PROSPECTIVE TRV FOR TEST DUTIES 1 AND 2 OF D.C. TRACTION 3 kV FUSES

Czucha J., Jakubiuk K., Lipski T.
Technical University of Gdansk
Gdansk, Poland

Abstract: Tests of the breaking capacity of 3 kV D.C. traction fuses shall incorporate the requirements on the prospective transient recovery voltage (P-TRV), analogous to the requirements on high voltage A.C. fuses. Up to now they are not incorporated. In the literature there is lack of data on required P-TRV for 3 kV D.C. traction. The paper summarises preliminary investigations carried out recently in Polish railways system and in one Polish test plant on mentioned P-TRV. The following methods of the P-TRV identification recommended by 56 IEC, 1987, have been used: no-load switching of test circuit, capacitance current injection, calculation from circuit parameters. Moreover small fuse rated current method was also applied. In this method switching of test circuit on short-circuit realised by a fuse of rated current 1 A and 3 A has take place. The major conclusion is that the quantitative data on P-TRV in case of 3 kV D.C. are more severe than for 3.6 kV A.C. The paper suggests streepness of P-TRV ab 500÷850 V/μs for the test duty 1 and ab. 150 V/μs for the test duty 2. Corresponding maximum values are 1.3÷1.7 U_n and 2 U_n respectively. The paper does not give suggestions about the P-TRV for test duty 3 because lack of such investigations. Finally the paper specifies the problems facing by identification of the P-TRV of 3 kV D.C. traction systems.

I. INTRODUCTION

In the case of high voltage (h.v.) current limiting A.C. fuses the breaking capacity tests shall be performed at a prescribed prospective transient recovery voltage (P-TRV). IEC 282-1, 1994, Standard [1] strongly requires a defined P-TRV, particularly during the test duties 2 and 3. It seems, for D.C. 3kV traction current-limiting fuses also a P-TRV should be defined. By now there is lack of such requirements on both state and international level. Also the requirements of particular railway managements do not define the P-TRV. It can create a problem how to test these fuses to fulfil the user requirements on P-TRV and have the comparable results of tests in different laboratories.

Particular railway management requires the breaking capacity tests using several currents too. Often these currents are limited to the test duties 1,2 and 3, understood as for h.v. A.C. current limiting fuses [1]. Decipher of the duties is: 1-rated breaking capacity, 2-breaking capacity within maximum arc-energy, 3-minimum breaking capacity. But some railway managements additionally require the breaking capacity of a short and long line short-circuit tests. In every case prescribed circuit parameters, i.e. source voltage, prospective current, time-constant are realised by the test's plant using different technical means. As a result, by the same parameters, the P-TRV can vary in wide limits.

The P-TRV of a 3 kV D.C. traction system can be absolutely different than that of 3.6 kV A.C. systems. A reason are the capacitances. In D.C. system an essential role play the filter condensers of semiconductor A.C./D.C. inverters, capacitance of which is significant, for example, of order several tenths μF and resonance frequency 300 Hz, 600 Hz, 1200 Hz a.s.o. (Fig. 1). Moreover, the line capacitance of 3 kV D.C. trolley line is ab 14 nF/km whereas of 3.6 kV A.C. systems is ab. 8 nF/km. Additionally to consider is an enhanced equivalent capacitance between the metallic roof of trains and the trolley. Moreover relatively significant are capacitances of the condensers built-in train filters of impulse train drives and lighting protection.

All this indicates that the frequency characteristics of the P-TRV in 3 kV D.C. traction should be complex ones, demonstrating several resonance frequencies.

Finally, it should be noted that, in principle, the test duty 1 of fuses has to be made with the defined values of P-TRV too. However, the current limiting fuses subjected to the test duty 1 usually due to hot fulgurite conductance are not sensitive to P-TRV circuit characteristics. The exception are fuses which generate the highest arc voltage immediately after initiation of the arc. Such behaviour normally show the fuse-links

