Simulation and Experimental Investigation of Single Stage Impulse Voltage Generator

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***Abstract*: Power system equipments such as station power transformers, transmission line insulators etc are exposed to various transient overvoltages like lightning surges, switching surges etc. Lightning surges have steep wave fronts and relatively longer tails and perhaps being the most hazardous abnormal voltages and when hit the transformer windings and insulators may cause breakdown of the insulation and produce heavy damage. In this paper a lightning impulse voltage of and switching voltage of 250/2500 μs duration and peak voltage of up to 5KVhas been designed simulated and experimented. This paper describes the design, simulation and experimental investigation of a one stage impulse voltage generator capable of producing lightning impulse 1.2/50μs and switching impulse of 250/2500 μs up to 5kV. 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 front time and tail time can be regulated by varying the values of front resistor and tail resistor. Both the simulation and experimental waveforms were compared and the results were very close and verified.**

Key words: single stage impulse generator, Lightning surge voltage, switching surge, wave front time, wave tail time.

I. INTRODUCTION

Power systems equipments subjected to lightning and switching surge voltages cause sudden building up of voltage. When such fast transient voltages hit the transformer windings, line insulators etc may breakdown the insulation and produce heavy damage or otherwise lessen the life of high cost power equipments. Thus it is very much essential to test the withstanding strength of the above said power system equipments against such unidirectional transient over voltages.

Firstly design of one stage impulse voltage is carried out and then is verified using Pspice simulation. The designed circuit is then experimentally analysed and tested. The equation for 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.

The allowable tolerances for the impulse wave are given by ±30% for wavefront time and ±20% for wavetail time [3-4]. In our work effort is made to design and develop a compact, economical, portable 5kV one stage impulse generator for demonstration of lightning & switching impulses in academic institutions and can be used for testing of dielectric strength of different power system apparatuses. In fact this work can be extended to develop a multi stage impulse generator.

II. CIRCUIT FOR THE ONE STAGE IMPULSE GENERATOR

The circuit to generate double exponential voltage waveform of the type given in equation (1) by different combinations of RLC or RC circuits. The most commonly used circuit is shown in fig 1.

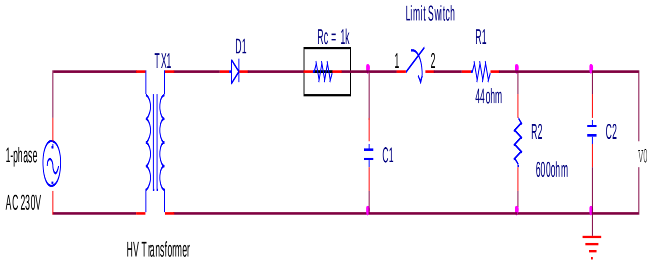

Fig. 1. Impulse generator circuit.

Based on the energy and voltage rating of the generator, the value of equivalent generator capacitance C_1 and load capacitance C_2 will be fixed. The desired impulse wave shape is obtained by controlling the wave shape resistors $R_1$and R_2.The approximate equations for computing the wave front and wave tail times, 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 to be between 6 and 106.5 and R_2 will be large and greater than R_1. The capacitors were chosen 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.

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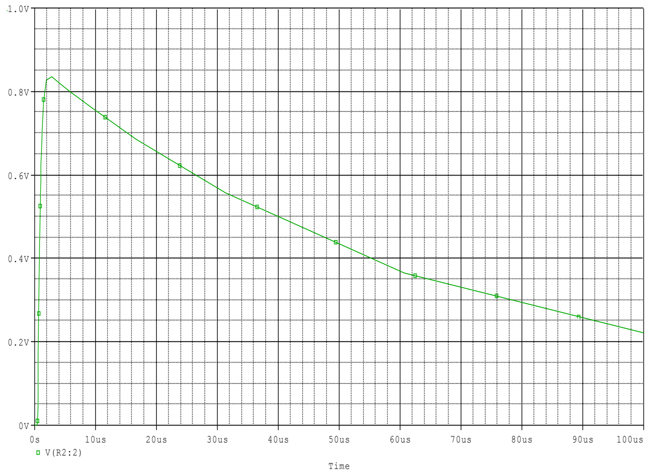
The simulation of Lightning and switching impulse waveform are carried out in PSPICE software [9]. This saves lot of time and the desired parameters can be estimated easily without performing the experiments. R_1& R_2 chosen for lightning & switching impulse circuits were 44Ω, 600Ω & 9.1 kΩ, 23.1 kΩ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



