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Effect of stray capacitance on MARX generator output voltage

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In this paper effect of stray capacitance on output voltage of the MARX Generator is studied. Stray capacitances formed between high voltage metallic structures of MARX generator and its ground enclosure play a critical role in determining the voltage and rise time of the output pulse. With increase in enclosure diameter erected leakage inductance increases and stray capacitance reduces, with decrease and vice versa. Eventually in both the cases output voltage reduces and rise time increases. This effect is predominant in fast rising low energy MARX generators having low erected capacitances. In this paper effort has been made to quantify these effects. Simulations were carried out for different enclosure structures to find out their effect on output voltage and rise time with a fixed load. It was observed that conical enclosure helps in mitigating this problem in MARX generator. Simulations were also carried out to optimize the flaring angle of the conical enclosure to obtain maximum output voltage. Simulated results are experimentally validated using a 22 stage 450 kV MARX generator. Details of the analysis, simulations and experimental results are narrated thoroughly in this paper.

Keywords: *MARX Generator, stray capacitance, rise time, stray inductance.*

1.0 INTRODUCTION

Marx Generators are mostly used in pulsed power application such as flash X-Ray, Ultra-Wide Band generation for impulse voltage generation. Marx generator consists of N-stage capacitors which are charged in parallel and discharge in series. Marx Circuit is basically a capacitive energy storage circuit which is charged to a particular voltage level and discharges quickly to the load, transferring all its stored energy to the load in very short amount of time. The simple circuit of a Marx generator is as shown in Figure 1. The theoretical value of the output voltage obtained for N-Stage Marx Generator with charging voltage equals to V is N×V. But in practical cases the output voltage obtained is less than N×V. This is due to the presence of stray capacitance and leakage inductance. Not only the output voltage gets reduced but the rise time also increases.

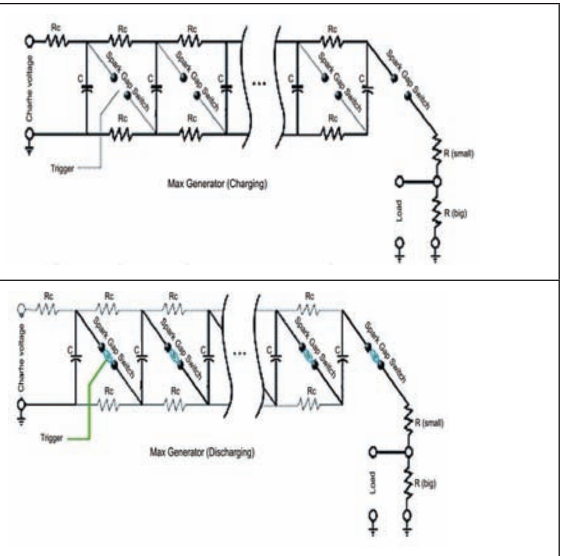

FIG. 1. CHARGING AND DISCHARGING CIRCUIT OF MARX GENERATOR

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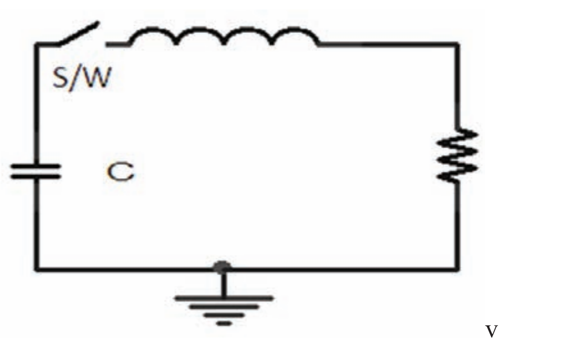
In this paper, the effects of stray capacitance and inductance which are related to the geometry of the enclosure of the Marx Generator have been studied. Efforts have been made to quantify these effects by using conical structure as the enclosure for Marx Generator. These effects have been observed in simulation of 22 stages 450 kV Marx Generator and are validated experimentally.

2.0 THEORY OF MARX GENERATOR

2.1 Circuit Parameters

The basic circuit of the Marx Generator is as shown in the Figure 2.

