Design, Layout & Simulation of Impulse Generator in High-Voltage Laboratory

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Abstract: *The main purpose of this paper is to prepare the High Voltage Laboratory of the Faculty of Electrical Power Engineering of the Yangon Technology University of Myanmar in order to carry out high voltage testing of electrical insulators, specifically lightning over-voltages tests, attending to international standards and solving some practical problems which were found. These over-voltages can run up to hundreds of thousands of volts, which cause dielectric stresses on insulators and could endanger normal and safe operation in electrical equipment. Electrical insulators are widely used in power station and substation equipment; for example, insulators are used for disconnectors, transformer bushings or condenser bushings; in high voltage transmission lines and distribution lines; or, in traction current lines for railways among other things. This paper is divided into three parts: the first part sets the theoretical fundamentals. It is important to know how lightning occurs and the range of over-voltages which is object of study. The second part presents the experimental work made to introduce the high-voltage laboratory equipment available, simulation of the process and principles established by the International Standards. Finally, the third part will show the results and discussion obtained. The steps for further work are given so that new projects can reach deeper points of knowledge and discover new aspects of high voltage engineering. It should not be forgotten that, in this field, experimentation is highly important.*

Key Words: *computer simulation, electrical insulator, electromagnetic coupling, High Voltage Laboratory, High Voltage lightning impulse testing.*

1. INTRODUCTION:

Electrical systems are strongly limited by an important characteristic of electrical energy; its storage is not possible on a large scale and it must be produced and transported to the places where it is required just at the moment. Production and consumption points are usually far away from each other; therefore it is necessary to resort to high voltage values in order to reduce losses in electrical lines and maximizes the efficiency of the electrical transport system. Thus, there is a wide range of values used in high voltage systems which are divided into five groups: medium voltage; high voltage; very high voltage; extremely high voltage; ultra-high voltage. The high voltage values need an appropriate insulation level and the higher the voltage, the higher the cost. The process called Insulation Coordination determines the proper insulation levels of the components in a power system as well as their arrangements so that costs can be substantially reduced. Insulation structure must withstand voltage and over-voltage stresses to which the system or equipment will be subjected. This area of knowledge requires simulation studies based on mathematical models and laboratory testing to precisely determine and allow for high electric field effects. Theoretical studies are carried out based on macroscopic or microscopic models. Macroscopic modelling is used when voltage, current and electric fields values in equipment must be tested and Microscopic modelling is used in order to study how insulators behave under voltage and over-voltage stresses, and, especially, how ageing and dielectric breakdown mechanisms appear. Experimental studies involve high voltage laboratory testing to measure certain parameters, but outdoor tests are also carried out when it is necessary to check electric equipment in its final place of use. In short, it is essential to accompany theoretical studies with experimental testing in order to ensure efficient and safe installations.

2. THEORECTICAL FUNDAMENTALS:

Lightning is occurred due to the extreme difference of charge between two regions. When the difference of charge reaches a certain point, air between both regions becomes ionized, that is, the air surround breaks down and lightning occurs. When that phenomenon happens, an extreme amount of energy is used up and is converted into light, heat and sound, which is seen as lightning and heard as thunder. There are different kinds of lightning discharge. They are: cloud to air; cloud to cloud; within cloud; cloud to ground, with negative and positive charge on earth's surface. Figure 1.Probable distribution in a thundercloud is as shown in Figure 1.

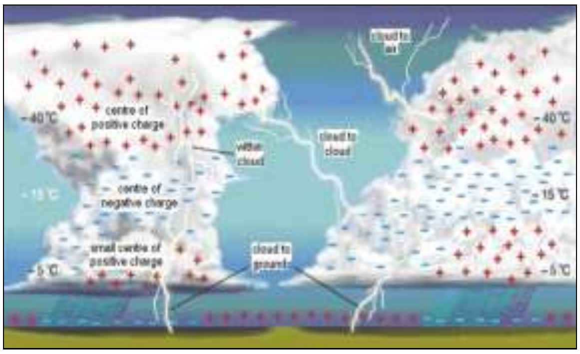

Figure 1.Probable distribution in a thundercloud

3. EQUIPMENTS OF HIGH-VOLTAGE LABORATORY:

The purpose of the High Voltage Laboratory of the Faculty of Electrical Power Engineering is to test electrical components and equipments which may be stressed by lightning impulse voltages that can reach hundreds of kilovolts or even more.

