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Estimation of load capacitance and stray inductance in lightning impulse voltage test circuits

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ABSTRACT

In order to obtain the lightning impulse voltage waveshape regarding front time, time to half and relative overshoot magnitude within the limits prescribed by IEC 60060-1, it is useful to accurately estimate the test circuit parameters, e.g. load capacitance and circuit inductance. A stray inductance consists of the inductance of impulse generator and the inductance of connecting leads. Load capacitance consists of voltage divider capacitance, test object and parasitic capacitances. In practice, the test object capacitance is often unknown. Capacitance measurement takes time and makes testing procedure more complex. Also, it is very difficult to estimate parasitic capacitances although their influence can sometimes be significant.

This paper presents a new genetic algorithm (GA) based method for fast and accurate estimation of load capacitance and circuit inductance during lightning impulse voltage testing of a capacitive load. Computational and experimental verification of the method is successfully performed for standard and non-standard lightning impulse waveforms with various relative overshoot magnitudes.

1. Introduction

High voltage equipment has to be tested with lightning impulse (LI) voltage in order to prove the capability against such overvoltages. In order to simulate the effect of transient overvoltage on high voltage equipment the various national and international standards define the impulse voltages and their appliance to a test object. Time parameters of lightning impulse voltage are shown in Fig. 1 according to IEC standard [1]. Tolerances of 1.2 μs ± 30% for front time T_1 and 50 μs ± 20% for time to half-value T_2 are permitted. The test circuit has an inductance which consists of the inductance of impulse generator, ground leads and the connecting leads. In some cases inductance causes overshoot and oscillation at the crest of the lightning impulse voltage waveform.

Overshoot usually occurs when the connecting leads from impulse generator to test object are very long and the inductance is comparably high. In case of a test object with high capacitance, low values of the impulse generator front resistors are used which in some cases can lead to oscillations occurrence. Fig. 2 shows the overshoot β which represents the increase of amplitude of an impulse voltage due to a damped oscillation (frequency range usually 0.1–2 MHz) at the peak caused by the inductance of the test circuit and the load capacitance.

Overshoot magnitude β is the difference between the extreme value of the recorded impulse voltage curve and the maximum value of the base curve. The base curve is an estimation of a full lightning impulse voltage without a superimposed oscillation. The relative overshoot magnitude β' represents the ratio of the overshoot magnitude to the extreme value and it is defined by expression (1).

$$\beta' = 100 \cdot \frac{U_e - U_b}{U_e}\%. \quad (1)$$

According to Ref. [1], the relative overshoot magnitude shall not exceed 10%.

In high voltage laboratories, lightning impulse voltages are most commonly produced using the Marx lightning impulse generator [2]. Equivalent circuit of the impulse generator is shown in Fig. 3.

The generator capacitance C_1 is slowly charged from a DC source until the spark gap G breaks down. Resistor R_1 primarily damps the circuit and controls the front time T_1, while resistor R_2 discharges the capacitors and controls the time to half T_2. C_2 represents the capacitance of test object and all other capacitive elements which are in parallel to the test object (e.g. capacitor voltage divider used

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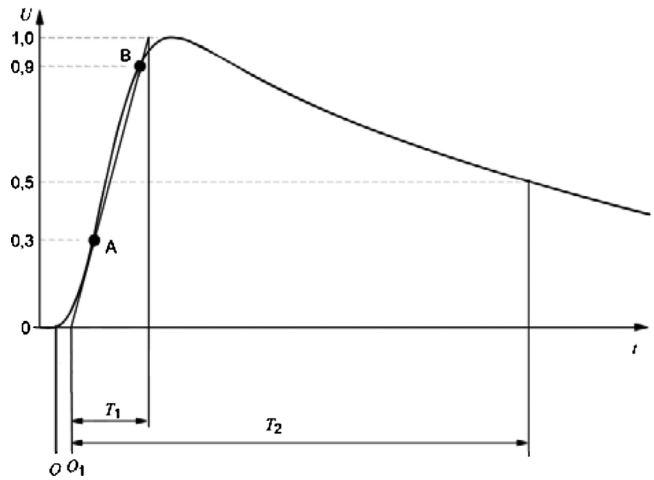

Fig. 1. Lightning impulse voltage time parameters [1].

