DESIGN AND PSPICE SIMULATION OF A 150KV/300A/1mS COAXIAL PULSE GENERATOR

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Abstract - **Coaxial pulse generators are well-suited devices for high voltage pulse generation in the range of nanoseconds or microseconds. Basically these devices consist of pieces of transmission lines charged in parallel and discharged synchronously in series into the load by using a single switch. The main problems with this type of generator are the presence of the shield cable impedance that contributes to the power loss of the device and the requirement of long lengths of lines for operation in the microsecond range. In view of that, this paper presents a construction method that minimizes these losses and reduces the generator size by coiling coaxial lines around cylindrical PVC tubes. In particular, we report the PSPICE circuit simulation of the input and output pulse voltages including the shield cable impedance, which is estimated from the inductance and the capacitance (with respect to ground) of the coaxial winding.**

Keywords – high voltage pulser, Blumlein line, coaxial pulse transformer, transmission line

I. INTRODUCTION

Coaxial pulse generators are high voltage generators made of pieces of transmission lines and normally used in a great variety of applications such as in x-ray generation, breakdown tests, surface treatment of plastics by plasma immersion ion implantation, etc [1-2-3]. Basically they consist of coaxial lines that are charged in parallel and discharged synchronously in series into the load by a single switch at the device input. For example, Fig. 1 shows a configuration circuit using 10 coaxial lines in which a negative pulse voltage is generated from a charging positive voltage +V. The principle of operation of the device can be summarized as follows: in the initial state the lines are positively charged, but the net output voltage is zero because of the initial voltage vector opposition as indicated in Fig. 1. As soon as the switch is closed, the pulse voltages propagate (to the left) down the active lines. After a propagation delay time the pulses arrive at the output where reflections occur converting the initial vector opposition to a series addition that remains for twice the line propagation time. This leads to an output voltage of nV for an open end or nV/2 for the case of a load nZ_0 matched to the generator output, where n is the number of lines and Z_0 is the line characteristic impedance.

Regarding the pulser configuration circuit, there are two important impedances in a cable, the inner cable characteristic impedance Z_0 and the impedance Z of the outer part of the shield (see Fig.1). The impedance of the outer part of the cable can allow some current to reach ground without going through the load. If the outer impedance can be made large, for example by winding the cable on a former so that the inductance of the outer part of the jacket be larger, reducing the output current and, thus, contributing less to the overall power loss of the device. In this paper we present a construction method to make $Z_2 >> Z_0$ of a high voltage coaxial pulse generator (150kV/300A/1 s) under construction in our laboratory [4]. Also we have included a PSPICE simulation of the input and output voltage pulses considering the shield cable impedance effect.

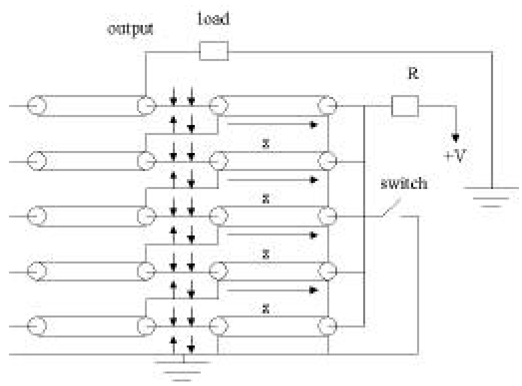

Fig. 1. A coaxial Blumlein pulser made of 10 lines.

II. CONSTRUCTION METHOD

The requirements of our pulser design are: 150kV/300A with pulse duration of 1 s. Thus the pulser load of 500 requires a design with 10 pieces of a 50- coaxial cable (or 5-stages). To ensure a high breakdown voltage, we choose the coaxial cable URM67/50 with the maximum rating of 40kV. Considering a pulser with 10 lines (i.e., with an ideal gain of n/2= 5) and its output nominal voltage 150kV gives a maximum charging voltage of 30kV, below the cable breakdown voltage. The length of each transmission line is 100 m as the selected cable URM 67 entails a double transit time of 10ns/m, which implies in the pulse duration of 1 s. To increase the device gain efficiency, the coaxial lines are coiled on cylindrical tubes, made from PVC and supported by an aluminum structure as shown by a picture of the pulse generator structure in Fig. 2.

Fig. 1. The pulse generator structure.

In practice, we have estimated the shield cable impedance by measuring the inductance L and capacitance C (with respect to ground) of one coaxial winding in the pulser structure. By using a L-C bridge meter we obtained an inductance of about 1.0mH for each coaxial coil. In relation to C, we verified that the meter provided approximately the same capacitance (on the order of 250pF) for each coaxial coil with respect to ground. Calculating through the well-known formula for the line characteristic impedance $\sqrt{L/C}$ gives a value of 2k for the cable shield impedance Z.

III. PSPICE SIMULATION

In this section, a PSPICE model circuit shown in Fig. 3 assesses the performance of the device. In the simulation, the pulse generator is modeled by ideal coaxial lines (with characteristic impedance Z_0=50 and transit time =500ns) connected to a resistive matched load of 500 . The open ends of the passive lines are simulated through high value resistors (1G) to avoid node list problems in the PSPICE simulation. The cable shield impedances are also represented in the model circuit by ideal transmission lines laid between the adjacent pulser lines (see lines T11-T14 in Fig. 3). This is so because the cable shielding impedance Z represents the characteristic impedance of a parasitic transmission line formed by the shielding itself and the ground plane. As each cable shielding at the switch side is grounded the parasitic lines are short-circuited at their input in the model by grounding the line inner conductors.