X- axis: time in µs Y- axis: voltage in volts

Fig. 2.Simulated Lightning impulse waveform

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

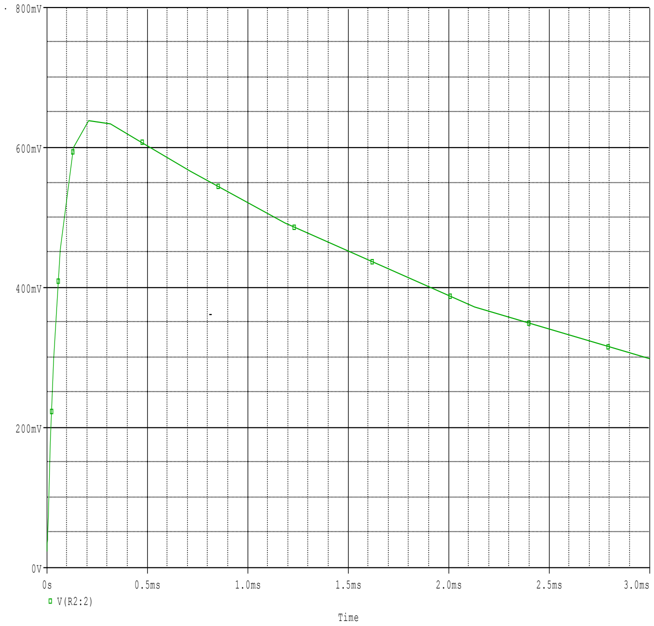
From fig 3, the time to front and time to tail of switching impulse wave are 265.8µs/2646µs respectively.

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].

III. EXPERIMENTAL MODEL

Fig.4 shows the experimental set up for generating a lightning impulse voltage with the obtained values of R_1=44 ohms and R_2 =600 ohms,C1=0.1µF and C2=0.01µF.

The arrangement of hv transformer, rectifier diode, auto transformer, capacitors, and wave shaping resistors for the



X- axis: time in µs Y- axis: voltage in volts

Fig. 3.Simulated Switching impulse waveform

Fig. 4. Arrangement of components for generating lightning impulse

The arrangement of HV transformer, rectifier diode, auto transformer, capacitors, and wave shaping resistors for the generation of lightning impulse are shown in the fig 5. To study the effect of variation of the change in the values of wave shaping resistors, provision was made for different values of R_1 with lower value (22 Ω), exact value (44Ω) and increased value (150Ω).

For the measurement of impulse waveform, one end of the Probe is connected across C_2 and the other to the ground.

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 as shown in Fig 5.

Fig.5.Digital oscilloscope for measurement of lightning impulse voltage

The lightning impulse waveform obtained experimentally is shown in Fig 4. The wavefront time and wavetail time for lightning were 1.4/ 50.4µs.

IV. RESULTS AND 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	1.4 / 50.4
150	4.92/60	4 /59.78

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%

V. CONCLUSIONS

This compact one stage Impulse voltage generator of 5KV rating can be useful in small-scale industries and academic institutions for demonstrating the impulse waveforms and dielectric insulation testing of small rating power system apparatuses. At our laboratory, the model was tested for a source voltage of up to 1KV and can also be done for up to 5KV. The simulation and the experimental results were compared and were found very close.

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

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