Portable High Voltage Impulse Generator

Generador Portátil de Impulsos de Tensión.

S. Gómez¹, M.P. Buitrago², F.A. Roldán³

Abstract— This paper presents a portable high voltage impulse generator which was designed and built with insulation up to 20 kV. This design was based on previous work in which simulation software for standard waves was developed. Commercial components and low-cost components were used in this work; however, these particular elements are not generally used for high voltage applications. The impulse generators used in industry and laboratories are usually expensive; they are built to withstand extra high voltage and they are big, making them impossible to transport. The proposed generator is portable, thereby allowing tests to be made on devices that cannot be moved from their location. The results obtained with the proposed impulse generator were satisfactory in terms of time and waveforms compared to other commercial impulse generators and the standard impulse wave simulator.

Keywords— Electrical insulation, voltage impulse generator, insulation coordination, power disruption, standardised waves, standardised wave simulator.

Resumen—En este trabajo se presenta un generador portátil de impulsos de tensión, diseñado y construido con un aislamiento hasta para 20 kV. El diseño fue basado en un trabajo previo en el cual se desarrolla un software de simulación implementado exclusivamente para ondas de impulso normalizadas. Los componentes empleados fueron en su totalidad de bajo presupuesto, comerciales y algunos generalmente no son usados en alta tensión. Con el generador de impulsos se obtuvieron resultados satisfactorios en cuanto a tiempos y formas de onda, comparados con otros generadores de impulsos comerciales y el simulador de ondas de impulso normalizadas. Los generadores de impulso utilizados en la industria y laboratorios eléctricos son normalmente de gran tamaño, costosos y fabricados para soportar trabajos en alta tensión, ocupando demasiado espacio e imposibilitando su transporte. De ahí la importancia de este proyecto, pues siendo portátil facilita realizar pruebas en elementos que no se puedan desplazar de su ubicación.

Palabras Claves: Aislamiento eléctrico, Coordinación de aislamiento, Disrupción eléctrica, Generador de impulsos de tensión, Ondas Normalizadas, Simulador de Ondas de Impulso.

1. INTRODUCTION

Dielectricstrength testsof materialsused aelectricalinsulators are part of widely used and internationally accepted qualitytests or trials and they are subject to rulesor standards established by corresponding institutions, such as the American Society for Testing of Materials (ASTM) and the International Electrotechnical Commission (IEC).

An insulation coordination study must be done to ensure that high voltage materials tolerateddifferent overvoltage throughout their life. These techniques are used to select the dielectric strength or insulation level for high voltage materials which must be able to support normalised voltages and different waveforms (the most common types are lightning and switching).

Some authors, (ASTM, 2004; IEC, 2001), have stated that impulse voltage generatorscapable of providing impulse waves large enough to cause apower disruption in the proof element are needed for dielectric stress testing. The tested material’s electrical parameters, such as capacitance, can affect magnitude and the waveform applied by the generator. Such capacitance should thus be taken into account when measuring, adjusting and monitoring the voltage waveform.

A portable impulse generator was designed in (Lora, 2008) where most of the project components were imported, expensive, not very commercial and built for very specific applications, this being the greatest disadvantage (high implementation costs).

A simulation and numerical optimisation tool was developed in (Carmano et al) which used a minimum squares variant to compare mathematical model output against the output system. This tool calculated electrical circuit values during impulse trials for elements which could be handled. It was stated that the optimisation model would be better as soon as the amount of difficult to obtain experimental data became expanded.

Another article (Electrical Testing Group) has shown how a voltage impulse generator is typically used in techniques for finding faults in electrical transmission and distribution systems in high and medium voltage, called high power reflectometry. It was concluded that an impulse generator allows testing transformerstooctain data representation, associated capacitance and fault detection regarding transformer insulation.

