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DESIGN AND CONSTRUCTION OF A 12 KV IMPULSE GENERATOR

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Abstract - This study gives the steps for design of a 1.2/50 µs lightning impulse generator. The generator has an output voltage up to 12 kV. The circuit is a single stage Marx generator with spherical gaps as switch. The flashover on the switch makes an interference to the electromagnetic environment and sometimes this interference reaches to a hazardous level for the electronic and sensitive devices.

I. INTRODUCTION

Instantaneous voltage rise in electrical installations bring many problems with. The most familiar external impulse voltage is the one formed by lightning. The aim for the generation of lightning impulse voltage in laboratories is for the estimation of the response of the systems and equipment and taking the necessary precautions against the disturbance effects of lightning. The generators constructed simulate the forces that equipment will be faced to. The most popular one of these generators is the one known as Marx generator. Charging the capacitors in parallel and then discharging them in series forms a multistage generator for lightning impulse voltage [1].

In this study, a single stage Marx generator of 12 kV is designed and constructed. The output voltage of the system is a standard lightning impulse with front time/time to half value of 1.2 / 50 µs [2].

The generator circuit constructed is evaluated in EMC terms. For this purpose, the level of interference from the generator is measured in two different environments and the results are given with waveforms.

II. LIGHTNING IMPULSE VOLTAGE

There are many different forms of lightning pulse voltage waveform defined in different standards. The most widely used one is defined in IEC 60060-1 (Figure 1). According to this document, the front time T_1 of a lightning impulse is a virtual parameter defined as 1.67 times the interval T between the instants when the impulse is 30% and 90% of the peak value. The time to half value T_2 of a lightning impulse is the time interval between the virtual origin and the instant when the voltage has decreased to half the peak value [3].

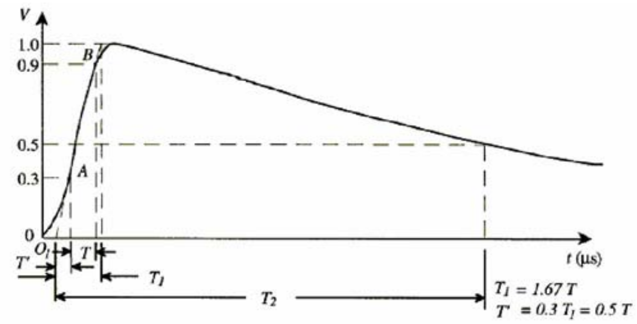

Figure 1. Standard lightning impulse

IEC 60060-1 document also defines the standard lightning impulse as the impulse having a front time of 1.2 µs ± 30% and time to half value of 50 µs ± 20%.

The most common circuit used for the generation of impulse voltage is given in Figure 2. Impulse capacitor, C_1 is charged with dc voltage up to a satisfactory level and then the spark gap is triggered, discharging C_1 onto load capacitor, C_2 following a path through damping resistor, R_1. When the maximum value of voltage is reached, C_2 starts to discharge over R_1 and discharging resistor, R_2. An impulse voltage of u(t) is generated on the terminals of C_2 [4].

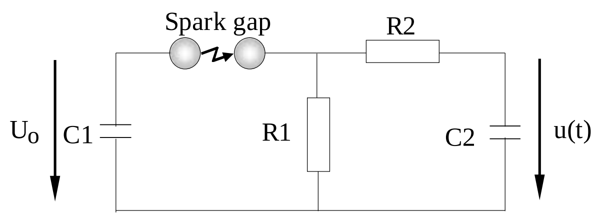

Figure 2. Impulse generator circuit

III. DESIGN OF THE GENERATOR

The method followed for the design and construction is determining main parameters, calculating the required values, computer analysis of the circuit with Pspice and next construction of a low voltage model of the circuit, after all, if the required results are obtained, construction of the high voltage circuit of the model one.

Following the method stated above, the first stage is determining main parameters. The generator to be constructed won't be the active test equipment for the high voltage lightning tests, but only a prototype of it, so a low level of voltage is chosen, as 12 kV.

The energy of the generators is usually determined according to the load and equipment to be tested. For the simplicity in calculations, an energy level of 10 J is found to be suitable.