A. Marx Impulse Generator

This system permits to test elements of power lines under a range of over-voltages which might occur during a product's service life due to lightning or transient voltage phenomena resulting from equipment association with power distribution systems. Basically, it consists of a stack of capacitors that are charged in parallel through charging resistors and discharged in series through discharging resistors (front and tail resistors). It is possible by means of sphere-gaps: at certain instant, when the disruptive discharge voltage is achieved in the air between the sparking points of the spheres, a flashover arc occurs and capacitors become connected in series through the short circuit. This is probably the most common way of generating a high voltage impulse for laboratory testing because capacitors are charged in parallel and, when they connect in series, the addition of the voltages permits to reach very high voltage values, that is, the power supply used to charge all the capacitors is multiplied by means of the use of sphere-gaps.

In Figure 2, the simplified circuit is depicted in order to explain the basic operation of an impulse generator. The design of the Impulse Test System of the High Voltage Laboratory is based in this circuit.

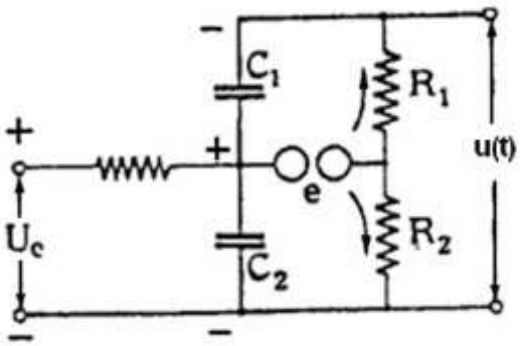

Figure 2. Simplified impulse generator [1].

Capacitors C_1 and C_2 are charged in parallel by the DC power supply U_c. These capacitors are called discharge capacitances and they store the energy of the impulse generator. The group C_1, R_1 and R_2 is connected in parallel regarding to the capacitor C_2 as far as the sphere-gap is not triggered. The voltages of C_1, C_2 and the sphere-gap are zero at the beginning. When the charging process starts, the voltage at these elements start increasing, and, at a certain moment, the air between both spheres breaks down and two new circuits appear. Thus, capacitors C_1 and C_2 are discharged through R_1 and R_2, respectively.

B. High Voltage Discharging Relay

The High voltage discharge relay is an electrically operated switch that opens when the charging supply is operating and closes when power is interrupted or if the generator is turned off. The switch is connected in series with a discharge resistor that absorbs the stored energy in the generator. The design of the high voltage discharge circuit is to rapidly discharge the high voltage capacitors to zero voltage under emergency conditions.

C. Impulse Generator Control System

Hipotronics Impulse Generator Control System Model C-100M, is an integrated system designated to charge and control the firing of the standard IG100-2.5 generator. The control console is shown in figure 3 below. The following items are found on the control console panel.

Figure 3. Front panel of the control console

D. Capacitive Mixed Divider

The capacitive voltage divider shown in Figure 4 measures the voltage of lightning impulse tests. The main system specifications of the capacitive voltage divider are shown in Table 1.

