Volt-time Curves of 24 kV Porcelain Insulators under Non-Standard Impulse Waveshapes

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***Abstract*— This paper presents an application of novel method in order to assess the characteristic of volt-time curves based on Disruptive Effect Model. The tests were performed on a pin-type, porcelain insulator of 24 kV class. Besides the standard 1.2/50 µs impulse voltage waveshape, four non-standard impulse waveshapes, of both polarities, were adopted in the tests, namely 1.2/4 µs, 1.2/10 µs, 3/10 µs, and 7.5/30 µs. The volt-time characteristics obtained from the tests were compared with those predicted by three different procedures related to the Disruptive Effect Model. The results show that the methods by Darveniza and Vlastos and by Hileman do not predict insulator breakdown for the lower peak voltage levels in some cases. On the other hand, a good agreement was found between theoretical and experimental results for the calculations performed using the method proposed by the authors.**

Keywords- volt-time characteristic; impulse voltage waveshape tests; modeling; power distribution lines

I. INTRODUCTION

Lightning causes important transient disturbances on transmission and distribution systems, with consequent damages to equipment, outages, and general decrease of the power quality. The assessment of the lightning dielectric strength of power equipment is generally based on tests performed using the standard lightning impulse voltage (1.2/50 µs waveshape) [1], although the characteristics of the lightning overvoltages depend on many parameters and may vary widely. The behavior of insulators when subject to non-standard impulses depends both on the voltage amplitude and waveshape, and therefore a reliable model is required to produce the corresponding volt-time curves.

Although there is no method universally accepted for this purpose, one of the most used is the Disruptive Effect (DE) model [2][3], which is based on the integration method concept. The application of this model involves the estimation of some parameters for which different procedures have been proposed in the literature [4], [5], [6], [7], [8], [9], [10].

The DE model is generally expressed by the following equation:

$$DE = \int_{t_0}^{t_b} [v(t) - V_0]^{\alpha\cdot\frac{v(t)}{V_0}} \cdot dt \qquad (1),$$

where $v(t)$ is the voltage stressing the dielectric at time t, V_0 is the onset voltage and can assume different values, t_0 is the time at which $v(t_0) = V_0$, α is obtained experimentally, and t_b is the time to breakdown.

However, as shown in [9] in some cases the optimum value for the parameter α cannot be precisely estimated using the procedure adopted in [5], [8], and an alternative technique has been proposed in [10].

II. TEST SETUP

Tests were performed to obtain the critical flashover overvoltages (V_{50}' or CFO) and the volt-time curves of a typical 24 kV porcelain pin-type insulator under five impulse voltage waveshapes, of both polarities, representative of lightning overvoltages: 1.2/4 µs, 1.2/10 µs, 1.2/50 µs, 3/10 µs, and 7.5/30 µs.

Different combinations of resistors, capacitors and air-core inductors were used for the generation of the impulse voltage waveshapes considered in the tests [11][12].

Fig. 1 shows the porcelain insulator used in the tests, which has the following characteristics: BIL of 125 kV, dry arc distance of 210 mm, leakage distance of 318 mm, and CFO of 140 kV and 170 kV for the positive and negative polarities, respectively.

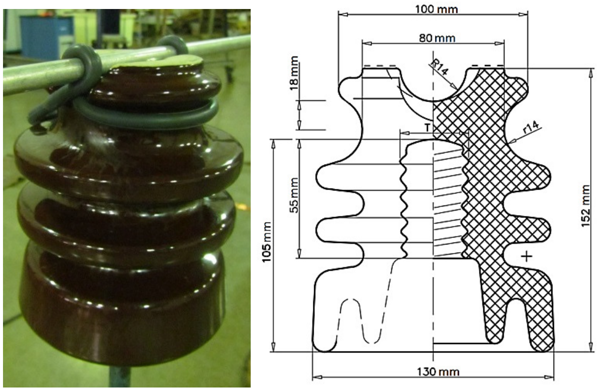

Figure 1. 24 kV pin-type insulator used in the tests.

III. TEST RESULTS AND ANALYSIS

Table I summarizes the measured data using the multiple-level method for the 24 kV insulator. The minimum and maximum values of the deviation σ/V_{50}' were found for the negative polarity of the 1.2/50 µs and 7.5/30 µs waveshapes, respectively. As expected, the V_{50}' values obtained for the negative polarity were always higher than those corresponding to the positive polarity.