Main step of the design is determining the value of the impulse capacitor. Using the energy formula,

$$W = \frac{1}{2} C_1 U_{o\,max}^2 \tag{1}$$

$$C_1 = \frac{2W}{U_{o\,max}^2} = \frac{2 \cdot 10J}{(12\,kV)^2} = 138\,nF \tag{2}$$

To obtain a higher efficiency, load capacitor C_2 must have a lower capacitance than C_1 so supposing $C_1 = 30\, C_2$, value of the load capacitor is calculated as $C_2 = 4.6$ nF.

Charge-discharge time period of the C_2 capacitor, thus the time constant is mainly controlled by R_1 and R_2. Their value is calculated using the fall time and time to half value of the impulse. For a 1.2/50 µs impulse, using the capacitances, $R_1 = 480\ \Omega$ and $R_2 = 90\ \Omega$ are calculated.

After obtaining the values of the main components of the circuit given in Figure 2, Pspice analysis of the circuit is done. The values theoretically obtained usually do not match or give the exactly true results on the circuit.

On the other hand, during the construction process, it is hard to obtain the absolutely same value of the components calculated theoretically. At this point, circuit with the components obtained is analysed on the computer and the optimum values that give the 1.2/50 µs waveform are selected.

The circuit designed theoretically on the computer is constructed with low voltage elements. Model generator consists of an adjustable ac supply, elements of the circuit on board and output terminals for scope (Figure 3).

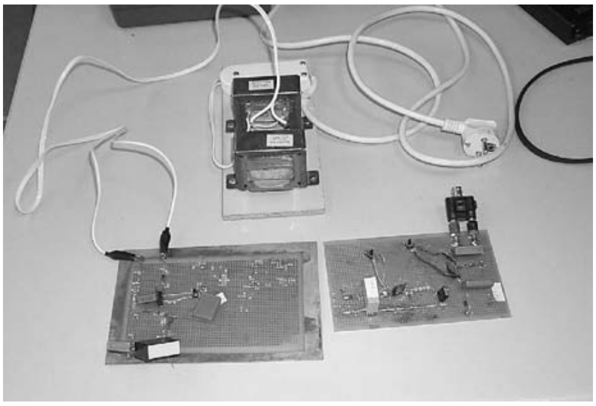

Figure 3. Model generator circuit

Adjustable supply is formed by using two reverse connected 220/110 V transformers and a dimmer. Transformer pair works as isolation transformer for safety and the dimmer is used for adjusting the voltage in 50V-200V interval.

Series resistor of 500 kΩ is connected for limiting the current and a 250V diode as a half-wave rectifier. Then the circuit given in Figure 2 is constructed using the components calculated with analysis. As it is seen from the Figure 2, circuit contains a fast switch, which is a spark gap at most. The model generator is triggered by a thyristor, which is fired by a mechanical micro-switch manually.

The BNC connector mounted to the terminals of the load capacitor C_2 is used for scoping the impulse waveform with an oscilloscope. Oscilloscope used is HP 54615B, a 500 MHz oscilloscope.

After the several tests performed on model generator, the exact components values for the 12 kV generator is determined. The decided components are $C_1 = 150$ nF, $C_2 = 4.7$ nF, $R_1 = 490\ \Omega$ and $R_2 = 100\ \Omega$.

IV. CONSTRUCTION OF THE GENERATOR

Design and performing the pretests on a low voltage model circuit is a cheaper, safer and the easier way for the first step of the construction of a high voltage circuit.

The impulse capacitor of the circuit is obtained by paralleling three capacitors of 50 nF, 18 kV. Waveform adjusting resistors R_1 and R_2 are determined as carbon resistances of 100 W. Load capacitor is formed by connecting two capacitors in series, one 4.7 nF, 30 kV as C_1, and the other 1000 nF as the voltage divider measurement capacitor.

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For limiting the current flowing in the circuit, a protective resistor R_0 of 300 kΩ is connected in series. The protective resistor is formed by parallel and series connection of 22 resistors (Figure 4).

For the input of the system a high voltage dc supply is used. The supply is an adjustable source, with maximum output of 25 kV, 100 mA.

