Simulation of Lightning Characteristics using Pspice Software

Madhu Palati

Department of Electrical & Electronics Engineering, School of Engineering and Technology, Jain University
Jakkasandra Post, Kanakapura Taluk, Ramanagara District, Karnataka- 562 112, India
E-mail : mfmadhu@gmail.com

Abstract - ***The performance of the Power systems depend on the reliability of its components such as Transformers, transmission lines, circuit breakers etc. The component reliability is affected by factors such as it's over voltage withstanding capability and surge current tolerance. The origin of such factors comes from a natural phenomenon, lightning and are called the Lightning impulses. These impulses are momentary and are of several kilovolts to few hundreds of kilo volts. These impulses are to be replicated in the laboratory for the testing of the power system equipments.***

This Paper presents the simulation results of the Lightning characteristics using Pspice software. The simulation circuit can be used to find out the desired front time, tail time and peak voltage for different charging voltages. This would save expense and time by not actually performing test impulse attempts.

Keywords - ***Lightning Impulse characteristics, Impulse waveform, Marx generator, Pspice.***

I. INTRODUCTION

Lightning is an electric discharge that occurs in the atmosphere between clouds or between clouds to ground. Lightning is a natural phenomenon, which generates simple unidirectional double-exponential impulses, which has a significant effect on power transmission system and equipment. Lightning surges induces high voltage of hundreds of kilovolts in the transmission towers and transmission lines. Lightning and switching surges due to transient over voltages cause steep building up of voltage on transmission lines and other electrical apparatus. The voltages are profoundly known as Impulse Voltages. These voltages/ currents are momentary and it is required to test the withstanding strength of the above said power equipments against such conditions.

To simulate impulse voltages in the laboratory, we need a test setup for which a Marx Generator can be used. It works on the principle of charging the capacitors in parallel and discharging into the load circuit by connecting all capacitors in series. Theoretically, the no load full output voltage is N* charging voltage (where N is number of stages). This high voltage output pulsed waveform is used for testing HV equipments/ components such as transformers, cables and insulators.

Many applications require a repetitive source of high voltage pulses having fast rise and fall times[3]. These applications include drivers for piezo-electric devices, ion tubes, gas tubes, liquid polarizing cells, beam steering applications, the generation of electric fields in aqueous solutions, and time-of-flight mass spectrometry measurements also application of Pulsed Electric Field (PEF) has been gaining momentum to preserve the quality of foods, such as to improve the shelf-life of bread, milk, orange juice, liquid eggs, and apple juice, and the fermentation properties of brewer's yeast.

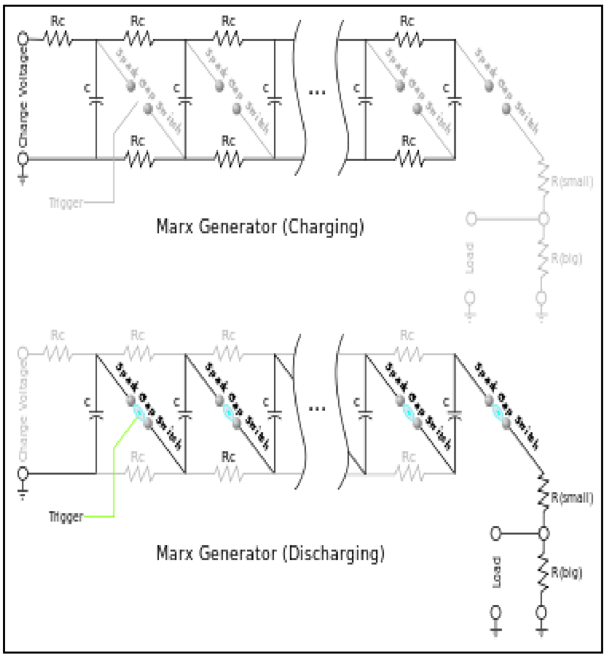

Fig. 1 : Schematic Representation of Charging and Discharging Marx Generator

The charging resistors, R_c need to be properly sized for both charging and discharging, generally in the order of 20-40 kΩ. They are sometimes replaced with inductors for improved efficiency and faster charging. A typical charging current would be in the range of 50-100mA [2].

