ESTIMATION OF ELECTRIC FIELD OF A MARX GENERATOR

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Abstract: *Marx generators find importance in defense, medical and civilian applications. For the existing Marx at BARC, an attempt is made to improve the magnitude of peak current and reduce the full width half maximum duration of the output waveform. A new configuration is proposed to achieve the desired values. Existing Marx is enclosed in a closed steel cylindrical shell of diameter 53cm, which is used as a current return path. In the proposed configuration, the return path is a plane copper sheet of 4mm thickness placed above the forward path. Perspex sheet of 25mm thickness is placed between the forward and return path to provide adequate insulation, to avoid flashover or breakdown. ANSYS software is used to compute the electric field distribution on the Perspex sheet used in the proposed configuration.*

Key words: *Marx generator, Perspex sheet, electric field, ANSYS*

1. INTRODUCTION

Marx generator works on the principle of charging the capacitors in parallel and during discharging, when the voltage across the spark gap is sufficiently high enough, the gap breaks and the voltage of each capacitor gets added up by connecting all the capacitors in series. Ideally the voltage across the load is n*V, where n is no of stages and V is the charging voltage. Conventional Marx generators find application in testing laboratories to test the power system equipment. In these generators inductance is not of much importance, where as the Marx generators used in pulsed power applications [1], inductance plays an important role in deciding the rise time of the output pulse. To generate the pulses of short rise time the inductance of the Marx generator has to be kept as low as possible.

To operate the Marx generator at higher voltages, it is placed in a closed cylindrical steel chamber and pressurized with a gas to improve the insulation of the components surrounding the Marx assembly [2-3].

Archana Sharma et al [4] designed and developed a Marx generator driven reflex triode system for the generation of high power microwaves. The Marx generator comprises of six stages, each stage has two capacitors connected in series and each capacitor was of rating 0.15μF, 50kV. The estimated value of the inductance of Marx circuit and full width half maximum were 2.5μH and 390 ns respectively. For a connected load of 31.48Ω and charging voltage of 12kV, Marx gave peak output voltage of 100kV. Due to the limiting value of the Marx inductance, high peak current and FWHM of less duration was not achieved.

1.1 Methodology to reduce Inductance of Marx

The existing Marx generator uses the steel cylinder of diameter 53cm as a current return path. Assume the forward path to be a conductor of 3mm diameter. The inductance of this configuration will be

$$\frac{\mu_o}{2\pi} ln\left(\frac{b}{a}\right) = 2 * 10^{-7} * ln\left(\frac{53}{0.3}\right) = 1.03\frac{\mu H}{m} \quad -(1)$$

The inductance can be reduced by reducing the volume occupied by the flux. If we consider a return path as a metal sheet placed above the conductor say 25mm, the inductance for this configuration is given by

$$\frac{\mu_o}{2\pi} ln\left(\frac{2h}{r}\right) = 2 * 10^{-7} * ln\left(\frac{50}{1.5}\right) = 0.7\mu H/m \quad -(2)$$

Thus, the inductance reduction of 33% is possible with this configuration. The characteristic impedance, Z_O is given by

$Z_O = \sqrt{\frac{L_T}{C_T}} \;\; ---(3)$ Where L_T is the total inductance of the Marx circuit and C_T is the equivalent capacitance of Marx during erection. If the Marx is terminated with matched load, the output peak current I_P is given by

$$I_P = \frac{V_O}{2\,Z_O} \;\; ---(4)$$

$$V_o = n * V \;\; ---(5)$$

In several applications, the time interval between 50% points on the front and tail is of great importance. This time interval is usually referred to "Full width at Half Maximum" or FWHM and is given by [5]

$$FWHM = \; 0.8 * \pi * \sqrt{L_T\, C_T} \;\; ---(6)$$

Thus, if inductance reduces, Z_O reduces and peak current given by equation (4) increases also from equation (6), FWHM reduces and subsequently shorter rise time is obtained.

