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Application of new pass criteria for SPD during water immersion test

***Abstract**. The article presents the research, which was to compare existed criteria in standards for the assessment of the water immersion test for low voltage overhead surge protective device. Assessment of the influence of environmental conditions, especially the influence of moisture penetration on the proper operation of surge arresters, is extremely important for their durability. For this purpose, laboratory tests were carried out and the obtained results were analyzed and compared with the test evaluation criteria existing in the standards.*

***Streszczenie.** W artykule przedstawiono badania, których głównym celem było porównanie istniejących w normach kryteriów oceny próby zanurzenia w wodzie dla napowietrznych ograniczników przepięć niskich napięć. Ocena wpływu warunków środowiskowych a szczególnie wpływu wnikania wilgoci na właściwą pracę ograniczników przepięć jest niezwykle istotna dla ich trwałości. W tym celu przeprowadzono badania laboratoryjne a uzyskane wyniki, poddano analizie i porównano z istniejącymi w normach kryteriami oceny prób. (**Zastosowanie nowych kryteriów oceny próby wnikania wody dla ograniczników przepięć - SPD**).*

Keywords: SPD, water immersion test, surge arrester, leakage current
Słowa kluczowe: SPD – urządzenie ograniczające przepięcia, próba zanurzenia w wodzie, ogranicznik przepięć, prąd upływu

Introduction

Surge Protective Devices (SPD) are used in low voltage power distribution and transmission network to protect system against atmospheric surges, temporary overvoltages, switching operation surges. The SPDs, which are mounted in the outdoor overhead lines, mostly are metal-oxide surge arresters without gaps. These SPDs are exposed to weather conditions stress: uv radiation, air, water and variable temperature. These conditions may cause that the moisture ingress to the inside of the SPDs - it may lead to increase the leakage current resulting in may cause developing short-circuit current. It is very important that enclosures of the SPDs should ensure no ingress of the moisture. The standard dedicated for polymer-housed surge arrester [3] claims that they ensure protection from the ingress of the moisture but standard for outdoor SPD [1] and [2] do not claim that.

Some papers show that water immersion test is very import ant test for ensure the long life of the constructions of the polymer-housed surge arresters: in the publications [4] and [5] authors observed influence of moisture on the tightness of the surge arrester what was visible by increasing of the power losses tested surge arresters during test.

The following studies are intended to show whether the water immersion test should be obligatory. Two variants of the proposal of the verification according to which the study was conducted, and the source of their origin, are shown in table1.

Comparison of the exist and proposal variants of the pass criteria water immersion test

Verify, that the interior of the SPD was penetrated by the water, based on the comparative tests. Analyzing test results before and after water immersion test can try to draw conclusions, how worsened the electrical parameters of SPD's.

Description of the laboratory tests

The water immersion test described in the standard [1] (cl. F2) is performed in accordance with guidelines from [3]. The test samples shall be kept immersed in boiling de-ionized water with the NaCl (1kg/m^3), for 42 hours. After this time, the SPD's shall remain in the vessel until the water has cooled down to 20°C (±15 K) and shall be stay in the water till verification tests are performed.

Table 1. Comparison of the variants of the evaluation of water immersion test

	Variant of the test evaluation no. 1 - existing in standard	Variant of the test evaluation no. 2 - new proposal	Variant of the test evaluation no. 3 - new proposal
References	Acc. EN 61643 - 11:2012 Described in Annex F, clause F3	Acc. EN 60099-4 2014 (10.8.11.3.2) For the analogous test of polymer-housed surge arresters for medium and high voltage system	Acc. EN 61643-11: 2012 (Table 4. Pass Criteria B, D and E)
Pass criteria	Criterion 1: Test result is passed when the leakage current measurement between parts of the enclosure, which are tightly wrapped in conductive foil, and all terminals connected together is lower than 25 mA	Criterion 1: The increase of the power losses measured at Uc from the initial measurements is not more than greater of 20 mW/kV(Uc) or 20% Criterion 2: change of the residual voltage before and after is not more than 5%	Criterion 1: (Pass criterion B) Voltage and current records and visual inspection shall show no indication of puncture or flashover. Criterion 2: (Pass criterion D) Values for measured limiting voltage after the test shall be below or equal to voltage protection level. Criterion 3: (Pass criterion E) Resistive component of the leakage current measured at the reference test voltage U_{REF}* shall not exceed a value of 1 mA, or the current shall not have changed by more than 20% compared to the initial measurements.