When fully charged, the lowest gap is allowed to breakdown from over voltage or it is triggered by an external source (if the gap spacing is set greater than the charging voltage breakdown spacing). This effectively puts the bottom two capacitors in series, thus applying excess voltage across the next gap up, which then puts the bottom three capacitors in series, which over voltages the next gap, and so forth. This process is referred to as 'erecting'. A common specification is the erected capacitance of the bank, equal to the stage capacitance divided by the number of stages, n.

In the Marx circuit, the impulse wave shaping circuit is connected externally to the capacitor unit. The wave shaping circuit includes front time resistor (R_1) and tail time resistor (R_2). The time taken for charging (rise time) is three times the time constant of the circuit and is given by;

$$3 * R_1 * C_1 * C_2/(C_1 + C_2) = t_r \qquad (1)$$

The time taken for discharging (tail time) is given by the time taken for 50% discharge that occurs through the parallel combination of the generator capacitance and the load capacitance and the series combination of R_1 and R_2.

$$0.7(C_1 + C_2)(R_1 + R_2) = t_f \qquad (2)$$

II. Development Of Model

The Pspice Software is used to build the models of Impulse voltage Generator. In the classic capacitor discharge impulse generator, the shape of the pulse is controlled by external impedances (usually resistors) at the "output" of the pulse generator. As voltages get higher, it gets harder to build practical resistors with low parasitic inductance that will also withstand the full impulse voltage. The usual remedy for this is to include the wave-shaping resistors in the Marx bank itself. The front resistor allows the front of the wave to reach peak in the desired time. The second resistor, referred to as the tail resistor, is required for the half-voltage level at the end or tail of the wave shape. Each stage front resistor value is 17.65Ω; the tail resistor value is 120Ω as used in the actual impulse generator [1].

The three-stage impulse generator was simulated using PSPICE software. The schematic of the simulated generator is shown in Figure-2. The stage sphere gaps were simulated by the use of switches, as shown in Figure-2. The output of the generator was also switched, and all four switches were closed at the same time. Each of the three stage capacitors were given an initial charge voltage value of 23 kV, is the same as that used in the actual impulse generator [1].

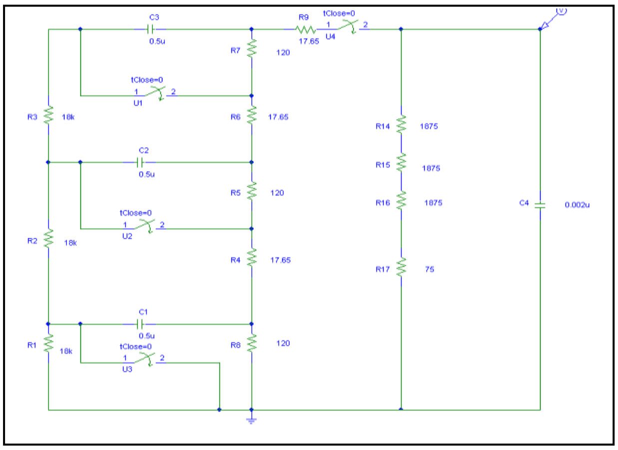

Fig. 2 : IG with potential Divider

Typically, a Resistive voltage divider consists of two resistances in series whose divider ratio reduces the applied value of voltage to a lower voltage value that is measured by an oscilloscope. This divider has a high voltage resistor value of 5625Ω and a lower leg value of 75Ω. This results in a ratio of 75:1 with output impedance to the oscilloscope of 75Ω.