Figure 4. Resistive voltage divider of the generator

TABLE 1

MAIN SPECIFICATIONS OF THE CAPACITIVE VOLTAGE DIVIDER

Working Voltage	175 kV RMS, 500 kV L.I., 450 kV (± S.I.)
High Voltage (HV) Arm, Capacitive	1500 pF ± 5 percent
High Voltage (HV) Arm, Series Resistive	50Ω
Low Voltage (LV) Arm	375 nF Nominal

E. Oscilloscope Used With Voltage Divider

An oscilloscope is connected to the low-voltage arm of the voltage divider by a coaxial cable. This is a RG11/U cable for measuring purposes of 15 meters approximately. The signal is attenuated by means of a high-voltage passive probe of 100X. The digital storage oscilloscope (DSO) is a Tektronix TDS 340 A (see figure 5).

Figure 5. Tektronix TDS 340 A

4. LAYOUT OF THE HIGH-VOLTAGE LABORATORY:

The High Voltage Laboratory (HVL) of the Faculty of Electrical Power Engineering is located in the room 2/1-41 of the Department of Electrical Power Engineering at Yangon Technological University. In operation, generator's parts are installed in a safe test area inside a Faraday cage or shield and controls are located nearby, although, the possibility of creating a control room nearby, in room 2/1-42, is proposed. The layout of the High Voltage Laboratory and location of the equipment are shown in Figure 6.

Figure 6. Layout of the Laboratory and earth connections

All elements in the Faraday cage must be connected to earth using star connection. The connection point must be as close as possible to the generator's structure. This point is (C) in figure 16. The metallic structure of the generator, where voltage transformer, trigger system and generator stack are mounted, is connected to earth by means of copper tape from point (C) to point (A) on the metal sheet. Voltage divider and insulator's base are connected to earth at the point (C) on the metallic structure of the generator. The control console and the oscilloscope, located out of the Faraday shield, are connected to earth at the point (B). All earth connection are made by means of copper tape with section (120 x 1.5) mm^2.

5. SIMULATION RESULTS & DISCUSSIONS:

By means of computer simulation with PSpice, it is possible to determinate peak voltage, front time and time to half value of a test waveform, and global efficiency of the system. It allows finding the best solution to comply with international standards and to compare the results obtained. As depicted in the above section, the impulse test system is set with the parameters shown there. Capacitors of stage are fixed, its capacitance is about 500 nF; charging resistors are also fixed, its resistance is about 18 kΩ; and, the impulse generator has a fixed number of stages, 5 stages. Therefore, there are two parameters, R_f and R_t, that may be changed in order to adjust the test waveform to requirements. These requirements may be: to obtain certain values of front time T_1 and time to half value T_2; to reach the maximum output voltage, that is, maximum peak voltage of the waveform; or to have the highest efficiency η of the system. As the main objective of this research paper is to establish the principles in order to adjust the equipment of the High Voltage Laboratory in general, it is not chosen any of the requirements said above, but it is purposed as a further work to adjust front time and time to half value of the waveform to comply with the international standard. Resistors available for the study of the impulse generator for this simulation are shown in table 2.

Table 2
Resistors Available for The Study of Impulse Generator By Means of Simulation

R_f	35 Ω	75 Ω
R_t	200 Ω	450 Ω

Output results are noted by front time T_1, time to half value T_2, peak voltage U_p and efficiency η. The peak value U_p is the maximum value of the test voltage for a lightning impulse. The front time T_1 of a lightning impulse is 1.67 times the time interval between the instants when the impulse is 30% and 90% of the peak value, that is:

$$T1 = 1.67(T_{90} - T_{30}) \qquad \text{Equation 1}$$

The time to half-value or tail time T_2 of a lightning impulse is the time interval between the origin of the wave-shape and the instant on the tail when the voltage has decreased to half of the peak value (50% of the peak value). And the efficiency of the process is, as commonly defined:

$$\text{Electrical Efficiency}=\frac{Useful\ Power\ Output}{Total\ Power\ Input} \quad \text{Equation 2}$$

Or, expressed in terms of the generator parameters:

$$\eta = \frac{Umax(out)}{n.Uc} \quad \text{Equation 3}$$

Where:

η – Efficiency; U_{max_out} – Maximum output voltage; n – Number of stages of the generator (n = 5); U_c – Charging voltage per stage.

