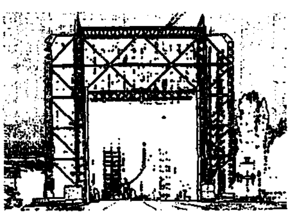

NINTH INTERNATIONAL SYMPOSIUM
ON HIGH VOLTAGE ENGINEERING

August 28 - September 1, 1995

GRAZ CONVENTION CENTER
AUSTRIA, EUROPE

9th ISH

INFLUENCE OF HIGH VOLTAGE INSULATOR POSITION ON POLLUTION FLASHOVER VOLTAGE

J.G. WAŃKOWICZ   Z. POHL

INSTITUTE OF ELECTRICAL ENGINEERING FUNDAMENTALS
TECHNICAL UNIVERSITY OF WROCŁAW, WROCŁAW, POLAND

Abstract

Results of pollution flashover voltage measurements and optical observation obtained for high voltage insulators placed in the vertical and the horizontal positions are presented. It was found that the well known difference between flashover voltages measured in tests of insulators placed in these positions was a function of the mean contaminant thickness and the uniformity of layer distribution on the insulators. On the basis of measurements of the ESDD conducted on insulators subjected to prolonged, natural contamination, their selfcleaning, in the vertical and horizontal positions, was determined.

1. Introduction

Electrical power engineers are of the general opinion that the flashover voltage for horizontally placed HV insulators is higher than for those placed in the vertical position. This effect can be explained by the better self-cleaning of horizontally placed insulators as well as by the elongation of moving arcs over the insulators. Some valuable data concerning this subject can be found in professional papers [1,2]. In order to complete it the results of systematic investigations of high voltage insulators placed in the vertical and the horizontal positions are presented in this paper. Tests have been conducted on ceramic cylindrical insulators and longrod insulators contaminated with solid layers using an auxiliary device in order to obtain uniform layers of reproducible parameters. They were so-called "thick" uniform layers, and layers of reproducible nonuniformity. In should be remarked that such a selection of the layers in the experiment is well justified by the periodically different accumulation of natural contaminant by the high voltage insulators.

2. List of symbols

SDD - the salt deposit density expressed in mg/cm^2
γ - the volume conductivity of deposited mixture expressed in μS/cm
h - the mean pollution deposit thickness on the insulator
S - the area of the insulator
κ_S - the mean surface conductivity determined on the basis of the probe measurements
D - the shed diameter
L - the leakage path
$U_{F50\%}$ - the 50% polluted flashover voltage
SD - the standard deviation
n - the slope of flashover voltage characteristics

3. Experimental procedure

Insulators of simple construction were selected for measurements, i.e. glazed cylinder insulators and longrod (12-shed) insulators LP 75/12 used in 110 kV overhead lines in Poland. The insulators are shown in Fig.1 (no.1 and 2 respectively). The artificial deposit was produced using kaolin mixed, in tap water, with common salt [3]. The solid layer was laid on the insulators by means of dipping into the slurry or by uniformly spraying them along their leakage paths. Spraying with the slurry and drying the insulators were performed using an auxiliary device which imparted rotation to the horizontally placed units in the range of rotational speeds between 10 and 40 rpm. (Fig.2). This method of contamination ensured uniform coating of the whole insulator surface as well as preliminary stabilization of the layer. Layers of reproducible nonuniformity were produced by dipping the insulators, drying them suspended in the vertical position. 10 insulators of each type contaminated with a dry deposit were cooled for a few hours in a cooling chamber to the temperature of -15 °C, before testing. Uniform wetting of the test objects was performed by absorption of clean fog in a wetting chamber for 20-30 min at the temperature of 25 ± 2 °C. Before the energization of the insulators (procedure A [3]) their resistance was measured, to calculate the surface conductivity. After voltage tests the SDD was measured too [3]. Flashover voltage measurements were carried out using a testing plant which complied with the requirements given in [3] and its performance in tests conducted on the LP 75/12 insulator, using " thick " layers, was presented in [4].

