Lightning and Switching Surge Node Voltage Distribution in Model Transformer Winding

Dr. Eranna[1] Kiran V [2], Manoj T [2], Pavan Kumar M [2], Raghavendra[2]

[1] Associate Professor EEE, Dr. Ambedkar Institute of Technology Bangalore

[2] EEE, Dr. Ambedkar Institute of Technology Bangalore

Abstract - Power transformers are vital components in electrical power systems, facilitating the transmission and distribution of electricity. However, they are susceptible to various electrical disturbances, among which surges pose a significant threat. Surges, also known as transients, are brief, high-voltage fluctuations in the electrical system that can potentially damage transformers and other connected equipment. The surge phenomenon in power transformers is a complex interplay of electrical and magnetic forces. It is often triggered by lightning strikes, switching operations, or faults in the system. Surges can travel through the power grid, reaching transformers and causing insulation breakdown or winding damage. Understanding the surge phenomenon is crucial for ensuring the reliability and longevity of power transformers. This project aims to delve into the mechanisms behind surges, their effects on transformers, and strategies to mitigate their impact. By comprehensively examining this phenomenon, we can develop better protection and prevention techniques, enhancing the overall resilience of power systems against surges.

PROBLEM STATEMENT - The Surge voltages such as lightning over-voltages 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 over-voltages 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. Though there are surge arrestors, which will protect the transformer when lightning strikes on transmission lines, but when the lightning strikes on the transformer bushings the winding insulation may fail. Hence analysis of surge voltage distribution in the HV winding of the transformer is utmost importance.

OBJECTIVES - This project aims to investigate the surge phenomenon in power transformers to enhance understanding of its causes, effects, and mitigation strategies. The specific objectives include:

1. Examining the behavior of surges in power transformers and their impact on transformer insulation and winding.
2. Evaluating existing surge protection measures and their effectiveness in safeguarding power transformers.
3. Proposing novel techniques or improvements to existing methods for mitigating surge effects on power transformers.
4. Providing recommendations for enhancing the resilience of power transformers against surges, thereby improving the overall reliability of electrical power systems

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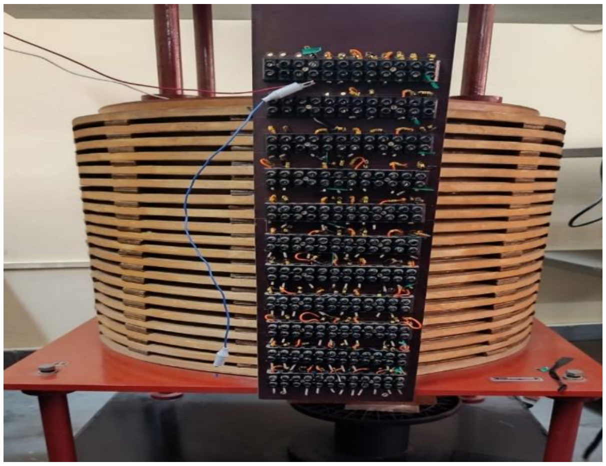
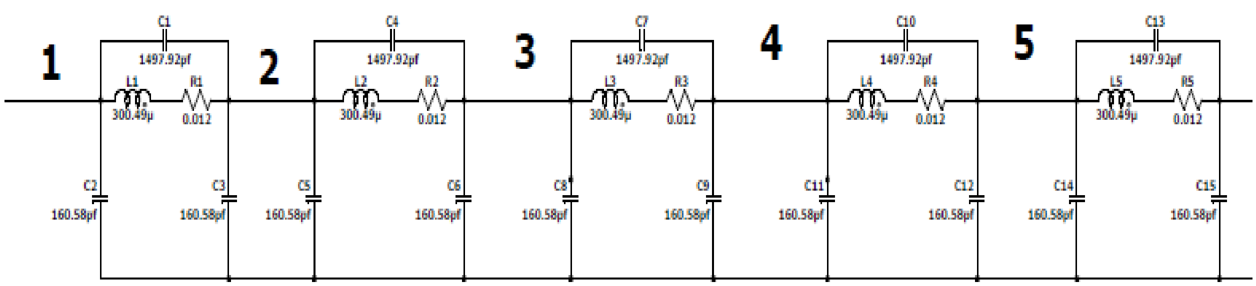


Model Winding Custom Impulse Generator Circuit

Specifications of winding sections

- Total number of discs: 20
- Number of Interleaved Discs: 10 Discs; 8 turns/disc
- Number of Non-Interleaved Discs: 10 Discs; 8 turns/disc
- Total 16 nodes 5 interleaved nodes and 10 non interleaved nodes a source node

R, L and C values for interleaved coil sections	R, L and C values for non-interleaved coil sections
R = 0.012 ohms L = 300.49 μH Shunt capacitance = 160.58 pF Self-capacitance = 1497.92 pF	R = 0.0063ohms L = 75.1 μH Shunt capacitance = 34.47 pF Self-capacitance = 2995.86 pF



INTERLEAVED COIL SECTION HAVING 5 NODES

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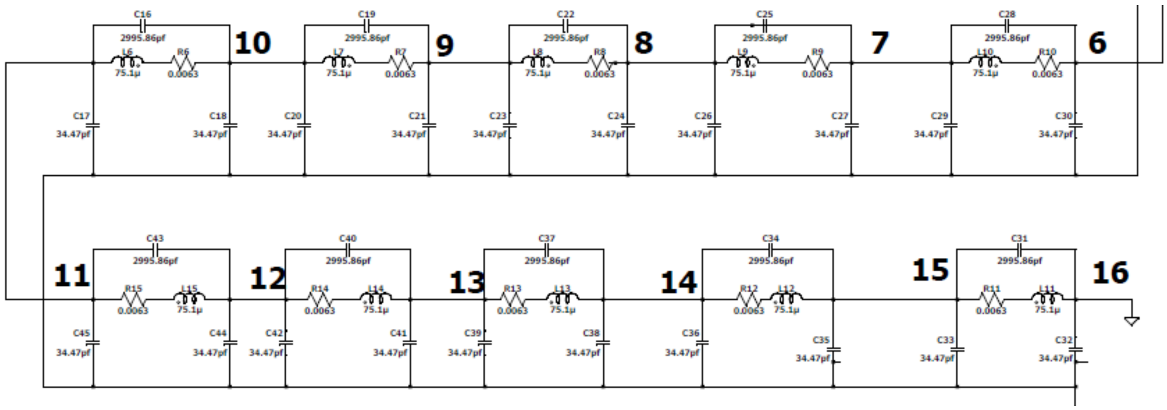
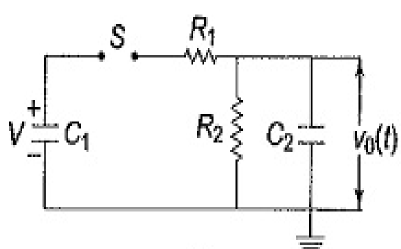


