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Internal Resonance Voltage Buildup and its Suppression using Varistors in a Transformer Model Winding

Javid Akhtar

Associate Professor, Department of Electrical and electronics Engineering
Ghousia College of Engineering, Ramanagaram, Karnataka, India

Dr. Mohd. Zahed Ahmed Ansari

Member IEEE, Professor and Head
Department of Electrical and Electronics Engineering
Ghousia College of Engineering, Ramanagaram, Karnataka, India

Abstract

Lightning, chopped and switching surge voltages with high dv/dt generates transient overvoltages of complex frequency oscillations. The matching of such transient frequencies with the natural frequencies of the transformer windings may give rise to resonance problems and hence will lead to internal voltage amplification that are dangerous to the insulation of transformer windings. In this paper complete frequency response characteristics of a 12 coil section transformer model winding is analyzed to identify the resonance frequencies in different coil sections, the effect of such frequencies and suppression of internal resonance voltage buildup in a transformer model winding is examined. To investigate this internal resonance problem a dry type transformer model winding consisting of 12 coil sections with 60 turns in each coil section with suitable tappings and distribution winding constant α=10 and 20 has been designed. Simulation analysis is realized with ac frequency analysis on the model winding with a frequency band of 100Hz to 1000KHz to identify the resonance frequencies in different coil sections. To examine the effect of such frequencies, sine waves of already established resonance frequencies are then applied to the model winding. The internal resonance voltage magnification problem within the 12 coil section transformer model winding is examined and suppressed using suitably modeled varistors.

Keywords: Dry type transformer model winding, internal resonance frequencies, transient overvoltages, high rise dv/dt, distribution winding constant α, winding insulation, varistor.

INTRODUCTION

The windings especially of high voltage power transformers during operation are exposed to a variety of transient overvoltages like lightning, chopped lightning and switching overvoltages. These overvoltages owing to high rise dv/dt generate high frequency complex oscillations [1, 2]. Internal resonance problems do take place inside the windings if the natural frequencies of the transformer windings match with those transient frequencies and may lead to internal voltage amplification problem that could damage the insulation of the windings and is a major concern for station power transformers [8]. In this paper a dry type transformer model winding is designed that consists of 12 coil sections with 60 turns per coil section with suitable tappings for measurement of voltages. The self-inductance of each coil and mutual inductances between the different coil sections are computed and considered in the investigation for improved accuracy [5, 6]. PSpice simulation using ac frequency analysis is carried out on the dry type model winding with a frequency band of 100Hz to 1000 KHz to identify the resonance frequencies in different coil sections. The windings behavior under such resonance frequencies is also studied by applying sine waves of the already recognized resonant frequencies. The internal resonance voltage buildup inside the transformer model winding is restricted using suitable modeled varistors.

DETERMINING THE FREQUENCY SPECTRUM IN DIFFERENT PARTS OF THE MODEL WINDING:

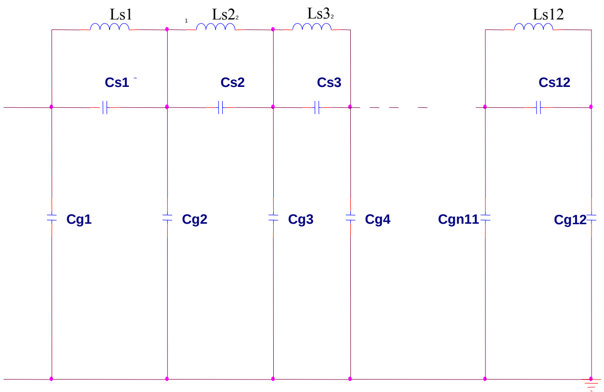


Figure 1: Single-phase equivalent of a 12 coil-section transformer model winding for determination of internal winding resonance frequencies

Figure1 illustrate the single phase equivalent of a transformer with 12 coil sections. Here Ls represents the self-inductance of each coil section, Cg represent the ground capacitance and Cs represent the series capacitance of the winding and α' is defined as the distribution winding constant, given by the ratio $\alpha=\sqrt{Cg/Cs}$. The mutual inductances between the different coil parts is also considered for better accuracy in the analysis [5].