The circuit shows the capacitor C which is equivalent capacitor of Marx Generator when erected, inductance L which is equivalent inductance of Marx Generator and Z the load impedance.



v

FIG-2 EQUIVALENT CIRCUIT OF MARX GENERATOR AT THE TIME OF ERECTION

The impedance of the system is given by equation

$$Z_0 = (L/C)^{1/2} \quad ...(1)$$

If the load impedance Z equals to Z_0 then the response is under-damp, whereas the load impedance with $2Z_0$ then the response obtain is critically damped [2].

The specifications required for Marx Generator are output voltage (V), load impedance (Z) and Energy of the pulse (E). These specifications help in calculating the number of stages of a Marx Generator, capacitance required in each stage and leakage inductance of each stage. The analysis for the design is also given in [1], which shows equation for peak output voltage, rise time and Full Wave at Half Maximum (FWHM) and are given by:

$$V_{peak} = 0.736 \times V \quad ...(2)$$

$$\text{Rise time} = (L \times C)^{1/2} \quad ...(3)$$

$$\text{FWHM} = 2.45 \times (L \times C)^{1/2} \quad ...(4)$$

From equation 2, 3 and 4 number of stages for Marx, per stage capacitance and per stage inductance can be calculated.

Formation of Stray capacitor

Stray capacitance is formed between high voltage metallic structures of Marx generator and its ground enclosure, and between the spark-gaps. They play a critical role in successive breakdown of the spark-gap and determining the voltage and rise time of the output pulse of Marx Generator. For achieving successive breakdown of spark-gap the stray capacitance should be larger than capacitance formed between spark-gap. But a very large value of stray capacitance can cause reduction in output voltage pulse. Therefore to avoid this reduction we tried to keep this capacitance to a low value which could be achieved by increasing the diameter of the enclosure. Increase in diameter of the enclosure not only causes reduction of stray capacitance but increases leakage inductance of the Marx circuit there by increasing the rise time of the output pulse. This is also given in literature [4], which shows that if the angle of conical enclosure is increased then stray capacitance and leakage inductance act against each other.

3.0 EXPERIMENTAL DETAILS

A 22 stage Marx Generator with a conical enclosure was constructed. A conical enclosure helps in minimizing the stray capacitance thereby increasing the output voltage. A Ceramic material capacitor was selected as it has a high dielectric strength. Each stage of Marx Generator was constructed with 15 capacitors connected in parallel, two charging resistors, one spark gap switch and Perspex disc which provide insulation between ground point of one stage and high voltage point of next stage.

Marx Generator was designed in such a manner that enough clearance was present between high voltage point and ground point. The gap between the spark-gap switch was around 4-5 cm. Proper value of the gap capacitance and stray capacitance were taken into consideration for erection of Marx Generator and it was enclosed in a SS cylinder of 20 cm bottom radius, 32 cm top radius and an axial length of ~115 cm. The inductance of Marx Generator is about 30 nH per stage for a load resistance of 100 Ω.

3.1. Simulation

The 22 stage Marx generator is simulated with help CST Microwave Studio software. There are 15 capacitors connected in parallel to form a single stage of Marx each having a capacitance of 400 pF and rated for 50 kV charging voltage. Therefore each stage of Marx Generator has 6 nF capacitance. Charging voltage was set to 50 kV. The enclosure is chosen to be conical structure whose bottom radius is set to 20 cm and top radius is set to (20+a) cm, where ‘a’ is varied from 0 to 12 cm in which 5 linear samples were taken. At a=0 the enclosure is cylindrical and gradually its flaring angle is increased by increasing the value of ‘a’. The output voltage was seen across a resistive load of 100 Ω. The result for each sample is tabulated in Table-1

TABLE 1

RESULT OF SIMULATION TAKEN FOR EACH SAMPLE

a (Top radius=(20+a) cm)	~Output Voltage (kV)
0	-250
3	-400
6	-440
9	-450
12	-454

It can be seen that from Table-1, that when the top radius and bottom radius are equal the enclosure is like a cylindrical enclosure and the simulated output voltage is~250 kV and as the top radius increases the output voltage increases. Maximum output voltage of 454 kV is found when the top radius is 12 cm.

Figure 3, 4 and 5 shows the geometry of the Marx Generator defined in CST Microwave Studio.

