STUDY ON THE NON-LINEAR CHARACTERISTICS OF METAL OXIDE VARISTORS

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Abstract – The Metal Oxide Varistor or MOV is a voltage dependent, nonlinear device that provides excellent transient voltage suppression. The current flowing through a resistor is directly proportional to the voltage applied across the ends of resistor. In case of a varistor, the current-voltage characteristics curve is not a straight line. A varistor is a component which has a voltage – current characteristics that is very much similar to that of a diode. This component is used to protect electrical devices from high transient voltages. They are planted in the devices in such a manner that it will short itself when a high current is produced due to the high voltage. The design of insulation is dependent on the surge voltage behavior of HV power transformer windings. The response of HV power transformer winding insulation for fast rising surge voltages which might have caused due to lightning over voltages, 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"]. Here in this paper the present computer simulation of HV power transformer model winding represented by 4 sections is analysed. The different alpha values of winding selected here are 5, 10 & 15. The MOVs are used in applications ranging from motor of few volts to High Voltage Transmission Lines. MOVs find applications in protection of High Voltage transmission system, DC motor switching, power supply surges, in the buck converter as surge arrester and many others.

Key words- Transformer windings, Transient voltage suppression, Winding insulation, Lightning Overvoltage

1. Introduction

The Metal Oxide Varistor or MOV is a voltage dependent, nonlinear device that provides excellent transient voltage suppression. The Metal Oxide Varistor can be considered as another type of variable resistor that can vary its resistance based on the applied voltage across it. When a high current passes through a MOV, its resistance value decreases and acts as a short circuit. Metal oxide varistors (MOVs) are commonly used to suppress transients in electrical systems. They exhibit an extremely non-linear V-I characteristic, that is, the resistance is very high during normal operations and very low when they are exposed to transients [3].

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 [2]. 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 [2]. In addition, there can be large voltage oscillations of various natural frequencies before the voltage distribution settles down towards steady state behavior. 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 [4].

2. 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. Each section is same and consists of series inductance "*L*" representing self-inductance of winding turns of a section series capacitance *C*s representing inter turn insulation and ground capacitance *C*g represents insulation between turns to ground[2].

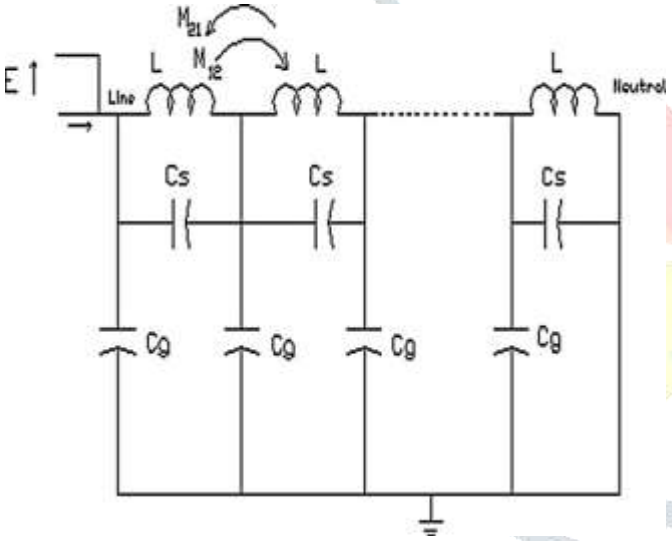

Fig 1. Equivalent circuit of transformer winding for surge voltages

3. Simulation Circuits

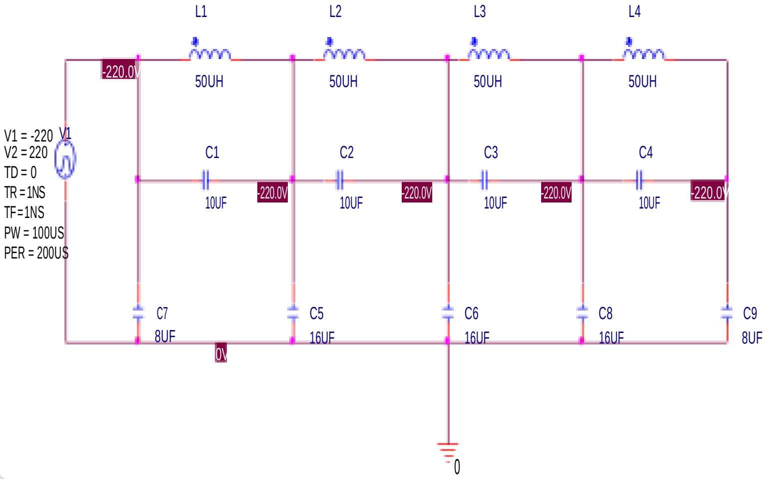

Fig 2 Transformer Windings with 4 sections (α=5)