According to the procedure of Darveniza and Vlastos [6], in the values of V_0 and K in equation (1) are $V_0 = 0.9 \times CFO$, where CFO is the critical flashover voltage (for the standard lightning impulse waveshape), and $K = \alpha \times v(t) / V_0 = 1$. Some impulse voltage tests with the 1.2/50 µs waveshape are necessary for the estimation of the critical value of DE (DE_C). For the Hileman procedure [7], $V_0 = 0.77 \times CFO$ and $DE_C = 1.1506 \times CFO^{1.36}$.

The DE parameters computed using the methods of Darveniza and Vlastos [6], Hileman [7], and the one proposed in [10] are shown in Tables II, III, and IV, respectively.

TABLE I. SUMMARY OF THE VALUES OBTAINED USING THE MULTIPLE-LEVEL METHOD.

Waveshape	Polarity	V_{50}' (kV)	σ (kV)
1.2 / 4 µs	Neg.	199.3	3.4
	Pos.	183.0	8.8
1.2 / 10 µs	Neg.	169.4	3.3
	Pos.	146.4	6.8
1.2 / 50 µs	Neg.	164.4	2.4
	Pos.	142.9	6.0
3 / 10 µs	Neg.	176.1	6.4
	Pos.	142.3	4.6
7.5 / 30 µs	Neg.	171.8	10.9
	Pos.	135.2	6.8

TABLE II. DE MODEL PARAMETERS ACCORDING TO THE METHOD OF DARVENIZA AND VLASTOS [6].

Polarity	V_0 (kV)	DE_C (kV·µs)
Neg.	148.0	42.9 ± 14.2
Pos.	128.6	78.8 ± 17.9

TABLE III. DE MODEL PARAMETERS ACCORDING TO THE METHOD OF HILEMAN [7].

Polarity	V_0 (kV)	DE_C
Neg.	126.6	10.0
Pos.	110.0	8.3

The minimum and maximum critical DE values (DE_C) calculated according to the Darveniza and Vlastos method were 13.3 kV ·µs and 81.5 kV ·µs, respectively, for the negative polarity, and 33.4 kV·µs and 109.6 kV·µs, respectively, for the positive polarity.

TABLE IV. DE MODEL PARAMETERS ACCORDING TO THE METHOD PROPOSED IN [10].

Waveshape	Polarity	V_0 (kV)	DE_c*	α*
1.2 / 4 µs	Neg.	127.8	4.36×10^{-5}	0.2086
	Pos.	78.7	3.78×10^{-5}	0.1133
1.2 / 10 µs	Neg.	130.6	2.08×10^{-4}	0.3133
	Pos.	65.8	1.12×10^{-4}	0.1298
1.2 / 50 µs	Neg.	135.5	1.26×10^{-4}	0.3243
	Pos.	71.6	1.05×10^{-4}	0.1329
3 / 10 µs	Neg.	99.6	2.43×10^{-4}	0.2395
	Pos.	87.2	5.51×10^{-5}	0.1648
7.5 / 30 µs	Neg.	42.4	1.05×10^{-2}	0.1622
	Pos.	54.2	4.98×10^{-4}	0.1718

DE_c*: optimal value of the critical disruptive effect DE_C.
α*: optimal value of α parameter.

Based on Tables II to IV, a comparison was made between measured volt–time curves for the five positive and negative polarity impulse voltage waveshapes and those predicted by the methods of Darveniza and Vlastos [6], Hileman [7], and the method proposed in [10].

Figs. 2–11 compare, for the five impulse voltage waveshapes of positive and negative polarities and the values of the DE parameters shown in Tables II–IV, the experimentally derived volt–time curves with those predicted using the methods presented in [6], [7], and [10]. In the figures, the curves obtained using [10] are identified as "This paper".

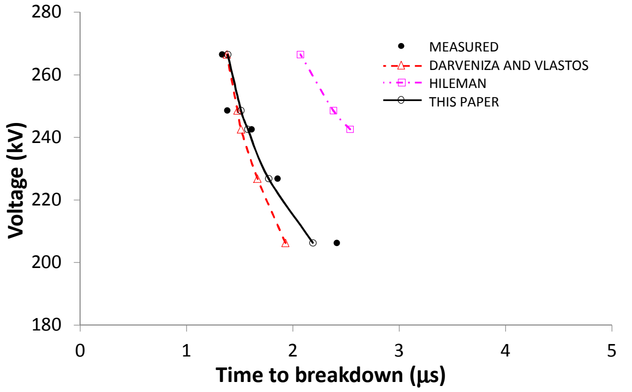

Figure 2. Volt-time curves for the 1.2/4 µs waveshape of negative polarity.