1.2 Significance of insulation between forward and return path

The insulating material is placed between the return path and forward path. When reducing inductance, other practical issues particularly the important aspects of electrical insulation, for the proposed configuration become significant. When the return path comes too close to the capacitor column (forward path), there can be unwanted flashovers. Thus, it becomes essential to use proper configuration and adequate insulation so that the smallest current loop is realized maintaining adequate insulation, smaller the loop, lower the inductance.

The electric field analysis of any power system equipment [6-7] is normally done using numerical techniques. The most preferred technique is finite element (FEM) analysis. It is time consuming and cumbersome to do the theoretical analysis, hence it is preferred to use the commercially available software's like ANSYS, MAGNET, FLUX-2D, MAXWELL, QUICKFIELD, COULOMB 3D etc. for estimating the electric field.

This paper discusses the proposed configuration developed in ANSYS and computation of electric field analysis. The results are compared with the standard specifications of the Perspex material [8].

2. ESTIMATION OF ELECTRIC FIELD FOR THE PROPOSED CONFIGURATION

The existing Marx comprising of six stages, gives 300kV on matched load. Two variants have been studied keeping in mind the essentiality of adequacy of the insulation to withstand the highest on-load impulse voltage of 300 kV (peak). A Perspex sheet of 25 mm thickness is placed as insulation on top of the HV electrodes of the capacitors (arranged in line) as shown in Fig 1.

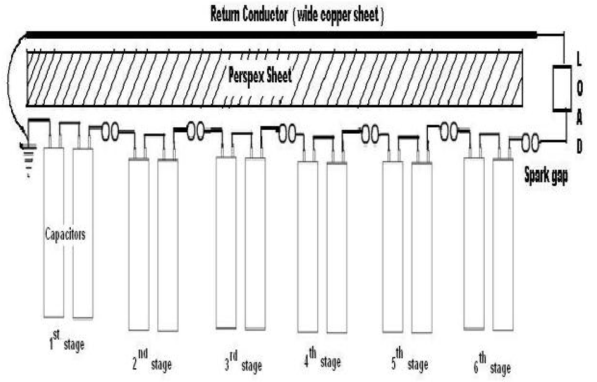

Fig. 1. Arrangement of Capacitors in a Marx

Obviously, the thickness of Perspex (mentioned as 25 mm) must be capable of withstanding the highest voltage on load i.e. 300 kV peak without puncture through the volume. Also, surface flashover from the HV electrode (at 300 kV) to the return path (zero potential) should be avoided.

The Dielectric strength depends on the thickness, also depends on the wave shape and duration of the applied voltage [8]. Perspex is the preferred material in pulsed field applications. The dielectric strength of commercial Perspex is quoted as 400V/mil [9] i.e. 16 kV/mm, for very short duration pulses the breakdown strength will be much higher, possibly around 30kV/mm (peak). However, considering that there would be a reduction in dielectric strength for thicknesses much more than 3mm, it appears safe to work with a value of 25kV/mm.

2.1 Procedure for performing electric field analysis

The procedure followed for performing the electric field analysis of the proposed model in ANSYS is described below:

i) Create the model with exact dimensions

ii) Apply the respective permittivity values for all the components (materials) used in the model
iii) Select the complete model and perform meshing
iv) Apply the boundary values i.e. voltage of HV and LV electrode
v) Run the analysis
vi) Select the contour/vector plot to view the results

For the configuration shown in Fig. 2, Simulation is carried out in ANSYS and the electric field is estimated, shown in Fig 3.

