

# Low Voltage Insulation Test Using Adjustable Output Impedance Pulse Generator

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**Abstract--** Testing insulation materials and surge arresters implies the use of high voltage impulse generators providing various waveforms and energies. This paper proposes an ignitron controlled impulse voltage generator 1.2/50 $\mu$ s with different output current shapes and output impedances. For this purpose the design steps and models are described, and the results proved by numerical simulation and electrical measurements performed on the generator.

## I. INTRODUCTION

Lightning and switching phenomena appearing in electrical circuits generate transient overvoltages in electrical and electronic devices. Because these are a potential danger for the equipment and for the user, a systematic research of these phenomena is needed.

There are known generators delivering standard impulse voltages (1.2/50 $\mu$ s) and impulse currents (8/20 $\mu$ s) as described in [1] and [2]. More interesting, however, is to add different current waveforms to form a so-called hybrid generator, which is designed for tests on test specimen with low non-linear impedance like e.g. surge arresters. This type of generator is more efficient than the standard impulse generator [3], which is not designed for various current shapes. Some applications for the hybrid generator are:

- Insulation co-ordination (i.e. design of insulation distances and overvoltage protection)
- Research on overvoltage limitations (i.e. how can a user handle with overvoltages)
- Tests on electrical and electronic components
- EMC (Electromagnetic Compatibility) tests

In this paper we propose a modified ignitron controlled impulse generator with standard 1.2/50 $\mu$ s voltage shape and 8/20 $\mu$ s short circuit current waveform in addition with different output impedances and current waveforms.

## II. OPERATION THEORY

Fig. 1 shows the electric schematic of the generator, with various impedance adapter drawers for different output impedances and output characteristics.

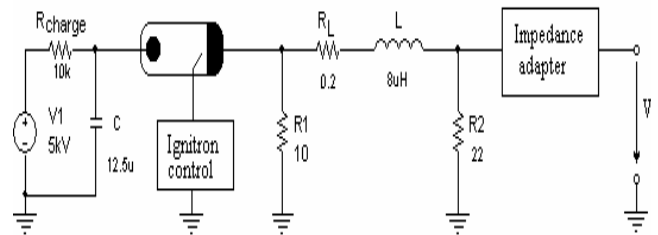


Figure 1. Electric schematic of the 1.2/50 $\mu$ s high-voltage pulse generator.

Because in practice there are various test specimens, variable output waveform and output impedance must be provided by a versatile impulse generator.

For this generator the design goals are:

- Standard impulse generator with a low output impedance (<2 $\Omega$ ) for short circuit tests
- Voltage impulse generator (1.2/50 $\mu$ s) with various output impedances (between 25 $\Omega$  and 136 $\Omega$ )
- Modelling and simulation of the impulse generator with various output impedances

## III. GENERATORS' DESIGN

The requirement on the generator is to deliver the standard impulse voltage (1.2/50 $\mu$ s) for open circuit and the standard impulse current (8/20 $\mu$ s) for short circuit with a minimal output impedance of the generator. Additional output impedances may be added later for energy limitation of the output signal.

The following calculations give the values of the circuit elements. The basic circuit for the waveform of the standard impulse voltage is illustrated in Fig.2,

$$\text{where } R_2^* = R_2 + R_L \quad (1)$$

When the switch S closes the circuit behaviour may be described using the Laplace transformation considering the following boundary conditions:

$$- \text{ initial capacitor voltage: } V_c(0) = V_0 \quad (2)$$

$$- \text{ initial output voltage: } V_{out}(0) = 0 \quad (3)$$

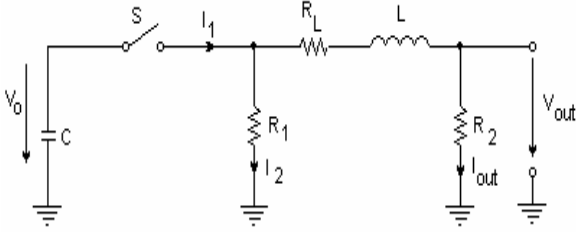


Figure 2. Equivalent circuit of the standard impulse voltage generator.