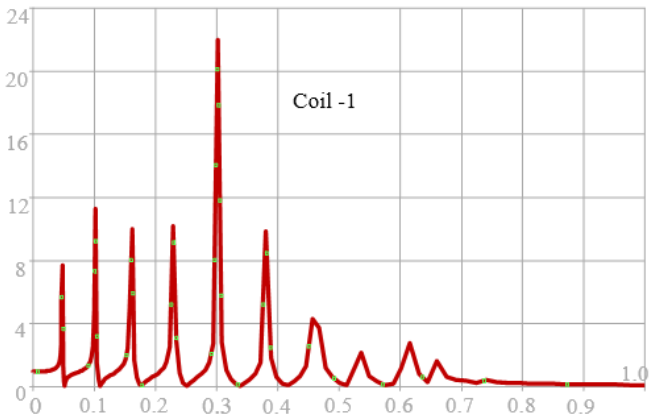
To determine the winding internal resonant frequencies in different parts of the model winding, ac frequency analysis is performed with application of sine voltage waveform of 1pu peak with a frequency band of 100Hz to 1000 KHz at the input terminals a-b.

No. of coil sections of the model winding = 12

Distribution winding constant α = 10 and 20

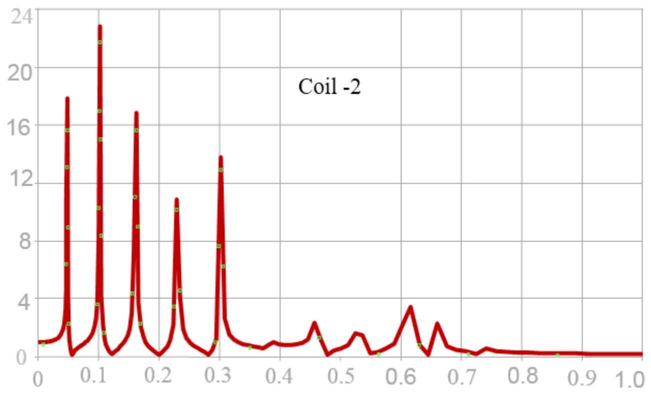
(i) α=10 (Frequency spectrums in selected parts of the model winding)

Figures 2-7 shows the frequency spectrums for **α**=10 and Figures 8-12 for α=20 in different selected parts of the transformer model winding with suitable tappings for measurement of voltages.



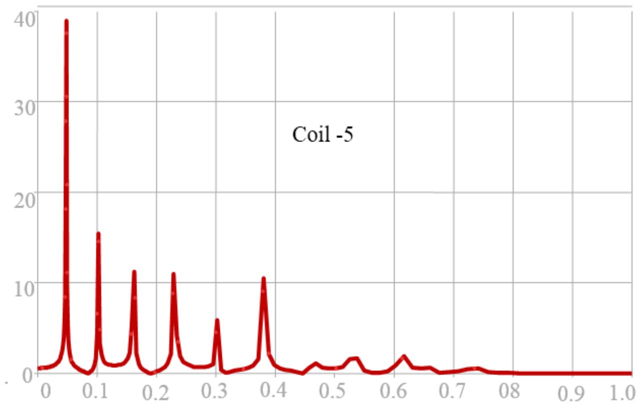
X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 2: Frequency response of coil-1



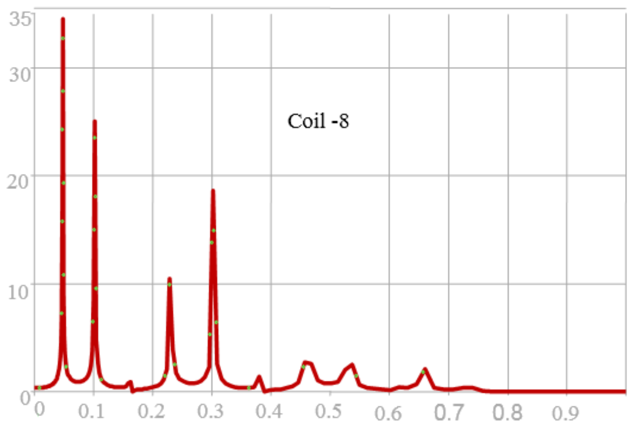
X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 3: Frequency response of coil-2