The cable connection is made on the low voltage arm of the divider, and this cable acts as a distributed transmission line. A traveling wave will be reflected from the end of the line if there is a difference between the characteristic impedance, Zo, and the terminating impedance. For this reason, the connections at both ends of the coaxial cable are made with impedance that is equal to the cable characteristic impedance, Zo (75Ω). Also, it has been found that the frequency-dependent transmission error can be decreased by shortening the cable connection

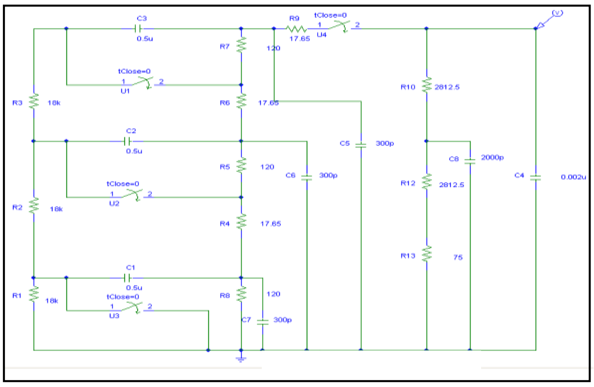

Fig. 3 : IG with Stray Capacitance

For impulse testing, the stray capacitance to ground of the resistive voltage divider is a consideration. Using a trial and error type of process the suitable values of stage and stray divider capacitances were found. The final capacitance values are those shown in the Figure-3. The values are 300pF for each stage and 2000pF for the divider stray capacitance.

III. Results

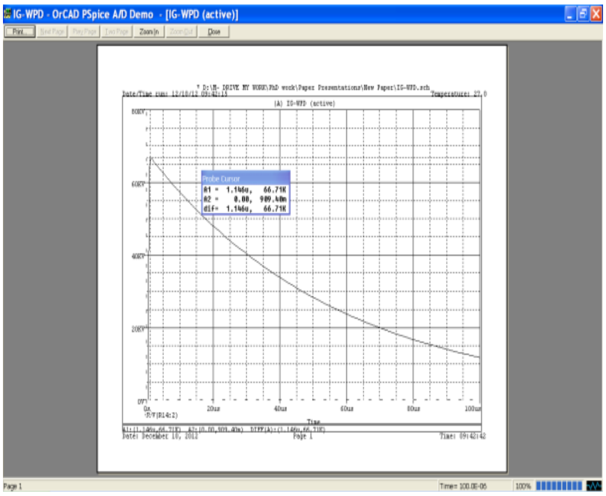

Fig. 3.1 : Impulse Generator with Potential Divider and without Stray Capacitance

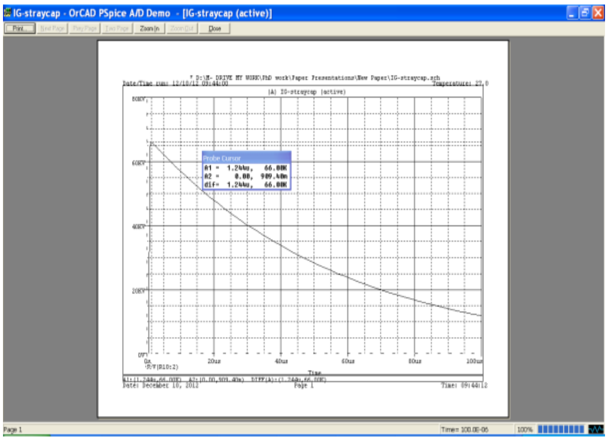

Fig. 3.2 : Impulse Generator with Potential Divider and with Stray Capacitance

Simulation was carried out for different simulation circuits to obtain the front time, tail time and peak output voltage

<u>Case-1:</u>

Impulse generator without Potential Divider and with R_1 and R_2 connected external to the Marx Circuit.

Front time, $t_f = 1.117$ µs

Tail time , $t_t = 48.78$ µs

Peak Output Voltage V_p =59.11 kV

<u>Case-2:</u>

Impulse generator with different values of R_1 and R_2 connected external to the Marx circuit

For same value of R_2 =360Ω and R_1 = 25 Ω & 100 Ω

Front time, t_f = 0.95 µs and 1.69 µs

For same value of R_1 =52.95 Ω and R_1 = 180 Ω & 720 Ω

Tail time, t_t = 36.26 µs and 89.56 µs

<u>Case-3:</u>

Impulse generator without Potential Divider and with R_1 and R_2 in the Marx Circuit .