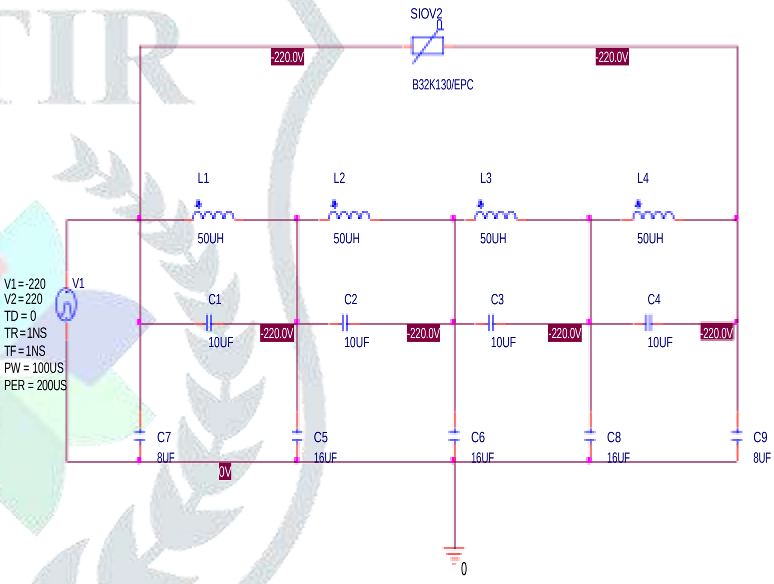

Fig 3 Transformer Windings with single MOV connected across all 4 sections (α=5).

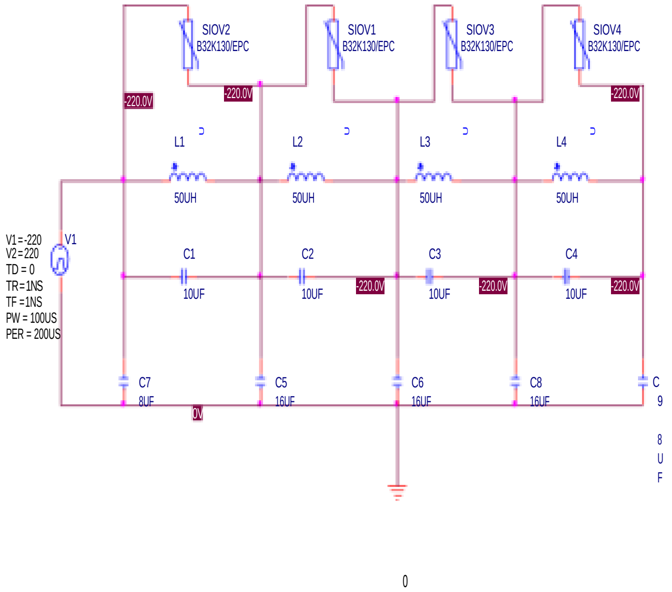

Fig 4 Transformer Windings with MOV connected across each section (α=5).

SIMULATION RESULT

For the Circuit in Fig 2 (with α= 5, 10, 15)