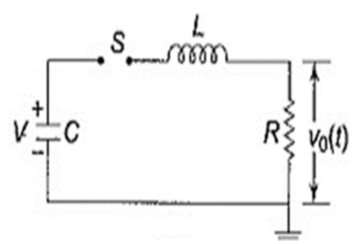
NON-INTERLEAVED COIL SECTION HAVING 10 NODES

SOFTWARE UTILIZED

LTspice® is a powerful, fast, and free SPICE simulator software, schematic capture and waveform viewer with enhancements and models for improving the simulation of analog circuits. Its graphical schematic capture interface allows you to probe schematics and produce simulation results, which can be explored further through the built-in waveform viewer.

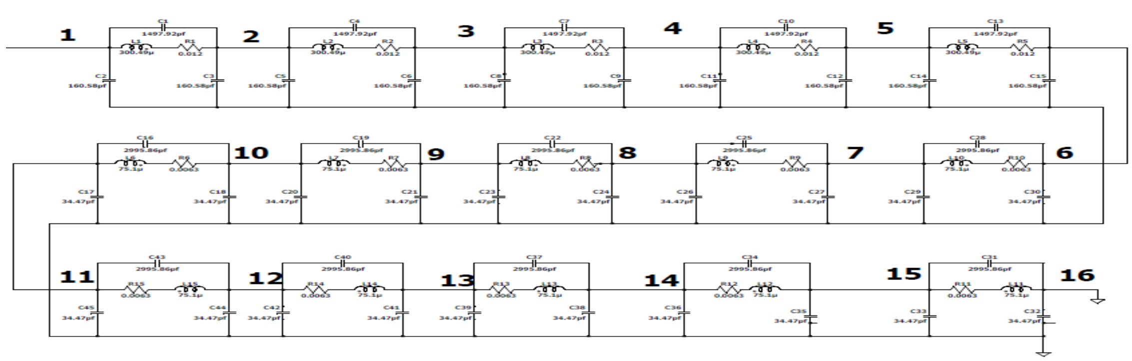
Circuits used to produce impulse voltage





The circuit above is utilized to produce the impulse voltages having front and tail time of

- 1.2 µs /50 µs, 2.5 µs /50 µs, 5 µs /50 µs, 10 µs /100 µs., 20 µs /100 µs, 50 µs /100 µs



COMPLETE SIMULATED WINDING MODEL

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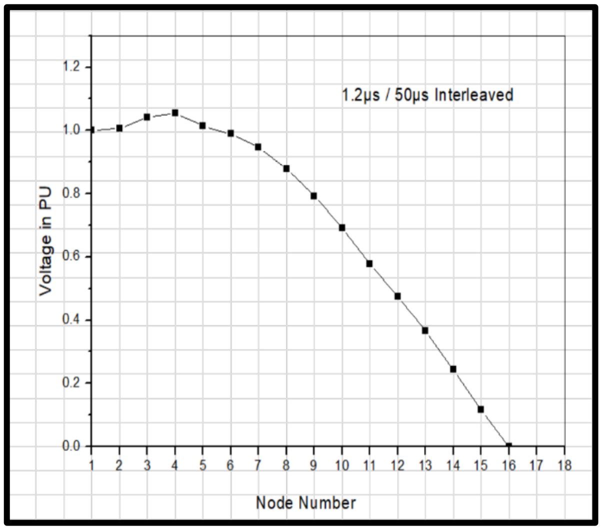
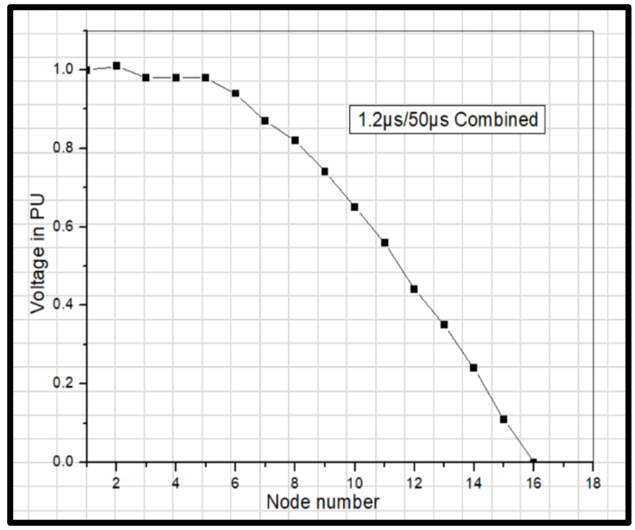
RESULTS - NODE NUMBER VS VOLTAGE PLOTS

1.2 µs/50 µs COMBINED

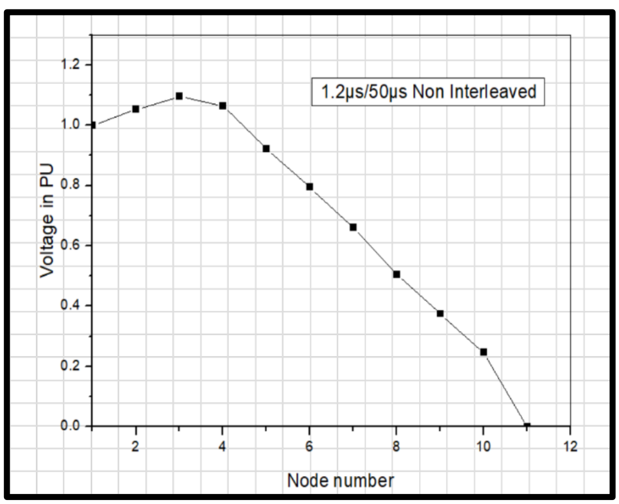
SIMULATED PRACTICAL

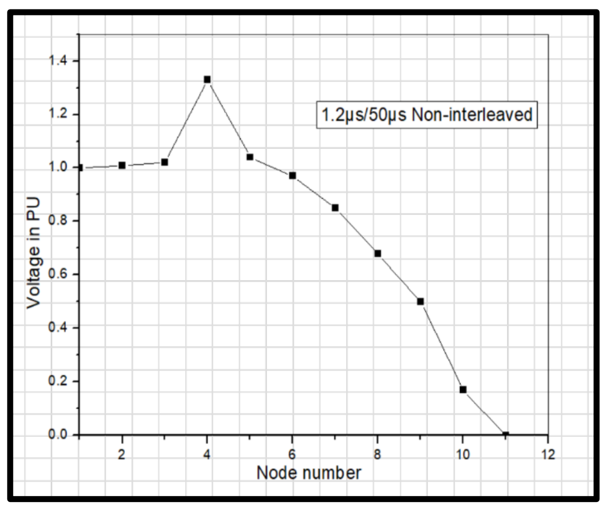




- The graph describes the voltage stress on a combined winding model which shows there is more stress(peak) at first 2-3 nodes than the rest nodes.