Front time, $t_f = 1.26$ µs

Tail time , $t_t = 43.2$ µs

Peak Output Voltage V_p = 67.39 kV

<u>Case-4:</u>

Impulse generator with Potential Divider and with R_1 and R_2 in the Marx Circuit.

Front time, $t_f = 1.146$ µs

Tail time, $t_t = 40.78$ µs

Peak Output Voltage V_p = 66.71 kV

<u>Case-5:</u>

Impulse generator with Potential Divider, with R_1 and R_2 in the Marx Circuit and with Stray Capacitance.

Front time, $t_f = 1.24$ µs

Tail time , $t_t = 41.39$ µs

Peak Output Voltage V_p = 65.9 kV

IV. Discussions

The Practical values of Impulse generator are taken from [1] and the same are compared with simulation results. The simulation results with stray capacitance included in the circuit closely matched with the practical values

Comparison of Wave Times

	Practical	Pspice
Front time, µs	1.22	1.24
Tail time, µs	44.5	41.4

Comparison of Peak output Voltage

	Practical	Pspice
Peak Output Voltage, kV	63.4	65.9

Changing the value of front resistor will affect the front time and also the peak voltage. If the value of the front resistor is increased, front time increases and peak voltage will decrease, and vice versa

Changing the value of Tail resistor will affect the Tail time and also the peak voltage. If the value of the Tail resistor is increased, Tail time increases and peak voltage will increase, and vice versa

By including the potential divider in the simulation circuit across the load capacitance, there was a small reduction in the front time, tail time and peak voltages.

The shape of output waveform is also affected by load capacitor. Peak voltage of the output waveform will increase if the value of the load capacitor is decreased, and vice versa

V. CONCLUSION

Marx generator is one of the best methods to design an impulse generator. The simulation circuit, with the stray capacitance added, closely approximated the actual base impulse generator.

The front time (t_f) is within 1.6 percent, the tail time (t_t) is within 6.9 percent and Peak voltage is within 3.9 percent of that recorded in calibration of the impulse generator [1]

Overall the simulation circuit results closely matched with the actual impulse generator 1.2/ 50μs wave shape for the provided test voltage (69 kV). The simulation circuit could be used to predetermine the front time, tail time and peak voltage of Impulse waves at any desired test voltage. This would save expense and time by not actually performing test impulse attempts.

VI. ACKNOWLEDGEMENT

Author is grateful to the Director & Management of School of Engineering & Technology, Jain University, Bangalore for their constant support and encouragement, in carrying out this research work.

VII. REFERENCES

[1] An Impulse Generator Simulation Circuit ," Steven E Meiners,B.S." EET, Miami University, 2002.

[2] Impulse Generator and Lightning Characteristics Simulation using Orcad PSpice Software ," Muhammad Saufi Kamarudin, Erwan Sulaiman, Md Zarafi Ahmad, Shamsul Aizam Zulkifli and Ainul Faiza Othman", Proceedings of EnCon2008

[3] Study of an Ultra-Compact, Repetitive Marx Generator for High-Power Microwave Applications," R. Bischoffa, R. Charona, J.-P. Duperouxa, B. Martina and S. Pinguetb", Proceedings of the 2nd Euro-Asian Pulsed Power Conference, Vilnius, Lithuania, September 22-26, 2008

[4] Y Choyal, Lalit Gupta, Preeti Vyas, Prasad Deshpande, Anamika Chaturvedi,K C Mittal And K P Maheshwari "Development of a 300-kV Marx generator and its application to drive a relativistic electron beam," Sadhana Vol. 30, Part 6, December 2005, pp. 757–764.

[5] Pai S T, Zhang Q 1989," Introduction to High Power Pulse Technology"

◈◈◈