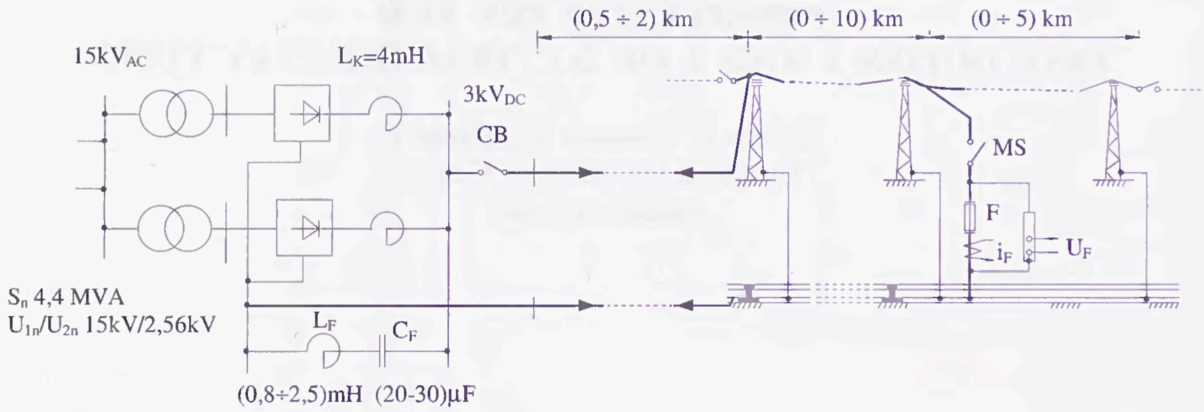


Fig. 1. Typical 3 kV D.C. traction feeding system; L_F - filter inductance, C_F - filter capacitance, CB - station circuit breaker, MS - making switch used during tests, F - fuse used during tests, i_F - current record, U_F - voltage record

of smaller rated currents, usually up to dozen A. The fuse-links of that rated currents prevail in 3 kV D.C. traction application. On the other hand, by the test duties 2 and 3, as it shows the A.C. test practice, the fuses irrespective of the fuse rated current are susceptible on applied P-TRV characteristic. Same behaviour one can expect in the case of 3 kV D.C. traction.

So bearing in mind all said above, the authors recently carried out several tests and simulations on the P-TRV in 3 kV D.C. traction system in Poland and of one Polish test plant.

II. METHODS OF P-TRV DETERMINATION

According to 56 IEC 1987, Appendix GG [2] the basic methods for determining the P-TRV waveforms for h.v. circuit-breakers tests are classified as follows:

- Group 1 - Direct short-circuit breaking.
- Group 2 - Power-frequency current injection.
- Group 3 - Capacitance current injection.
- Group 4 - Model networks.
- Group 5 - Calculation from circuit parameters.
- Group 6 - No-load switching of test circuits including transformers.

These same methods are recommended for h.v. A.C. fuses [1]. It seems, there is no obstacle to appy them also in the case of 3 kV. D.C. traction systems.

During described investigations only three of above mentioned methods were applied, viz.:

1. - No-load switching of test circuit.
2. - Capacitance current injection.
3. - Calculation from circuit parameters.

Beyond this also a small rated current fuse method [3] was also applied. The fuse-element of such fuses, after the MS (Fig. 1.) switching on, due to short-circuit current immediately explodes and interrupts the circuit within microseconds time. A cold conductor explosion is not associated with the arcing phenomena. This method, however, resembles no-load switching method, on the other hand, resembles also a direct short-circuit breaking one, mentioned in the Group 1. The use of switching on a fuse will be presented together with no-load switching.

II.1 No-load switching of test circuit

Using this method the following tests were carried out in:

a) - a real railway trolley system fed by A.C./D.C. inverter equipped within filter arrangements (Fig. 1),

b) - a test plant without filter arrangements but with extremely large prospective short-circuit current adjusted by a resistance and inductance.

In the case *a* the circuit-breaker CB (Fig. 1), normally used for outgoing feeder protection, was switching on as a making-switch to get P-TRV across fuse terminals on:

1) - an unloaded trolley overhead line directly connected to the steel rail throughout a fuse F, but with removed fuse-link,

2) - as above but with installed 1A, 3 kV D.C. standard fuse-link.

Then analogous, as in p. 1 and 2 above, also next two switching on combinations were performed, but keeping the circuit-breaker CB in closed position, whereas the making switch MS was performing the switching on operations.

Records of P-TRV were also obtained in doing similar tests in a test plant according to item *b* above. The only difference was 3 A fuse rated current instead 1 A.

II. 2 Capacitance current injection

A special indicator working on the capacitance current injection base [2], has been used to identify the P-TRV, but only in the case of a 3 kV D.C. test plant mentioned in II.1.b). Indicator capacitance with C_0 = 130 μF (Fig.2) was pre-charged to the voltage 100 V. It has been evaluated that C_0 value is much greater than the capacitance of the tested circuit. So the last can be neglected by considering the test result. After changing position of the switch P from *1* into *2* the capacitor is discharged through impedance of the test circuit. Thanks to a specially selected diode the current flow ended nearly exactly in first current zero of its natural frequency.