1.2µs/50 µs NON-INTERLEAVED





- Above graph shows application of 1.2µs/50 µs impulse wave on only non-interleaved winding having much stress on insulation as compared to combined winding that distorts the insulation strength.

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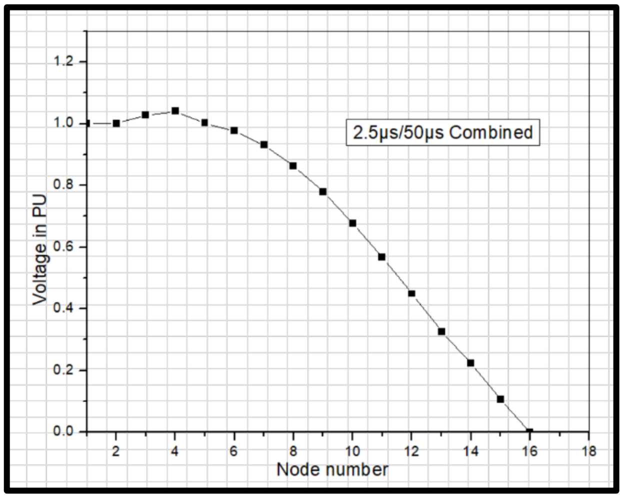
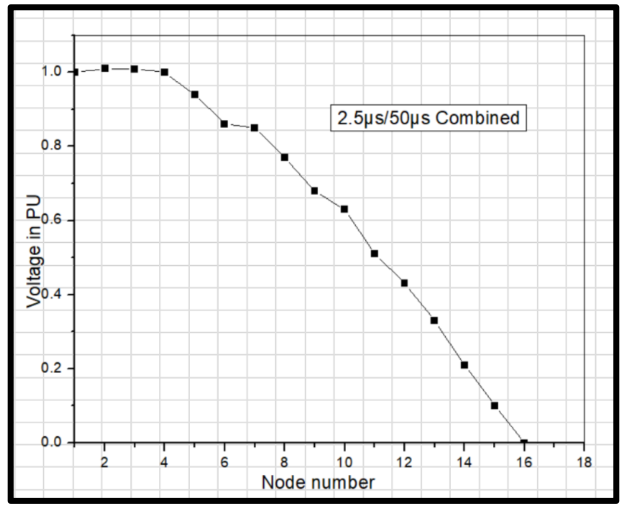
2.5µs /50 µs COMBINED

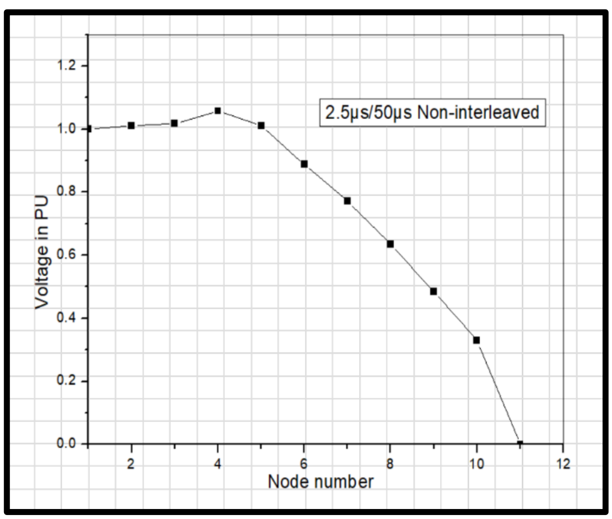
SIMULATED PRACTICAL

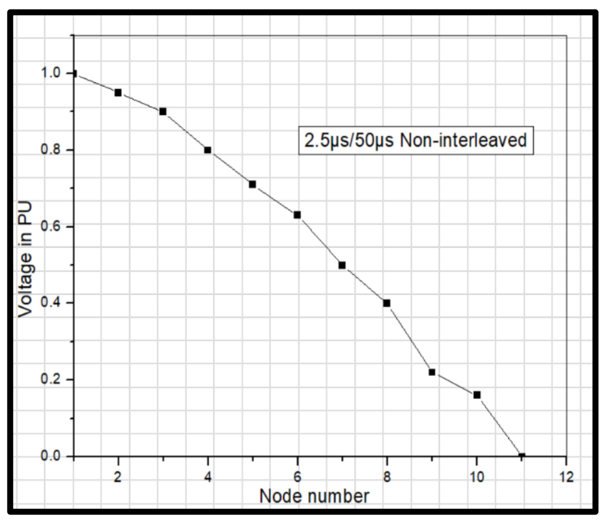




- The graph depicts that due slow rise time the voltage stress on the winding has been reduced and there isn't much stress at first 2-3 nodes as compared to standard impulse waveform 1.2µs/50 µs

