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Research paper

Modeling and system improvements for a fast rise time Marx generator

Madhu Palati [a,*], Ritu Agarwal [b], Archana Sharma [b], Nagabhushana G.R. [a]

[a] *Dept. of EEE, SET, Jain University, Jakkasandra Post, Karnataka, 562112, India*
[b] *Energetics and Pulse Power Section, APPD, BARC, Mumbai, Maharashtra, 400085, India*

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Abstract

This paper discusses the modeling of fast Marx generators particularly with reference to improve the performance in terms of output current pulse characteristics, namely peak current, rise time and full width half maximum (FWHM) duration. As the inductance of the circuit critically influences the characteristics of the output current pulse, possible reduction in inductance of the Marx by bringing the current return path closer to the Marx generator and other practical issues, particularly the need of electrical insulation, are discussed. Characterization of the Marx capacitors & optimization of the Marx generator have been studied.

Keywords: Marx generator; Peak current; Full width half maximum; Fast rise time; Inductance; Capacitance; Characteristic impedance

1. Introduction

In high voltage pulsed power systems (a few hundreds of kilovolts), very fast current pulses (rise times of microseconds down to less than a nano second) of high magnitude (a few kiloAmpere to tens of kiloAmpere) are required to be achieved in many applications such as directed energy weapons, repetitive pulsed power generators, particle beam generators, linear induction accelerators, laser drivers, electromagnetic pulse simulators, medical applications (Pai and Zhang, 1995; Akiyama et al., 2007; Fukawa et al., 2008; Spahn et al., 2011; Jang et al., 2004; Anon., 2016a; Jayaram, 2000; Sharma et al., 2011) etc. All these devices give output pulses of rise times in the range of a few nano seconds to a microsecond.

The most conventional method of generating high voltage (HV) high current pulses is by using Marx generators. In a conventional Marx generator, used globally & very extensively for generation of 1.2/50 μs voltages to simulate lightning over voltages (faced by power-system components), inductance of the generator does not play a major role.

* Corresponding author.
E-mail address: mfmadhu@gmail.com (M. Palati).
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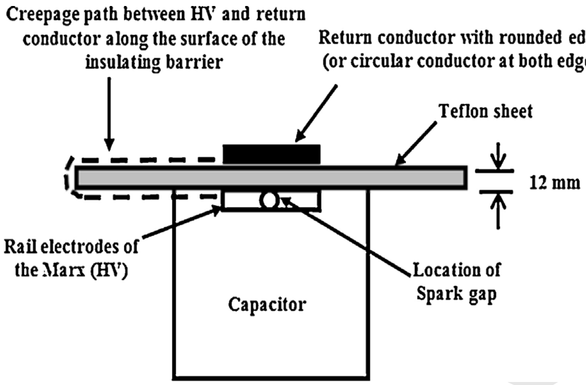

Fig. 1. Schematic cross-sectional view.

However, when pulses of much shorter rise times, less than 0.5 µs are required, inductance of the generator starts becoming important and becomes very crucial when rise times in the nanosecond range are required (Palati, 2015).

2. System overview

BARC has a Marx generator (Marx 1) having 6 stages, each stage having two capacitors in series, identified here as type-1, each rated 0.15 µF, 50 kV. The Marx is placed in a closed cylindrical shell of internal diameter 53 cm which is used as a return path. This Marx can deliver approximately 300 kV to a matched load. The output current (being a very important parameter) has a peak value of about 10 kA (I_P), rise time of 200 ns and full width half maximum duration (FWHM) of about 300 ns. The desired values were 20 kA (peak) current or more with a FWHM of 200 ns or lower. The rise time would be correspondingly smaller.

2.1. Estimation of inductance of the Marx with the metallic cylindrical shell as return path

As mentioned above, in achieving faster rise times & FWHM, reduction of inductance of the circuit is crucial. To appreciate the significance of return path on inductance, assume the forward path (representing the Marx column) to be a conductor of 3 mm diameter and the return path to be the metal tube of diameter 53 cm (Sharma et al., 2011; Palati and Sharma, 2015). The inductance of this configuration will be

$$\frac{\mu_0}{2\pi}\ln\left(\frac{b}{a}\right) = 0.2 * 10^{-6} * \ln\left(\frac{53}{0.3}\right) = 1.03 \mu\text{H/m} \quad (1)$$

The basic principle in reducing the inductance is to reduce the volume occupied by the flux between the forward and return paths. The coaxial cylindrical return conductor used presently has a diameter of 53 cm and results in a large volume (occupied by flux) and hence in larger inductance.

Now consider a return path comprising a metal sheet at a spacing of 20 mm from the center of a 3 mm diameter rod (considered in above example). The inductance would be

$$\frac{\mu_0}{2\pi}\ln\left(\frac{2h}{r}\right) = 0.2 * 10^{-6} * \ln\left(\frac{40}{1.5}\right) = 0.66 \mu\text{H/m} \quad (2)$$

This is a reduction of 36% from the previous value of 1.03 µH/m which can be very useful in the limiting conditions that are always faced in such applications.

In the light of the above, it was decided to use a plane sheet of conductor as the return path placed close to the forward path, consistent with the fact that there must be adequate insulation to withstand the full level output voltage (on matched load). This insulation is proposed to be in the form of a teflon (PTFE) sheet of sufficient thickness, 12 mm.The teflon sheet should have sufficient width to provide adequate surface creepage distance to avoid surface flash over. This exercise was conducted on a second Marx generator, Marx 2, having 7 stages, each stage with two 0.15 µF, 50 kV in series. A schematic of the arrangement of capacitor, teflon insulating sheet & metallic return plate is shown in Fig. 1.

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