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A new method for estimation of time parameters of standard and non-standard switching impulse voltages

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ABSTRACT

In this paper, a new method for estimation of time parameters of standard and non-standard switching impulse voltages is presented. Method is based on estimation of time difference between true and virtual origin of the switching impulse waveform. An analytical expression was derived for calculation of time to peak, which is more accurate than the expression given in IEC 60060-1. The presented method was verified with mathematically generated double-exponential waveforms and waveforms given in IEC 61083-2 with time to peak values within the range 20–300 µs and time to half values within the range 1000–4000 µs. An experimental verification of the proposed method was successfully demonstrated by comparison with an approved impulse voltage measuring system.

1. Introduction

Switching overvoltages (SOVs) in high voltage networks, which are caused by circuit breaker operations, stress the insulation of the high voltage equipment [1]. Therefore, most of high voltage equipment designed for operating voltages above 245 kV should be tested under laboratory simulated switching-impulse voltages [2].

Test requirements along with definitions of standard switching-impulse voltage parameters are given in [3]. The time parameters of standard switching-impulse voltage are shown in Fig. 1. True origin O is an instant where the recorded curve begins a monotonic increase (or decrease for waveforms of negative polarity). Virtual origin O_1 is an intersection of the time axis with a straight line drawn through the reference points A and B in the front. Time to peak T_p is a time interval from the O to the time of maximum value of a switching-impulse voltage, while time to half value T_2 is a time interval between the O and the instant when the voltage has first decreased to half the maximum value. Standard switching-impulse voltage has a T_p of 250 µs and a T_2 of 2500 µs. Acceptable tolerances between specified values and those recorded in laboratory conditions are: ± 20% for T_p, ± 60% for T_2 and ± 3% for value of test voltage. T_p for standard switching-impulse voltages is defined as follows [3]:

$$T_p = K \cdot T_{AB}, \quad (1)$$

where K is a dimensionless value given by:

$$K = 2.42 - 3.08 \cdot 10^{-3} T_{AB} + 1.51 \cdot 10^{-4} T_2, \quad (2)$$

and T_{AB} is given by:

$$T_{AB} = t_{90} - t_{30}. \quad (3)$$

There are several issues when estimating time parameters of switching impulse voltages. In practice, it is not easy to determine an instant O and time at which maximum of recorded waveform occurs. The reason are oscillations caused by operation of impulse generator around O and noise present in the recorded signal. In the peak area of the impulse there is a problem related to analogue-to-digital conversion which is used for sampling the recorded analogue signal and quantizing its amplitude. Due to this process, the signal values are only available at discrete time intervals. Therefore, the signal amplitude cannot be clearly determined even with high resolution recorder because there can be several discrete points in the peak area often with the same value. Noise could be reduced by averaging the recorded signal, but this affects the parameters of the recorded waveform.

Literature survey showed that only a few papers have been published regarding the issues mentioned above. In [3] it is stated that for non-standard impulses, T_p can be determined by various methods of digital curve fitting dependant on the actual shape. The problem is that there is no guidance on how to determine T_p for non-standard impulses.

The requirements for software used for evaluation of impulse parameters from recorded impulse voltages are given in [4]. It provides test waveforms and reference values for the software required to meet the measuring uncertainties and procedures specified in [3,5–7]. Some

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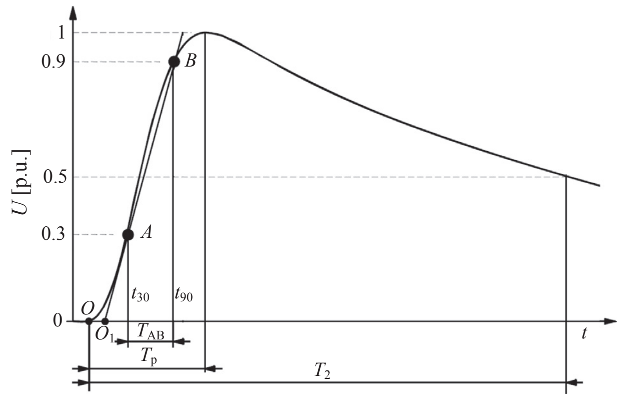

Fig. 1. Standard switching-impulse voltage.

of these waveforms are non-standard with T_p within the range 20–200 µs and T_2 within the range 1000–4000 µs. Expression (1) cannot be applied to all these impulses since it is valid only for standard switching-impulse voltages.

In [8] an impact of lightning and switching impulse definitions on the test results for insulation systems is discussed. The time to peak of a standard switching impulse can be determined more accurately by applying a procedure like the one used for lightning impulses.

In [9] an improved method for evaluation of switching-impulse parameters has been proposed. Similar approach of fitting a double exponential function has already been accepted for lightning impulse voltages and the same algorithm can easily be adapted for T_p evaluation of switching-impulses.

A system for automatic evaluation of voltage impulses according to [3,5] has been described in [10,11]. The results of the validation tests show that in few cases the errors in estimation of switching impulse voltage parameters were higher than the acceptance limit and the errors tends to increase with the noise level.