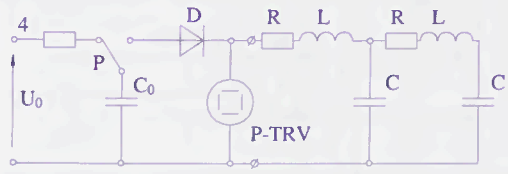


Fig. 2 Scheme of indicator to measure of P-TRV by use of capacitance current injection method; U_0 - D.C. charging voltage; P-turn over switch; C_0 - pre-charged capacity; Sh - shunt; D - nearly „ideal" diode; R, L, C, r - parameters of test plant

II.3 Calculation from circuit parameters

The calculations pertain to the scheme given in Fig. 3, which is equivalent to the shown in Fig. 1

During numerical modelling arise the problem of identification of the parameters of circuit elements. Basic parameters of the traction 3 kV D.C. network are more or less known. However, the resistance R_i and conductance G_i can vary due to skin effect (R_i), inductive couplings, contamination (G_i), a.s.o. Also a problem is with the identification of C_i and L_i in respect of magnitudes and mutual relation between them of particular circuit components. Superimposed resonance frequencies of the individual system members can have a substantial influence on the P-TRV.

In the case of small fuse rated current method a very troublesome problem is how to model the real making - switch MS (Fig.1) and fuse F. In case of MS, during the contact approaching, the air gap can get break down by 3 kV D.C., before the final contact making. However, the time duration of a possible spark or a glow partial discharge can lasts some tenths or even hundred microsecond only, but this time is essential in respect of the discharge phenomena interference on the P-TRV recorded. The interference is possible due to instabilities in the mentioned discharge.

Moreover, how to model the possible contact bounce of the MS, arising immediately after their first touch. All these troublesome problems were omitted in the calculations, assuming an ideal MS.

Also modelling of the fuse-link operation of rated currents 1A and 3A, particularly the discharge arising in it, is a very hard task. In the simulations, the fuse discharge problem was solved by taking some variable resistance.

III RESULTS OF INVESTIGATIONS OF P-TRV

Several characteristic results (Table 1, Figs. 4÷12), using all given above four methods of P-TRV identification, indicate a wide range of the measured parameters. In turn the calculation for a small fuse rated current (No 4) shows only a qualitative but acceptable agreement with the test results given under No 3.

Generally, the results do not allow to point out completely convincing conclusion on recommended parameters of P-TRV for the breaking capacity tests of 3 kV D.C. current-limiting fuses. In spite of that several positive statements can be pushed forward.

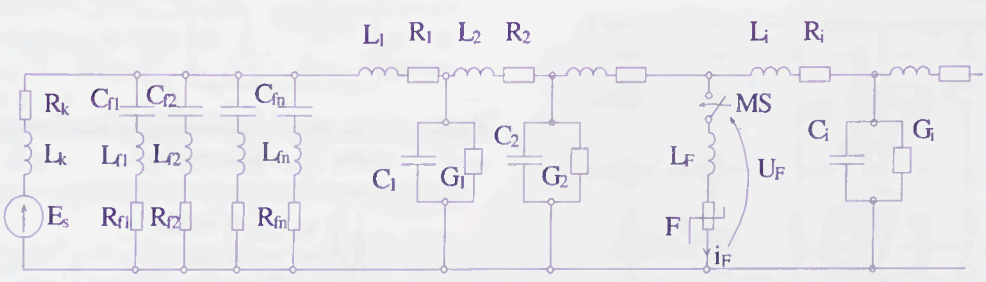


Fig.3 Equivalent scheme of traction system given Fig.1 taken into considerations of P-TRV; E_s - mean value of rectified voltage; L_K, R_K - parameters of cathode chock; C_{fn}, L_{fn}, R_{fn} - parameters of n-branch of filter; L_i, R_i, C_i, G_i - parameters of feeding cables and traction network; L_F - inductance of fuse F branch; U_F, i_F - voltage across and current of fuse

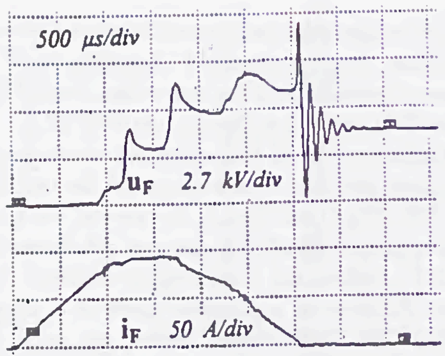


Fig.4. Test record No.1 using small fuse rated current in test plant. U_F, i_F - fuse voltage and current