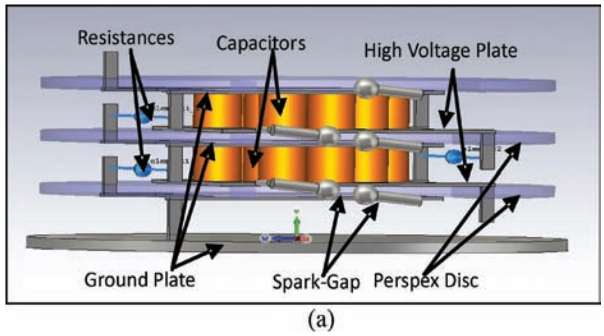


FIG. 3 (A) FIRST TWO STAGES OF MARX GENERATOR (YELLOW-CAPACITOR, BLUE- CHARGING AND GROUND RESISTOR)

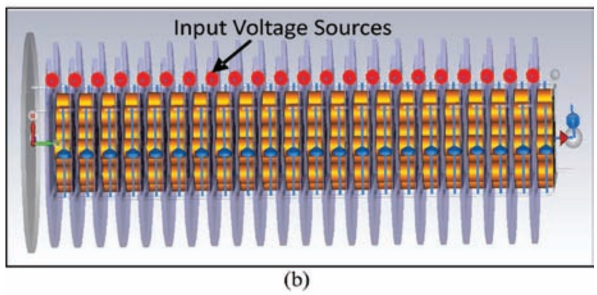


FIG. 3 (B) 22STAGE MARX GENERATOR ON CST MICROWAVE STUDIO

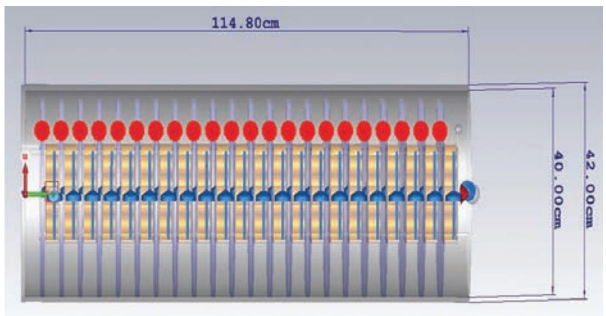


FIG. 4 MARX GENERATOR ON CST MICROWAVE STUDIO WITH ENCLOSURE AS CYLINDER (A = 0CM).

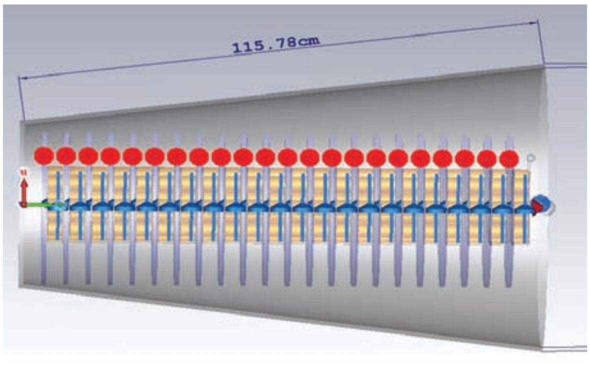


FIG. 5. MARX GENERATOR ON CST MICROWAVE STUDIO WITH CONICAL ENCLOSURE (A = 12CM).

Figure 6 shows the output waveform of the Marx Generator seen across the load, which is also tabulated in Table-1

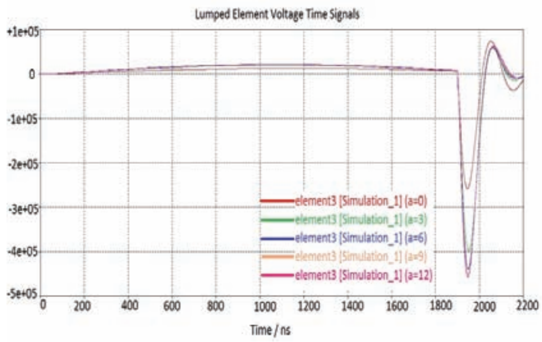


FIG. 6. SIMULATED OUTPUT WAVEFORM OF MARX GENERATOR ON CST MICROWAVE STUDIO WITH TOP RADIUS FROM 20 TO 32CM (5 SAMPLES) WITH LOAD RESISTANCE OF 100Ω