For this case the circuit diagram is presented in Fig.3.

$$\text{If one introduces } Z = \frac{R_1 \cdot (R_2^* + sL)}{R_1 + R_2^* + sL} \quad (4)$$

the current through the capacitor becomes

$$I_1 = \frac{V_0 C}{1 + sCZ} \quad (5)$$

$$\text{and the output current } I_{out} = I_1 \cdot \frac{R_1}{R_1 + R_2^* + sL} =$$

$$= \frac{V_0 C R_1}{R_1 + R_2^* + s(L + C R_1 R_2^*) + s^2 L C R_1} \quad (6)$$

Using the notations

$$a = \frac{L + C R_1 R_2^*}{2 L C R_1}, \quad b = \frac{R_1 + R_2^*}{L C R_1}$$

$$\text{and } x_{1,2} = a \pm \sqrt{a^2 - b}, \quad \forall a^2 > b \quad (7)$$

the output voltage appears as

$$V_{out} = R_2 I_{out} = V_0 \frac{R_2}{L} (s^2 + 2as + b)^{-1} \quad (8)$$

In the time domain the output voltage is:

$$v_{out}(t) = V_0 \frac{R_2}{L(x_1 - x_2)} [e^{-x_2 t} - e^{-x_1 t}] \quad (9)$$

For the values of the components show in Fig.1 the shape of the voltage in equation (9) is due to the specifications of the standard impulse 1.2/50 $\mu$ s.

Similarly, the equivalent schematic for the 8/20 $\mu$ s short circuit current waveform is presented in Fig. 4.

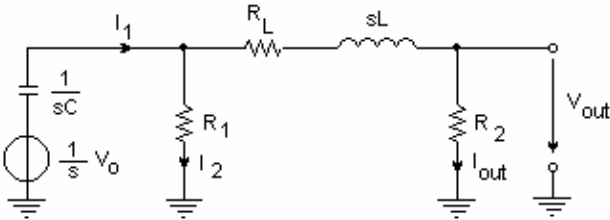


Figure 3. Equivalent Laplace transformation schematic.

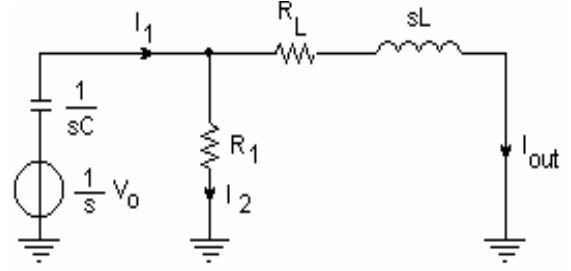


Figure 4. Equivalent Laplace transformation schematic for short circuit current output.

For the boundary conditions equations (2) and (3) are valid, but the output voltage is zero all the time. Furthermore, the resistor  $R_2^*$  is equal to  $R_L$ :

$$\text{Equation (4) becomes } Z = \frac{R_1 \cdot (R_L + sL)}{R_1 + R_L + sL} \quad (10)$$

and the output short circuit current

$$\begin{aligned} I_{out} &= I_1 \cdot \frac{R_1}{R_1 + R_L + sL} = \\ &= \frac{V_0 C R_1}{R_1 + R_L + s(L + C R_1 R_L) + s^2 L C R_1} = \\ &= V_0 \frac{1}{L} (s^2 + 2a^* s + b^*)^{-1} \end{aligned} \quad (11)$$

where:

$$a^* = \frac{L + C R_1 R_L}{2 L C R_1}, \quad b^* = \frac{R_1 + R_L}{L C R_1}$$

$$\text{and } x_{1,2}^* = a^* \pm \sqrt{a^{*2} - b^*}, \quad \forall a^{*2} > b^* \quad (12)$$

The response of the output current in the time domain

$$\text{is } i_{out}(t) = V_0 \frac{1}{L(x_1^* - x_2^*)} [e^{-x_2^* t} - e^{-x_1^* t}] \quad (13)$$

For the values of the components shown in figure 1 the short circuit output current in equation (13) follows specifications of the standard impulse current.

#### IV. NUMERICAL SIMULATION

The electric schematic in Fig.1 was modified for numerical a simulation using SPICE simulator releasing the equivalent schematic shown in Fig. 5.

The ignitron (type BK7703) in the generator has been modelled [4] using a controlled switch S with very low on resistance (0.1m $\Omega$ ), a diode D and a resistor R in the schematic. Simulated waveforms of the short circuit current for different output impedance are illustrated in Fig.6. One may observe that on high output impedance the current waveform has the same shape as the voltage in open circuit. The reason for this is the very low (2 $\Omega$ ) equivalent impedance of the generator.