To complement the aforementioned work, a voltage impulse wave simulator was developed based on wave normalisation using a graph technique or nomogram studied in (Aguet and Ianoz, 1990) and previously used in the proposed simulation by...
(Idarraga and Roldán, 2005), where it was only necessary to set the components to be simulated without obtaining preliminary experimental data to conduct an impulse wave analysis. A portable generator was thus designed from simulation results, considering the field application noted above; a portable impulse generator was then constructed giving normalised voltage waves for lightning and switching types, using low-cost implementation components. Because of the small scale design, there were limitations on the voltage generator supply as the generator only delivered up to 20kV impulse voltage waves.

2. THEORETICAL BACKGROUND

Voltage impulse generators produce waves which can be classified as impulse lightning and impulse switching, with 1.2-250 µs standard front time and 50-2,500 µs for tail time (IEC Standard 60060-1, 1989).

![Fig. 1. Lightning Impulse](image)

A. Time measurements for a lightning wave

Front time $T_f$ for a lightning impulse is 1.67 times time interval $T$ (Figure 1, IEEE Standard 4, 1995) between the instants when an impulse is 30% and 90% of peak value. Tail time $T_t$ for a lightning impulse is the time interval between virtual origin $T_v$ and the instant on the tail when the voltage has decreased to half (50%) peak value. Standard tolerances for front and tail time are 30% and 20%, respectively (IEEE Standard 4, 1995; Kuffel and Zaengl, 1970).

B. Time measurement for a switching wave

Front time $T_{cr}$ is measured by reaching peak voltage, while tail time $T_{tr}$ is measured when maximum voltage drops to 50%. Standard front and tail timetolerances are 20% and 60%, respectively (IEEE Standard 4, 1995; Kuffel and Zaengl, 1970).

C. Impulse generator

The generalised schemes for a single stage with capacitive, resistive and inductive components are used to generate a standard impulse wave, as shown in Figure 2.

![Fig. 2. RLC Circuits. Rs1, Rs2, Rs: Front resistor, Rp: Tail Resistor, Cc: Discharge capacitor, Cc: Charge capacitor, L: Inductor](image)

These kinds of circuit give an impulse wave as output (such as that in Figure 3) resulting from subtracting two exponential functions (Aguet and Ianoz, 1990).

![Fig. 3. Characteristic Impulse Voltage](image)

Equation (1) describes this kind of impulse:

$$u_c(t) = \frac{C_p}{A h} U_g \left[ e^{-p_1 t} - e^{-p_2 t} \right].$$

where, $p_1$ and $p_2$ are time constants depending on circuit components (Aguet and Ianoz, 1990).

D. Normalising the wave equation

According to (Aguet and Ianoz, 1990), impulse wave (2) is used for normalisation:

$$\eta U_c(t) = \frac{\alpha U_g}{\sqrt{\alpha^2 + 1}} \left[ e^{-\left(\alpha^{-\sqrt{\alpha^2 + 1}}\right) \frac{t}{\beta}} - e^{-\left(\alpha + \sqrt{\alpha^2 + 1}\right) \frac{t}{\beta}} \right].$$

Such simplifications associated with a graph called nomogram or abacus (shown in Figure 4) (Aguet and Ianoz, 1990). This graph relates the determinant factor.
of voltage impulse shape, and the determinant coefficient of time $\theta$.

Expressions for $T_2/T_1$, $\theta_2=\alpha T_1/\theta$ and $T_2/T_2$ are derived from the nomogram curves used for component and time calculations.

These equations simplify the characteristic component calculation for an impulse generator from the type of known voltage wave or voltage impulse waveregarding the components being used.

### E. Characteristic coefficients

Characteristic coefficients $\alpha$, $\theta$ and $\eta$ are determined for each type of circuit according to the equations shown in Table 1, which were obtained from (Aguet and Ianoz, 1990).

**Table 1. Formulas for the characteristic coefficients**

<table>
<thead>
<tr>
<th>Circuit</th>
<th>$\theta_{ii}$</th>
<th>$\eta_{ii}$</th>
<th>$\alpha_{ii}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table><p>ight)) | (1 + \frac{R_1}{C_1} + \frac{R_2}{C_2}) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) |
| 2       | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) |
| 3       | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) |
| 4       | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) |
| 5       | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) | (\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right)) |</p>

The equations presented in Table 2, which were obtained from (Aguet and Ianoz, 1990), can be used for calculating the components based on the selection of the kind of scheme.