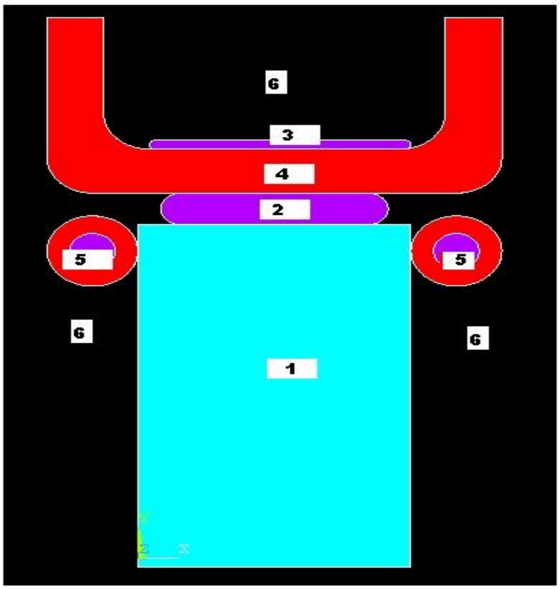

Fig. 2. Perspex sheet, 25 mm thick bent upwards to avoid surface flashover

1. Capacitor
2. HV electrode of the capacitor (of the last stage & hence at highest voltage of 300 kV)
3. LV electrode – Return path of the Marx
4. Perspex insulation between HV electrode (25 mm in this figure) and Return path
5. Inter stage charging Inductors (of the Marx)
6. Compressed air – Ambient medium in which items 1 to 5 are located

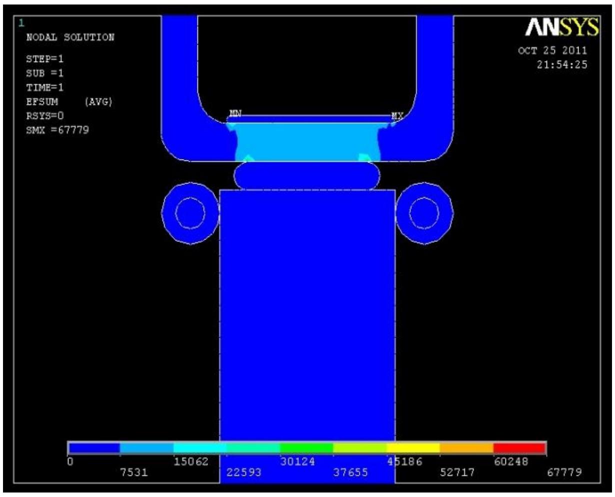

Fig. 3. Electric Field pattern corresponding to Fig. 2

In Fig. 3, highest stress may be seen to be approximately 37 kV/mm at the triple junction of HV electrode, compressed air and Perspex. However, this stress occurs over an extremely small region. Otherwise, the maximum stress is 15 kV/mm inside the Perspex volume.

In the configuration of Fig. 2, it may be seen that the magnetic flux still spreads over a large area implying avoidable inductance. To eliminate this extra flux, configuration of Fig. 4 is considered. Here the ground electrode is much wider (though bent) and extends upto approximately the centre of the charging inductor. Corresponding field-pattern is shown in Fig 5.