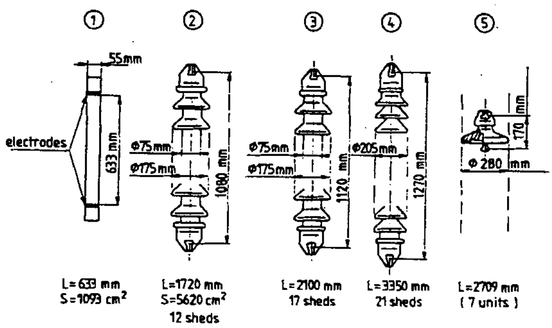

Fig.1. Shapes of insulators used in tests.
1 - porcelain cylinder, 2,3,4 - longrod ceramic insulators, 5 - string of cap- and -pin insulators (7 units)

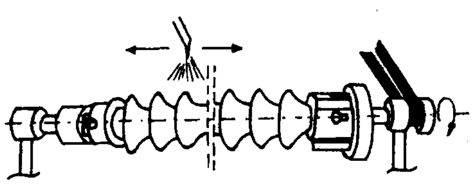

Fig.2. Contamination of rotating insulator.

Some development of the procedure applied to determine the SDD parameter enabled the measurement of the mean thickness, h, of the pollution layer on insulators or on their surface elements. This measuring method was described in [4]. Results of probe measurements of surface conductivity carried out at 18 different points of the cylindrical insulator surface and 36 points of the longrod insulator surface were used for the evaluation of layer uniformity. Movement of burning arcs along the insulator surface were carried out using a video camera. Fig.1 presents insulators no. 3,4 and 5 subjected to the self-cleaning tests under outdoor conditions. The accumulation of natural contaminant on the insulators was determined on the basis of the ESDD measurements. The insulators subjected to the measurements have been installed for 12 years at a pollution field station. The area according to [5] belongs to a very heavy polluted zone.

4. Selection of slurry composition

Investigations were carried out for the same values of the SDD parameter applying two kinds of layers, i.e. thin and thick ones. The selected compositions were as follows:
- thin layer - kaolin 40g per 1 dcm^3 of tap water + wetting agent 5 ml + NaCl [3].
- thick layer - kaolin 120g per 1 dcm^3 of tap water + Aerosil 200, 20g + NaCl.

Standard deviation of surface conductivity measurements carried out on insulators coated with the thin and thick layers was in the range of 14-17% respectively. Distributions of surface conductivity, κ_S, and mean thickness, h, along cylindrical and longrod insulators coated with the thick layer for two different methods of contamination are shown in Fig. 3. It can be concluded that more homogenous and more uniform coatings were obtained with the application of the rotating device.

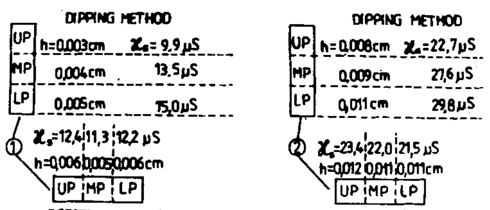

Fig.3. Surface conductivity κ_S and layer thickness h on insulator surfaces as a function of contamination methods.
1 - porcelain cylinder, 2 - longrod insulator, LP - upper part of the insulator, MP - middle part of the insulator, LP - lower part of the insulator.

5. Pollution flashover voltage of the cylindrical insulator

Fig.4 presents relationships between $U_{F50\%}$ and SDD for the cylindrical insulator (no.1 in Fig.1) contaminated with the thin layer by means of different methods. The remaining part of data measured (or calculated) in this test is given in Table I. On the basis of results presented in Fig.4 it can be seen that the flashover voltage of the horizontally placed cylindrical insulator was only insignificantly higher (about 10% for SDD equal to 0,06 mg/sq.cm) than that measured for this insulator placed in the vertical position. Details are given in Table I. The influence of applied contamination methods on the flashover voltage of the insulator was insignificant too.

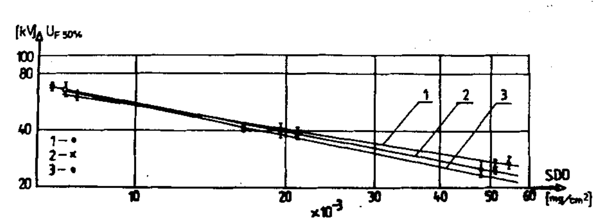

Fig.4. The relationships between $U_{F50\%}$ and SDD for the porcelain cylinder covered with the thin layer.
1 - horizontal position of uniformly polluted insulator, 2 - vertical position of uniformly polluted insulator, 3 - vertical position of nonuniformly polluted insulator