*) U_{REF}– acc. to [1] cl. 3.1.45 – r.m.s. value of the voltage used for testing which depends on the mode of protection of the SPD, the nominal system voltage, the system configuration and the voltage regulation within the system.

After this test the samples should be subjected the dielectric test according to [1] (cl. F1) – the tested samples (SPD with non-conductive housing with non-conductive or without mounting bracket) shall be tightly wrapped in conductive foil to within 15 mm of any non-insulated lead or terminal. The samples shall be subjected to a dielectric test at a power frequency sinusoidal voltage of 1000 V + $2 \cdot U_{REF}$ for 60 s and the measured leakage current during test shall be lesser than 25 mA. The required test voltage shall be applied between the conductive foil and all terminals or external leads connected together.

In the standard [3] the water immersion test is one of the parts of the bending moment test - it is last part of the all test sequence: after bending moment test with specified short-term load (SSL), terminal torque preconditioning, thermo-mechanical preconditioning with specified long-term load (SLL). The procedure to perform the water immersion test is the very same as was described above- different is in the value of the temperature up to cool down of the water- 50°C. Before and after bending moment test should be measured: watt losses measured at U_c, internal partial discharge and residual voltage - the arrester shall passed the test among others if :

-the increase in the watt losses, measured at U_c is not more than the greater of 20 mW/kV(U_c) measured at U_c or 20%- final measurement has to carry out 8 h after cooling,

- the internal partial discharge measured at 1,05 U_c doesn't exceed 10 pC,

- the residual voltage measured at the same current value measured after test is not more than 5% different from the initial measurement.

The laboratory practice show that hardest to meet requirements applying increase of the watt losses - this measurement can be treated as indicators

For the experimental testing program in this study a total of 21 commercially available SPD (Class II) were chosen from 5 different manufacturer (15 samples have polyamide enclosures, 3 samples have silicone enclosures and 3 samples have ceramic enclosures) - see Table 2.

For these object was carried out initial measurement:

- measurement of the resistive component of the leakage current at the reference test voltage (r.m.s. value of the voltage used for testing which depends on the mode of protection of the SPD, the nominal system voltage, the system configuration and the voltage regulation [1] - for all the tested SPD the U_{REF} = 255 V) measured at the crest of the sine wave, because this measurement is used in this standard commonly as one of the pass criteria for the tests.

- watt losses measured at U_c,

- residual voltage at the nominal discharge current I_n.

After initial measurement the tested samples were immersed in the water for 42 hours.

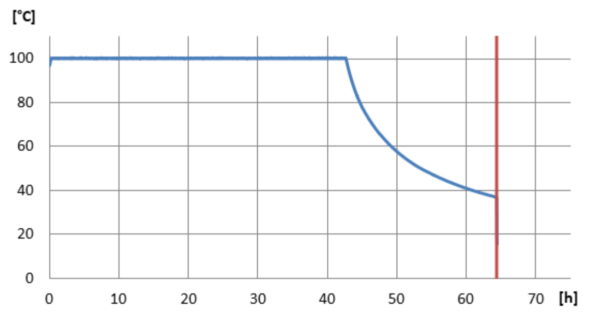

Fig. 1. Variation of the temperature of the water during water immersion test

After 42 hours the temperature of the boiling water was cooled down to 35°C and then the tested objects were removed from the water. Next the SPD's were cleaned water and dried. After cooling within 8 hours were carried out the verification tests:

- measurement of the resistive component of the leakage current at the reference test voltage
- watt losses measured at U_c,
- leakage current measurement between parts of the enclosure, which are tightly wrapped in conductive foil, and all terminals connected together.

Residual voltage at the nominal discharge current I_n was measured in another time (beyond time 8 h).