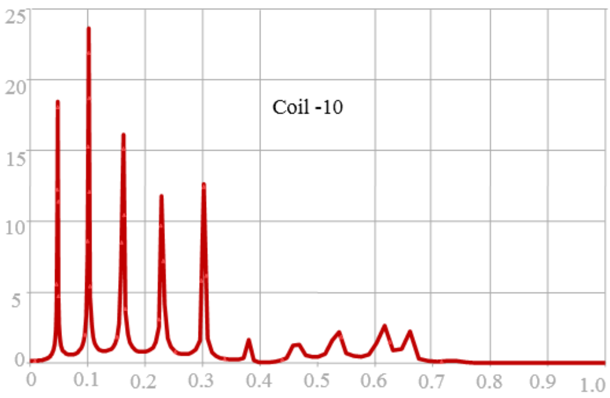
X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 4: Frequency response of coil-5



X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 5: Frequency response of coil-8



X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 6: Frequency response of coil-10

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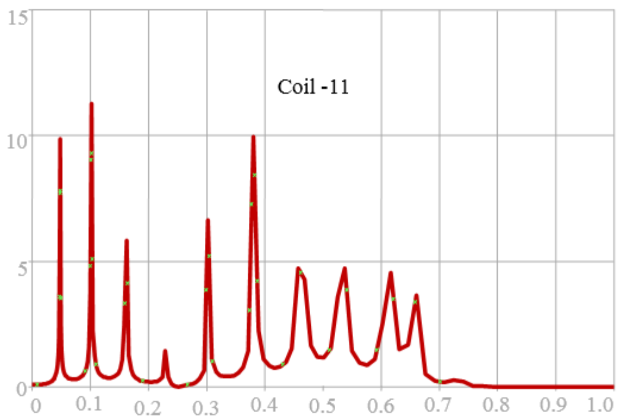
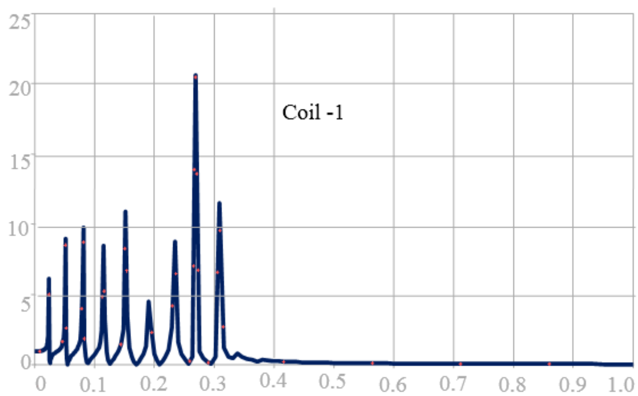


X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

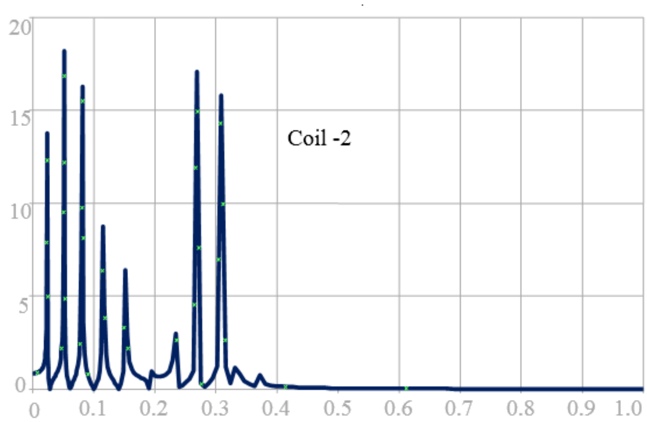
Figure 7: Frequency response of coil-11

(ii) α=20 (Frequency spectrums in selected parts of the model winding)



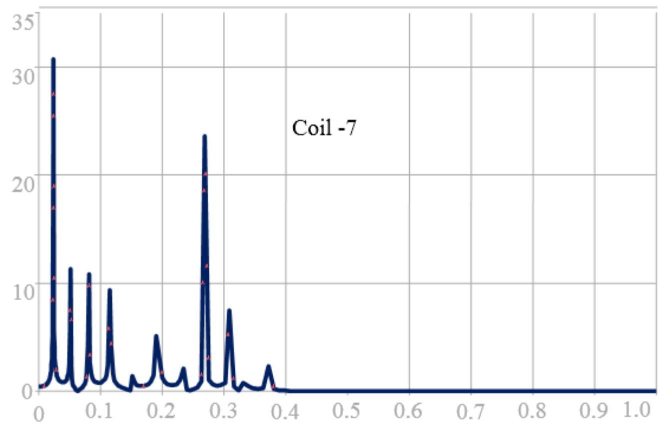
X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 8: Frequency response of coil-1