Firing of the circuit is done with a pair of adjustable, spherical spark gap having a diameter of 15.6 mm

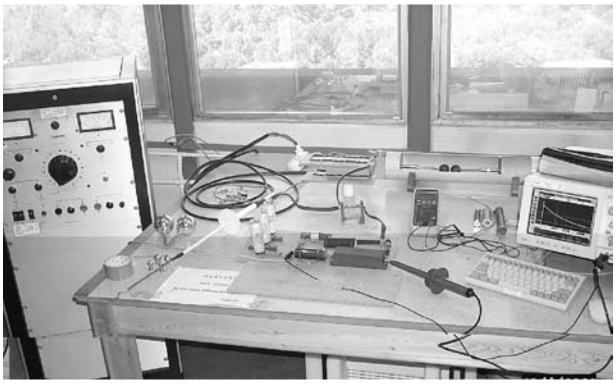

Figure 4. Construction and test of the impulse generator

The output of the generator is scoped on the terminals of the 1000 nF measuring capacitor, with Agilent Tech. Infiniium, a 1 GHz,4 Gsa/s oscilloscope. The conversion ratio of the divider is 1000nF / 4.7nF ≈ 210. The amplitude of the impulse seen on the scope is multiplied with a factor of 210 for obtaining the true value of the output. The same result is determined by using a high voltage probe, HP 34111A with a ratio of 1000:1.

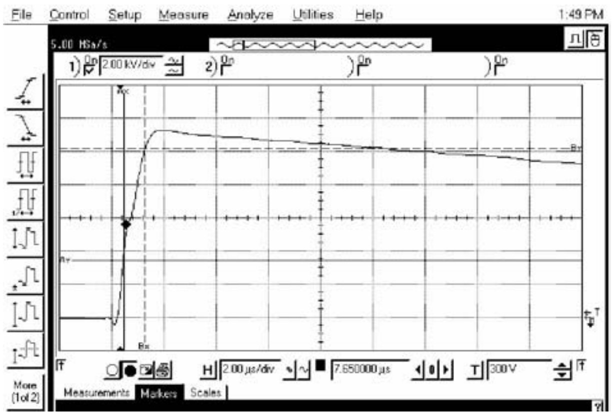

Figure 5. Output waveform of the generator

Output waveform of the system is given in Figure 5. For an input of 12 kV, 11.5 kV output is observed, thus an efficiency of 95%. Front and decay to half value intervals satisfies the tolerances, as 1.3 µs / 53 µs.

The construction requires some special effort for safety and clear output waveform. Proper grounding is the first step of the safety precaution. Isolation of the whole circuit and the components themselves must be satisfied. For the remaining voltage stored in the capacitor, an external grounding rod is prepared and capacitor is fully discharged manually after the pulse, in order not to face an accident.

Main problem in a pulse generator circuit is the unwanted inductive effect causing ripples in the output waveform and forming an obstacle for a shorter duration of pulse. This effect is mainly reduced by making relatively short connections between the components and using busbars as connection units, rather than wiring [5].

V. EMI TEST OF THE GENERATOR

For laboratory environment, EMC is an important requirement [6], [7]. For this reason lightning impulse generator constructed is tested for the level of EM interference it produced. Tests are performed in three different environments for several voltage levels.

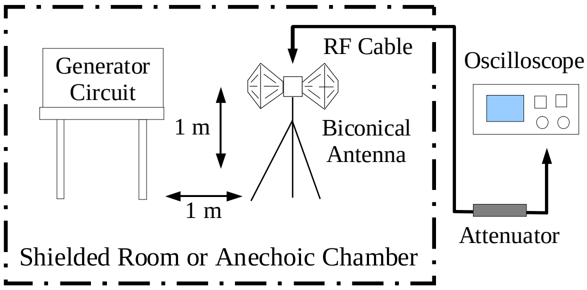

Figure 6. EMI test setup

Setup for the test is given in Figure 6. First, setup is formed in an anechoic chamber. In order not to cause any reflections, the dc voltage supply is placed outside the chamber, together with the oscilloscope.

Connections between the systems are made through the ports of the chamber. For a protective precaution, an attenuator of 10 dB is connected to the input of the oscilloscope. An example for the result of this test is given in Figure 7, for a voltage level of 15 kV.

The same test is performed in a shielded room. This room is a small chamber, walls dyed with metalic (copper) paint. An example result for this room is given in Figure 8, for a voltage of 18 kV.