### 3. EXPERIMENTAL FRAMEWORK

#### A. Simulator

The standardised voltage impulsesimulator shown in Figure 5 was designed using the Matlab platform guide. This software allows the user to obtain the waveform for the type of selected circuit from five possible options by determining front and tail times for lightning or switching. The component values can also be obtained using the type of impulse, the selected circuit and capacitor values.

**Table 2. Formulas for the components**

<table>
<thead>
<tr>
<th>Circuit</th>
<th>$X(i)$</th>
<th>$R(i)$</th>
<th>$R(i)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
</tr>
<tr>
<td>2</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
</tr>
<tr>
<td>3</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
</tr>
<tr>
<td>4</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
</tr>
<tr>
<td>5</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
<td>(\frac{1}{\eta_0}\left(\frac{1}{\eta_0} + \frac{R_1}{C_1} + \frac{R_2}{C_2}\right))</td>
</tr>
</tbody>
</table>

The procedure can be summarised by the scheme presented in Figure 6.
The simulator was used to test commercial generator databases and select appropriate values for space requirements, construction costs, and electrical insulation. It was then decided to build the elements using the values described in Table 3.

### Table 3. Nominal Values of Generator Components

<table>
<thead>
<tr>
<th>Impulse Type</th>
<th>Circuit Type</th>
<th>Capacitors</th>
<th>Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(C_g(\mu F))</td>
<td>(C_c(\mu F))</td>
</tr>
<tr>
<td>Lightning</td>
<td>2</td>
<td>0.025</td>
<td>0.0012</td>
</tr>
<tr>
<td>Switching</td>
<td>2</td>
<td>0.025</td>
<td>0.0012</td>
</tr>
</tbody>
</table>

### B. Capacitors

The proposed capacitor had to withstand 20kV voltage and their small capacitances were not commercially available. For each condenser, it was necessary to assemble series of capacitors, insulated from each other by rigid polyurethane foam and encapsulated in acrylic, thereby obtaining greater dielectric strength. The building models are shown in Figure 7 (a) and 7 (b).

Table 4 summarizes the technical characteristics and required amounts of elements used to build the capacitors for the portable voltage impulse generator.

### Table 4. Capacitors design and construction

<table>
<thead>
<tr>
<th>Impulse Type</th>
<th>Charge Capacitor (C_g(\mu F))</th>
<th>Discharge Capacitor (C_c(\mu F))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\text{Individual Value (\mu F)})</td>
<td>(\text{Amount of Capacitors})</td>
</tr>
<tr>
<td>Lightning &amp; Switching</td>
<td>0.56</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>(0.025 \mu F)</td>
<td></td>
</tr>
</tbody>
</table>

### C. Resistors

The resistors were made from traditional electronic carbon resistors connected in series to withstand the required stress. The resistors were isolated from each other by using rigid polyurethane foam and encapsulating them in acrylic, thereby obtaining greater dielectric strength. Table 5 shows the values for the resistors used; the resistance configuration for lightning is presented in Figure 7 (c).

### Table 5. Resistors design and construction

<table>
<thead>
<tr>
<th>Impulse Type</th>
<th>Front Resistor (R_{s1}(\Omega))</th>
<th>Tail Resistor (R_p(\Omega))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\text{Individual Value (\Omega)})</td>
<td>(\text{Amount of Resistors})</td>
</tr>
<tr>
<td>Lightning</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>(360 \Omega)</td>
<td></td>
</tr>
<tr>
<td>Switching</td>
<td>4.7k</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>(47k \Omega)</td>
<td></td>
</tr>
</tbody>
</table>
D. Sphere Gap

The sphere gap is used as voltage switch in voltage impulse generators, as in IEEE Standard 4, 1995; Bedoya, 2004). Due to the impulse generator’s designed voltage, the sphere gap was proposed for uniform field distribution, using horizontal arrangement and supported on an acrylic structure. The switch could thus be calibrated to the generator’s maximum possible voltage.