Test circuits used for tested surge protective devices.

Test circuit used for measure residual voltage U_{RES}, was shown on fig. 2.

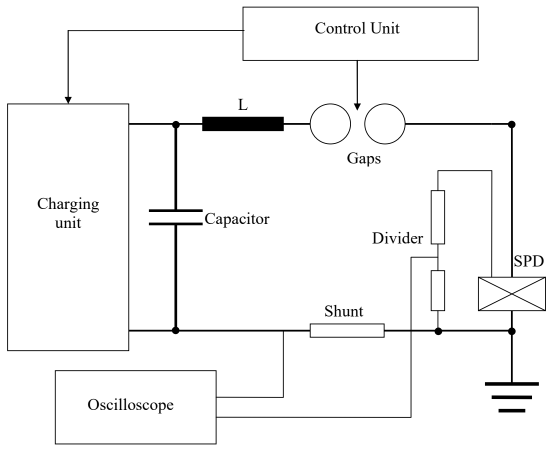

Fig. 2. Electric circuit to measure the residual voltage U_{res}

Test circuit used for measure leakage current, was shown on fig. 3.

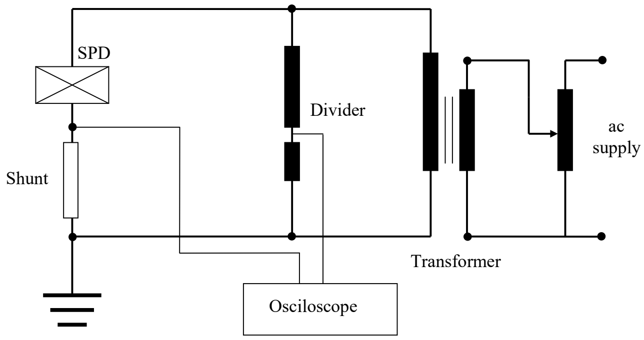

Fig. 3. Electric circuit to measure the leakage current

On Fig. 4 was show flow chart of the test system for the water immersion test.

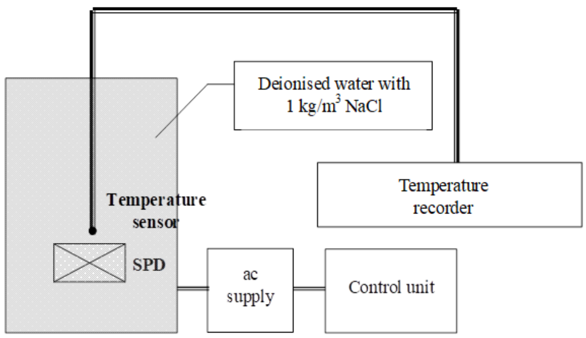

Fig. 4. Flow chart of the test system for the water immersion test

Test results

The test results of laboratory tests are shown in the drawings and tables below.
Figure 5 - 7 shown the example of the measurements of the power losses and resistive component of the leakage current.

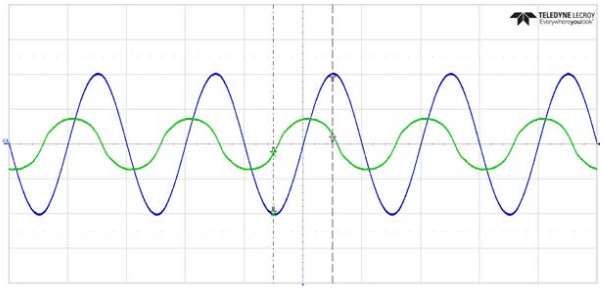

Fig. 5. Measurement of the power losses (18,9 mW) at U_c = 280 V for samples no.7 - before test - green trace presents the leakage current (0,5 mA/div)- blue trace shows the voltage (200 V/div)-(10 ms/div)