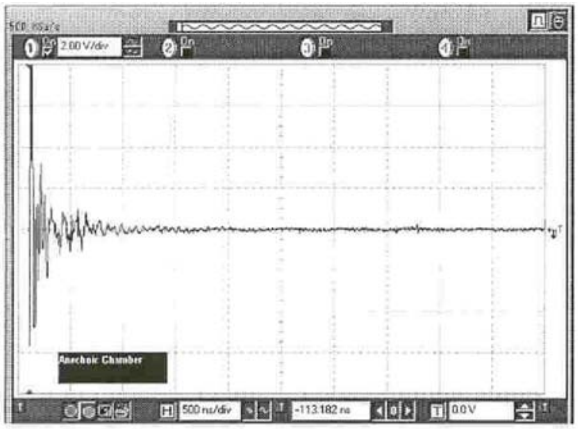

Figure 7. Interference in anechoic chamber

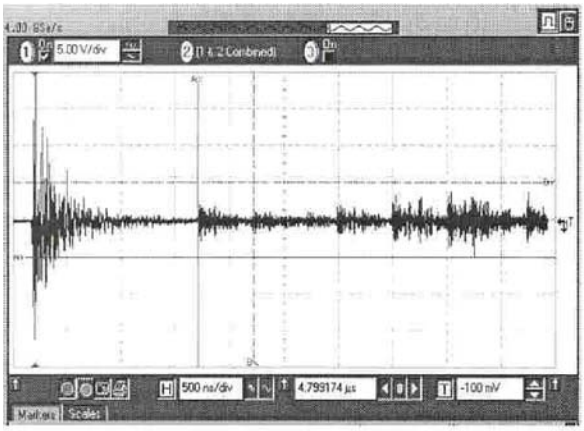

Figure 8. Interference in shielded room

Several tests for different levels of voltage is performed at anechoic chamber, shielded room and normal laboratory conditions. The E-field values obtained for various levels of voltage is given in Figure 9.

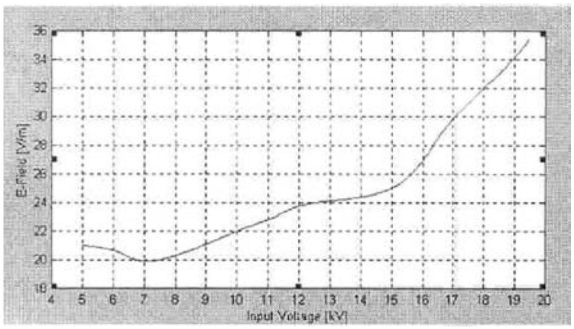

Figure 9. Amplitude of E-field radiated

Results show that the amount of interference caused by the circuit is proportional to the amplitude of the input voltage. Examining the waveforms of the figures 6 and 7, we can state that the pulses have a total duration of 20-30 ns, with a front time of a few nanoseconds. In Figure 7, reflections of the waves generated by the circuit are seen. These reflections have a frequency of 2 MHz.

Evaluating the circuit, it is clear that the ringing waves formed are generated by the spherical spark gap used for switching. Frequency analysis (FFT) of the result is given in Figure 10.

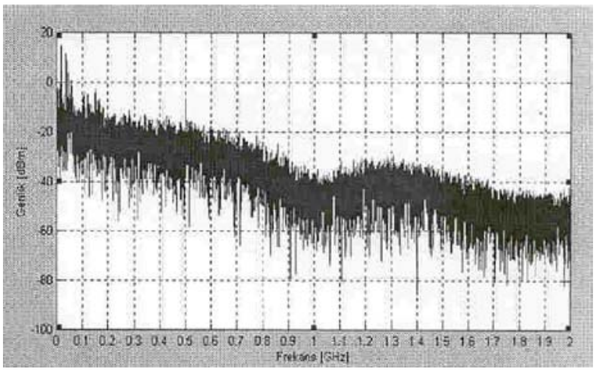

Figure 10. FFT of the interference

VI. CONCLUSIONS

This study explains steps to be followed for design and construction of a high voltage lightning impulse voltage generator. Evaluation of the generator shows that some precautions must be taken for obtaining EMC. Locating the spark gap switch in a shielded enclosure will decrease the interference to a satisfactory level.

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