2.5µs/50 µs NON-INTERLEAVED

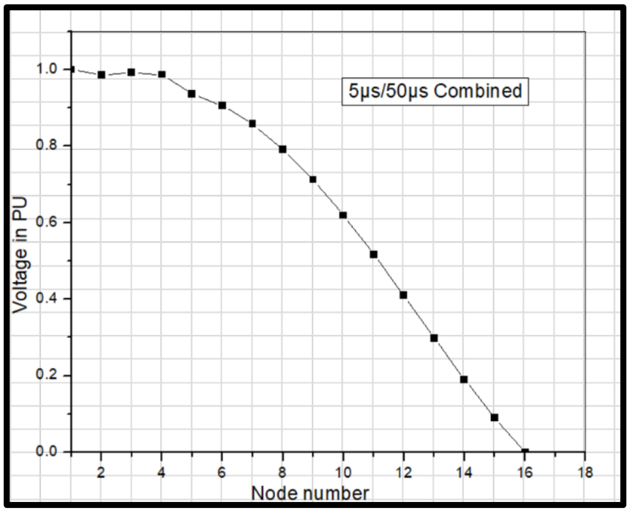


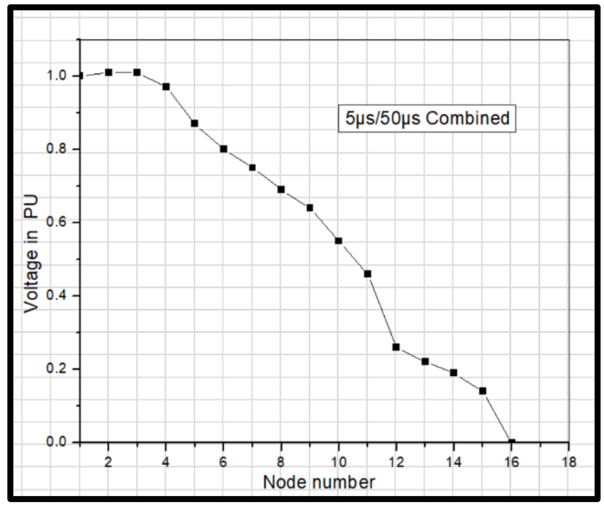


- There is gradual decrease in the voltage stress but still non-uniform distribution at the nodes. The stress on insulation is considerably higher than the combined winding.

5µs/50 µs COMBINED

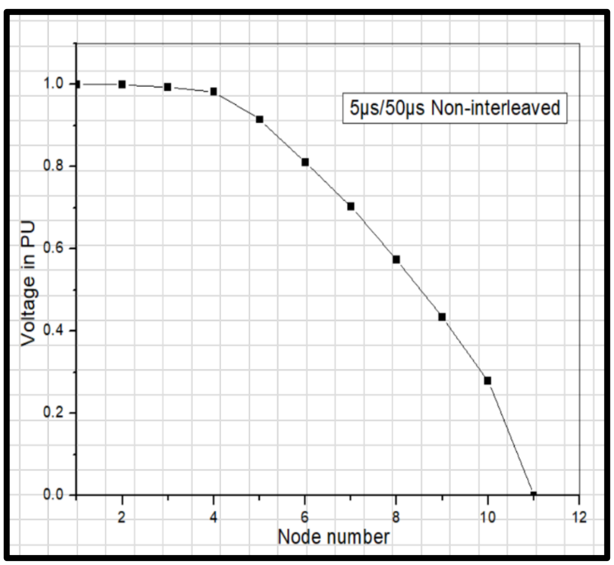
SIMULATED PRACTICAL

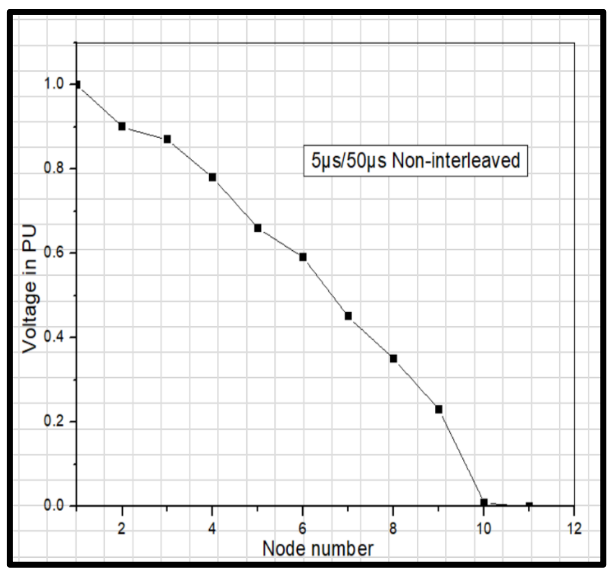




- From the graph it is observed that the stress on insulation has been gradually decreased as there isn't much voltage peak at any subsequent nodes than the second node.

5µs/50 µs NON-INTERLEAVED

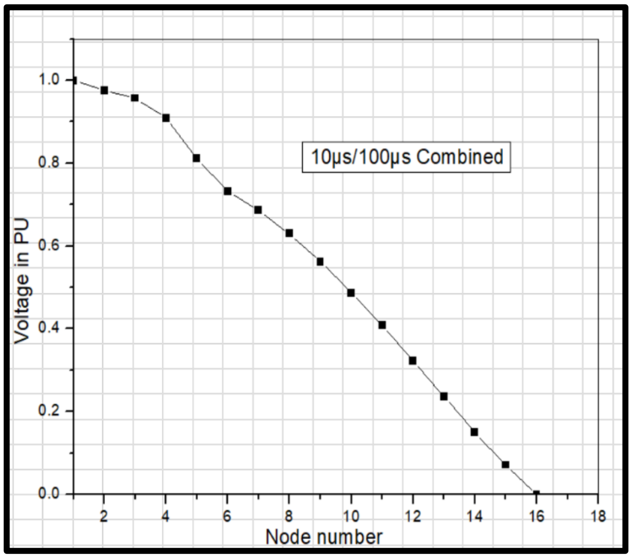




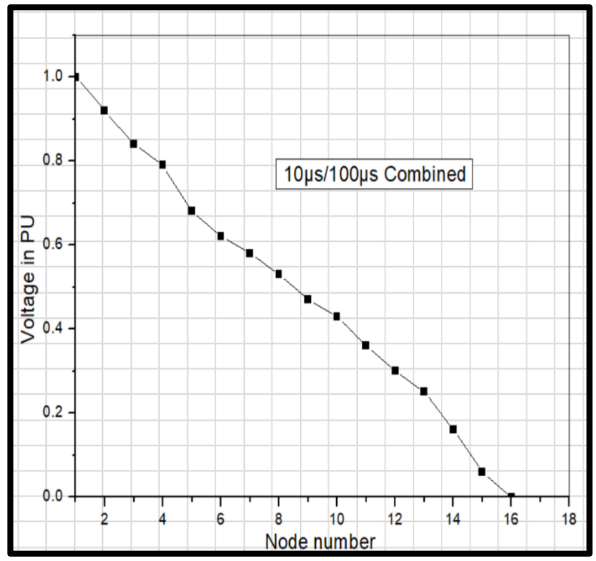
- The graph for the non-interleaved section is as shown above which describes that the stress on the insulation is further reduced due to it's rise time. This improves the reliability of the insulation.