3.2 Experiment

FIG. 7. 22-STAGEMARX GENERATOR WITH CONICAL ENCLOSURE

The 22 stages are assembled by stacking one over the other vertically. Each stage consist of 15 number of Ceramic based capacitor of 400 pF rated 50 kV, one charging and one ground resistor each of value 2 kΩ which are wire wound Nichrome resistor having corona ring at the end of the connections and one spark-gap switch. The capacitor of each stage is mounted on Perspex disc. The whole stack was then enclosed in a stainless steel vessel of cylindrical and conical structure which act as a return path while erection of the Marx generator. Both the side of these two enclosures was sealed air-tight by O-rings. The Marx system is pressurized with Nitrogen gas at 3-3.5 kg/cm^2. Each Stage of the Marx generator is charged to 40 kV voltage. The Figure 7 shows the whole system enclosed in a conical structure enclosure. No external triggering system was employed in this system and; the system was erected on self-trigger phenomena. The output voltage was measured across a dummy load of 100Ω on oscilloscope which is shown in figure 8 and 9 for cylindrical and conical enclosure respectively.

From the output wave form shown in Figure 8 and 9 we can see that the maximum output voltage obtain for cylindrical enclosure is 250 kV and that for conical enclosure is 450 kV, we could also note that with change in enclosure the rise time of the output voltage also increased from 30 ns to 50 ns for cylindrical and conical enclosure respectively which also shows there is a change in the inductance of the circuit.

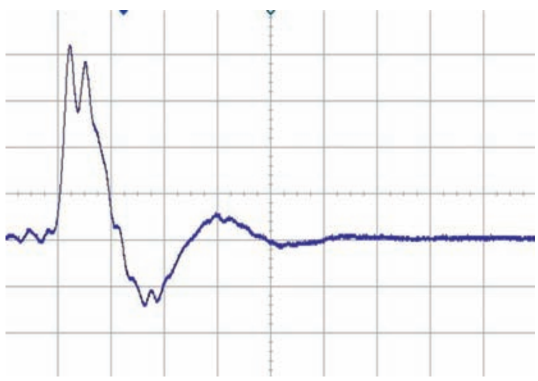


FIG. 8. MEASURED OUTPUT VOLTAGE WAVEFORM OF THE 22-STAGE MARX GENERATOR WITH CYLINDRICAL ENCLOSURE.

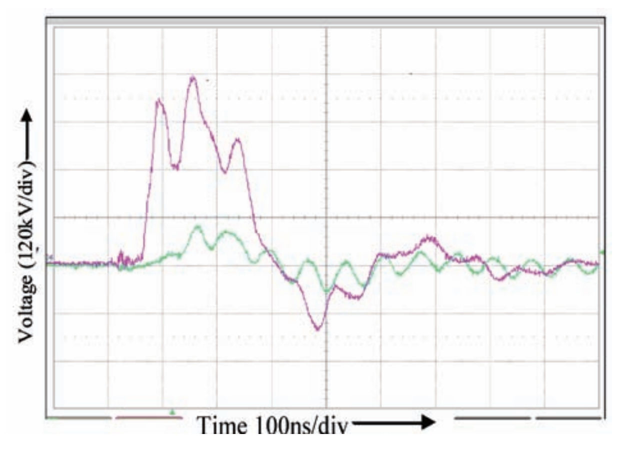


FIG. 9 MEASURED OUTPUT VOLTAGE WAVEFORM (PINK) OF THE 22-STAGE MARX GENERATOR WITH CONICAL ENCLOSURE

4.0 CONCLUSION

A CST simulation and experiment on a 22 stage Marx Generator was carried out to find the effect of stray capacitance on the Marx generator's output voltage and it was found that as the enclosure of the Marx generator was changed from cylindrical to conical structure the output voltage of the Marx generator was increased. In simulation we observed that the maximum output voltage was ~250 kV with ~40 nS rise time and for the same enclosure structure maximum output voltage obtain experimentally was ~220 kV with ~30nS. When the enclosure was changed to conical structure the maximum output voltages obtained were found to be ~454 kV with ~45 nS rise time and ~460 kV with ~50 nS rise time for simulation and experiment respectively. This shows that as the enclosure clearance from high voltage point has increased the stray capacitance of the Marx generator decreases and thus causes an increase in the output voltage.

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