Table I

SUMMARY OF TEST PARAMETERS

Cylindrical insulator (10 units per SDD value) thin uniform layer							
Position	γ μS/cm	h cm	κ_s μS	SDD mg/cm^2	$U_{F50\%}$ kV	± SD kV	n
Vertical	4030 12000 30000	0,0016 0,0016 0,0016	2,1 6,5 15,9	0,007 0,021 0,052	66,2 39,1 27,9	1,8 1,7 1,3	0,47
Horizontal	4030 10500 30000	0,0018 0,0017 0,0017	1,5 3,5 14,6	0,008 0,020 0,055	58,8 40,3 28,0	2,2 1,3 1,1	0,40
thin nonuniform layer							
Vertical	4030 12000 30000	0,0017 0,0013 0,0015	1,4 3,5 15,6	0,007 0,017 0,048	64,2 42,7 27,3	3,4 0,5 1,1	0,49

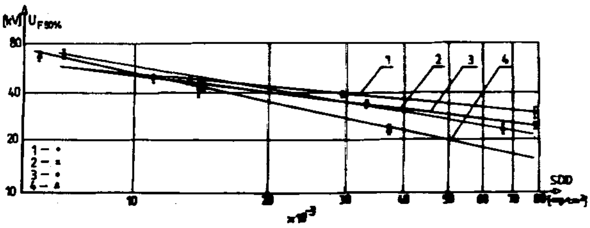

Fig.5. The relationships between $U_{F50\%}$ and SDD for the porcelain cylinder covered with the thick layer. 1 - horizontal position of uniformly polluted insulator, 2 - vertical position of uniformly polluted insulator, 3 - horizontal position of nonuniformly polluted insulator, 4 - vertical position of nonuniformly polluted insulator

Table II

SUMMARY OF TEST PARAMETERS

Cylindrical insulator (10 units per SDD value); thick uniform layer							
Position	γ µS/cm	h cm	$\varkappa_s$ µS	SDD mg/cm^2	$U_{F50\%}$ kV	SD ±kV	n
	1800	0,006	1,5	0,007	69,7	2,6	
Vertical	3500	0,014	11,1	0,033	34,3	0,5	0,46
	10000	0,010	27,0	0,068	24,3	1,8	
	1800	8,011	3,9	0,013	48,5	1,3	
Horizontal	3500	0,013	10,5	0,029	39,7	0,6	0,26
	10000	0,012	24,0	0,079	30,6	1,5	
Thick nonuniform layer							
	1800	0,005	1,5	0,006	71,5	0,1	
Vertical	3500	0,006	6,1	0,014	43,3	0,4	0,60
	10000	0,006	26,0	0,037	24,8	1,2	
	2350	0,005	5,1	0,011	51,0	0,1	
Horizontal	3500	0,006	7,1	0,014	45,0	2,2	0,35
	10000	0,012	24,0	0,080	25,5	1,3	

Optical observations carried out by means of a video camera showed that convection of the burning arc took place for lengths of the arc approaching its critical length. It is clear that the weakness of the convection effect observed here could not significantly affect the flashover voltage level. Fig.5 presents the relationships between $U_{F50\%}$ and SDD for the cylindrical insulator coated with the thick solid layer. The remaining part of data measured (or calculated) in this test is given in Table II. On the basis of the presented results it can be concluded that the difference between flashover voltage levels for the uniformly polluted insulator placed first in the horizontal and then in the vertical position was about 20 % (SDD equal to 0,06 mg/sq.cm). For the nonuniformly polluted insulator this difference was equal to 33 % (SDD equal to 0,06 mg/sq.cm).

6. Pollution flashover voltage of the longrod insulator

Fig.6 presents the relationships between $U_{F50\%}$ and SDD for the longrod insulator LP 75/12 coated with the artificial thick layer. The remaining part of data measured (or calculated) in this test is given in Table III. It follows from the presented results that the flashover voltage of uniformly polluted longrod insulators placed in the horizontal position was about 30 % (SDD equal to 0,06 mg/sq.cm) higher than measured for this insulator in the vertical position. In the case of the nonuniformly distributed layer this difference was equal to just 15,9 %. (SDD equal to 0,06 mg/sq.cm). In contrast to results presented for the cylindrical insulator, findings obtained for the longrod one

