CONSTRUCTION AND EVALUATION OF SINGLE STAGE MARX GENERATOR

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Abstract: *Often the Power system equipments are subjected to lightning and switching impulse voltages. To simulate these voltages and test the above said equipment in laboratories, Marx generator is commonly used. This generator produces Lightning impulse voltages of 1.2/50µs duration and switching impulse voltages of 250/2500 µs duration. This paper describes the development of a cost effective and easily portable compact single stage Marx Generator capable of producing lightning impulses as well as switching impulses upto 10kV. This generator can be used by small scale industries and academic institutions to demonstrate impulse voltages and also to perform testing on insulators of lower rating in laboratory. The duration of the waveform i.e. time to front and time to tail can be controlled by varying the values of front resistor and tail resistor. The experimental wave form was compared with the PSPICE simulation waveform and the both waveforms were in close agreement.*

Key words: *Marx generator, Lightning impulse, switching impulse, front time, tail time.*

1. INTRODUCTION

In the present scenario, to reduce the gap between demand and generation, power systems reliability is of utmost importance. Reliability of power systems depends on performance of equipments such as transformers, transmission lines, circuit breakers and insulators. When Power systems components are subjected to lightning and switching over-voltages cause steep building up of voltage. These voltages are profoundly known as Impulse Voltages and are momentary. It is required to test the withstanding strength of the above said power system equipments against such conditions.

The above said voltages are simulated in laboratories for testing the power system equipment, using Marx generator which works on the principle of charging the capacitors in parallel and discharging all the capacitors in series. The standard impulse voltage is represented by a double exponential wave [1-2] given by

$$V = V_0[\exp(-\alpha t) - \exp(-\beta t)] \quad \text{--- (1)}$$

Where α and β are constants in microseconds.

International Electro technical commission IEC60060-1 specifies that the insulation of transmission line and other equipments should withstand standard lightning impulse voltage of wave shape 1.2/50 µs and for higher voltages (220 kV and above) it should withstand standard switching impulse voltage of wave shape 250/2500µs. The tolerances [3-4] that can be allowed for the impulse wave are given by ±30% for time to front and ±20% for time to tail.

From above, it is evident that Marx generators play an important role in generating impulse voltages. In certain applications like testing of 1200kV power line components, generation of higher voltages is required; therefore, the number of stages of Marx generator is increased.

The design, development and work carried out on the compact Marx generators, for generation of fast current pulses, by the earlier researchers are briefly presented. Neuber et al [5] developed a 25 stage, 500kV, 500J compact Marx generator for generation of high power microwaves. Prabaharan et al [6] developed a 10 stage, 2.4ns rise time, 300kV, 500MW compact coaxial Marx generator for driving a coaxial electron beam generator. Bischoff et al [7] developed a 10 stage, 500kV ultra compact generator for repetitive high power microwaves generation application. Archana Sharma et al [8] designed and developed a six stage, 600kV, Marx generator for driving a reflex triode system.

In this paper attempt is made to develop a compact, inexpensive, portable 10kV single stage impulse generator for demonstration of lightning & switching impulses in academic institutions. Also this work can be extended to develop a multi stage Marx generator.

2. IMPULSE GENERATOR CIRCUIT

Double exponential waveform of type mentioned in equation (1) can produce impulse waves by different combinations of RLC or RC circuits. Most commonly used circuit is shown in fig 1.

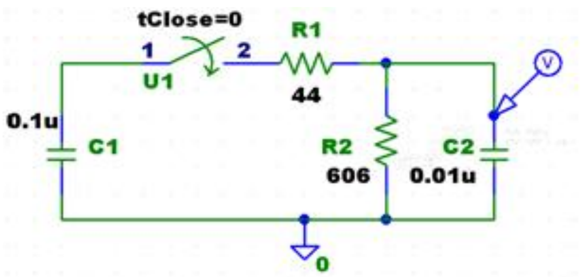

Fig. 1. Impulse generator circuit.