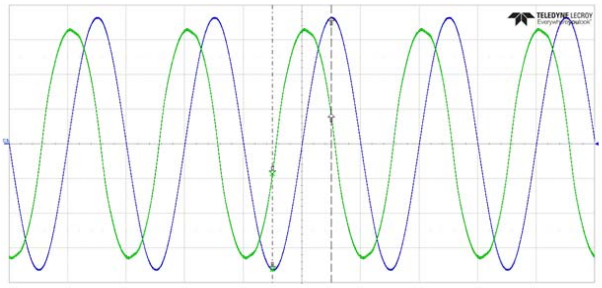

Fig. 6. Measurement of the resistive component of the leakage current (85,69 mA) at U_{REF}=255 V for samples no.7 - before test; green trace presents the leakage current (0,1 mA/div)- blue trace shows the voltage (100 V/div)-(10 ms/div)

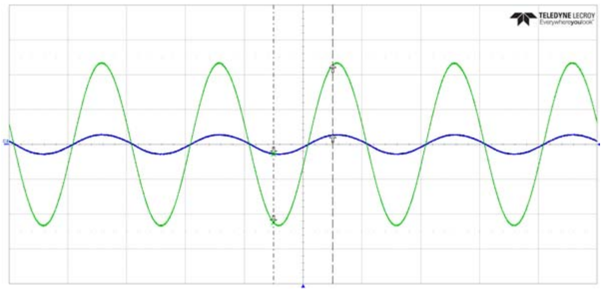

Fig. 7. Measurement of the leakage current (23 mA) and power losses at lower voltage (19,82 V) after test, because the current is very high compared with measurement before test; green trace presents the leakage current (10 mA/div)- blue trace shows the voltage (100 V/div)-(10 ms/div)

Table 2. Rated data and characteristics of the tested objects

Samples	A1-A3	B4-B6	C7-C9	D10-D12	E13-E15	F16-F18	G19-G21
U_c [V]	280	440	280	280	440	500	500
I_n [kA]	5	10	10	5	10	10	10
Housing	porcelain	silicone	poliamide	poliamide	poliamide	poliamide	poliamide

Table 3. shown the comparison of the measurement of the resistive component of the leakage current I_r before and after water immersion test.

Table 3. Comparison of the measurement of the resistive component of the leakage current I_r before and after water immersion test; (the yellow area means that the I_r was measured at the lower value of the voltage than $\mathbf{U_{REF}}$ because the value of the I_r was very high)

Samples	Before test		After test		Result
	U_{REF} [V]	Ir [μA]	U_{REF} [V]	I_r [μA]	I_r exceeds 1 mA
A1	257,3	49,51	**256,9**	48,46	no
A2	256,8	40,73	**25,6**	21380	**yes**
A3	255,7	44,54	**25,5**	22134	**yes**
B4	256,4	30,15	**256,5**	36,36	no
B5	256,2	27,21	**256,5**	35,51	no
B6	256,4	33,21	**255,3**	42,7	no
C7	256,3	85,69	**19,8**	22756	**yes**
C8	256,7	76,69	**20,1**	22370	**yes**
C9	257,1	70,83	**16,0**	21864	**yes**
D10	257,2	20,51	**228,6**	23249	**yes**
D11	257,2	19,68	**199,3**	22735	**yes**
D12	257,3	15,39	**145,4**	22083	**yes**
E13	257,0	6,89	**258,3**	10,08	no
E14	257,0	6,96	**258,1**	10,08	no
E15	257,0	5,9	**258,1**	9,38	no
F16	256,7	18,36	**22,6**	20581	**yes**
F17	256,7	16,35	**16,6**	21946	**yes**
F18	256,7	17,58	**16,2**	21699	**yes**
G19	256,6	37,7	**253,9**	19594	**yes**
G20	256,7	34,56	**256,2**	1274	**yes**
G21	256,3	46,66	**256,6**	5563	**yes**

Table 4 contains the results based on variant of the test evaluation number 2.