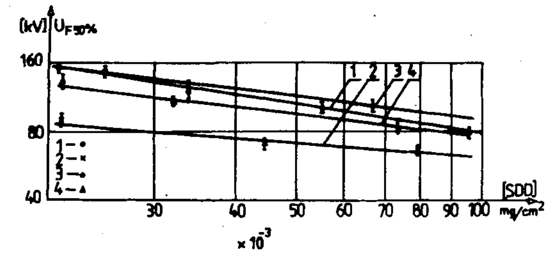

Fig.6. The relationships between $U_{F50\%}$ and SDD for the longrod insulator contaminated with the thick layer. 1 - horizontal position of uniformly polluted insulator, 2 - vertical position of uniformly polluted insulator, 3 - horizontal position of nonuniformly polluted insulator, 4 - vertical position of nonuniformly polluted insulator

Table III

SUMMARY OF TEST PARAMETERS

Longrod insulator (10 units per SDD Value); thick uniform layer							
Position	γ µS/cm	h cm	$\varkappa_s$ µS	SDD mg/cm^2	$U_{F50\%}$ kV	SD ± kV	n
	2000	0,013	10,1	0,021	94,2	3,1	
Vertical	5000	0,012	18,4	0,044	75,5	2,4	0,26
	10000	0,012	53,3	0,080	64,7	1,6	
	2000	0,017	12,3	0,025	152,4	2,7	
Horizontal	4000	0,019	27,0	0,056	103,8	4,8	0,50
	10000	0,015	54,7	0,096	79,0	2,6	
Thick nonuniform layer							
	2000	0,013	9,5	0,022	139,0	2,0	
Vertical	4000	0,012	14,7	0,032	111,3	1,8	0,34
	10000	0,013	38,3	0,073	84,2	2,0	
	2000	0,013	9,4	0,021	157,1	1,2	
Horizontal	4000	0,013	18,9	0,034	128,3	3,1	0,33
	10000	0,012	37,9	0,067	102,5	0,2	

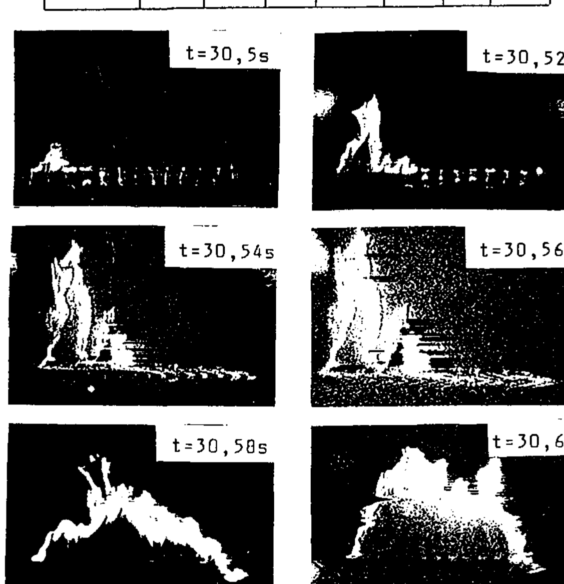

Fig.7. Arc development on the longrod insulator in the horizontal position.

Table IV
Relationship of the ESDD and insulator position

Date of measurements	Dry March of 1983 year			Wet March of 1992 year			Parameters of the insulator profiles							
Position	Vertical	Horizontal	Ratio	Vertical	Horizontal	Ratio								
ESDD	$ESDD_V$ mg/cm^2	$ESDD_H$ mg/cm^2	$\frac{ESDD_H}{ESDD_V}$	$ESDD_V$ mg/cm^2	$ESDD_H$ mg/cm^2	$\frac{ESDD_H}{ESDD_V}$	L cm	$\frac{s}{p}$	p cm	c cm	C.F.	P.F.	α ...°	D cm
insulator no.5	0,16	0,05	0,31	0,10	0,01	0,10	276,5	1,9	8,4	14	-	-	-	28
insulator no.4	0,25	0,07	0,28	0,08	0,01	0,12	335	0,8	6	3,8	3,1	1,1	37/28	19,5
insulator no.3	0,04	0,01	0,25	0,02	0,005	0,25	210	1	5	4,1	2,3	1,2	18/10	17

pointed out that the effect of layer nonuniformity was less important than the effect of layer thickness. Fig.7 presents successive stages of arc development observed on the insulator no.2 coated with the " thick " uniform layer (Table III), *in the horizontal position.* It appears that convection of the arc was clearly observable already in the stage of partial arc creation, far below the critical length of the arc. Such a development of this phenomenon can explain the effect of stronger influence of insulator position on its pollution flashover voltage measured for insulators coated with the thick layer. It can be noted (Tables II and III) that because of the stronger convection of the arc the stronger contamination increases the flashover voltages of the insulators in the horizontal position as well. It means that the self-cleaning of the naturally polluted insulators will be responsible for the size of the position effect.