10µs/100 µs COMBINED

SIMULATED

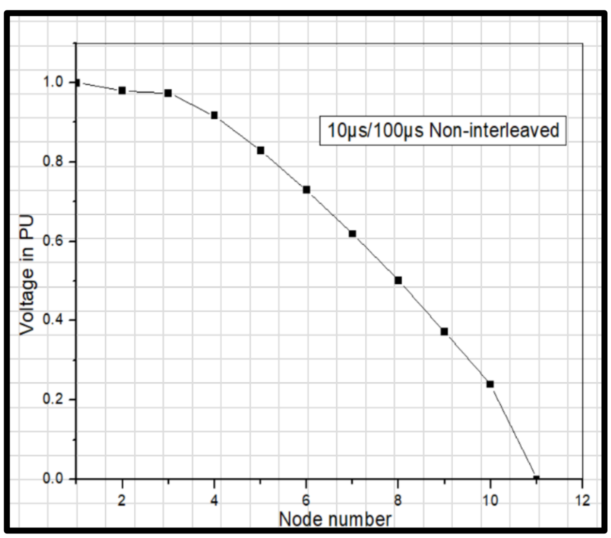


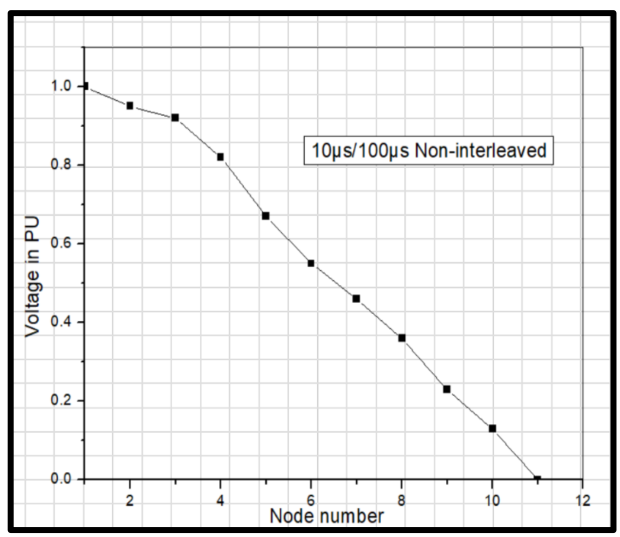
PRACTICAL



- Above graph shows that the increased rise time of the impulse wave has made voltage to be distributed uniformly compared to the standard impulse wave shape.

10µs/100 µs NON-INTERLEAVED

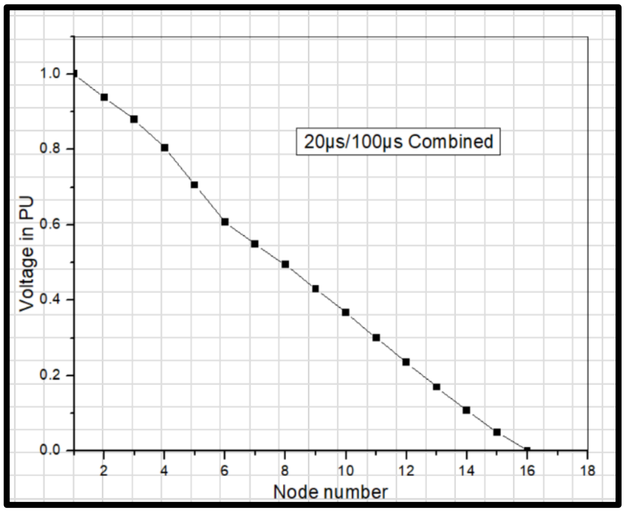


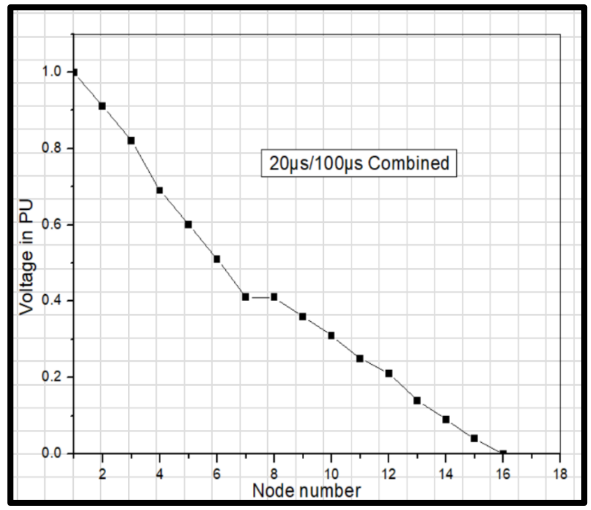


- There is less stress on the insulation which leads to improved reliability but still the non-interleaved winding does not have uniformity compared to the combined winding.

20µs/100 µs COMBINED

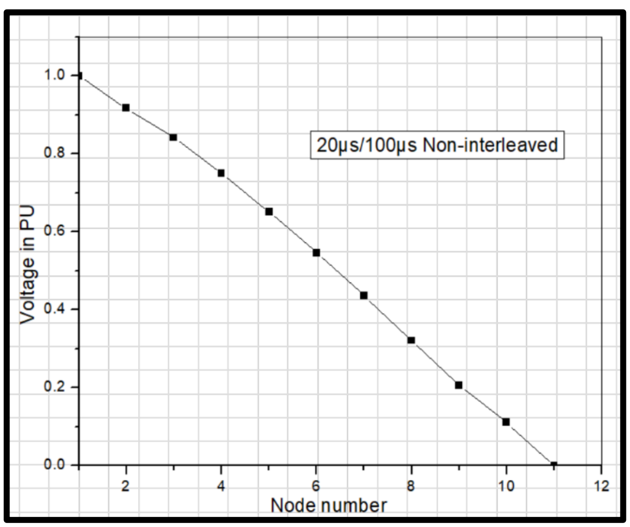
SIMULATED PRACTICAL

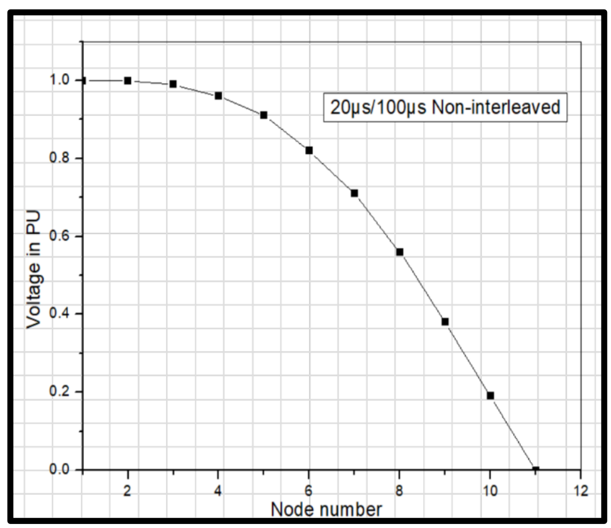




- Further increase in the rise time has improved the uniform distribution of the voltage at nodes along the winding. It is seen that there is no more peaks as it was in the case of the standard wave shape.

