GENERATION OF STEEP FRONT SHORT DURATION IMPULSES FROM CONVENTIONAL STANDARD IMPULSE GENERATOR — A SIMULATION STUDY

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Abstract — **The paper presents the circuit analysis of the generation of high voltage (HV) steep front short duration pulse of several hundred kV from a conventional standard impulse generator using co-axial cable as pulse forming line (PFL). Two different circuits have been analyzed using the PSPICE circuit analysis program. The effects of impulse characteristic and the charging time of the cable on the wave shape of the resulting pulse has been studied. The pulse amplitude and the pulse shape (rise time and width) depend on the load impedance, the matching resistance, the ground connection of the sheath of co-axial cable and the type of HV switch (trigger gap). As it is time consuming and expensive to build such HV circuits in the laboratory, the simulation studies are important to gather design data on HV circuits in order to determine the type of pulse that can be generated for given cable and impulse source characteristics.**

I. INTRODUCTION

It is common practice to use full lightning (1.2/50 μs) and switching (~ 200/2500 μs) impulses as standard impulse voltages to test power equipment. However, it is becoming necessary to test the dielectric strength under short duration steep front (SDSF) impulses as these high frequency over voltages occur in the system frequently during switching operations [1-2]. In addition the steep front nanosecond (ns) pulses find many applications in laser technology [3]. Generation of these steep fronted ns pulses has become an important issue for both manufacturers and utilities. Different techniques that are available for the generation of the high voltage ns pulses are: magnetic core pulse transformers, air core dual resonant transformers and Marx generators [4-6]. Use of magnetic core pulse transformers and air core dual resonant transformers requires additional pulse transformers to pulse charge the pulse forming line (PFL) or pulse forming network (PFN) which is then discharged into the load circuit. The requirement of multiple sets of energy storage devices adds to the overall system size and weight and hence these methods are less preferred [6]. Marx generators offer advantages over the other two methods as large energy storage devices like transformers are minimized; however, the inductance of the overall circuit must be kept low in order to get steep front (fast risetime) pulses.

The circuits based on the Marx principle that are used to generate these ns pulses consist of a pulse forming transmission line, a high speed switching devise and a high voltage source [5]. The high voltage source used for charging purpose could be either a dc voltage source or a multistage impulse generator. Most high voltage laboratories are normally equipped with standard impulse generators and it is therefore economical to upgrade these existing installations by suitable modifications rather than to use different technology [7]. As it is highly time consuming and expensive to build such high voltage circuits in the laboratory, it is necessary to obtain sufficient information on the type of pulse that can be generated for a given cable and impulse source characteristics by simulation studies [8]. With the increasing availability and use of high speed digital computers it has now become possible to analyze these high voltage circuits using "circuit analysis" programs. The paper presents the results of such a study using PSPICE. The effects of impulse characteristic and the response time of the pulse forming line (coaxial cable) on the wave shape of the resulting SDSF pulses have been discussed for two different pulse generator designs.

II. PSPICE Simulation Studies

A. High Voltage Pulse Generators :

Schematic of pulse generators (circuit-A and circuit-B) which can be used for the generation of steep front pulses based on Marx circuits are shown in Figs. 1 and 2. The two circuits differ in the way in which their cable sheath is connected to the ground. In circuit-A (Fig. 1), the cable sheath is connected to ground directly; whereas, in circuit-B (Fig. 2), the cable sheath at both ends of the cable is connected by a small distance, ideally zero and is grounded through a high voltage switch (spark gap). The distance between both the ground points, those of the terminating resistor and the switch in circuit-B, should be minimized, which is a major restriction of this circuit as the load and the high voltage switch are close to each other [5].

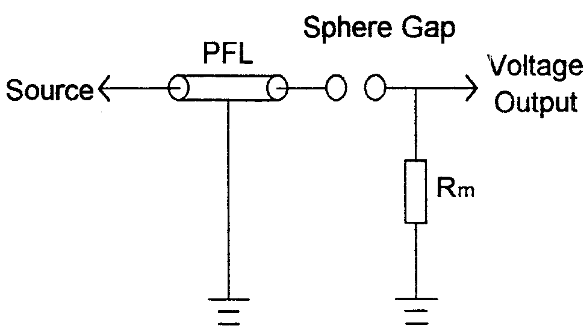


Fig. 1. Schematic of high voltage pulse generator of circuit-A.

Both circuits are capable of generating almost rectangular pulses with steep front; however, the decay of the voltage pulse for circuit-A depends on the impedance of the load. The voltage efficiency, i.e. the ratio of the output voltage to the charging voltage is about 50% for the circuit-A and about 100 % for the circuit-B. As regards to pulse width, the circuit-A produces longer pulses, almost twice the pulse width compared to those pulses that can be produced by the circuit-B. Depending on the requirement for the pulse amplitude and width, either of the circuits can therefore be used.