7. Self - cleaning of the naturally polluted insulators

The insulators no.3 and 4, in Fig.1, have been commonly used, for many years, in Polish overhead transmission lines and they can be characterized as the constructions having respectively excellent and very poor self-cleaning The string of cap and pin insulators (no.5 in Fig.1) subjected to industrial-type contamination had the self-cleaning as poor as insulator no.4. The parameters of the insulator profiles marked according to [5] are given in Table IV.It can be noted (Table IV) that the self-cleaning of the insulators in the horizontal position is far better in both dry and wet weather conditions as compared to these insulators operating in the vertical position. Because of that the influence of the insulator profiles on its self-cleaning performance can be clearly observed in the vertical position only. Checking with the probe the nonuniformity of natural contaminant on surfaces of the insulators placed in horizontal position pointed out that its distribution is quasi-uniform and therefore can be compared to the "thin" uniform coating. The natural layer on insulator no.3, in vertical position, can be compared to the "thin" nonuniform coating, which applies also to contaminants on insulators no. 4 and 5 after heavy wetting (Table IV). In the case of heavily polluted insulators no.4 and 5 in vertical position, any approximation with an artificial layer is very inaccurate. The distribution of the natural contaminant (Table IV) is very nonuniform and for insulator no.4 a dry deposit is mainly concentrated in cavities between neighbouring sheds, while the more heavily convoluted insulator no.5 is often subjected to clogging of its bottom disc surfaces. Under these conditions the assumption of its similarity to the "thick" nonuniform coating can stand for a very rough approximation only and a notable " position effect " for the insulators can only result from their very poor self-cleaning.

8. Conclusions

1. Different methods of contamination of insulators with a thin solid layer insignificantly affected results of the flashover voltage measured for their vertical and horizontal positions.
2. Pollution flashover voltage of insulators contaminated with a thick layer depends on their position and is about 20-30 % higher for the horizontal position.
3. The combination of the effect of layer nonuniformity and the effect of insulator position results in an increase of differences between measured values of voltages. These differences considerably exceed those obtained for measurements conducted for uniform layers.
4. Results of optical observations show that the elongation of the arc channel due to its convection is the main cause of differences between flashover voltages measured for insulators tested in the vertical and the horizontal positions. The intensity of this process grows along with the increase of the mean thickness of the surface pollutant on insulators tested in the horizontal position.
5. Better self-cleaning of the insulators in the horizontal position as compared to those in the vertical one also results in their better outdoor performance. Commonly used insulator profiles hardly influence the selfcleaning of the insulators in the horizontal position.

References

/1/ M.Kawai, "Research at project UHV on the performance of contaminated insulators", IEEE Trans. on PAS, vol. PAS-92, pp. 1102-1120, May/June 1973.

/2/ P.J. Lambeth, J.S.T. Looms, M. Sforzini, R. Cortine, Y. Parcheron, "The salt fog test and its use in insulator selection for polluted localities", IEEE Trans. on PAS, vol. PAS-92, pp. 1876-1887, Nov./Dec. 1973.

/3/ "Artificial Pollution Tests on HV Insulators to be used on AC Systems", IEC Publication 507, April 1991.

/4/ J.G.Wańkowicz, K. Chrzan, Z. Pohl, "Influence of pollution layer thickness on flashover voltage of h.v. insulators", Proc. of 7th Int. Symp. on H.V. Eng. (ISH-91) paper no. 43.01, Dresden, Germany, August 1991.

/5/ "Guide for the selection of insulators in respect of polluted conditions", IEC Publication 815, 1986.

Address:
J.G. Wańkowicz
Technical University of Wrocław (I-7)
Wyb. Wyspiańskiego 27, 50-370 Wrocław, Poland