20µs/100 µs NON-INTERLEAVED





- It can be observed that non-interleaved winding faces more insulation stress as compared to the combined winding because the stress exists even at the subsequent nodes of the first one. This shows that non-interleaved section faces a challenge of uniformity in voltage distribution.

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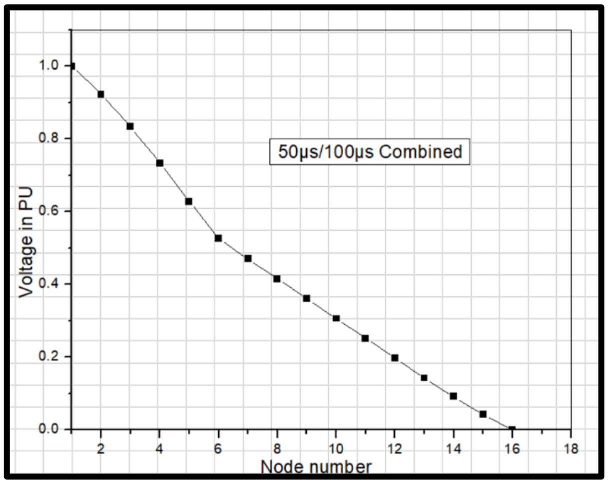
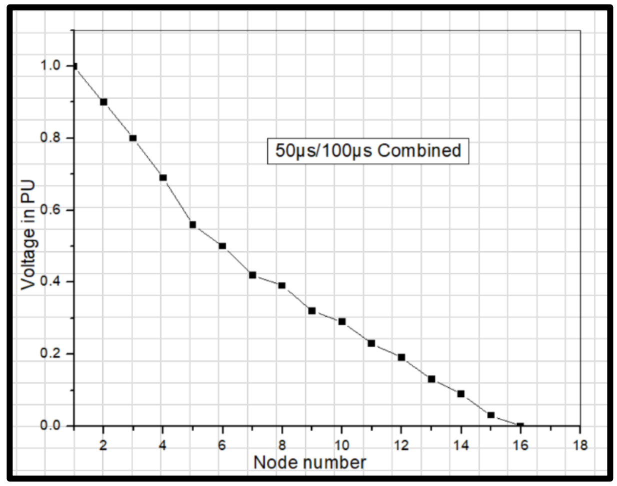
50µs/100 µs COMBINED

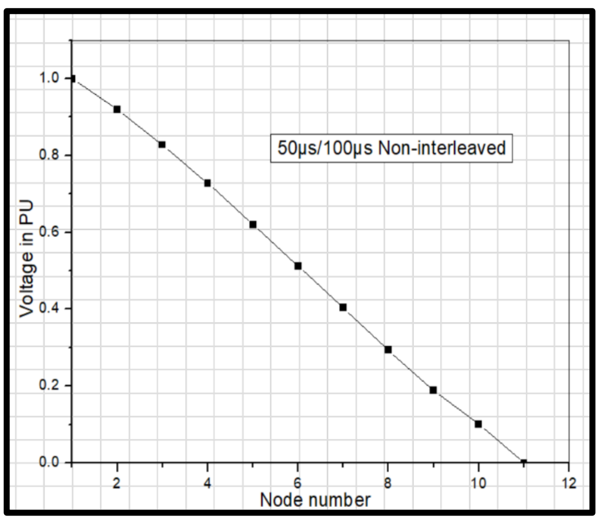
SIMULATED PRACTICAL

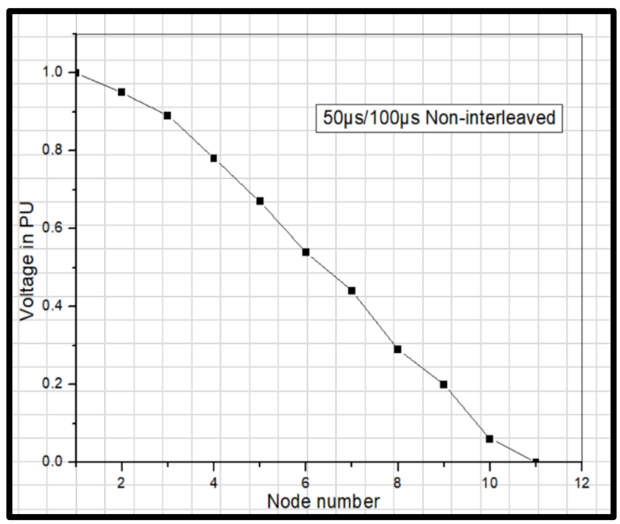




- The rise time of 50µs makes the stress on the insulation to be much less compared to the standard impulse waveform. Even there is a uniform voltage distribution along the winding.

50µs/100 µs NON-INTERLEAVED





- The graph shows the voltage stress on the non-interleaved winding has been improved and gradually suppressed at the end having no higher peak compared to the first node.

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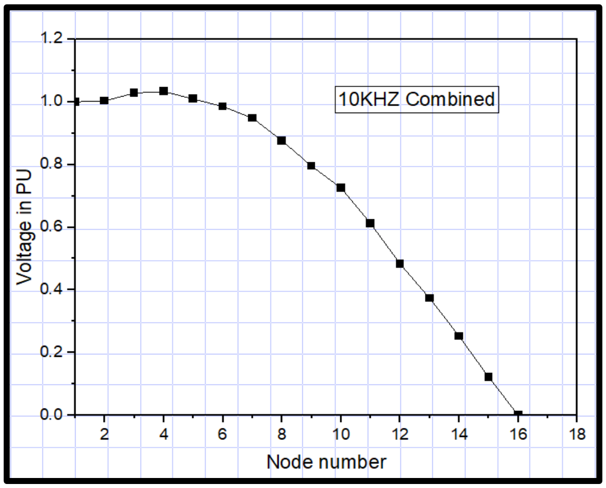
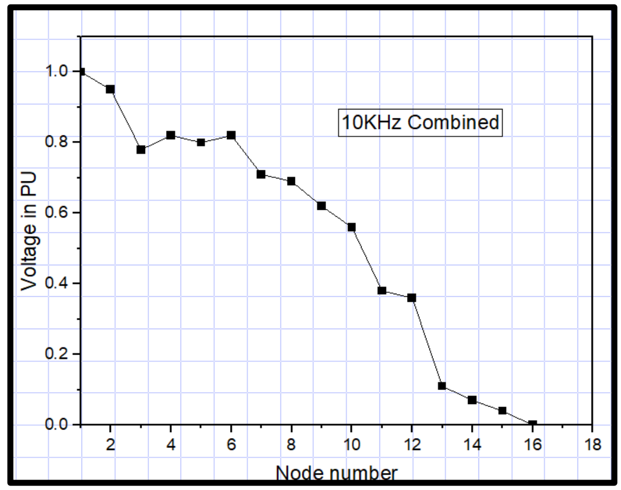
DAMPED SINUSOIDAL WAVE