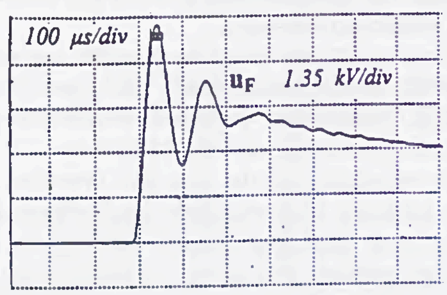


Fig.5. Test record No.2 using no load switching in test plant. U_F, - fuse voltage

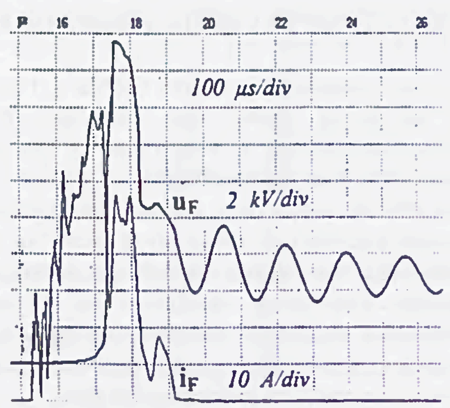


Fig.6. Test record No.3 using small fuse rated current in traction network. U_F, i_F - fuse voltage and current

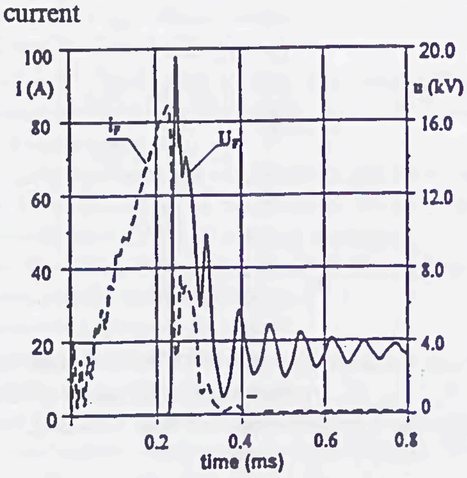


Fig.7. Profiles of calculation results (No.4) using small fuse rated current (1) in traction network. U_F, i_F - fuse voltage and current

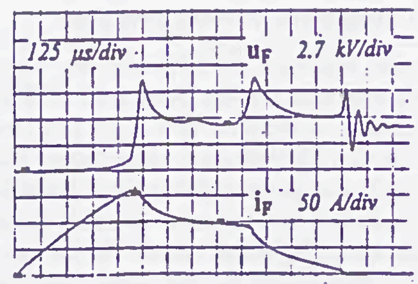


Fig.8. Test record No.5 using small fuse rated current in test plant. U_F, i_F - fuse voltage and current

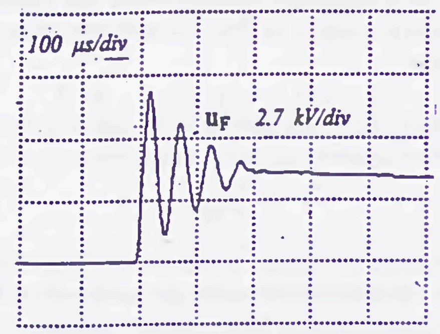


Fig.9. Test record No.6 using no load switching in test plant. U_F, - fuse voltage

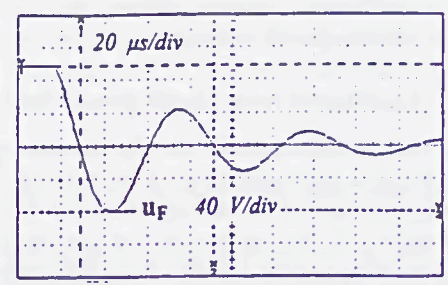


Fig.10 Test record No.7 using capacitance injection in test plant. U_F, - fuse voltage

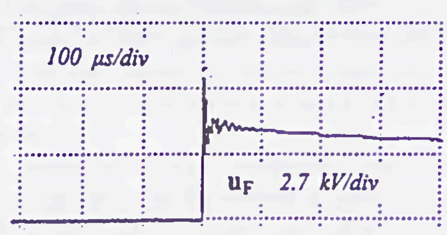
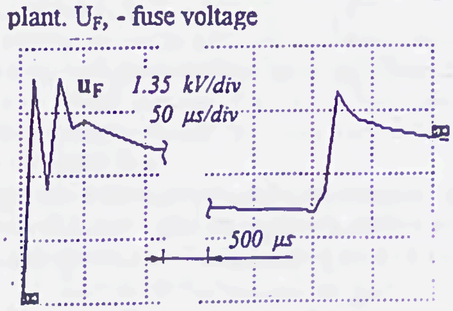