The circuit used in the simulation is shown in Figure 7 and simulation result of impulse generator is as shown in Figure 8 with the highest values for front and tail resistors are 75Ω and 450Ω.

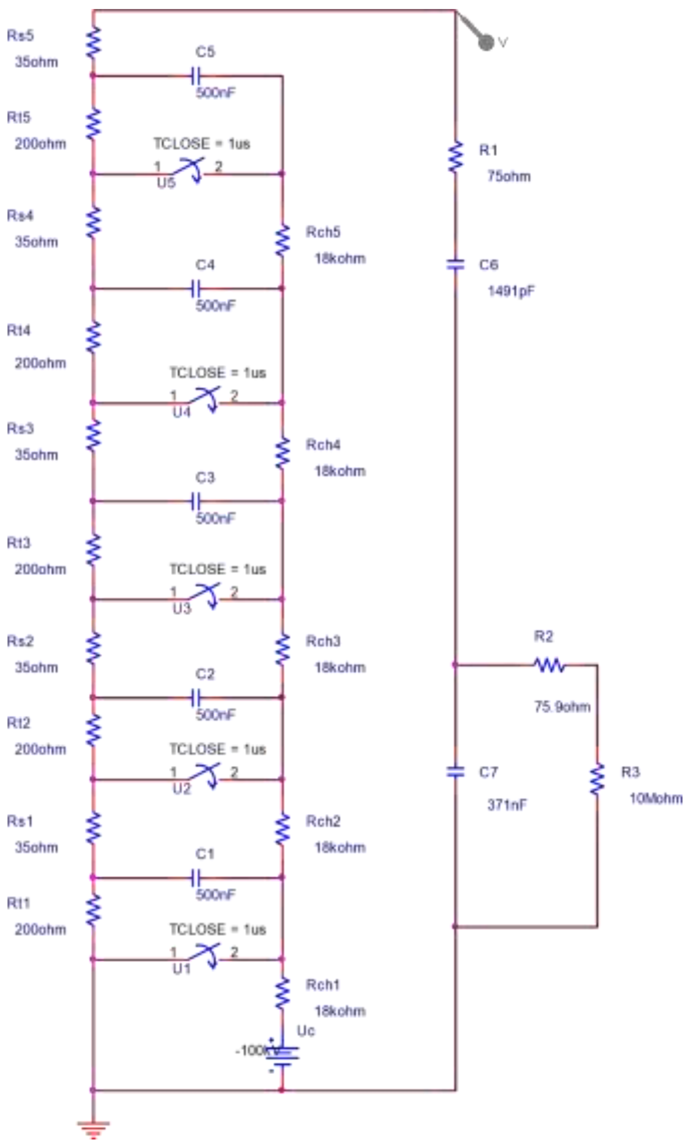

Figure 7. Impulse Generator Circuit Used in Simulation with PSpice

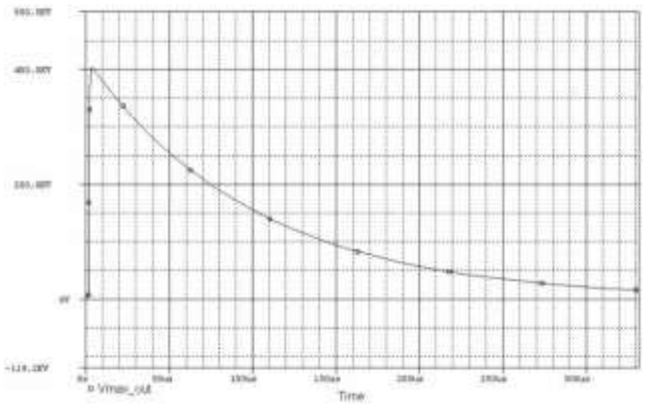

Figure 8. Simulation Result of Impulse Generator

The criterion chosen in order to study how parameters change according to front and tail resistors is to simulate with the highest, the lowest and medium values for front and tail resistors are shown in Table 3, 4 and 5.