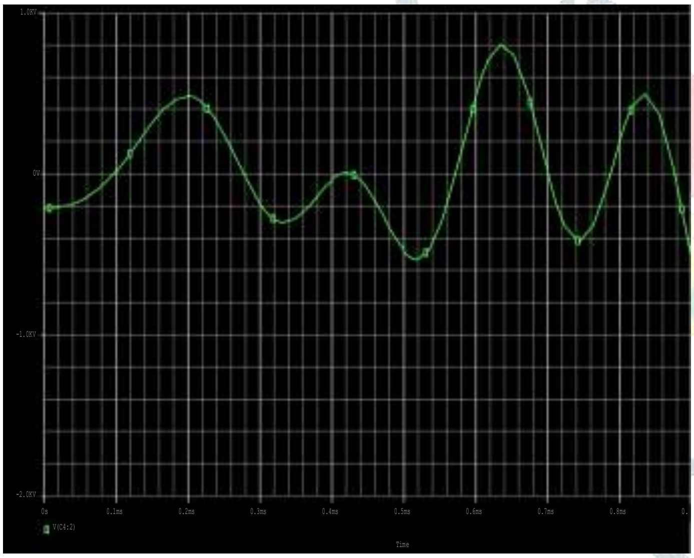

Fig 5 Waveform across C4 without MOVs connected (α=5)

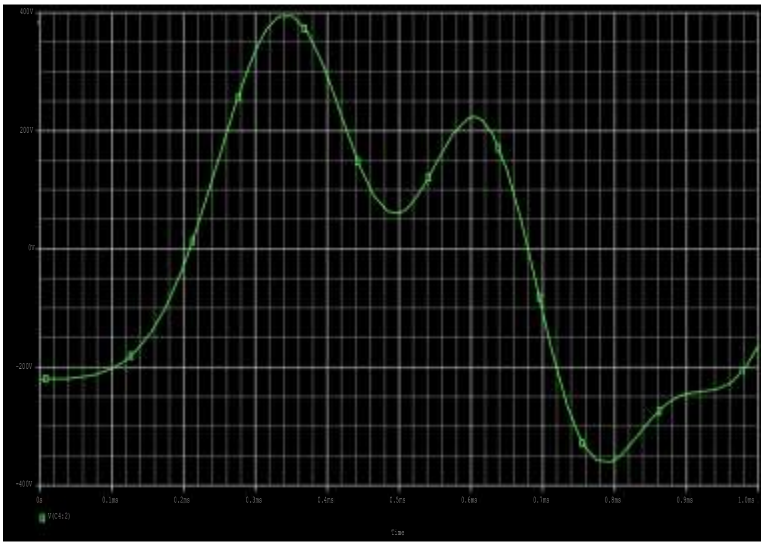

Fig 6 Waveform across C4 without MOVs connected (α=10)

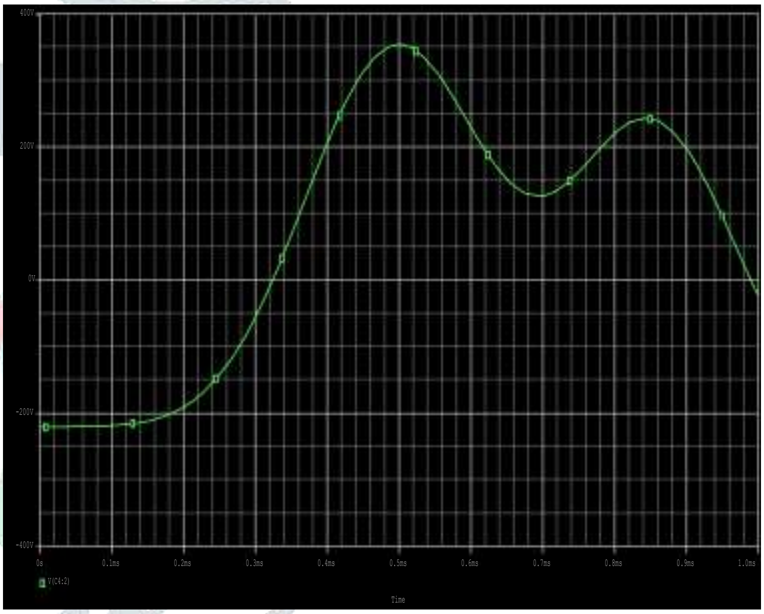

Fig 7 Waveform across C4 when without MOVs connected (α=15)

The above three output waveforms are voltage waveforms across the capacitor C4 in the circuit as shown in fig.2 but with different values of **α (5, 10 and 15)**. The circuit consists only the inductance, series capacitance and the ground capacitance. We have not included Metal Oxide Varistor in transformer winding section. The output waveforms above clearly show that the voltage waveform at the terminal of C4 is not uniform and it is varying largely with respect to time. This may result in the failure of the insulation of winding because of voltage spikes if any present. It leads to the non-uniform voltage distribution across transformer winding sections. Hence by adding MOV we can achieve uniform voltage distribution. The waveforms also vary depending on the value of alpha which is in turn dependent on the value of series and ground capacitance.