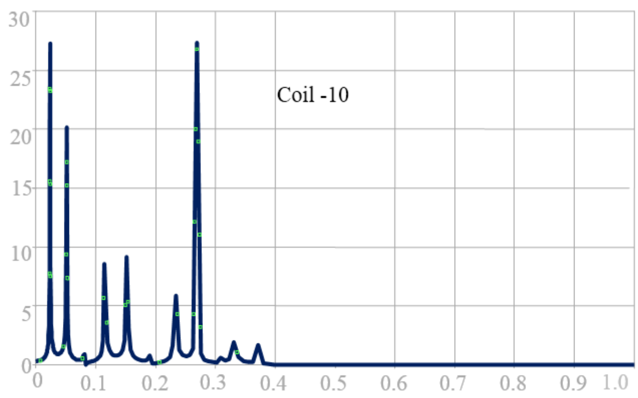
X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 9: Frequency response of coil-2



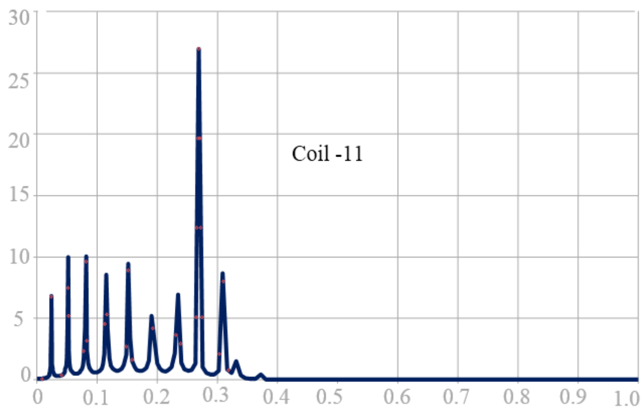
X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 10: Frequency response of coil-7



X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 11: Frequency response of coil-10



X-Axis: Frequency (MHz) Y-Axis: Voltage (pu)

Figure 12: Frequency response of coil-11

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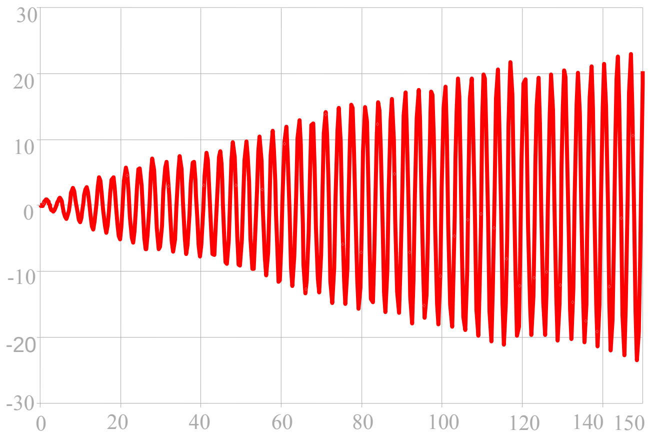
Investigation of internal resonance voltage magnification problem:

To examine the internal resonance voltage magnification problem within the 12 coil section transformer model winding with distribution winding factor α=10, the 60 turns of coil-1 and coil-2 respectively are selected and are split into ten equal parts of 6 turns each with tappings at every 6 turns to measure the internal resonance voltages.

Case-1 without varistor

(i) The first 60 turns of coil-1:

A sine pulse of frequency (equal to the already establish peak resonant frequency 301.995 KHz) is applied to the splitted coil-1.