In the simulation, the parasitic line characteristic impedance is equal to the shield cable impedance given by $\sqrt{L/C}$, where L and C are respectively the coil inductance and capacitance described in section II. Moreover, it is assumed that all the parasitic lines have the same transit time T=$\sqrt{LC}$. By using the same measured values for L and C we tested the model with Z=2k and T=0.5 s. Fig. 4 shows the simulation of the output and input pulse voltages in a short time scale (1.6 to 4 s) for an initial charge voltage of about 10 kV. First observe in this figure that the charging input voltage (thin line) decreases rapidly to zero (in less than 100ns) as soon as the switch is closed at a set time on the order of 1.8 s. As is supposed a very low inductance at the switch connections of about 10nH, we verify in the simulation that the rise time of the output pulse voltage is also less than 100ns, being defined basically by closure time characteristic of the switch. Also observe that the output voltage is generated after a line delay time of 500ns with pulse duration equal to the double propagation time as expected. Moreover due to the shielding cable impedance effect we verify some power loss in the device, as the output pulse amplitude on the order of 45kV is lower than the expected value of 50kV. From this, we can infer that pulse generator efficiency is on the order of 90 %.

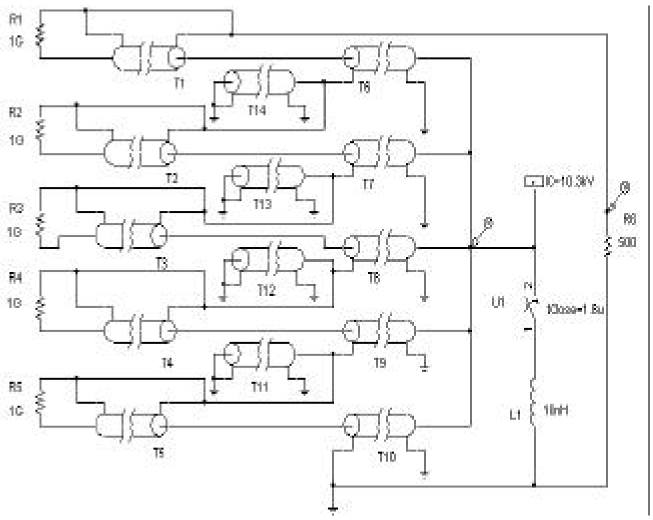

Fig. 3. PSPICE circuit model.

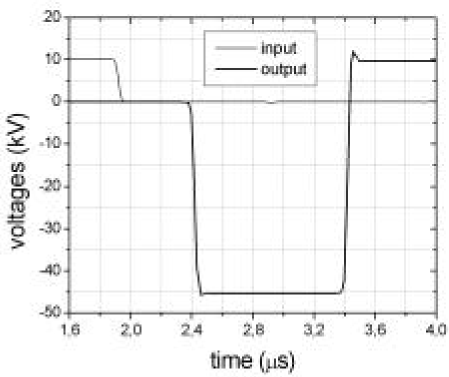

Fig. 4. Simulations of the input/output voltages.

IV. DISCUSSION

In this work we have presented the design and simulation of a 150kV/300A high voltage Blumlein pulse generator for long pulse operation in the 1 s range. Basically the pulser has been built by connecting long lengths of transmission lines coiled up on insulating tube formers to minimize the adverse effect of the shield cable impedance on the voltage gain of the device. At present the pulser is operating at peak voltages of about 45kV for an initial charging voltage of about 10kV and with an increased pulse rise time on the order of 300ns caused by a high inductance switch connection on the order of 700nH. The thin line in Fig. 5 shows this result. As expected the obtained experimental data confirms some power loss in the device (on the order of 10%). Also we have simulated the pulser operation by using the PSPICE circuit simulator program, where ideal transmission lines represent the coaxial cables as well as the parasitic shielding lines. The good agreement shown in Fig. 5 between the simulated and experimental results gives confidence in our model and suggests a useful simulation tool for the design of coaxial line pulse generators. Because of the pulser efficiency loss (10%) we intend to charge the coaxial cables up to 33kV (instead of 30kV) in order to reach the specified value of 150kV. For this final test, we will employ a high voltage switched-mode power supply with a maximum voltage capability of 35kV and charge rate of 8kJ/s.

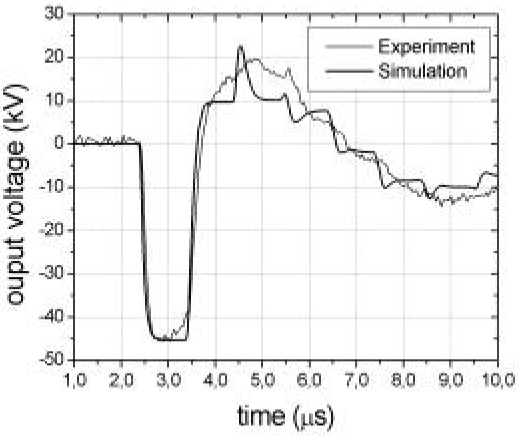

Fig. 5. Pulser output voltage.

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