impulse voltage input (α=20)

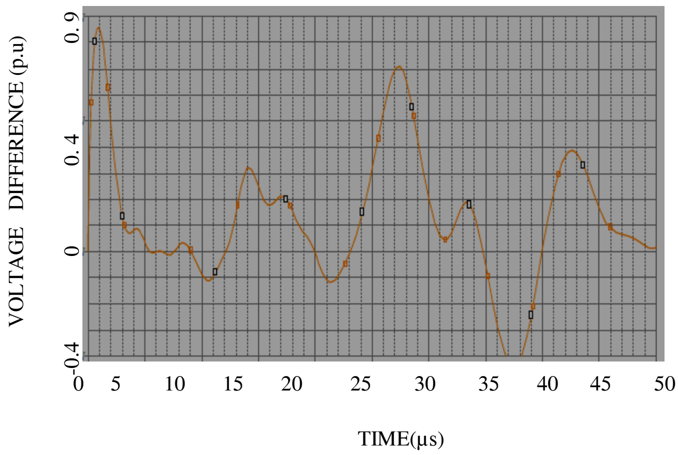


Figure11: Voltage difference between 1st node and 4th node for 24 sections standard lightning impulse voltage input (α=20)

The computer simulations were also carried out by including resistance of winding section in series with inductance of section. The maximum difference between node voltages computed including resistance of winding sections and without resistance of winding sections was only ±2.5%. Therefore, analysis without including resistance of winding sections are reported in this paper. For analysis of voltage stresses appearing across sections of windings, voltage difference between adjacent nodes are plotted as a function of time. These are shown in Figures 6 for 8 section representation and Figure.7 shows voltage difference between corresponding nodes for 16 section representation for α=5 for 1p.u crest value standard lightning impulse voltage input at line terminal. From these figures we observe considerable difference between waveforms plotted as a function of time. To facilitate comparison of these data, maximum voltage difference between adjacent nodes for 8 sections representation and those between corresponding nodes for 24 sections representation are tabulated in Table1.

Similar data referring to 8 sections representation and 16 sections representation are tabulated in Table2.

The corresponding time of occurrence of these maximum voltage difference (other than data corresponding to zero initial time instant) are also indicated in the tables.

TABLE.1 MAXIMUM VOLTAGE STRESSES ACROSS WINDING SECTIONS

	Maximum voltage between adjacent nodes 8sections[(V1-V2),(V2-V3),…(V7-V8)]		Maximum voltage between corresponding nodes 24sections[(V1-V4),(V4-V7),…V(22-V25)]		%Accuracy Based on average
SL. No	Voltage in(pu)	Time in (μs)	Voltage in(pu)	Time in (μs)	
1	0.464	53.05	0.442	17.96	± 2.4
2	0.338	79.56	0.516	2.56	±20.8
3	0.278	68.89	0.519	4.27	±30.25
4	0.352	56.08	0.556	6.01	±22.5
5	0.378	48.98	0.267	24.73	±17.4
6	0.270	75.70	0.132	9.33	±34.5
7	0.384	46.68	0.236	3.95	±23.9
8	0.426	46.64	0.283	9.823	±20.3

TABLE.2 MAXIMUM VOLTAGE STRESSES ACROSS WINDING SECTIONS

	Maximum voltage between adjacent nodes 8sections[(V1-V2),(V2-V3),…(V7-V8)]		Maximum voltage between corresponding nodes 16sections[(V1-V3),(V3-V5),…(V15-V17)]		%Accuracy Based on average
SL. No	Voltage in(pu)	Time in (μs)	Voltage in(pu)	Time in (μs)	
1	0.464	53.05	0.454	17.8	± 1.1
2	0.338	79.56	0.465	15.5	±15.7
3	0.278	68.89	0.505	3.2	±28.8
4	0.352	56.08	0.500	4.5	±17.4
5	0.378	48.98	0.478	6.0	±11.7
6	0.270	75.70	0.480	6.8	±28.3
7	0.384	46.68	0.307	8.5	±11.3
8	0.426	46.64	0.409	9.46	±2.15

Observation of data shown in Table.1 indicate that there can be large difference between computer simulated maximum voltages appearing across corresponding adjacent nodes of model transformer winding for 24 sections representation and 8 sections representation of same winding. However data in Table.2 indicate some improvements in accuracy. Based on computer simulation analysis of same model winding for 8, 16 and 24 sections representation, for alpha values 5, 10 and 20, it is suggested that 16 sections representation can provide improved results for alpha values used in the present investigation.

IV. CONCLUSIONS

Computer simulations of transformer model winding has indicated that the maximum difference between voltage to ground for 24 sections representation and 8 sections representation of same model winding is about 8% for higher α value windings corresponding to zero initial time instant. However, the results shows that there can be large difference between maximum voltage appearing across corresponding nodes for 24 sections and 8 sections representation of same model winding at other instants of time. The simulation investigations have shown that 16 sections representation of model winding can provide better results for alpha values 5,10 and 20.

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