Based on the energy and voltage rating of the generator, the value of equivalent generator capacitance or discharge capacitance C_1 and load capacitance C_2 will be fixed. The desired wave shape is obtained by controlling the wave shape resistors i.e. front resistor R_1 and tail resistor R_2. The approximate formulas for computing the time to front, time to tail, efficiency and output voltage are given by

$$T_1 = 3R_1 * \frac{C_1C_2}{C_1+C_2} \quad \text{--------(2)}$$

$$T_2 = 0.7(R_1 + R_2)(C_1 + C_2) \quad \text{---------(3)}$$

$$\eta = \frac{C_1}{C_1+C_2}\left(\frac{R_2}{R_1+R_2}\right) \quad \text{---------(4)}$$

$$V_0 = \eta * nV \quad \text{--------- (5)}$$

The ratio of C_1/C_2 chosen [2] to be between 6 and 106.5 and R_2 will be large and greater than R_1. The available capacitors in our laboratory were of rating C_1=0.1 μf, 10 kV and C_2=0.01 μf, 10 kV. For obtaining standard lightning impulse waveform i.e. T_1 =1.2μs, T_2 =50μs and by substituting the above said values of C_1 and C_2 in the equations (2) & (3), R_1 & R_2 were obtained and are 44Ω & 605.3Ω respectively. Similarly for obtaining standard switching impulse wave i.e. T_1 =250μs, T_2 =2500μs, the computed values of R_1 & R_2 are 9.167kΩ and 23.3kΩ respectively.

The simulation of Lightning and switching impulse waveform are carried out in PSPICE software [9]. This saves lot of time and the desired parameters can be estimated easily without performing the experiments. R_1 & R_2 chosen for lightning & switching impulse circuits were 44Ω, 600Ω & 9.1 kΩ, 23.1 kΩ respectively. The simulation was carried with the above said values and the PSPICE waveform for Lightning impulse & switching impulse are shown in fig 2 & fig 3 respectively.

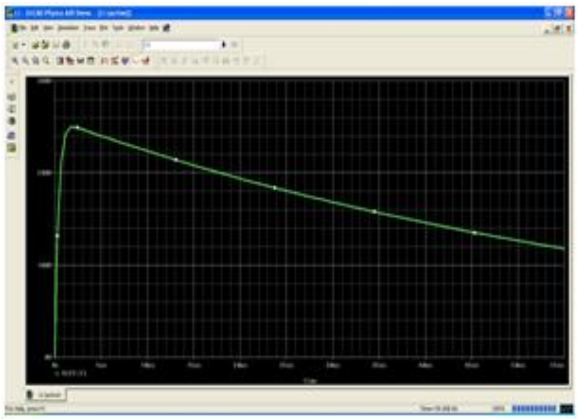

Fig. 2. PSPICE waveform of Lightning impulse

From fig 2, the time to front and time to tail of lightning impulse wave are 1.7μs/50.3μs respectively.

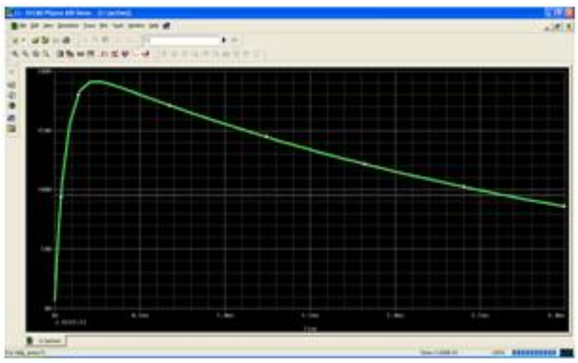

Fig. 3. PSPICE waveform of switching impulse

From fig 3, the time to front and time to tail of switching impulse wave are 265.8μs/2646μs respectively.

In practice Marx circuit comprises of several stray inductances, each component has some residual inductance and the circuit loop contribute further inductance. This inductance may vary from

0.1μH to several hundreds of μH [2]. Simulation is carried out in PSPICE by adding an inductance of 1μH, the simulation waveform of lightning impulse showing the effect of inductance on time to front is shown in fig 4. Due to addition of inductance the time to front is 1.89μs compared to 1.7 μs.

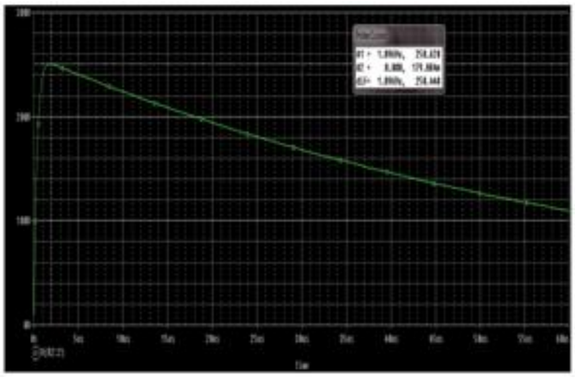

Fig. 4. Simulation waveform of lightning impulse showing effect of inductance on time to front

3. EXPERIMENTAL MODEL

With the obtained values of R_1 and R_2, develop a wave shaping circuit on the PCB. As the resistor with obtained value of resistance is not available in market, resistors of standard ratings are formed in series/parallel combination to obtain the required value. For example resistor R_2 is a series combination of six 100Ω resistors, shown in fig. 5.