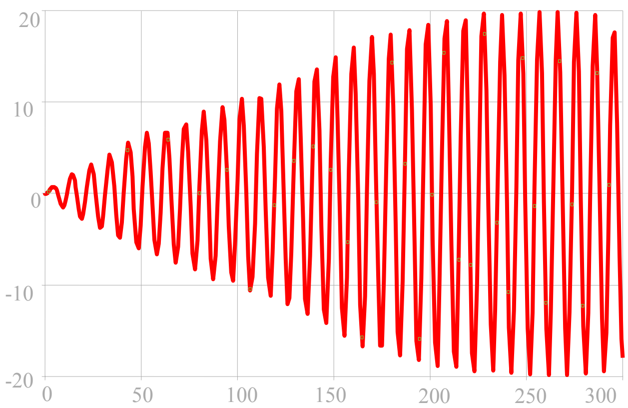


X-Axis: Time (µs)   Y-Axis: Voltage (pu)

Figure 13: Internal voltage buildup in the mid 6 turns of coil-1 without varistor

ii) The second 60 turns of coil-2:

A sine pulse of frequency (equal to the already establish peak resonant frequency 102.32 KHz) is applied to splitted coil-2.



X-Axis: Time (µs)   Y-Axis: Voltage (pu)

Figure 14: Internal voltage buildup in the mid 6 turns of coil-2 without varistor

Case-2

(i) With Varistor shunted to the first 60 turns of coil-1:

The zinc oxide varistors have steep nonlinear V-I characteristics and best suitable for safeguard of windings insulation of high voltage power transformers against fast rising transient overvoltages that generates complex frequency oscillations. Varistors offer very high resistance to normal power frequency sinusoidal voltages and low resistance for fast rising overvoltages, thus it protects the piece of equipment it shunts and avoid expensive system damages. The varistor is modeled by a simple electrical model as shown in Figure 15 [9].

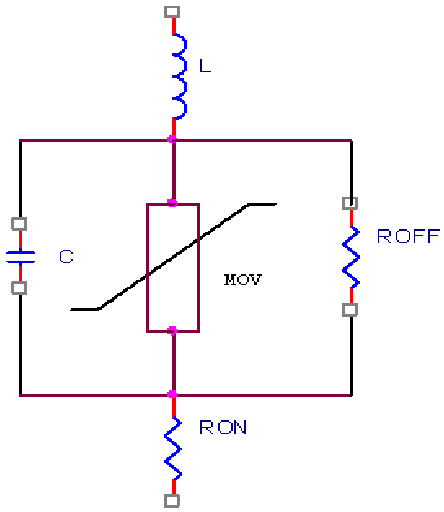
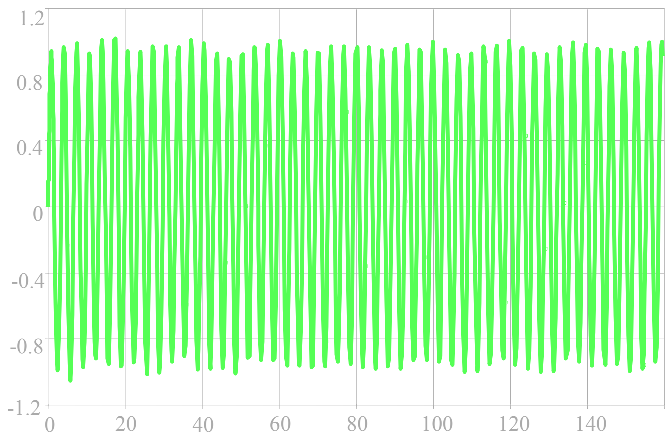


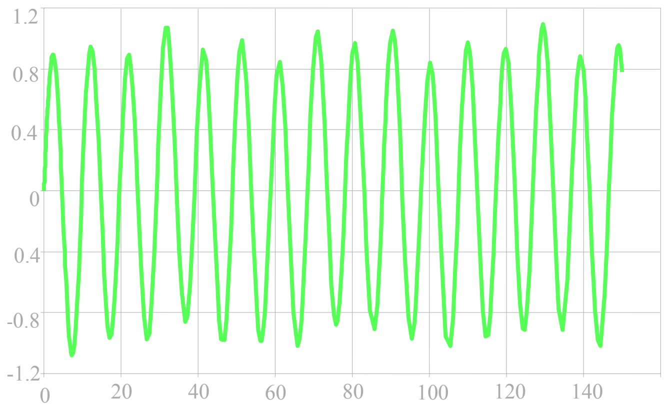
Figure 15: A Simple electrical model of a varistor



X-Axis: Time (µs)   Y-Axis: Voltage (pu)

Figure 16: Suppression of internal voltage buildup in the mid 6 turns of coil-1 using varistor

ii) With Varistor shunted to the second 60 turns of coil-2:



X-Axis: Time (µs) Y-Axis: Voltage (pu)

Figure 17: Suppression of internal voltage buildup in the mid 6 turns of coil-2 using varistor

It can be seen from figures 16 and 17 with varistor shunted to the first and second resolved coils, there is no internal resonance voltage buildup inside the windings and is almost equal to the applied 1pu peak sine voltage of resonant frequency 301.995 KHz and 102.32 KHz respectively.