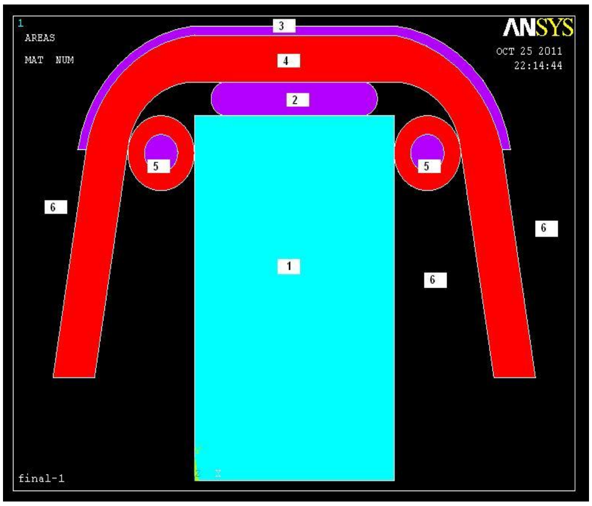

Fig. 4. Perspex sheet bent downwards extended upto centre of charging inductor

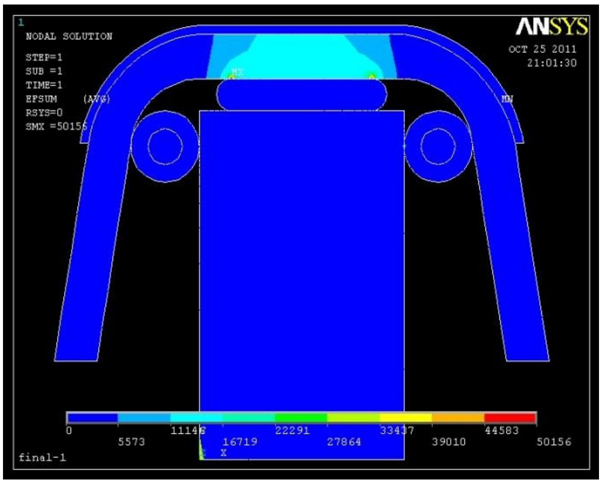

Fig. 5. Electric field pattern corresponding to Fig. 4

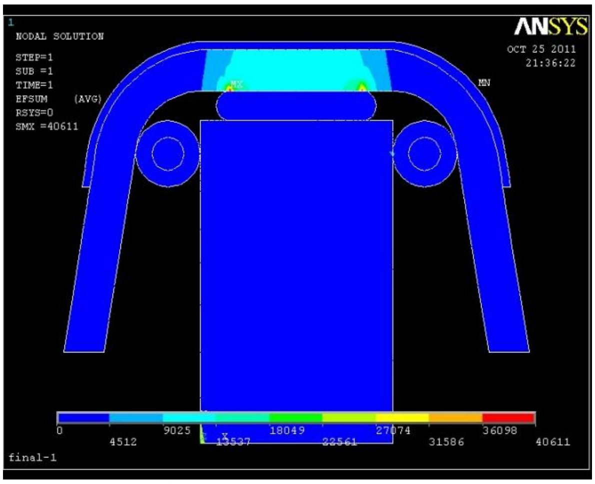

Fig. 7. Electric field pattern corresponding to Fig.6

In Fig.5,

a) $E_{max} \simeq$ 44 kV/mm at junction of Perspex and electrode of capacitor
b) Field inside the main Perspex volume is 12 kV/mm and
c) In some region of the Perspex volume, the field may marginally exceed 12 kV/mm

The maxima occur over very small regions. In the immediate vicinity, the field is in the range of 11 kV/mm to 16 kV/mm. This, again matches closely with $\frac{300\,kV}{25\,mm} = 12\,kV/mm$.The high values given in 'a' above are at triple junctions (as in Fig. 5) and exist in extremely small regions

Fig. 6 shows a minor variant of Fig.4, the variation being extension of the LV electrode downwards approximately corresponding to the bottom edge of the charging inductor. The corresponding field-pattern is shown in Fig.7

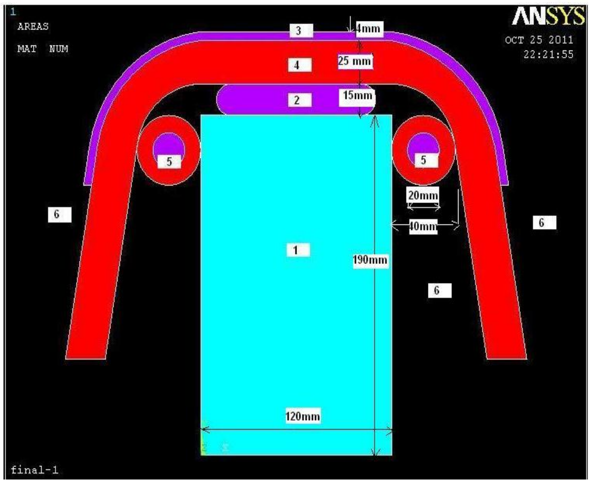

Fig. 6. Perspex sheet bent downwards and extended beyond the charging inductor

In Fig.7,

a) $E_{max} \simeq$ 36 kV/mm at junction of Perspex and electrode of capacitor
b) Field inside the Perspex volume is approximately 12 kV/mm and
c) Over a small range of Perspex (cross section), field marginally exceeds 12 kV/mm.

