Design of A 500 kV Pulse Generator with the Rise Time of Nanosecond Level

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***Abstract*—An electromagnetic pulse (EMP) generator with output voltage of 500 kV is designed. It mainly consists of three parts, a low inductance Marx generator, a gas-sealed peaking circuit and a trigger source. PSPICE simulation of the generator is shown in this paper. The Marx generator uses a series circuit and charged by a ±50 kV high voltage DC source. A peaking part is utilized to steep the rise time of the output of Marx generator.**

Keywords—PSPICE simulation; Marx generator; rise time; peaking circuit

I. Introduction

The software PSPICE can be used to simulate many kinds of generators, for example, the very fast transient overvoltage (VFTO) generator, the lightning wave generator, and the EMP generator, etc.

As is known, the HEMP created by the detonation of a nuclear device at high altitude can cause serious damage to the electronic equipment [1]. Therefore, pulse generator is needed to simulate this situation to examine the working condition of electronic equipment under HEMP environment. Nowadays, the standard of IEC61000-2-9 [2] is widely adapted [3], so the pulse generator in this paper is designed based on it.

High pulsed power technology can produce the waveform with the rise time of nanosecond level. Marx generator is most widely used for the purpose of pulse energy compression [4].

II. Design and Simulation

A. Design Principle

Typically, Marx generator could be used to produce fast rise time pulse. However, the output voltage is about 500 kV, so many levels of switches are needed, which would introduce high inductance and slow down the rise time. Therefore, a peaking circuit is necessary in order to shorten its rise time.

The Marx generator is designed to have seven levels, and each level has one gas spark switch and two capacitors charged by a high voltage source with ±50 kV DC output. The peaking circuit includes a peaking capacitor and a peaking switch. In addition, there is also a trigger source to trigger the first three levels to make sure the synchronism of Marx generator.

The load of the pulse generator is designed as 150 Ω. According to the standard of IEC61000-2-9, the full width half maximum (FWHM) is 23 ns. Then the equivalent total capacitor of this Marx generator C_m can be calculated by equation (1).

$$t_{0.5} = 0.693RC_m \tag{1}$$

As a result, the value of C_m is 221.3 pF, then the value of each capacitor C is $C=14C_m=3.1$ nF. For rough estimation, the inductance of each spark gap switch and capacitor is 60 nH and 40 nH respectively, then the whole inductance of Marx generator L_m is about 1.05 μH. Equation (2) could be used to calculate the value of peaking capacitor.

$$C_p = \frac{L_m}{R^2} \tag{2}$$

Therefore the value of peaking capacitor is 46.7 pF. In order to make sure the uniformity of charging, two large resistors should be connected to the DC source. At last, the value of the two resistors is selected as 10 MΩ.

B. Simulation of the Pulse Generator

After determining the value of each part, PSPICE is employed to simulate the working condition of the pulse generator, as shown in Fig. 1.

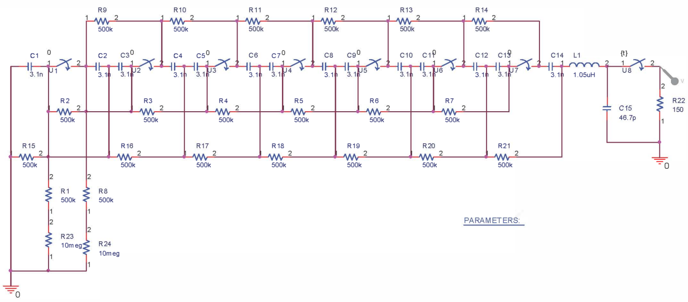

Fig. 1. PSPICE simulation circuit of pulse generator

This circuit can be simplified as shown in Fig. 2. It is assumed that the initial voltage of C_m is V_0, then the KVL equation of the left circuit can be written as (3).

$$L_m \frac{di}{dt} + \frac{\int idt}{C_p} = V_0 \tag{3}$$

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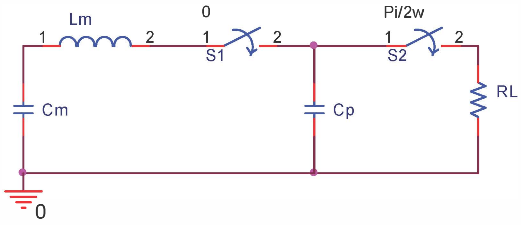

Fig. 2. Simplified circuit of pulse generator

When t=0, switch S1 is closed, the current of the left circuit can be calculated by formula (4).

$$i(t)=\frac{V_0}{\omega_0 L_m}\sin\omega_0 t \tag{4}$$

Based on this, the voltage of C_p could be expressed by formula (5).

$$V_{Cp}(t)=V_0(1-\cos\omega_0 t) \tag{5}$$

The ω_0 in formula (4) and (5) is equals to $\frac{1}{\sqrt{L_m C_p}}$. Further analysis shows when $t=\frac{\pi}{2\omega_0}=\frac{T}{4}$, V_{Cp} equals V_0 and the increasing rate of V_{Cp} becomes the maximum. Therefore, in order to achieve the steepest rise time, peaking switch (S2) should be closed at this time.

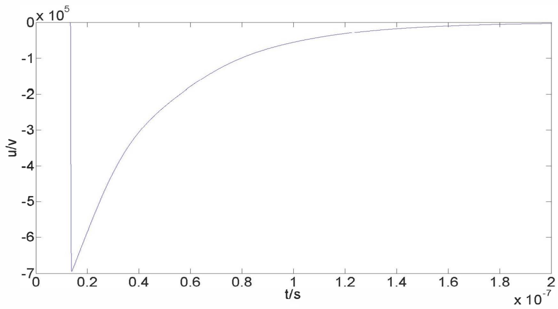

Fig. 3. Output waveform of simulation

The waveform of output is shown in Fig. 3. The rise time and FWHM of waveform measure up to the standard of IEC61000-2-9.