Fig.11. Test record No.8 using no load switching in test plant. U_F, - fuse voltage



Fi.12. Test record No.2 using no load switching in test plant. U_F, - fuse voltage

Table 1. Results of P-TRV measurements in 3 kV D.C. test plant, real trolley traction network and exemplary calculations

No.	Measurement method	Place of test	Fig	Circuit parameters					Results of measurement				
				U_n	I_p	R	L	L/R	U_c	t_c	U_c/t_c	U_c/U_n	$f_{P\text{-}TRV}$
				kV	kA	•	mH	ms	kV	µs	kV/µs	–	kHz
1.	small fuse	test plant	4	4.0	1.67	2.4	39	16	10.2	60	0.17	2.5	8.7
2.	no load on	test plant	5	3.6	1.67	2.4	39	16	6.5	50	0.13	1.8	10
3.	small fuse	tr. network	6	3.4	~3.1	~1.1	~16	15	7.6	68	0.11	2.2	7.4
4.	calculations	tr. network	7	3.4	3.1	1.1	16	15	6.8	56	0.12	2.0	8.7
5.	small fuse	test plant	8	4.0	3.3	1.2	13	11	8.1	28	0.29	2.0	18
6.	no load on	test plant	9	3.8	3.3	1.2	13	11	7.6	25	0.30	2.0	~20
7.	capac. inject.	test plant	10	4.0	3.3	1.2	13	11	7.2 1)	24	0.25	1.8	16
8.	no load on	test plant	11	3.8	3.0	1.2	3	2.5	5.7	6.5	0.87	1.5	~75
9.	no load on	test plant	12	3.8	45	0.07	1.6	24	4.9	10	0.49	1.3	20
10.	IEC 282 - 1,	3.6 kV A.C. 2)		3.6	I_1	cos• =0.07		45	6.2	40	0.15	1.2	~12
11.	1994				I_2	- 0.15		- 21	6.6	140	0.05	1.3	~4

Denotations: U_c - peak value of P-TRV; t_3 - time to peak value of P-TRV; U_c/t_3 - mean value of steepness of P-TRV; U_c/U_n - overvoltage coefficient; $f_{P\text{-}TRF}$ - equivalent frequency of P-TRV;

Notes: 1) - calculated for equivalent 4 kV network voltage

2) - given for comparison under No.10 and 11 A.C. data are taken from IEC 282-1,1994 for A.C. h.v. current limiting fuses

P-TRV in a 3 kV D.C. trolley traction systems, in a comparison with 3.6 kV A.C. systems, can demonstrate faster increase up to the voltage maximum. As a result one can suggest U_c/t_3 in the limits ab 500÷850 V/µs for the interrupting tests of the prospective currents of order few kA. This suggestion, it seems, should be correct for the test duty 1, i.e. for the rated breaking capacity of fuses. Moreover it can be suggested U_c in the range ab 1.3÷1.7 times fuse rated voltage U_n. In turn, for the test duty 2 can be proposed for further considerations U_c/t_3 = ab 200 ÷ 300 V/µs and U_c = ab 2 U_n. Unfortunately because of lack a such tests the results do not allow to state some corresponding values of U_c/t_3 nor U_c for the test duty 3.

The problems arising during endeavourings to identify desirable parameters of P-TRV lays in several specific features of 3 kV D.C. traction systems. They are:

- complicated structure resulting in multi-frequence P-TRV (Fig.3),
- substantial influence of the filter capacitances (Fig.1),
- experimental results in the case of small fuse rated current (Figs. 6, 8) additionally can get some very serious interferences of U_F - trace at least from the commutating processes in making-switch MS (Figs. 1 and 12),
- in the calculations practically it is not possible to model metioned switching processes,
- from just mentioned reasons a simple comparison of the results of experiments and calculations is not realistic one.

IV FINAL STATEMENTS

The results given above obviously are not final ones. But they confirm the authors conviction that the P-TRV for the breaking capacity test of 3 kV D.C. traction fuses shall be defined and therefore it is still a problem for further investigations. In this context are desirable similar more extensive investigations in the railway systems not only the Polish one.

ACKNOWLEDGEMENTS

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REFERENCES

[1] IEC 282-1 "High voltage fuses, Part 1: Current limiting fuses",1994.

[2] 56 IEC 'Methods of determining prospective transient recovery voltage",1987.

[3] T. Lipski, "Fuse switching overvoltage as a killing shot of an aged h.v. cables electrical insulation". XI Symp. On Electrical Discharges in Gases. Pasym. Poland, 1987, p. 278-292