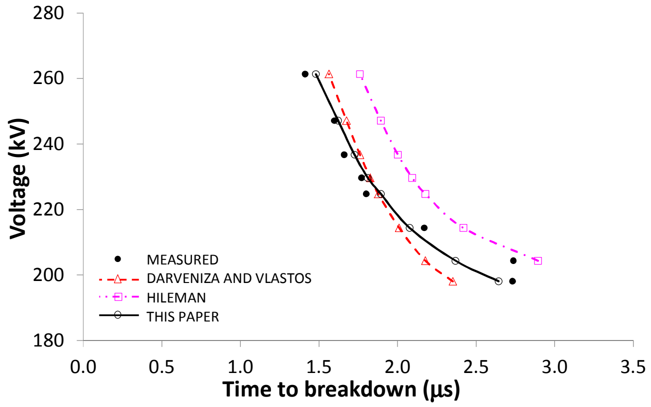

Figure 3. Volt-time curves for the 1.2/4 µs waveshape of positive polarity.

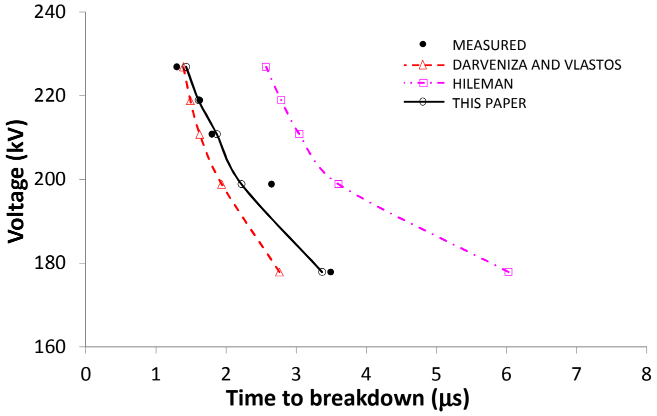

Figure 4. Volt-time curves for the 1.2/10 µs waveshape of negative polarity.

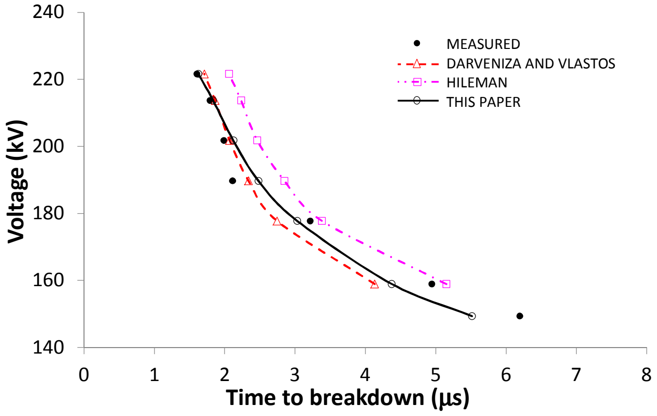

Figure 5. Volt-time curves for the 1.2/10 µs waveshape of positive polarity.

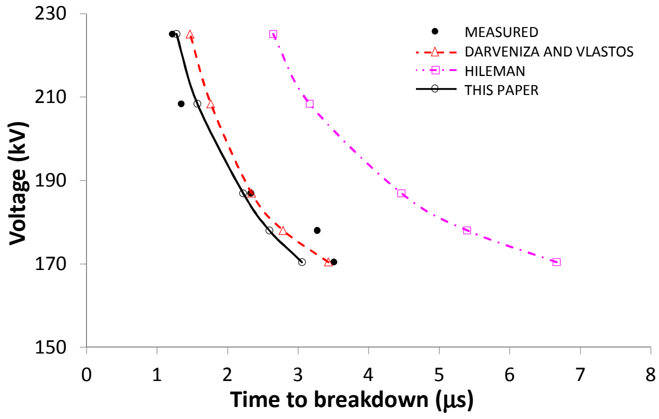

Figure 6. Volt-time curves for the 1.2/50 µs waveshape of negative polarity.