Simulation output for the Circuit in Fig 3 (with α= 5, 10, 15)

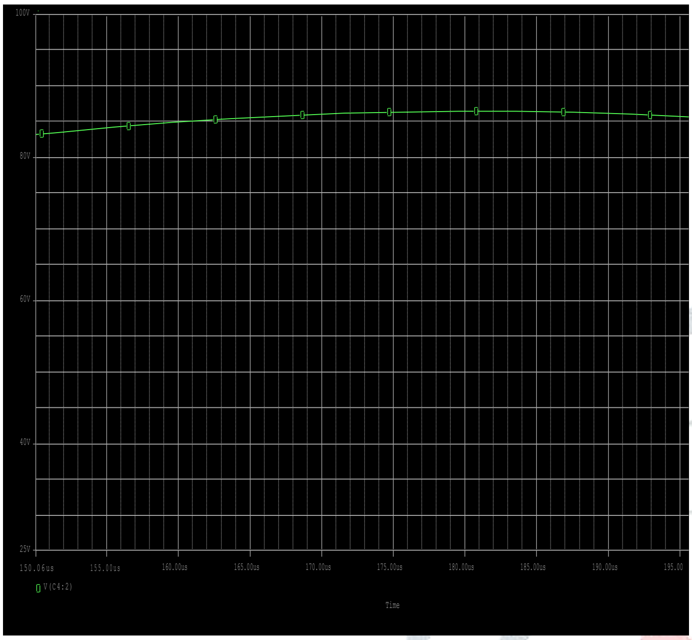

Fig 8 Voltage waveform across C4 with MOV connected (α=5)

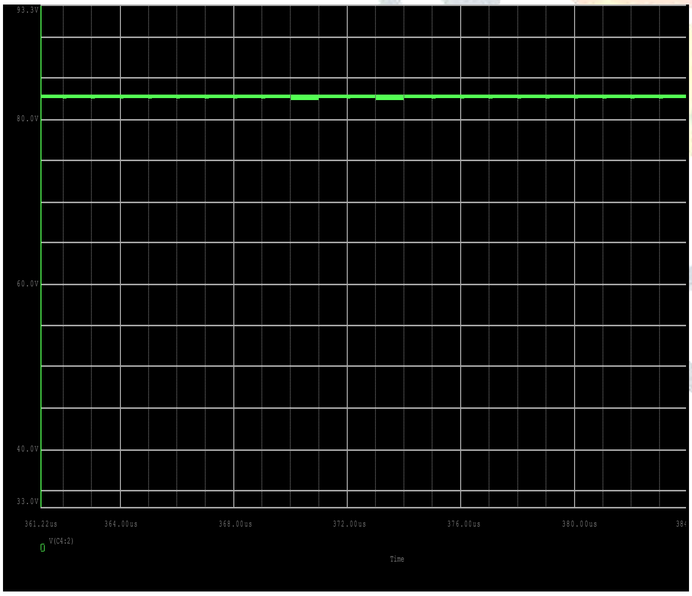

Fig 9 Voltage waveform across C4 with MOV connected (α=10)

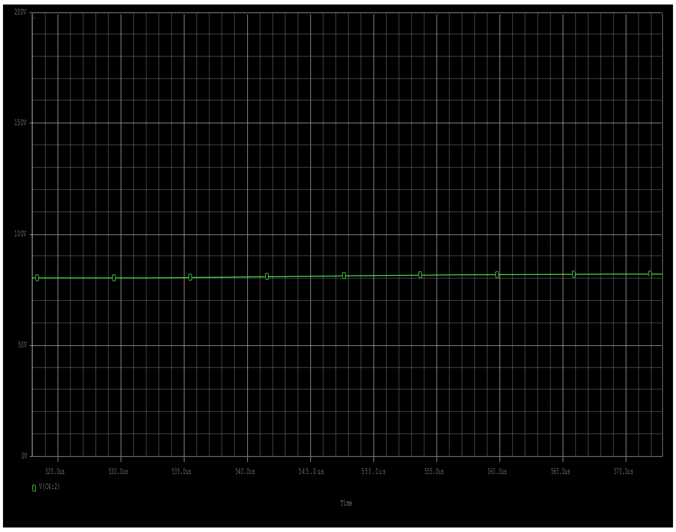

Fig 10 Voltage waveform across C4 with MOV connected (α= 15)