10KHz COMBINED

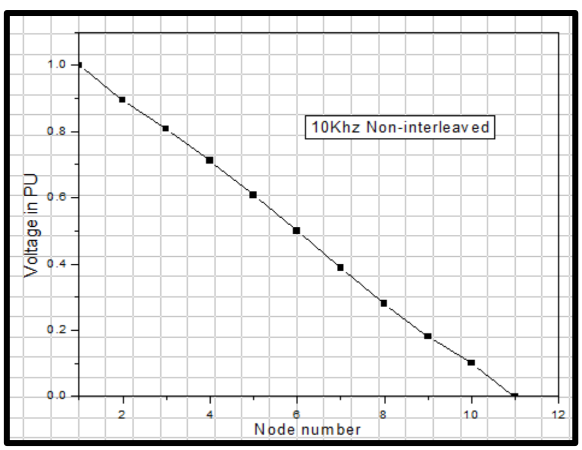
SIMULATED PRACTICAL

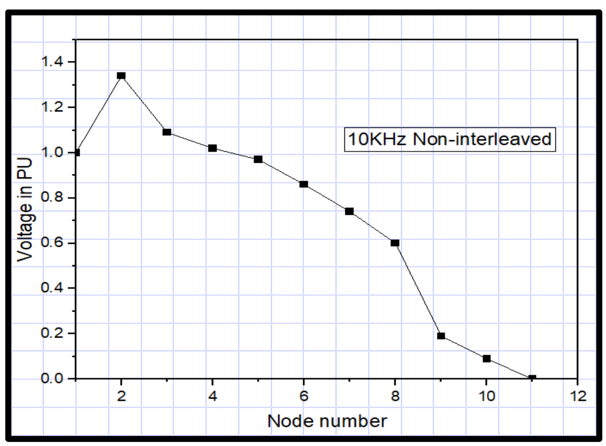




1. The above fig represents the voltage stress on the combined winding model still persists but not at greater level.

10KHz NON-INTERLEAVED





1. Compared to the combined winding the non-interleaved winding faces greater stress on the insulation, which leads to distortion of the winding insulation if it sustains for longer period.

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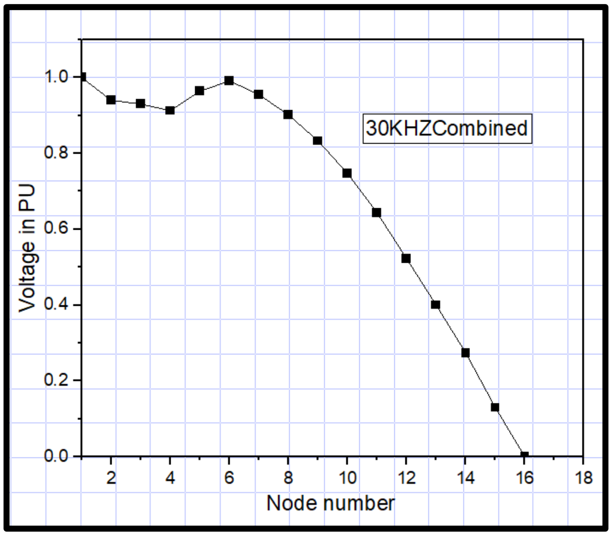
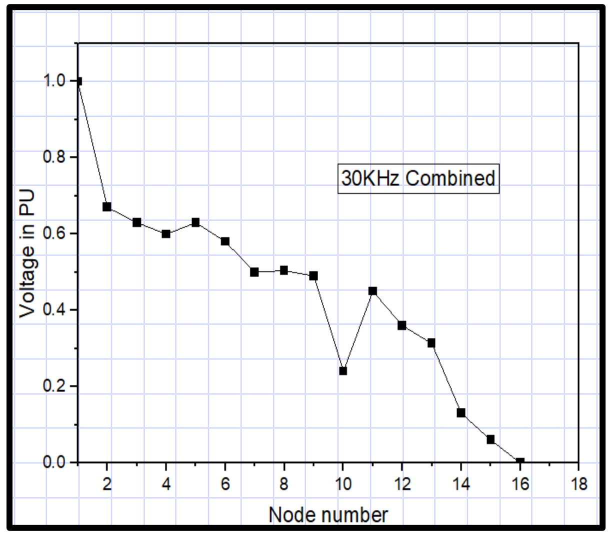
30KHz COMBINED

