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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

Abstract—**Lightning characteristics and standard impulse waveform are related to each other. But the lack of realization about the relation between them would make the solution to produce better protection against lightning surge becomes harder. Natural lightning surge waveform has been compared to standard impulse waveform as evidence that there have similarity between them. The standard impulse waveform could be used to test the strength of electrical equipment against the lightning. Therefore designing and simulating the impulse generator are the purpose of this project beside to get better understanding about lightning characteristics. This project aims to develop an impulse generator circuit using OrCAD PSpice software to produce a lightning waveform according to IEC61000-4-5 standard. For this reason, Marx generator has been used as the main principle of the design with some parameters and components modifications. The output waveform from simulation was compared to IEC61000-4-5 surge standard, and the values in the developed circuit were adjusted so that the characteristics of the waveform are in acceptable limits. As the result, the correct lightning waveform in the form of voltage versus time has been generated from an impulse generator circuit OrCAD PSpice software. In the conclusion standard impulse waveform has been fulfilled and the value of each component used truly influence the resulted waveform. The lightning waveform can be used in further research such as determination of V-I characteristics of surge arresters and other lightning protection purposes.**

***Keywords*:** lightning characteristics, impulse generator, PSpice, Marx generator.

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. The over-voltage or over-current resulting from a lightning incident will propagate not only into the power lines but also into the low voltage lines, such as the communication and telecommunication system.

In order to get the lightning generator output waveform, it is necessary to learn and understand the characteristics of the lightning. The best understood source of lightning is cumulonimbus, ordinary thunderstorm clouds. The majority of cloud related lightning discharges are intra-cloud, and are not visible from earth. Visible types of discharges include cloud-to-cloud, cloud-to-air, ground-to-cloud, and cloud-to-ground.

A. Lightning characteristics

Accurate information about lightning characteristics is very important in estimating the risk of lightning strike. A research on the wave shapes of lightning currents has been done by Berger in year 1967. The common characteristic features and complete current flow in a multiple negative polarity lightning flash is illustrated in Figure 1. The steeped leader has a current rise time of 10 to 15μs while the subsequent strokes currents in multiple lightning flashes have much shorter rise time than the first current, which is 1 to 2μs to reach the crests. The crest currents of those dart leaders are slightly lower than the first current. However, three of them have a quite similar tail time.

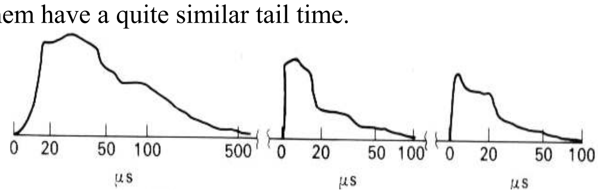

Figure 1: Current in multiple negative lightning flashes

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The occurrence of lightning depends on the atmosphere condition and electrical potential difference between clouds to ground. The multiple fast rise lightning impulse seems to have more similarity to the natural characteristics of the lightning phenomenon because the wave shape of natural lightning is sometimes unpredictable [1].

B. Types of impulse rating for the surge

There are two types of impulse rating for the lightning surges which are used to simulate what may happen in real life surges [2]. They are impulse voltage surge and impulse current surge. The impulse is applied to a test object to verify its capability of withstanding surges of high voltage and high current.

In determining waveform for lightning impulse, there are many waveforms could be formed, such as 8/20 µs and 10/100 µs. The most common used is 8/20 µs for impulse current surge and 1.2/50 µs for impulse voltage surge. Actually, lightning-induced surge currents are characterized as having very rapid rising "front edges" and long decaying "tails". To a first approximation, the first number of the surge waveforms indicates the time taken for the surge to reach 90% of its peak value, while the second number indicates the time taken for this surge to decay from its peak to its half way value. It could simply mean or write as (t_p/t_f) µs.

C. OrCAD PSpice

Orcad family products offer a total solution for core design tasks such as schematic and VHDL based design entry; FPGA and CPLD design synthesis, digital, analog, and mixed-signal simulation and printed circuit board layout. Orcad family also is a suite of applications built around an engineer's design flow which not just a collection of independently developed point tools. Orcad Capture is just one element in the total solution design flow [3].

D. IEC 61000-4-5 - Surge Standard

The IEC 61000-4-5 standard defines a transient entry point and a set of installation conditions. The transient is defined in terms of a generator producing a given waveform and having specified open circuit voltage and source impedance. Two surge waveforms are specified: the 1.2 x 50µs open-circuit voltage waveform and the 8 x 20µs short-circuit current waveform (Figures 2 and 3 respectively) [4].