The spheres had 30mm diameter and maximum 8 mm distance; they were made of aluminum and designed to withstand a maximum 20kV voltage. The sphere gap is shown in Figure 7d.

E. Powersupply

The power supply was formed by a 120/7,000V elevator transformer followed by a Schenkel voltage doubler circuit, as proposed in Aguet and Ianoz, 1990), to achieve maximum 15kV voltage. The circuit was built using two 0.07µF/8000V capacitors and two rectifier diodes having 7,000V peak inverse voltage.

4. RESULTS AND DISCUSSION

The portable voltage impulse generator was tested in the laboratory to confirm that the results conformed to established standards and were within the tolerances set by them. Simulations were made to test the generator’s performance.

Table 6 (a) shows the data obtained from laboratory testing for lightning impulse using the portable voltage impulse generator. The data obtained for a commercial impulse generator (having the same resistor and capacitor values) and the values calculated by the impulse wave simulator are also presented.

Table 6. a). impulse lightning results

<table>
<thead>
<tr>
<th>Time [Front/Tail] (µs)</th>
<th>Portable Generator</th>
<th>Commercial Generator</th>
<th>Wave Simulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,184/43.2</td>
<td>1.172/43.1</td>
<td>1.25/45.36</td>
<td>10-20</td>
</tr>
</tbody>
</table>

Table 6. b). impulse typeswitching results

<table>
<thead>
<tr>
<th>Time [Front/Tail] (µs)</th>
<th>Portable Generator</th>
<th>Commercial Generator</th>
<th>Wave Simulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>224/2140</td>
<td>----</td>
<td>256.4/2,360</td>
<td>10-20</td>
</tr>
</tbody>
</table>

The lightning impulse registered by the oscilloscope as described by (IEC Standard 60060-1, 1989; IEEE Standard 4, 1995) is presented in Figure 8 (a).

Table 6 b) presents the measured switching impulse values from a portable voltage impulse generator compared to those supplied by the impulse wave simulator. The switching impulses recorded by the oscilloscope as described by (IEC Standard 60060-1, 1989; IEEE Standard 4, 1995) is presented in Figure 8 (b).

Fig. 8. Waves from Portable Generator

Lightning and switching impulses were within established standards when error rate associated with the portable voltage impulse generator was within such range (Table 7).

Table 7. Tolerances

<table>
<thead>
<tr>
<th>Impulse Type</th>
<th>Admissible Error [Front/ Tail] (%)</th>
<th>Portable Generator [Front/ Tail] (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightning</td>
<td>30/20</td>
<td>1.33/13.6</td>
</tr>
<tr>
<td>Switching</td>
<td>20/60</td>
<td>10.4/14.4</td>
</tr>
</tbody>
</table>

The result showed that the error calculated for lightning and switching impulses came within the percentage limits set by the aforementioned regulations.

The final version of the portable voltage impulse generator components is presented in Figure 9. Tuning tests were performed with a bell-type insulator and the results showed that the generator outputs came within the range of tolerances mentioned above.
5. CONCLUSIONS

This paper has presented the design and construction of a portable high voltage impulse generator. The proposed generator’s performance was compared to that of commercial generators and the established standards for such instruments. The results came within the ranges established by the standards and the generator could thus be regarded as being valid.

The generator satisfied the main objective and needs proposed in this work due to the low cost of its implementation and its comfortable size for use and transport.

Future work will be aimed at expanding insulation components and power supply level to encompass jobs in high-voltage ranges and diversify the number of components to be tested.

6. ACKNOWLEDGEMENTS

The authors are grateful to the Universidad Nacional de Colombia in Manizales, especially the High Voltage research group for their support in carrying out laboratory practice.

This work was supported in part by the National University of Colombia, Manizales.

7. REFERENCES


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