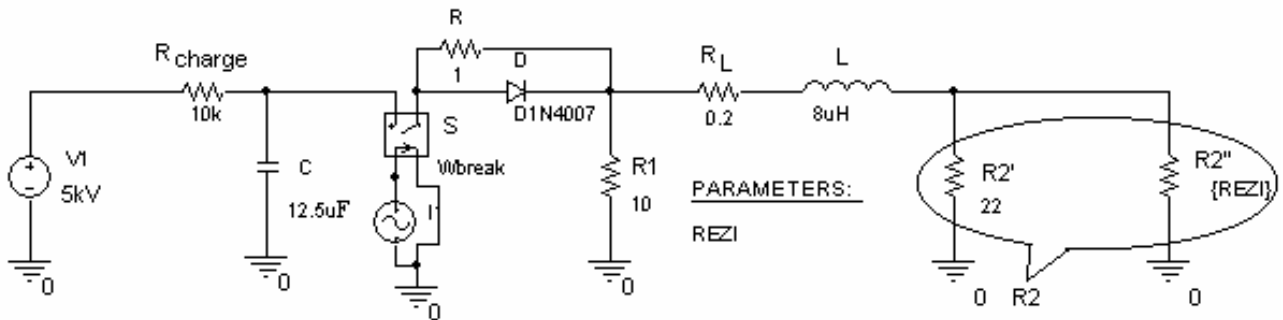


Figure 5. Schematic of the generator for SPICE simulation.

The charge resistor  $R_{charge}$  provides the right voltage for the capacitor C from the power supply V1. The output resistance is given by the parallel group  $R2'$  and  $R2''$ , where  $R2'$  is the always present safety discharge resistor. For the minimal output resistance the output short circuit

current is near 5kA peak, almost twenty times greater than the next value. For this reason in Fig.6 and Fig.7 these large currents are represented on a ten times reduced scale with respect to the other currents.

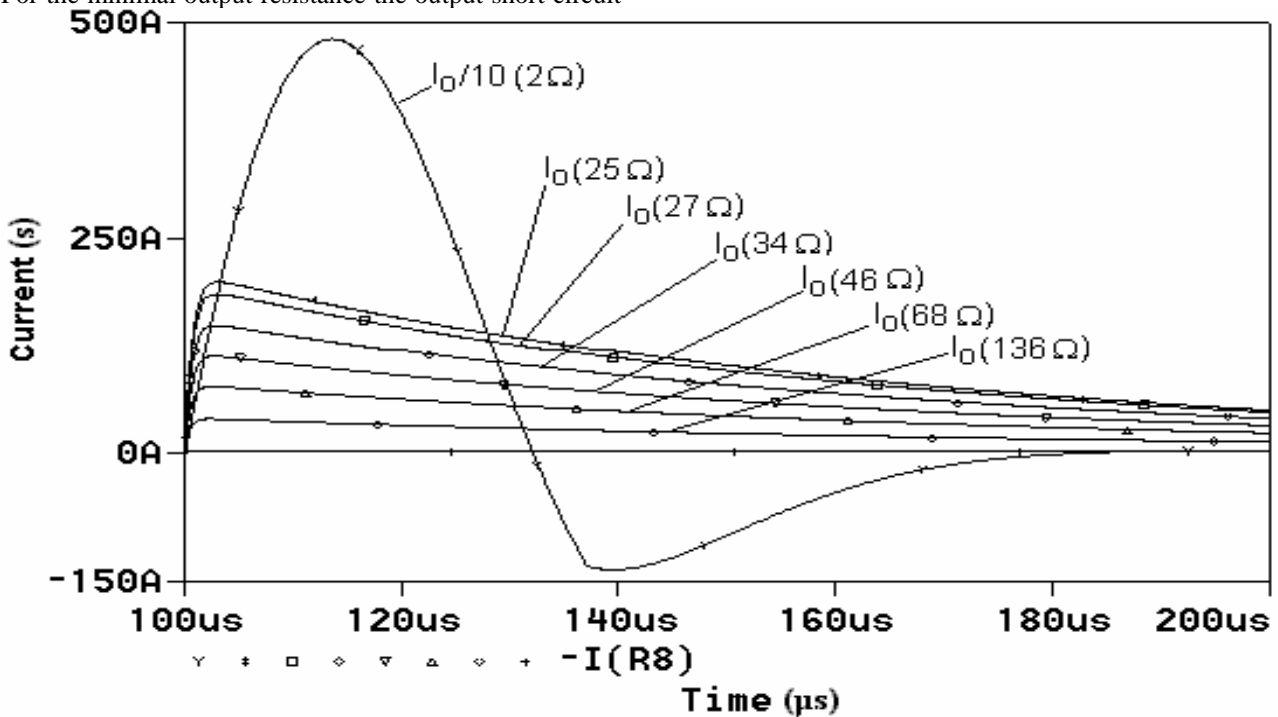


Figure 6. Currents for the pulse generator simulated with SPICE.