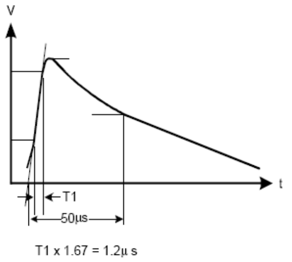

Figure 2: IEC 61000-4-5 Voltage impulse

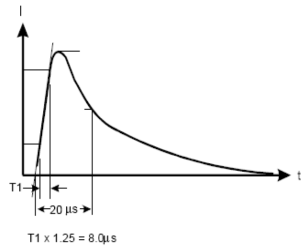

Figure 3: IEC 61000-4-5 Current Impulse

II. METHODOLOGY

A. Multistage Impulse Generator (Marx circuit)

The arrangement for charging the capacitors in parallel and then connecting the capacitors in series for discharging was originally proposed by Marx.

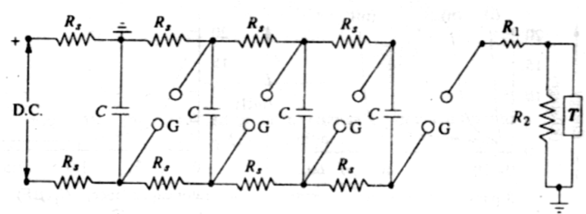

Figure 4: Schematic diagram of Marx generator circuit arrangement for multistage impulse generator

Usually charging resistance R_s is chosen to limit the charging current to about 50 to 100 mA while the generator capacitance C is chosen such that the product CR_s is about to 10s to 1 minute. The discharge time constant CR_1/n (for n stages) will be too small (microseconds), compared to the charging time constant CR_s which will be few seconds.

Impulse generators are nominally rated by the total voltage (nominal), the number of stages and the gross energy stored. The nominal output voltage is the number of stages multiplied by the charging voltage [5]. The nominal energy stored is given by:

$$E = \frac{1}{2} C_1 V^2 \quad (1)$$

where;

V = nominal maximum voltage (n times charging voltage)

C_1= discharge capacitance

The discharge capacitance, C_1 given by:

$$C_1 = \frac{C}{n} \tag{2}$$

where;

C = capacitance of the generator

n = number of stage

III. RESULTS AND ANALYSIS

The impulse generator is designed based on Marx generator. The basic circuit of Marx generator is shown in Figure 5. According to [6], there is a standard ratio of C_1/C_2 for that particular Marx generator circuit, as depicted in Table 1. Calculation for one stage Marx generator:

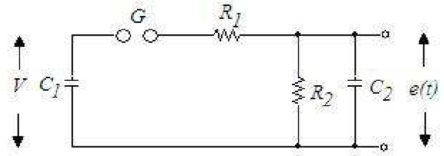

Figure 5: Circuit for producing impulse voltage wave

Note that, C_1 = Stage capacitor

C_2 = Load capacitor

R_1 = Front resistor

R_2 = Tail resistor

Table 1: Limiting Values of C_1/C_2 For Different Standard Waves

Circuit	Value measured	T_1/T_2 (μs)			
		1.2/5	1.2/50	1.2/200	250/2500
Figure 10	Max(C_1/C_2)	-	40	185.19	6.37

From standard waveform of Marx generator,

$$T_1 / T_2 = 1.2/50\mu s$$

$$T_f = \frac{T_1}{2.96}; \ \therefore T_f = 0.4054\mu s$$

$$T_r = \frac{T_2}{0.73}; \quad \therefore T_r = 68.49\mu s$$

where T_r and T_f are time constant.

Therefore, Max(C_1/C_2) = 40 Let $C_1 = 0.5\mu F$

$$C_2 = \frac{C_1}{40}; \quad \therefore C_2 = 0.0125\mu F$$

$$T_r \approx R_2(C_1 + C_2)$$

$$R_2 = \frac{T_r}{C_1 + C_2}; \therefore R_2 \approx 134\Omega$$

$$T_f \approx \frac{R_1(C_1 + C_2)}{C_1 + C_2}$$

$$R_1 = \frac{T_f(C_1 + C_2)}{C_1 C_2}; \ \therefore R_1 \approx 33\Omega$$

In designing the circuit using PSpice software, the sphere gap for triggering the lightning was simulated by the use of a switch, as shown in Figure 6. The output of the generator was also switched, and all switches were closed at the same time.