Table 4. Comparison of the measurement of the watt losses measured at U_c before and after water immersion test; ($\Delta P = (P_{at}-P_{bt})/U_c$ where P_{at} – power losses after test, P_{bt} – power losses bef ore test ΔP – The increase in watt losses, measured at U_c should not more than greater 20 mW/kV or 20%)

Samples	Before test		After test		ΔP	Result
	U_c [V]	P_{bt} [mW]	U_c [V]	P_{at} [mW]	[mW/kV]	ΔP≤20 mW/kV
A1	280,6	9,731	282,3	11,798	7,38	passed
A2	280,7	11,656	25,62	396,179	1373,30	not passed
A3	286,2	12,349	25,5	404,008	1398,78	not passed
B4	441,3	38,918	442,2	41,11	4,98	passed
B5	445,1	35,049	441,6	38,57	8,00	passed
B6	447,2	49,83	443,1	55,76	13,48	passed
C7	284,7	18,905	19,82	326,588	1098,87	not passed
C8	286,5	18,29	20,06	327,214	1103,30	not passed
C9	281,3	15,075	16,02	261,441	879,88	not passed

D10	283	**3,986**	228,58	**3415**	12182,19	not passed
D11	287,8	**4,058**	199,3	**2916**	10399,79	not passed
D12	281,4	**2,699**	145,44	**2227**	7943,93	not passed
E13	440,8	**2,665**	441,4	**4,027**	3,10	passed
E14	444,8	**2,6**	443,4	**4,960**	5,36	passed
E15	441,5	**2,766**	444,5	**4,389**	3,69	passed
F16	502,3	**17,571**	22,59	**325,68**	616,22	not passed
F17	502,9	**17,272**	16,57	**271,782**	509,02	not passed
F18	501,8	**16,423**	16,18	**261,78**	490,71	not passed
G19	503,3	**36,588**	253,89	**3285**	6496,82	not passed
G20	506,8	**32,383**	256,16	**211,764**	358,76	not passed
G21	502,3	**45,684**	256,64	**901,136**	1710,90	not passed

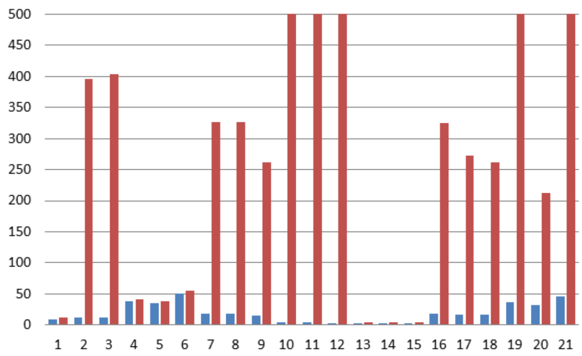

Fig. 8. Power losses before (red) and after (blue) water immersion test (power losses were measured in [mW])

Table 5. The measurement of the leakage current, which flow between all terminals connected together and conductive foil, which was tightly wrapped on the housing

Samples	**U_{test} [kV]**	**I_L [μA]**	**Result**
			I_L> 25 mA
A1	1,510	11,5	no
A2	1,523	10,6	no
A3	1,527	21,6	no
B4	1,535	6,7	no
B5	1,532	7,2	no
B6	1,518	6,6	no
C7	1,524	666,8	no
C8	1,524	457,4	no
C9	1,538	432,9	no
D10	1,533	983	no
D11	1,515	195,8	no
D12	1,515	272,2	no
E13	1,527	59,7	no
E14	1,514	92,8	no
E15	1,518	57,44	no
F16	1,504	291,7	no
F17	1,504	246	no
F18	The surface of the SPD has conducted.		**yes**
G19	1,527	558,3	no
G20	1,498	475,3	no
G21	1,576	508,3	no

Figures 9 - 10 contain examples of the measurement of the residual voltage for samples no.17.