The voltage waveforms across capacitor C4 was not uniform with respect to the circuit as shown in fig. 3 for any values of alpha. Now We add only one metal oxide varistor across the entire circuit. The metal oxide varistor because of its nonlinear characteristics and electrical properties works to bring down the raise in voltage and maintain it uniform across the transformer winding section. This uniform voltage ensures the safety of winding insulation and thus protecting it. The graph in fig (8,9,10) clearly shows how the metal oxide varistor maintains a uniform voltage across the section when alpha values are 5, 10 and 15 respectively. The uniform voltage obtained depends on the time scale used also.

Simulation out for the circuit in Fig 4 (α=5)

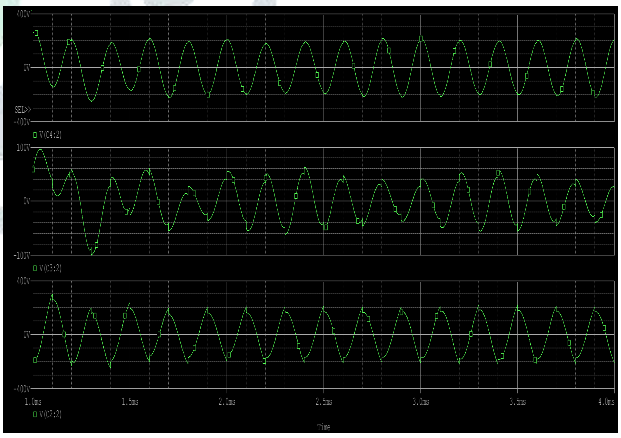

Fig 11 Voltage waveform across C2, C3, C4 with varistor connected across each section

The Metal Oxide Varistors are used across the transformer windings to make sure that there is uniform distribution of voltage across each winding. The figure 4 shows the waveform across the series capacitors C2, C3 and C4. Unlike the other two circuits, this has a metal oxide varistor connected across each of the winding section. The voltage waveform across the capacitor in the circuit in the absence of MOV was completely non uniform. Later we just added one varistor across the whole circuit and thus we got a uniform voltage distribution. This circuit has MOV across each section and its behavior is slightly different. This is carried out for the alpha value of only 5 and voltage waveform across each series capacitance is measured. The voltage across each capacitor has high spikes where the metal oxide varistor tries to reduce it and provide a lower voltage value. The voltage waveforms also show clearly that metal oxide varistors make the waveform exactly to a proper amplitude and reduces any spikes present. This clearly shows that metal oxide varistors work to provide them with a proper waveform.

4. CONCLUSION AND FUTURE SCOPE

The research on MOVs has advanced a lot. Different types of varistors are being manufactured. The MOVs can be used from a small power application to high voltage applications with necessary changes in its composition and construction. MOVs will be most widely used in different types of lightning and surge arresters in coming days. Improving the temperature range and thermal ability would make MOVs to be used in most of the applications. Thus MOVs are used in protection of various devices like motors, converters, high voltage transmission systems and several other appliances. MOVs have proved to be the best devices to ensure the uniform distribution of voltage across the windings of transformer and protect it from any voltage surges.

The non-uniform distribution of the voltage across the transformer windings causes the insulation failure. Thus MOVs are the best devices to be used to ensure the uniform voltage distribution. Either a single MOV can be connected across the entire circuit or across each transformer winding. This leads to ensure the safety of the transformer windings.

The lightning surge over voltage is dominant factor for the insulation design of power system and substation. Whenever lightning strikes the top of a transmission tower, a lightning current flows down to the bottom of the tower and causes transmission line outage and damage of equipment. Surge arresters (or lightning arresters or surge dividers) which are made up of MOVs are installed on transmission lines between phase and earth in order to improve the lightning performance and reduce the failure rate. Surge arresters are semiconductors with nonlinear resistance from a few Ω to several MΩ. MOVs of Lesser ratings are used for protection in buck converters.

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