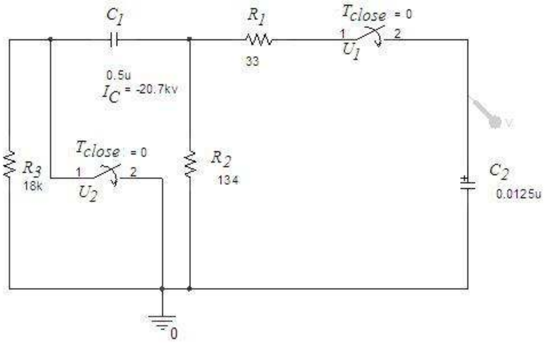

Figure 6: One stage Marx generator

The stage capacitor, C_1 was given an initial charge value, i.e. -20.7 kV. The output waveform of the simulated circuit is shown in Figure 7, with peak voltage of 19.69 kV, rise time of approximately 2µs, and fall time of 50.3 µs.

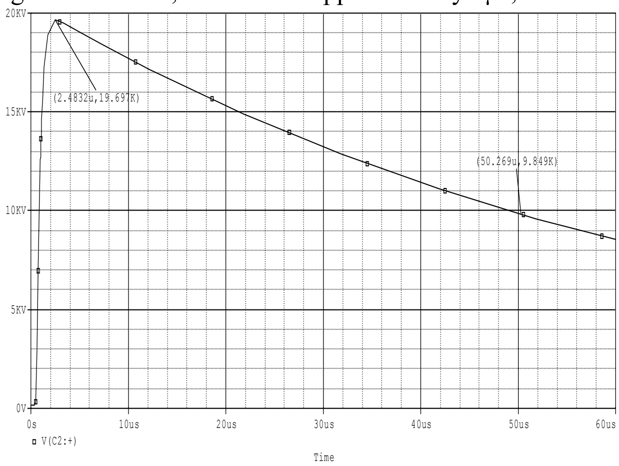

Figure 7: Resulted waveform from calculation for one stage Marx generator

Based on this result, a four-stage Marx generator was designed by cascading for single-stage Marx generators using Orcad PSpice software. The schematic of the simulated generator is shown in Figure 8. The sphere gaps for triggering the lightning were simulated by the use of switches, as shown. The output of the generator was also switched, and all switches were closed at the same time. Each of the four stage capacitors was given an initial charge voltage value, which is equal to ¼ of the total kV test voltage.

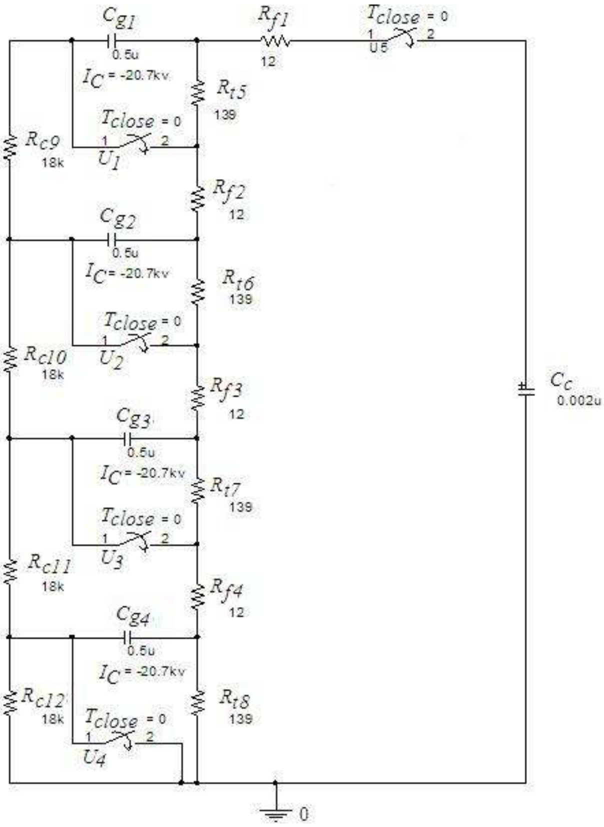

Figure 8: Four-stage Marx generator circuit

Figure 9 is a sample of 1 80 kV simulation output using the circuit from Figure 8. The time to peak is 1.2245 μs with a peak voltage of 80.739 kV. The tail of wave time (T_2), 50 percent of the peak voltage, was approximately 50 μs.