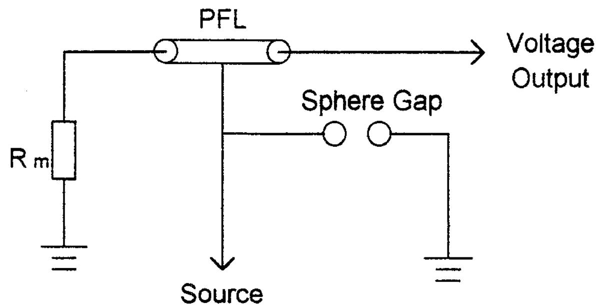


Fig. 2. Schematic of high voltage pulse generator of circuit-B.

B. Circuit Modeling:

The equivalent circuits used in the simulation studies using the PSPICE circuit analysis program for the pulse generators shown in Figs. 1 and 2 are respectively given in Figs. 3 and 4. The multi-stage impulse (Marx) generator has been modeled using a lumped parameter concept for stage resistances (R_1-R_4) and capacitances (C_1,C_2). A standard 1.2/50 µs impulse has been used as the charging voltage for the pulse forming line. The high voltage cable used as a pulse forming line has been modeled by its surge (characteristic) impedance (Z_0) and delay time,

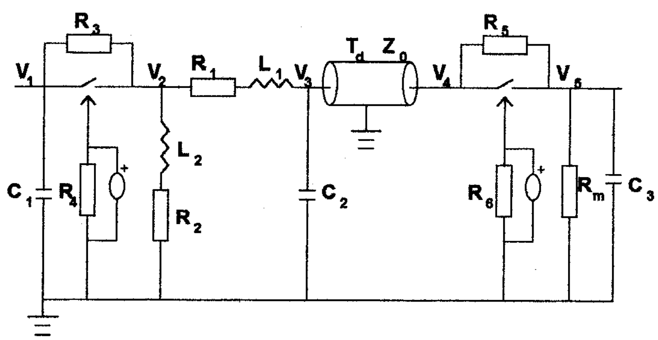


Fig. 3. Equivalent circuit representation of the pulse generator of circuit-A used in PSPICE simulation studies.

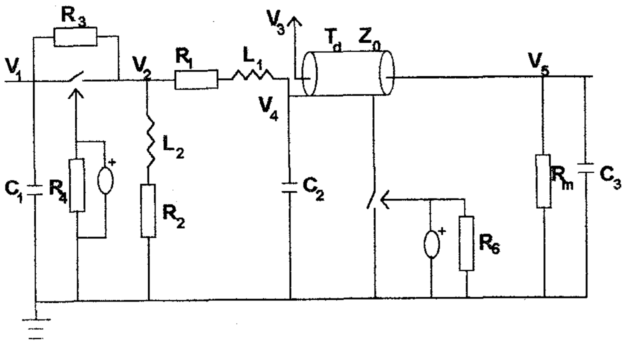
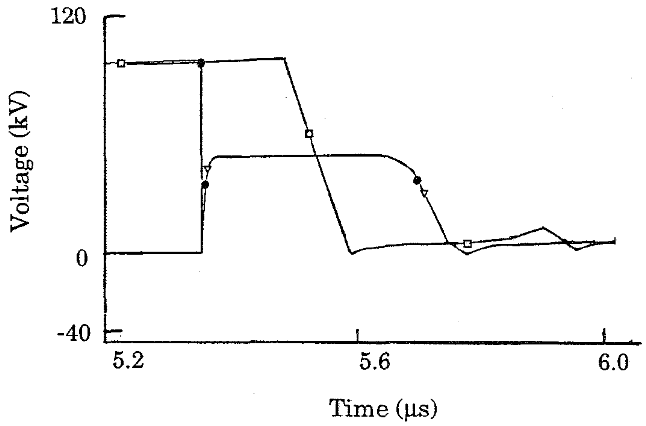
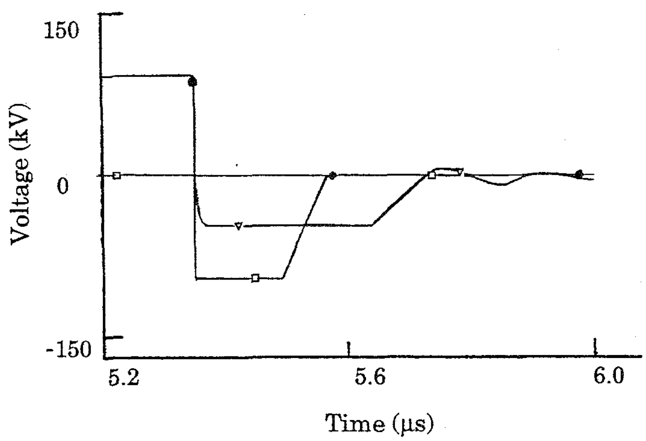


Fig. 4. Equivalent circuit representation of the pulse generator of circuit-B used in PSPICE simulation studies.



V_3 : Squares V_4 : Circles V_5 : Triangles

Fig. 5. PSPICE results for circuit-B; Voltage waveforms (a) during charging and discharging; (b) during discharging.