Therefore, in this paper a new method is proposed for estimation of time parameters of standard and non-standard switching impulse voltages. The main advantage of the proposed method is better accuracy in estimation of switching impulse parameters compared to the expression given in [3].

2. Relation between true origin and other time parameters for double-exponential waveforms

To accurately determine T_p and T_2 it is necessary to know the time instant of true origin O. In recorded waveforms, O can be masked with oscillations caused by triggering and noise. Therefore, relation of O to parameters of the impulse voltage which can easily be determined such as T_{AB} and O_1, was analysed on a group of mathematically generated double-exponential waveforms.

Mathematically generated waveforms were used in the analysis since they have uniquely defined parameters and no noise or oscillations. Switching impulse waveforms were mathematically described by using double-exponential function:

$$u(t) = A\cdot(e^{\alpha t}-e^{\beta t}), \tag{4}$$

where α is negative number specifying falling slope, β is negative number specifying rising slope and A is number proportional to the peak value of surge. There is no analytical expression which relates α and β with T_p and T_2 so genetic algorithm (GA) was used to determine α and β for a large number of T_p and T_2 pairs [12]. The flowchart of the algorithm is shown in Fig. 2.

At first, the GA generates a population of parameters α and β. Population size specifies how many individuals there are in each generation (in this case 1000 α and β elements per generation). Initial population is created randomly with a uniform distribution from a

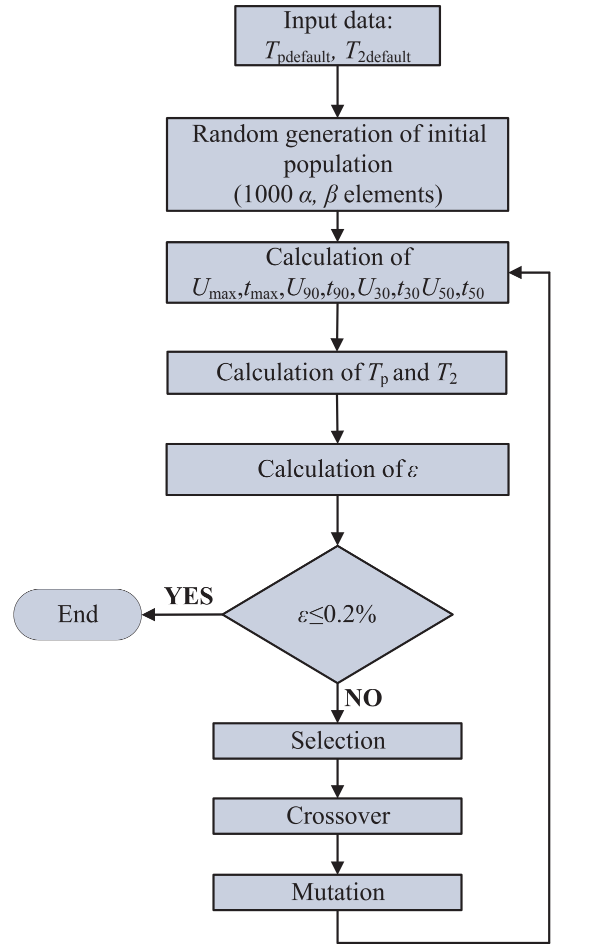

Fig. 2. Flowchart of the algorithm for determination of parameters α and β of the double-exponential function for a given T_p and T_2 pair.

predefined range. After the creation of the initial population, T_p, T_2 and fitness function ε are calculated for each α and β element in the initial population. The fitness function ε is the objective function minimized by the GA, which in this case considers the percentage error for each calculated T_p and T_2 regarding known values $T_{pdefault}$ and $T_{2default}$. The fitness function is calculated by using the following expression:

$$\varepsilon = \max\left(\left|\frac{T_p-T_{pdefault}}{T_{pdefault}}\right|,\left|\frac{T_2-T_{2default}}{T_{2default}}\right|\right)\cdot 100\% \tag{5}$$

Each T_p and T_2 is then rated according to the value of the fitness function. T_p of the switching impulse voltage is obtained by deriving Eq. (4):

$$\frac{du(t)}{dt} = 0. \tag{6}$$

Expression (7) shows the solution of the Eq. (6).

$$T_p = \ln\left(\frac{\alpha}{\beta}\right)\cdot\frac{1}{\beta-\alpha} \tag{7}$$

If the best fitness value is less than or equal to the value of the fitness limit, the algorithm stops. In this case, the fitness limit was set to 0.2%.

For each mathematically generated waveform, time parameters were calculated and a correlation between time difference from O to O_1 and T_{AB} value was determined. Computed results are shown in Fig. 3 which shows $O-O_1$ time difference versus T_{AB} with T_p and T_2 as parameters.

It can be noticed that family of curves can be well approximated with a straight line. A linear dependence between T_{AB} and $O-O_1$ time