Table 3
Highest Values for Front and Tail Resistors

R_{fmax}	75 Ω
R_{tmax}	450 Ω

Table 4
Lowest Values for Front and Tail Resistors

R_{fmin}	23.86 Ω
R_{tmin}	139 Ω

TABLE 5
Medium Values for Front and Tail Resistors

R_{fmed}	49.47 Ω
R_{tmed}	294.5 Ω

Obtained values in the simulation process are shown in Table 6 below. Maximum and minimum values for maximum peak voltage U_p, front T_1 and tail T_2 times, and efficiency η are highlighted.

Table 6. Obtained results: values for front time

Rf [Ω]	Rt [Ω]	Umax_out [kV]	Efficiency [%]	Front time (T1) [µs]	Tail time (T2) [µs]
75,00	450,00	404,243	80,85	2,00	160,400
75,00	294,50	401,885	80,38	1,95	107,354
75,00	139,00	394,712	78,94	1,79	53,928
23,86	139,00	403,613	80,72	0,75	51,800
23,86	294,50	407,665	81,53	0,75	106,200
23,86	450,00	408,599	81,72	0,75	158,200
49,47	294,50	405,262	81,05	1,50	106,125
49,47	450,00	406,545	81,31	1,42	159,200
49,47	139,00	400,223	80,04	1,34	52,650

As a note, it is possible to say that the impulse generator with R_f = 49.47Ω and R_t = 139Ω complies with the international standard. The standard waveform has a front time of 1.2 µs and a time to half value of 50 µs; therefore, the waveform obtained in the simulation with times 1.34 µs and 52.65 µs respectively is within tolerance limits defined by the Standard [6]. According to table 6, the maximum peak voltage and, therefore, the maximum efficiency, are obtained with the minimum value of front resistor and the maximum value of tail resistor, and vice versa. It is because, the lower the front resistance, the lower the voltage drop of the discharging circuit. And, the higher the tail resistor, the higher the discharging time and, therefore, the waveform reaches higher peak voltage. Figure 9 shows the change of the peak voltage when front resistance increases, and for a constant tail resistance of 450Ω. The higher front resistor, the lower peak voltage.

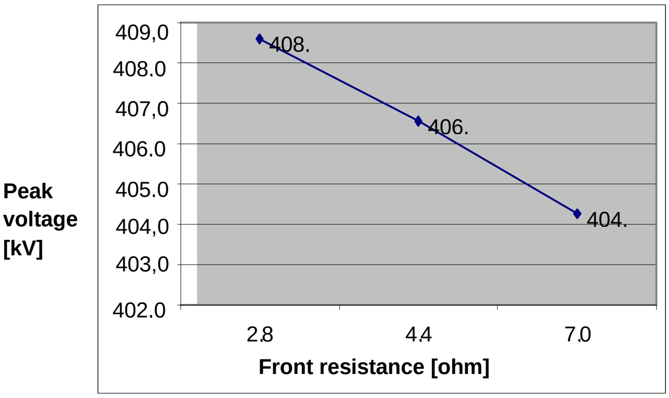

Figure 9. Variation of peak voltage in kV according to front resistance in ohms. It is considered a constant tail resistance of 450Ω

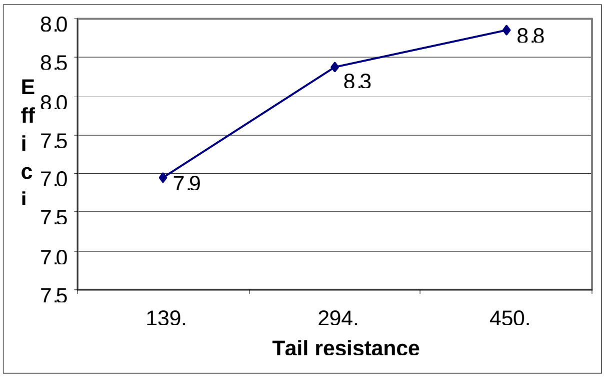

Figure 10. Variation of the efficiency in percentage according to tail resistance in ohms. It is considered a constant front resistance of 75Ω.