V_3 : Squares V_4 : Circles V_5 : Triangles

Fig. 6. PSPICE results for circuit-A; Voltage waveforms (a) during charging and discharging; (b) during discharging.

(T_d). The high speed switch composed of a spark gap has been modeled as a time controlled switch, where the voltage amplitude is preset. Once the charging voltage level reaches this preset value, the gap is fired which is equivalent to closing of the switch. A suitable terminating resistor (R_6) has been included in the pulse generator circuit in order to damp out the high frequency oscillations. The high voltage divider which is a part of the pulse generator has been modeled using a lumped capacitance, C_3 (Figs. 3 and 4).

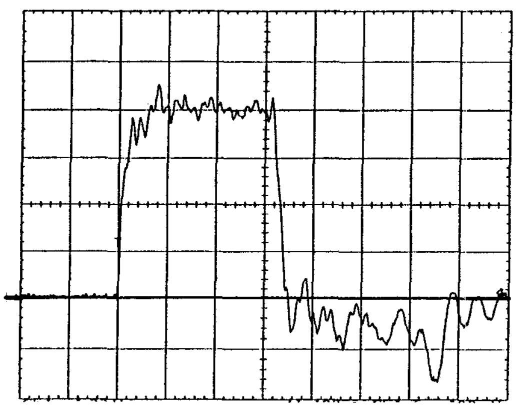
C. Simulation Results

The shape of the wavefront of the output pulse is determined by the arrangement of the switch, the load impedance, and the grounding points of the sheath of the cable as well as the position of the switch itself. Figs. 5 and 6 show the voltage waveforms at different locations in the circuits of Figs. 3 and 4. A sag in the pulse amplitude is unavoidable due to the attenuation of the traveling wave in the cable with first type of circuits (circuit-A, Fig. 3). The spark-gap was triggered after about 5.35 μs which is the time delay introduced by the PFL. The time controlled switch was set to activate by responding to this delay. The triggering of the spark-gap which is actually been modeled as a voltage controlled voltage source and thus controlled by setting time delay to close the switch for predetermined voltage level for trigger purpose.

The amplitude of the charging voltage (V_4) and the output voltage (V_3) are of same magnitude in Fig. 6 for circuit-B and it is about 50% for circuit-A (Fig. 5). The polarity of the output voltage is opposite to that of the charging voltage in method 2, whereas, the output voltage polarity is same as the charging voltage in method 1. A rise time of the order of 30 ns and duration of 350 ns was obtained with the first circuit and the corresponding one produced by circuit-B has a duration of 175 ns with similar risetime. In order for one to generate a pulse of 100 kV amplitude, a cable of approximately 100 m long cable is required.

III. Verification Of PSPICE Results

An actual laboratory simulation of the SDSF pulse generator was made using the facilities at high voltage laboratory for circuit shown in Fig. 3. A 20 m long RG- 233/U co-axial cable was used as a pulse forming line. A positive polarity dc voltage was used for charging the PFL instead of a standard impulse voltage. The cable was terminated with a resistor to match the characteristic impedance of the PFL. SF_6 filled spark (sphere) gap was used as a high voltage high speed switch between the dc source and the PFL. The output voltage was measured by a high impedance capacitive probe and the rise time of the measuring circuit is less than 5 ns. A pulse of width ~ 350 ns with rise time ~ 30 ns has been obtained. As expected the amplitude of the output voltage was 50% of the charging dc voltage.

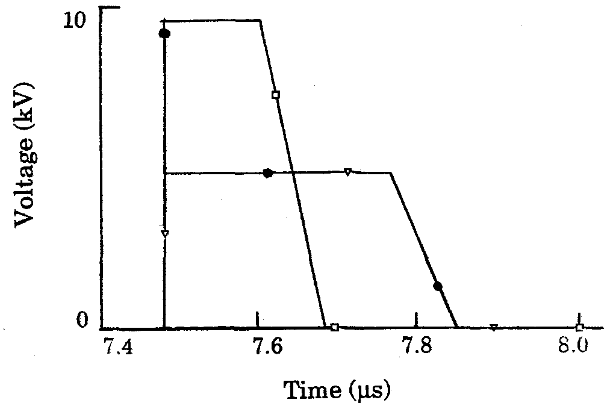


x-axis : Time   1 Div. = 1.2 kV

y-axis : Voltage   1 Div. = 100 ns

Fig. 7. Laboratory simulated pulse voltage for circuit-A with dc as charging voltage.

Fig. 7 shows the laboratory generated output pulse voltage for 10 kV dc charging voltage. The corresponding PSPICE simulated result for this test case with dc as charging voltage is given in Fig. 8.



V_3 : Squares V_4 : Circles V_5 : Triangles

Fig. 8. PSPICE results for circuit-A with dc as charging voltage.

There exists good correlation between the experimentally simulated waveform and PSPICE results. It is thus demonstrated that circuit analysis programs like PSPICE or EMTP are useful in gathering information on the amplitude and the shape of the output pulse that can be generated in the laboratory for a given cable and impulse source characteristics.

Acknowledgment

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