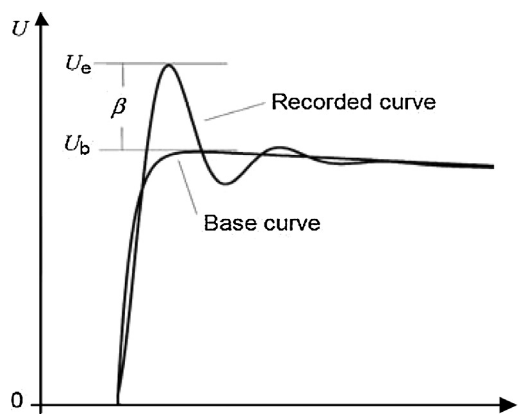

Fig. 2. Determination of overshoot β magnitude from the recorded lightning impulse voltage and base curve.

for measurement, additional load capacitor, sometimes used for avoiding large variations of T_1 and T_2 if the test objects are changed, and parasitic capacitances). L represents the inductance of impulse generator and the connecting leads.

Available values of R_1 and R_2 are limited in practice and therefore the standardized nominal values of T_1 and T_2 are difficult to achieve. Changing these resistors on the generator usually requires a trial-and-error process or accumulated experience with previous impulse tests on similar equipment. For this reason it is obvious that the simple and easy-to-use method for generator parameter determination would make lightning impulse testing procedure less complicated and less time-consuming.

Many published papers deal with the calculation of impulse generator parameters: Thomason [3] determined circuit formulas of the most commonly used impulse generators circuits; Feser [4], Kannan and Narayana [5] and Del Vecchio et al. [6] investigated circuit design for the lightning impulse testing of transformers; Khalil

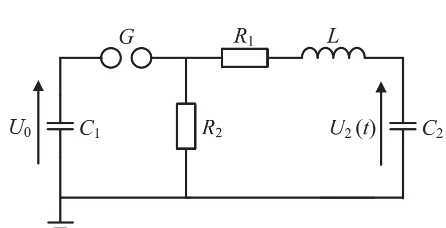

Fig. 3. Single-stage impulse generator circuit.

and Metwally [7] developed a computerized method to reconfigure the impulse generator for testing different types of objects. Methods described in the previously mentioned papers use C_2 as an input parameter which means that the load capacitance should be known or measured before testing. In practice, test object capacitance is often unknown and the measurement of it takes time and makes testing procedure more complex. Also, parasitic capacitances cannot be taken into account by this approach although their influence can be significant especially when testing low capacitance objects of large dimensions.

Genetic algorithm [8,9] and other optimization methods [10,11,12] have already been used for curve fitting based estimation of lightning impulse parameters such as peak value, front time and time-to-half-value.

However, the aim of this paper is to introduce a new genetic algorithm [13] (GA) based method for obtaining test circuit parameters in case of a capacitive load testing. The main advantage of this method is a fast estimation of the load capacitance and test circuit inductance from the recorded lightning voltage impulse and from the known values of generator capacitance, front and discharge resistance. Once when all circuit parameters are known it is less complicated to determine circuit elements which will provide T_1, T_2 and β' that are within limits prescribed by Ref. [1]. Hence, the presented method saves time and makes the reconfiguration of impulse generator easier.

2. Analysis of the lightning impulse voltage test circuit

The method presented in this paper estimates lumped stray inductance and load capacitance in a test circuit. In the real situation, a stray inductance consists of the inductance of impulse generator and the inductance of connecting leads while load capacitance consists of voltage divider capacitance, test object capacitance and their parasitic capacitances. By taking this into account a more realistic equivalent scheme of the test circuit would be obtained. However, this model is more complex and solving it would take more time and the algorithm has to be fast in order to be applied in practice. The presented method cannot differentiate all individual inductances and capacitances mentioned above. However, estimation of lumped inductance and capacitance in a test circuit proved sufficient for practical application. In Refs. [2,14,3] it is demonstrated that the calculations can be made much more easily if certain approximations are used, and these are found not to introduce appreciable errors in practice. Even more complicated circuit representations have been examined, particularly by Thomason [3], but the resulting expressions are of little more than academic or mathematical interest, especially as the stray capacitances and inductances are distributed throughout the circuit and no precise numerical values can be assigned to them. Therefore in practice it is convenient to simplify the calculations and use equivalent circuit shown in Fig. 3. Since in this paper excellent results were obtained by using equivalent circuit shown in Fig. 3 it is not convenient to take into account a more realistic equivalent scheme of the test circuit because it would not significantly improve the results. For that reason, a simplified circuit represented in Fig. 3 was used. The capacitances of the test object and of the voltage divider (and their stray capacitances) were lumped together in C_2, while the total inductance within the generator – load circuit is combined to a single inductance L.

Laplace transform of the circuit for lightning impulse voltage testing form Fig. 3 is shown in Fig. 4.

Voltage U_1 is determined by using the expression (2).

$$U_1(s) = \frac{U_0 \cdot Z_2}{s(Z_1 + Z_2)}, \tag{2}$$