## V. MEASUREMENTS' RESULTS

The electrical measurements performed on the designed generator are demonstrated in figure 7. In this figure the waveform of the output voltage for open circuit and the shape of the short circuit current is presented for different output impedances. As this figure shows, the short circuit current without any additional output resistors is the standard impulse current. This particular waveform is suitable for tests on surge arresters as varistors, air gaps, etc. If lower energy of the output signal is required, a serial resistor will reduce the output current, but in this case the shape of the current is similar to the waveform of the impulse voltage.

## VI. CONCLUSIONS

A high voltage impulse generator was designed following the specifications of the standard impulse voltage (1.2/50μs) and current (8/20μs) with an equivalent output resistance less than 2Ω. Use of additional resistors provides the variable output impedance. Design goals were validated by numerical SPICE simulation of the generator. Measurements confirmed the output behaviour of the generator in all instances considered.

Instrument's output characteristic makes it useful for surge arresters or other insulating materials characterisation even for high energy or smaller energy demands.

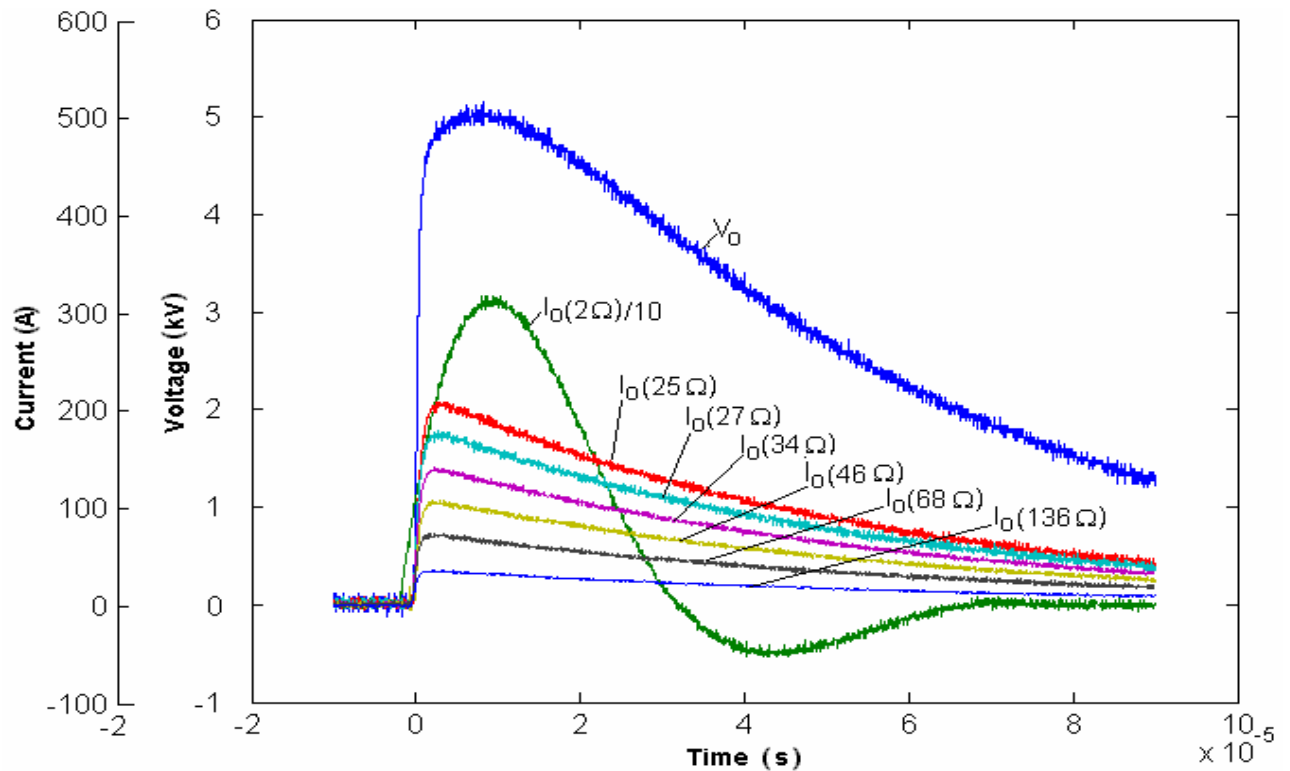


Figure 7. Output voltage (1,2/50 $\mu$ s) measured in open circuit, and output short circuit currents for different output impedances. Typical 8/20 $\mu$ s curve achieved for minimal impedance.

#### REFERENCES

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