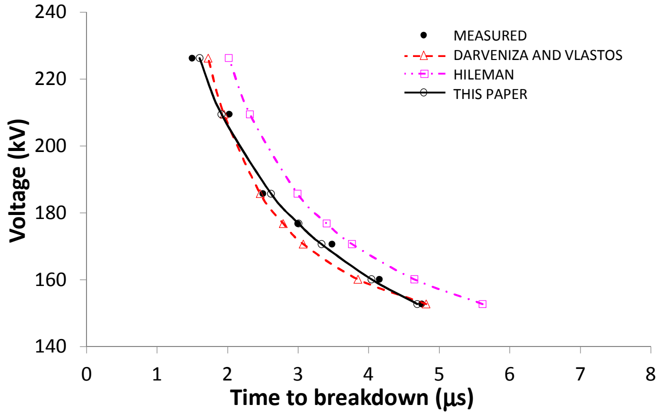

Figure 7. Volt-time curves for the 1.2/50 µs waveshape of positive polarity.

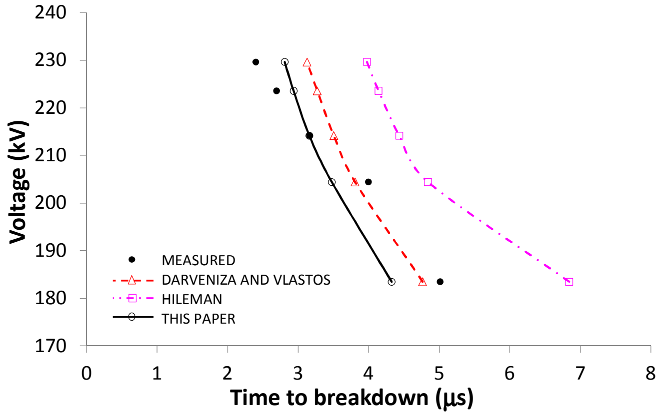

Figure 8. Volt-time curves for the 3/10 µs waveshape of negative polarity.

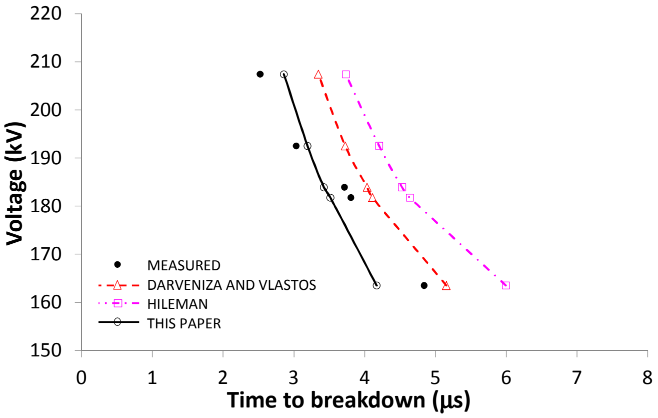

Figure 9. Volt-time curves for the 3/10 µs waveshape of positive polarity.

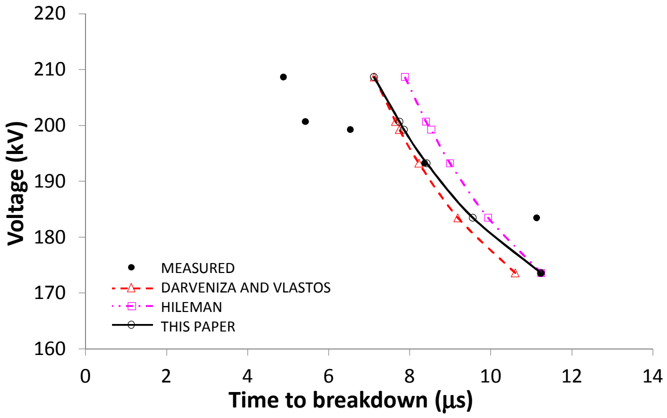

Figure 10. Volt-time curves for the 7.5/30 µs waveshape of negative polarity.