The maxima occur over very small regions. In the immediate vicinity, the field is in the range of 9 kV/mm to 13 kV/mm. This, again matches closely with $\frac{300\ \mathrm{kV}}{25\ \mathrm{mm}} = 12\ \mathrm{kV/mm}$.The high values given in 'a' above are at triple junctions (as in Fig. 7) and exist in extremely small regions

From the above it may be seen that configuration shown in Fig.6 (corresponding field map in Fig.7) is the best as it gives the lowest electric field everywhere, it is proposed to develop on this further. The experimental work is in progress and the experimental set up of capacitors is shown in Fig.8

Fig.8 Experimental set up of capacitors

3. DISCUSSIONS

The field plots indicate the following

i) Obviously, the field inside the bulk of Perspex is 12 kV/mm which corresponds to $\frac{300\,kV}{25\,mm}$

ii) At the triple junction of electrode– Perspex –air, the field is much higher. Theoretically, the values can be much higher. However, the volume where such fields exist is very small and depends on the workmanship.

iii) Based on Paschen's law, for such very small dimensions the breakdown strength of the compressed air medium will also be much higher than 8.1 kV/mm

iv) It is a big advantage that the excitation is of pulsed nature; the peak exists for a very small fraction of a microsecond.

v) On the whole, the damage due to the partial discharges at the triple junction is likely to be very small but cannot be overlooked as it can decide the life of the Perspex barrier. Experience will be the most reliable guide in this aspect.

vi) Use of smaller thickness of Perspex may be acceptable to
   a) Reduce the inductance further and
   b) Make the manufacturer of the bent Perspex easier

   But the fields at the triple-junction are likely to get worse and thereby likely to reduce life.

4. CONCLUSION

In this paper, the configuration to reduce the inductance of the Marx generator was discussed. The model was developed in ANSYS and electric field was estimated. When compared to other configurations, configuration shown in Fig.6 gave best results i.e. low values of electric field 12 kV/mm, throughout the Perspex sheet.

Over a small portion of Perspex i.e. triple junction of Perspex, HV electrode and air, the electric field marginally exceeds 12kV/mm, the peak voltage exists only for a fraction of microsecond and the damage caused to Perspex is minor. For pulsed fields, the breakdown strength of Perspex [8] is 11 to 5MV/cm over the temperature range of 20 to 100^{o}C, which is much more compared to 12kV/mm. Hence it is reliable to conduct the experiments on the proposed configuration.

With proper workmanship, the sharp points at triple junction can be avoided bringing down the electric field to some extent.

5. ACKNOWLEDGMENTS

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NOMENCLATURE

μ_0 = absolute permeability =4Π *10^{-7}, μH/m
n = number of stages in a Marx generator
V= charging voltage of Marx per stage, volts
V_0 = no load output voltage of Marx generator, volts
b= diameter of cylinder, cm
a = diameter of forward path, cm
Z_o = characteristic impedance of Marx generator, ohms
L_T = Total inductance of Marx circuit, Henrys
C_T = Equivalent capacitance of Marx generator during discharging, farads
I_P = Peak output current, Amps
FWHM= time duration between 50% points of front and tail portion of output waveform, seconds
E_{max} = Maximum electric field, V/m
HV electrode= High voltage electrode
LV electrode=Low voltage electrode (ground electrode)

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