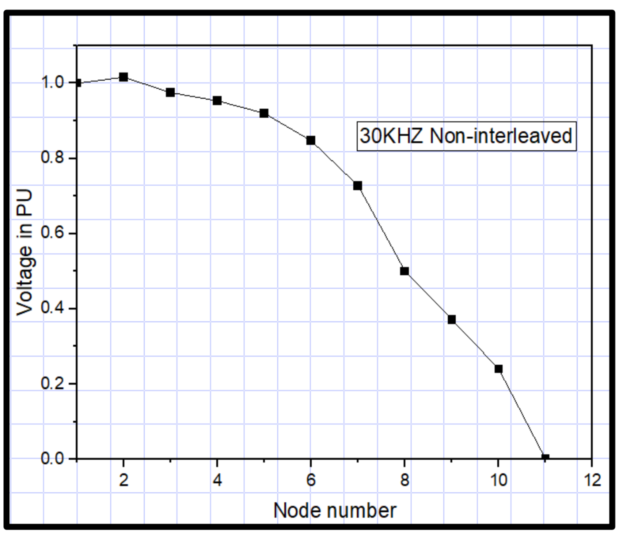
SIMULATED PRACTICAL

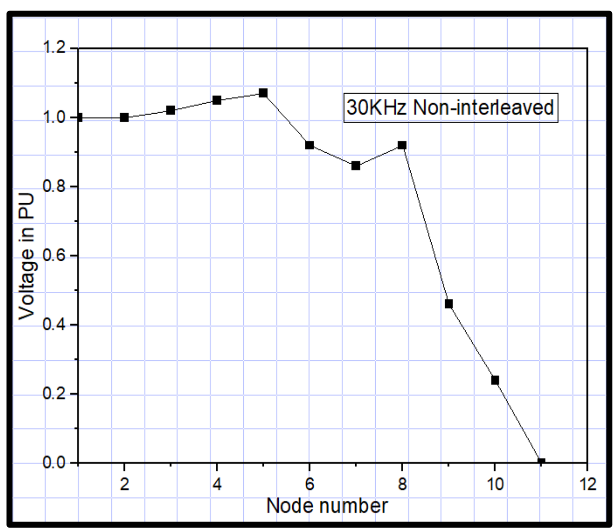




1. The 30KHz damped sinusoidal wave creates more stress on the insulation with more voltage spikes along the winding.

30KHz NON-INTERLEAVED





1. As seen above there is more voltage peaks compared to the combined winding model this shows that winding is subjected to greater stress if the winding is a normal disc one.

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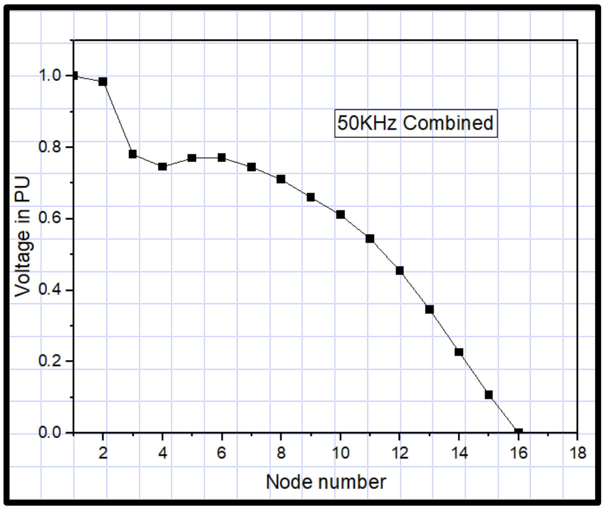
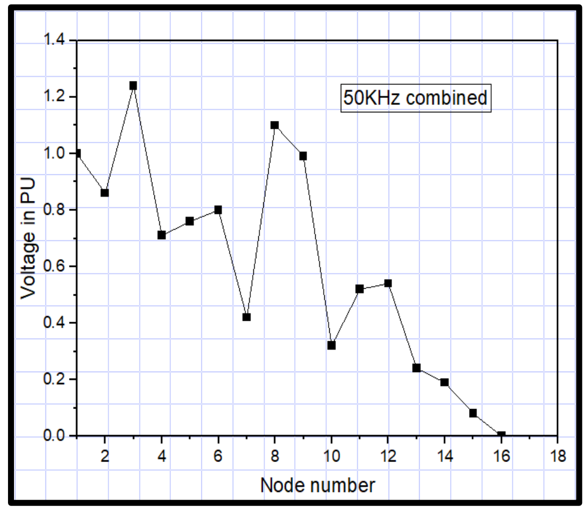
50KHz COMBINED

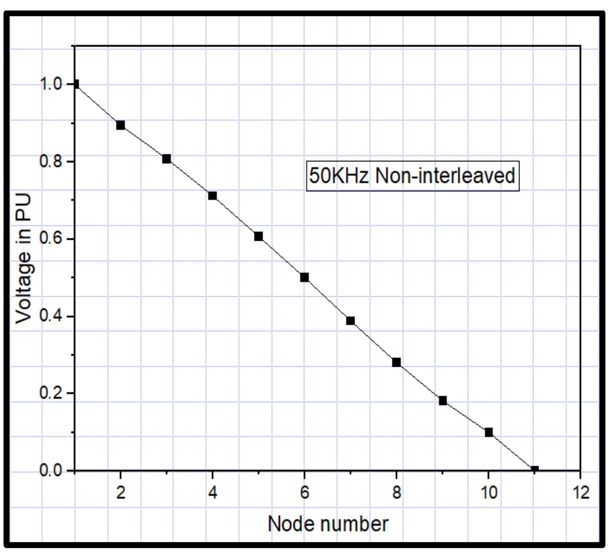
SIMULATED PRACTICAL

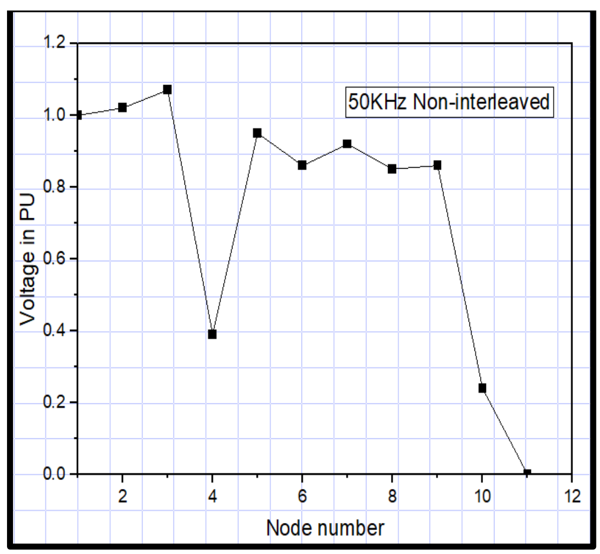




1. Since the 50KHz makes it to be a higher frequency damped sinusoidal wave shape, the winding experiences a lot of voltage stress and breakdown in insulation might occur.

50KHz NON-INTERLEAVED





1. It is observed that the non-interleaved winding section subjected to 50KHz damped sinusoidal wave faces a challenge of uniform voltage distribution along the winding and even the stress on insulation is of greater level compared to any another frequency of damped sinusoidal wave.

CONCLUSION

The stress on insulation of the transformer winding reduces with the use of the inter-leaved winding as its insulation strength will be more as compared to the normal winding also the stress on the winding model reduces as the rise time (time of front) of an impulse waveform increases the greater the rise time lesser is the stress on winding model.

Damped sinusoidal wave generates the transient voltage which causes the insulation to breakdown the use of the inter-leaved winding model helps to withstand these transients caused by the damped sinusoidal waveform.

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