Mainly, front and tail time vary more according to front and tail resistors respectively. Thus, figure 11 shows the wave “front time T_1-front resistor R_f” for a constant value of tail resistance of 450Ω, and figure 12 shows the wave “tail time T_2-tail resistor R_t” for a constant value of front resistance of 75Ω. It is seen that the higher front resistor, the higher front time; and, the higher tail resistor, the higher tail time.

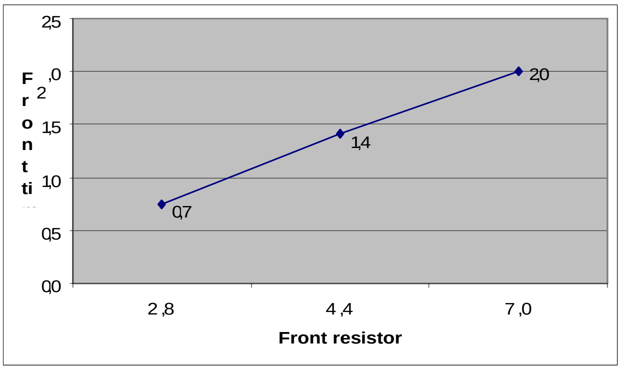

Figure 11. Variation of the front time in microseconds according to front resistance in ohms. It is considered a constant tail resistance of 450Ω

The impulse test system is designed to reach up to 500 kV, but the efficiency of the system, around 82% according to simulation, decreases this value to about 409kV. In the real test, front and tail time, peak voltage and efficiency can be measured from the test waveform obtained by means of the measuring device, that is in the High Voltage Laboratory, the oscilloscope Tektronix TDS 340 A.

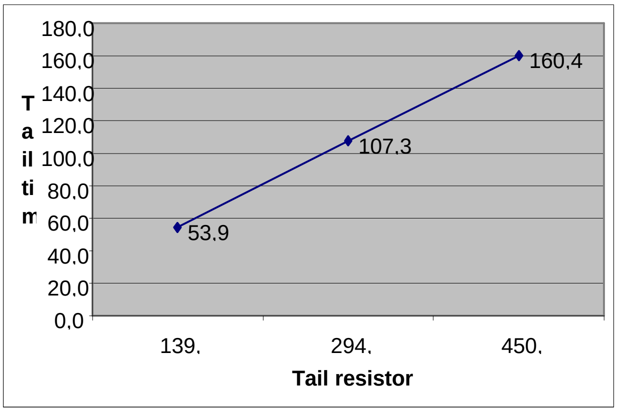

Figure 12. Variation of the tail time in microseconds according to tail resistance in ohms. It is considered a constant front resistance of 75Ω.

6. CONCLUSIONS:

A wide knowledge of the High Voltage Laboratory is presented in this paper, from theoretical fundamentals to application of the international standards. This work has studied most of the possible future projects which may be carried out and set important points such as the safety in a high-voltage installation or the solution to the problems with the measuring device. The practical part of this work has given a very useful experience in solving real problems in electrical equipment and it has been collected in this research paper, so that it can be helpful in the High Voltage Laboratory. In short, this paper presents a collection of the most important information necessary for further works at the Laboratory, what will allow reaching deeper points of knowledge in High Voltage Engineering.

7. ACKNOWLEDGEMENTS:

The author acknowledges especially to Dr.Okka for his guidance, criticisms, encouragement, comments, suggestions and correction on this paper. The author would like to also thank teacher, Dr. Soe Win, from Electrical Power Engineering Department, Yangon Technological University, for his suggestions.

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