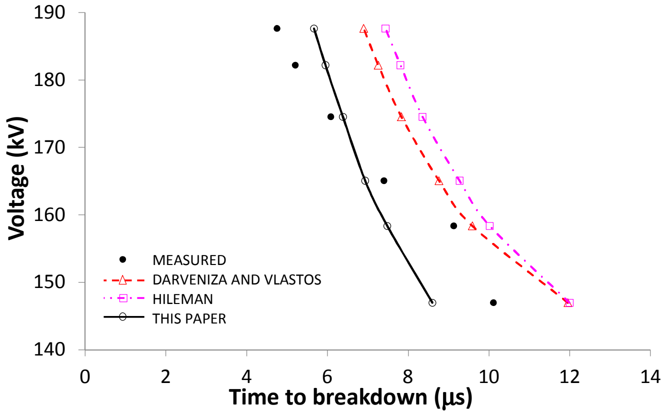

Figure 11. Volt-time curves for the 7.5/30 µs waveshape of positive polarity.

Figs. 2–11 indicate that the curves calculated according to the procedures by Darveniza and Vlastos [6] and by Shigihara et al. [10] have in general good agreement with those obtained from the tests for the five impulse voltage waveshapes considered. However, the former method [6] was not able to predict the occurrence of insulator breakdown for the lower voltage levels in the case of the 1.2/4 µs and 1.2/10 µs waveshapes of positive polarity (Figs. 2 and 5, respectively).

Similarly, the method of Hileman [7] also did not predict insulator breakdown for the lower voltage levels for the 1.2/4 µs waveshape, of both polarities (Figs. 2 and 3), and the 1.2/10 µs waveshape of positive polarity (Fig. 5).

In comparison with the results presented in [9] for a 15 kV pin-type porcelain insulator, the performances of the procedures by Darveniza and Vlastos [6] and Hileman [7] were much better for the 24 kV insulator. In most of the cases corresponding to the 15 kV insulator [9], the volt-time curves calculated using the procedure by Darveniza and Vlastos did not predict breakdown for the lower voltage levels, while, for some impulse waveshapes and polarities, breakdown was not predicted when the procedure by Hileman [7] was used.

The absolute values of the maximum differences between measured and calculated times to breakdown, for each waveshape and polarity, are shown in Table V. It shows that in most of the cases the results obtained using the procedure proposed in [10] lead to better agreement between measured and calculated times to breakdown. However, in two cases (1.2/50 µs and 7.5/30 µs waveshapes of negative polarity), the differences obtained using the procedure of Darveniza and Vlastos [6] are slightly lower.

The times to breakdown predicted using the procedure by Hileman [7], which was formulated for application to transmission line insulator chains, are in general much longer than the measured ones, although the maximum observed difference was 3.16 µs, corresponding to the 1.2/50 µs waveshape of negative polarity.

TABLE V. ABSOLUTE VALUES OF THE MAXIMUM DIFFERENCES BETWEEN MEASURED AND CALCULATED TIMES TO BREAKDOWN (µS)

Waveshape	Pol.	Darveniza and Vlastos [6]	Hileman [7]	Shigihara et al. [10]
1.2 / 4 µs	Neg.	0.48	1.00	0.23
	Pos.	0.56	0.38	0.37
1.2 / 10 µs	Neg.	0.73	2.53	0.43
	Pos.	0.81	0.74	0.57
1.2 / 50 µs	Neg.	0.48	3.16	0.68
	Pos.	0.41	0.86	0.15
3 / 10 µs	Neg.	0.72	1.83	0.69
	Pos.	0.82	1.21	0.67
7.5 / 30 µs	Neg.	2.24	3.00	2.32
	Pos.	2.15	2.69	1.65

IV. CONCLUSIONS

In this paper the volt-time curves of a commonly used 24 kV pin-type insulator, calculated using three different procedures for estimation the parameters required for the application of the Disruptive Effect Model (DE), were compared. The curves correspond to five impulse voltage waveshapes of positive and negative polarities.

The obtained results show that, for the cases considered, both the methods proposed by Shigihara et al. [10] and by Darveniza and Vlastos [6] lead to volt-time curves which are generally in good agreement with those obtained from the tests. The times to breakdown predicted using the procedure by Hileman [7] are usually much longer than the measured ones, although the maximum observed difference was 3.16 µs. In some cases both the procedures by Darveniza and Vlastos and by Hileman do not predict insulator breakdown for the lower voltage levels.

The authors' plans for further work include the evaluation of the possibility of having a unique DE model for all waveshapes and polarities. Such a model, which could be used in standards as IEEE Std 1410 [13], would certainly be useful for distribution system's designers.

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