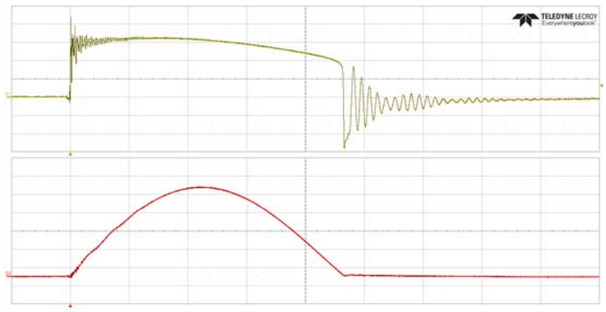

Fig. 9. Measurement of the residual voltage for samples no.17. before test; red trace present the discharge impulse current (9,8 kA- 2 kA/div) – 5 μs, yellow trace shown the residual voltage (1656 V) (500 V/div)- visible differences between traces before test and after test

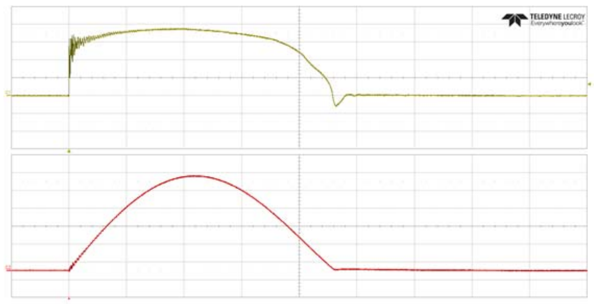

Fig. 10. Measurement of the residual voltage for samples no.17 after test; red trace present the discharge impulse current (10,64 kA- 2 kA/div) – 5 μs, yellow trace shown the residual voltage (1889 V) (500 V/div)- visible differences between traces before test and after test

The residual voltage at nominal current was measured before and after the test. One samples (no.17) was punctured. Three samples had change of the residual voltage (before and after test) greater than 5%- after test the residual voltage was smaller about 43 % for sample no. 7 and about 6% for samples no.1 and no.2. These 3 samples didn't meet the requirements described in criterion 2 in variant of the test evaluation no. 2 (see Table 1).

Discussion about test results

Analyzing the results of laboratory tests can be stated that:

1. Most of SPD tested in the water immersion test (20 of 21), acc. standard [1] shown fulfill pass criteria. (variant of the test evaluation no. 1) The pass criteria allow for the assessment of surface resistance of the material from which the enclosure is formed to weather conditions (moisture).
2. A much more effective tool for the evaluation of the fact that moisture gets into the housing SPD is either measuring the power dissipated at a continuous operating voltage (acc. variant of the test evaluation no. 2) or measuring the resistive component of the leakage current (acc. variant of the test evaluation no. 3). Only 7

of 21 samples fulfilled these criteria. Significant increase in power loss or the resistive component of the leakage current can attest to the fact that the design of the SPD may be susceptible to moisture ingress in exploitation conditions, which may ultimately lead to its failure.

Table 6. Comparison of the proposals of the test evaluations and the test results

	Variant of the test evaluation no. 1 - existing in standard	Variant of the test evaluation no. 2 - new proposal	Variant of the test evaluation no. 3 - new proposal
References	Acc. EN 61643-11:2012 Described in Annex F, clause F3	Acc. EN 60099-4 2014 (10.8.11.3.2) For the analogous test of polymer-housed surge arresters for medium and high voltage system	Acc. EN 61643-11: 2012 (Table 4. Pass Criteria B, D and E)
Comparation of the test result	20 samples of 21 met requirements	Criterion 1: 7 samples of 21 met requirements Criterion 2: 17 samples of 21 met requirements	Criterion 1: 20 samples of 21 met requirements Criterion 2: 20 samples of 21 met requirements Criterion 3: 7 samples of 21 met requirements
Results	20 samples of 21 passed the test	7 samples of 21 passed the test	7 samples of 21 passed the test

Conclusions

In the standard [1], procedure of the water immersion test is described as informative in annex F. Besides this test is only checking the resistance of the surface of the enclosure (material) to weather conditions (water with NaCl). The pass criterion for this test ignore possibility of the water penetration inside SPD-the occurrence of this phenomenon can lead to the development of short-circuit current. The above-described tests show that the enclosure of the tested SPD's does not provide protection against the ingress of moisture inside. The introduction of new pass criteria (basing on the guidelines for polymer-housed surge arrester in the standard [3]: measurement of power losses or the resistive component of the leakage current) for the water immersion test enforces manufacturers to improve the tightness of housings of the SPD's.

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