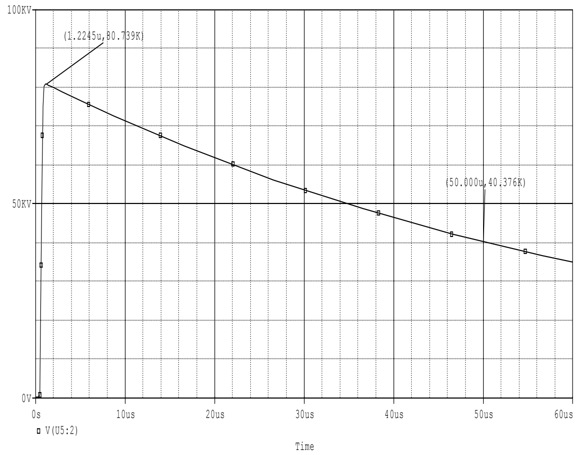

Figure 9: Output waveform at load capacitor

The maximum peak voltage that capacitor could charging depends on the number of stages of the Marx generator other than its initial charge (IC). The relation between maximum peak voltage and the number of stages could be expressed in equation as:

$$V_{max} = \text{Initial charge x No of stages} \quad (3)$$

From the waveform, the maximum peak voltage for 3-stage Marx generator could be calculated as below:

$$V_{max} = \text{Initial charge x No of stages}$$
$$= (-20.7kV)(3)$$
$$= 62.1\ kV$$

Thus the maximum peak voltage for 2-stage Marx generator could be calculated as:

$$V_{max} = \text{Initial charge x No of stages}$$
$$= (-20.7kV)(2)$$
$$= 41.4\ kV$$

Front resistor and tail resistor are not dependent on the value of initial charge (IC). Although the value of initial charge has been changed, wave front and wave tail of the resulted waveform still fulfill the standard waveform of impulse generator.

Note that, even the wave front and wave tail not dependent on initial charge, but the output peak voltage still depends on the initial charge value.

The waveform of impulse generator could be in positive or negative shape (refer to peak voltage). It depends on the initial charge of capacitors either positive or negative. For negative charge, the waveform should be in negative peak voltage and vise versa for positive charge.

IV. DISCUSSION AND CONCLUSIONS

A. Discussion

1) Stray capacitance could be added across every resistor except charging resistor to get the small difference of measurement between simulation and the real impulse generator (practical).

2) Tail resistor should be adjusted in order to get similar waveform as standard waveform of impulse generator. From try and error, if the value of the tail resistor is high, then the tail of the output waveform will also increased. In other words, the tail of the output waveform is directly proportional to the value of the tail resistor.

3) Changing the value for front resistor will affect the peak voltage. If the value of the front resistor is increased, the front voltage will decrease. In other words, the tail of the peak voltage is inversely proportional to the value of the front resistor.

4) 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.

B. Further recommendations

1) For impulse testing, the stray capacitance to ground of the resistive voltage divider is a consideration. The high voltage is applied to the top of the divider and the stray capacitance is distributed along the length of the resistor stack. The current flow through the resistor will vary as it moves down the resistor stack. One important quality factor for impulse voltage measurement is the divider time constant, τ, in response to a step input.

$$\tau = \frac{(R \times C_t)}{6} \quad (4)$$

where C_t represents the total capacitance to ground of the divider. A typical value for total capacitance, C_t, is 15 to 20 pF/m. For a 1.2 μs rise-to-peak voltage impulse wave the time constant, τ, should be about 200 ns or less for accurate measurement.

The divider resistance, R should be small enough to allow accurate response to the fast impulse wave. Solving the equation (1) for R gives:

$$R = 6 \times (\tau / C_t) \quad (5)$$

By substituting for C_t = 20 pF/L and τ = 200 ns a value of R can be derived as follows:

$$R \leq 60000/L \quad (6)$$

where L is the length of the voltage divider [7].

2) Add voltage divider across the load capacitor. Voltage divider is added to the impulse generator circuit to reduce the level of the voltage to a measurable value. It consists of two impedances in series.

3) Load of Marx generator used to test the effect of lightning. In this project capacitor with value 0.002 µs has been used to acts as load. In other or further project the load could be change to any other load such as resistor and inductor load (R-L load).

4) The other software that suit for high voltage circuit simulation is PSCAD (Power Systems Computer-Aided Design). PSCAD is a fast, accurate, and easy-to-use power system simulator for the design and verification of all types of power systems. Modeling and simulation of power electronic design for high voltage applications including HVDC could be done easily using PSCAD.

C. Conclusion

Circuit of multistage generator which is also called as Marx generator could be designed by using many types of software. Although the circuit design is not the same, but the output waveform of the surge should be fulfill the standard impulse waveform.

As a conclusion, Marx generator is one of the best methods to design an impulse generator. The unique idea from Marx generator is charging capacitor in parallel then discharging it in series would get the desired output waveform which fulfill the standard waveform of 1.2/50 µs according to IEC61000-4-5 surge standard. From the resulted output waveform, the characteristics of the circuit could be identified and also could be a reference for further study.

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