RESULTS AND DISCUSSIONS:

(i) The investigation of internal resonant frequency characteristics of the 12 coil transformer model winding with α = 10 and 20 are as follows:

For the first coil, the major resonance frequency is found to be 301.995 KHz at which the voltage gets magnified by 21.996 times the input peak and the band of resonant frequencies is from 47.86KHz to 660.693KHz (47.86KHz, 102.217KHz, 162.101KHz, 229.08KHz, 301.995KHz, 380.189KHz, 457.68KHz, 537.03KHz, 616.595KHZ and 660.693KHz) with voltage magnification from 1.626 to 21.996 pu.

For the second coil, the major resonance frequency is 102.32 KHz at which the voltage gets magnified by 22.66 times the input peak and the band of resonant frequencies is same as that of first coil with voltage magnification from 2.127 to 22.66pu.

In case of fifth coil, we have five major distinct resonance frequencies 47.86 KHz, 102.217 KHz, 162.181 KHz, 229.08 KHz and 380.189 KHz at which the voltage magnification is 38.959, 15.478, 11.272, 10.995 and 10.535 times respectively the input peak and the band of resonant frequencies is same as first coil with voltage magnification from 10.535 to 38.959pu. Likewise for the other resolved coil sections.

For α = 20

For the first coil, the major resonance frequency is found to be 269.154 KHz at which the voltage gets magnified by 20.641 times the input peak and the band of resonant frequencies is almost half the band with α = 10 and is from 23.412KHz, 51.286KHz, 81.28KHz, 114.815KHz, 151.356KHz, 190.546KHz, 234.423KHz, 269.154KHz, 309.03KHz with voltage magnification from 4.506 to 20.641 pu.

In second coil, the major resonance frequency is found to be 51.286 KHz at which the voltage gets magnified by 18.191 times the input peak and the band of resonant frequencies is sane as that of coil-1 with voltage magnification from 2.967 to 18.191pu.

In case of seventh coil, there two major resonance frequencies are 23.412 KHz and 269.154 KHz at which the voltage gets magnified by 30.709 and 23.568 times the input peak and the band of resonant frequencies is sane as that of coil-1 with voltage magnification from 7.084 to 30.709pu. Likewise for the other resolved coil sections.

(ii) Internal resonance voltage magnification:

(i) Without Varistor

If no varistors shunted, there was fast voltage buildup of up to ±22.5pu in the mid 6 turns of coil-1 and ±19.845pu in the mid 6 turns of coil-2 of the model winding.

(ii) With Varistors shunted to the first and second coil sections

With varistors shunted, there is no internal resonance voltage oscillations buildup inside the windings.

CONCLUSION

On determination of resonant characteristics of the 12 coil section transformer model winding, it is observed that the band of internal resonant frequencies is same in all parts of the winding but the major distinct resonance frequencies and voltage magnification factors differ. For the same model, when the distribution winding constant α increases from 10 to 20, the band of internal resonant frequencies gets modified by almost half the value with no resonant frequency matching and with different voltage magnificent factors. This suggest that when the winding is energized at these band of frequencies, internal resonance will take place that cause voltage amplification by the above magnification factors and could damage the insulation of the winding and is a major concern for station power transformers.

Also investigated the internal resonance fast voltage buildup in the 60 turns of coil-1 and coil-2 of the model winding. The voltage buildup without varistor was of about ±22.5pu which is sufficed to cause interturn flashover and may breakdown the turns insulation of the windings. With the varistors shunted to the resolved first and second coil sections, the internal voltage build up was completely suppressed.

Thus the varistor devices have outstanding characteristics that can suppress the huge buildup complex oscillations inside the windings and thereby protecting the winding insulations.

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