After resembling the generator, there should be three steps to let the peaking switch close at the time $t=\frac{\pi}{2\omega_0}=\frac{T}{4}$. Firstly, fill in the peaking switch with enough SF_6 to avoid the switch breakdown, then acquiring the output voltage waveform by using a divider. Usually, the waveform is periodical, therefore the duration of T/4 can be measured. After the first step, the two output waveforms of the terminal load and the peaking capacitor can be obtained by utilizing two dividers. So the interval between the summits of the two waveforms can be calculated as Δt. In the end, equalize Δt to T/4.

There are two ways to adjust the close time of peaking switch. One is to change the pressure of SF_6 in the peaking switch, the other is to alter the distance between the two electrodes of the peaking switch. These two methods can both change the voltage endurance capability of the peaking switch, which has close connection to the close time of the switch.

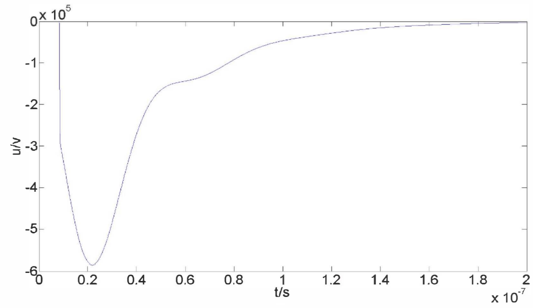

Fig. 4. Breakdown ahead of time

If the switch S2 closes at the inappropriate time, the output waveform will be unacceptable. Fig. 4 shows the situation of peaking switch closes ahead of time. Apparently, the rise time becomes slowly and shows a step.

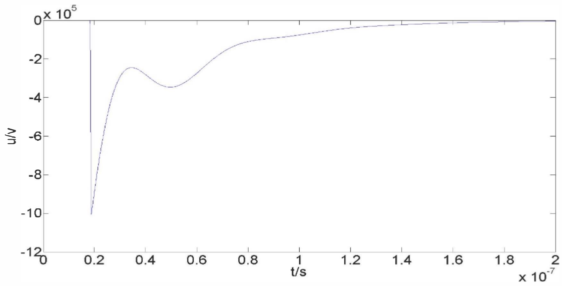

Fig. 5. Breakdown delayed

Fig. 5 shows the close time of peaking switch is delayed. Obviously, the waveform has two summits after the rise time and the FWHM of the waveform is much less.

In the real test, it will take many times to alter the close time of peaking switch to make sure the peaking performance of the switch.

III. COMPONENTS OF THE PULSE GENERATOR

There should be three main parts of this pulse generator, i.e. a Marx generator, a peaking part and a trigger source. The sketch of the system is shown in Fig. 6.

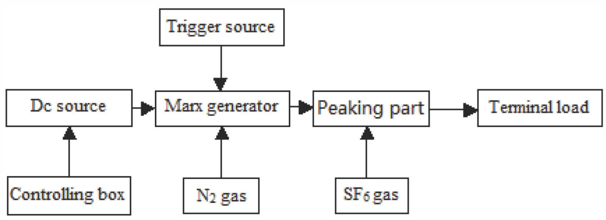

Fig. 6. Sketch of the system

A. Marx Generator

The Marx generator can adopt a series circuit with two sides charging circuit. Each switch in Marx generator should be a low inductance electric field distortion gas gap spark switch with three electrodes including a positive, a negative and a trigger electrode respectively. Before assembling, switches need to be discharged for hundreds of times under DV to pass the aging test, which will make them much more stable.

Each switch should be filled with nitrogen and supported between two capacitors closely to reduce the total inductance of Marx generator. All the charging resistors and the resistors between each level are designed as 500 kΩ. Moreover, the system should be entirely put in a metal tank filled with transformer oil to avoid discharging.

B. Peaking Part

This part mainly consists of two parts, peaking capacitor and peaking switch. Inside of the capacitor, there are many layers of polyester films in coaxial structure [5]. The peaking switch is a self-breakdown gas gap spark switch with two electrodes. These two parts should be both put into an independent gas sealed organic glass box with 0.1 MPa SF_6 to make sure the insulating property inside.

The peaking capacitor could be designed as a mooncake-shaped capacitor on the bottom of the organic glass box. Then the peaking switch can sits on the capacitor. This kind of structure is used to minimize the inductance of the system. Between the capacitor and the switch, there should be a copper bar connected with the output of Marx generator. Under testing circumstance, the capacitor and the peaking switch must be filled in SF_6.

C. Trigger Source

The trigger source is utilized to make sure the synchronism of the Marx generator. The output of the source is connected to the first three switches of Marx generator by a transmission line. It is composed by a capacitor and a self-breakdown gas gap adjustable spark switch with two electrodes. The whole system is in an independent oil sealed organic glass box. At last, the output waveform of the generator can be acquired by a voltage resistance divider.

IV. Conclusion

A 500 kV pulse generator with the rise time of nanosecond level is designed and simulated. The generator is composed of a seven-level Marx generator, a compact structure of peaking circuit and a trigger source. With terminal load of 150 Ω, the generator can produce an output voltage waveform of standard IEC61000-2-9.

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