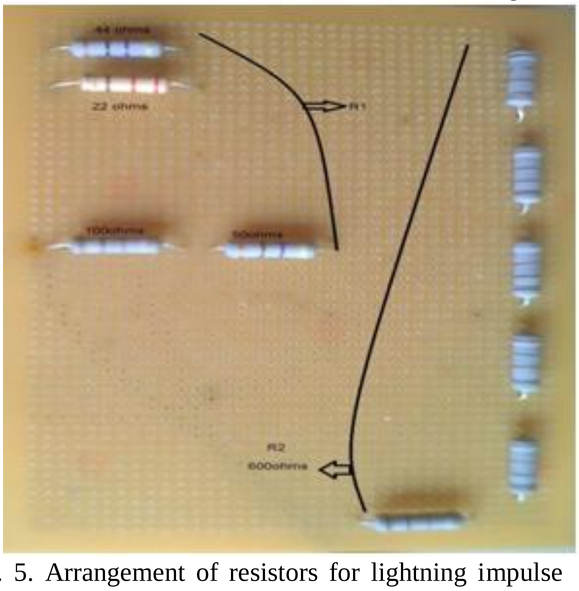

Fig. 5. Arrangement of resistors for lightning impulse circuit

The arrangement of wave shaping resistors for the generation of lightning impulse and switching impulse are shown in the fig 5 & fig 6 respectively. To study the effect of variation of the change in the values of wave shaping resistors, provision was made on PCB for different values of R_1 with lower value (22 Ω), exact value (44Ω) and increased value (150Ω).

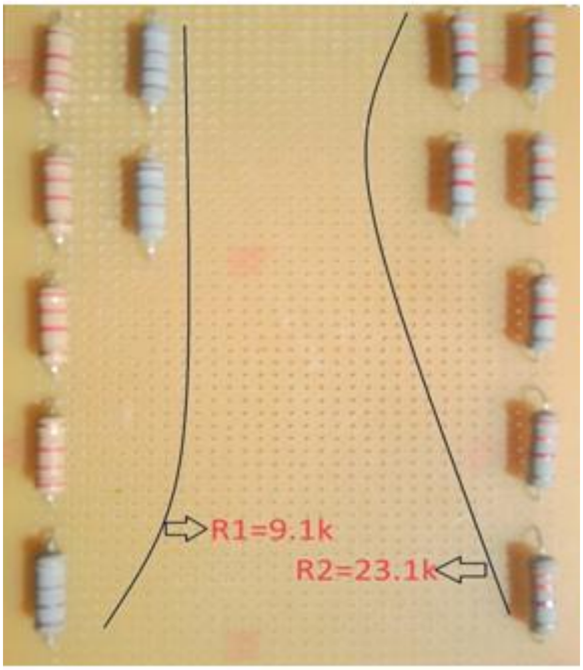

Fig. 6. Arrangement of resistors for switching impulse circuit

Fig 7 shows the complete set up of both lightning & switching circuits, which are placed on the middle layer of the wooden sheet and terminals of wave shaping resistors are brought on to the top layer of sheet and all the ground connections are given to the bottom layer of the sheet. For the measurement of impulse waveform, one end of the Probe is connected across C_2 and the other to the Digital storage oscilloscope.

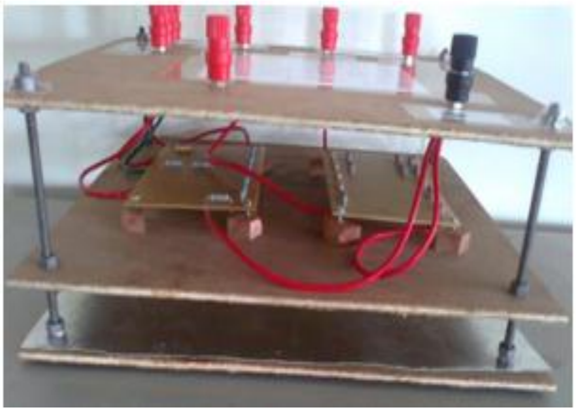

Fig. 7. Set up of impulse wave circuit

Capacitor C_1 is charged from DC supply, when it fully gets charged, the air breakdown occurs in the spark gap connected between C_1 and R_1. Thus, discharge takes place from C_1 to C_2. The voltage waveform across the capacitor C_2 is captured on the Digital storage oscilloscope screen.

The lightning impulse & switching impulse waveforms obtained experimentally are shown in Fig 8 & Fig 9 respectively. The time to front and time to tail for lightning & switching impulse were 1.6µs/ 51.2µs and 275µs/ 2700µs respectively

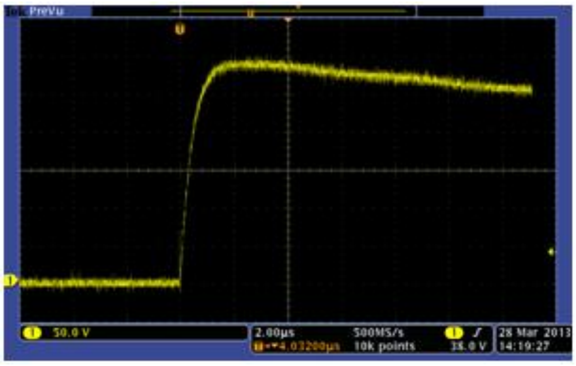

Fig. 8. Experimental waveform of Lightning impulse

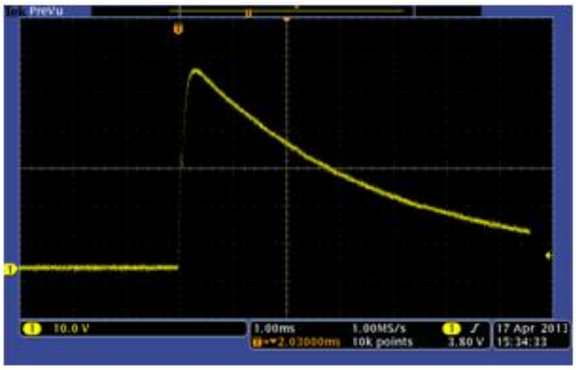

Fig. 9. Experimental waveform of switching impulse

4. DISCUSSIONS

The experimental and simulation results of lightning impulse waveform were in close agreement and are well within the tolerance limits. Keeping the value of tail resistor constant, experiments were conducted on different values of front resistor. Table 1 shows the effect of variation of front resistor on the time to front, lower the resistor value, lower will be the time to front and higher the value of R_1, higher will be the time to front.

Table 1 Effect of variation of R_1 on time to front T_1

Front Resistor R_1' Ω	**Simulation** T_1/T_2, µs	**Experimental** T_1/T_2, µs
22	0.86/48.2	0.8/48.18
44	1.7/50.3	1.6 / 51.2
150	4.92/60	4 /59.78

The experimental and simulation results of switching impulse waveform are 275µs/ 2700µs and 265.8µs/2646µs; they are in close agreement and within the specified tolerance limits. Also to study the effect of inductance of the waveform, simulation was carried out in PSPICE and observed that for the increasing values of inductance, time to front increases.
The efficiency of the impulse generator for both lightning and switching impulse circuits is estimated and shown in table 2

Table 2 efficiency of Impulse generator

Case	Analytical	Simulation	Experimental
Lightning	84.7	82.6	81.3
Switching	65.3%	62.9%	61.9%

5. CONCLUSION

In this paper, the design & development of a compact single stage Impulse generator of small rating which is economical viable and useful in small-scale industries and academic institutions for demonstrating the impulse waveforms and testing of low rating power system components has been discussed. This impulse generator can generate peak impulse voltage of 10kV. Due to unavailability of high rating DC voltage source at our laboratory, the model was tested for a source voltage of 300V and the experimental results were compared with simulation results which were in close agreement.

The time to front gets affected accordingly with the change in the front resistor value, also peak voltage changes. Similarly the time to tail and peak voltage gets affected accordingly with the change in the tail resistor value. The simulation circuit used in this work can be used to predetermine the time to front, time to tail and peak voltage of Impulse waves at any desired test voltage and the results can be compared with the developed model. This would save expense and time by not actually performing test.

5. ACKNOWLEDGMENTS

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

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