POLLUTION PERFORMANCE OF 110 kV METAL OXIDE ARRESTERS

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Abstract – Pollution test results of single unit 110 kV metal oxide surge arresters with porcelain housing according to the solid layer and salt fog methods are presented. During 6 hours of testing, the internal and external charge and maximum temperature along the varistor column were measured. The formation of single stable dry bands on the housing was often observed, especially during salt fog tests. In such cases, the varistor temperature can reach about 70°C. The simple electrical model of the arrester enabling calculations of voltages and currents as a function of arrester and pollution parameters is shown.

I. INTRODUCTION

Pollution affects the temperature behavior of metal oxide surge arresters by two ways:

- galvanic coupling: the external leakage current flows into the varistor column through flanges in case of multi–unit MOA's
- capacitive coupling: the external current flows into the varistor column due to the capacitance between the pollution layer and the varistor column [1].

It is (was) believed that the galvanic coupling is predominant and, therefore, there is no need to test single unit arresters [2]. However, our laboratory tests have shown that in case of single, stable dry bands on the porcelain housing a significant temperature increase is measured. The phenomenon of stable dry band formation and discharges was observed earlier during aging tests on polymer insulation under salt fog conditions[3]. In these experiments the highest material degradation was observed under an electrical stress of 0.3 – 0.4 kV/cm with a fog conductivity in the range of 1 – 5 mS/cm. In case of higher fog salinity, there was no stable dry band formation, although the leakage currents were higher, resulting in a less severe stress for the insulation system. Recently, stable dry band formation and discharges have also been proved to exist on polymer insulators at Koeberg Outdoor Pollution Test Station in South Africa using an UV image intensified video camera [4]. Thus such phenomena can occur in natural conditions too.

At multi–unit arresters the separation of both mechanisms is complicated: the galvanic coupling causes uniform varistors heating and capacitive coupling causes non linear temperature increase along the varistor column. The non linear temperature distribution inside multi unit arresters tested with salt fog [5] shows that also in this case the capacitive coupling is very important. For single unit arresters only the capacitive coupling has to be taken into account. With increasing rated voltages of single unit arresters this mechanism will become more and more important.

96 SM 400-2 PWRD A paper recommended and approved by the IEEE Surge Protective Devices Committee of the IEEE Power Engineering Society for presentation at the 1996 IEEE/PES Summer Meeting, July 28 - August 1, 1996, in Denver, Colorado. Manuscript submitted December 22, 1995; made available for printing April 23, 1996.

II. TEST ARRANGEMENT AND TEST PROCEDURE

Single unit metal oxide arresters with porcelain housing and with the varistor column in the center were tested. To protect the varistors against internal discharges or internal arcing the arrester was equipped with a 1 cm thick insulating coating. The arrester unit used for investigations has the following specifications:

max. continuous operating voltage	77	kV
overall length with flanges	1440	mm
core diameter of porcelain	180	mm
inner diameter of porcelain	120	mm
shed diameter (large / small)	270/230	mm
number of sheds (large / small)	16/15	
leakage distance	3300	mm
form factor of the housing	5.7	
diameter of varistor elements	55	mm
length of varistor column	1150	mm

The arrester was tested for 6 hours or longer in salt fog, and also according to the solid layer method. The tests were carried out with different fog conductivities in the range of 0.5 mS/cm to 17 mS/cm and with the same wetting rate as described in IEC standard 507. To limit the washing off of the pollution layer during solid layer tests the clean fog with about three times smaller wetting rate was used. Two different layer thicknesses and degrees of pollution severity (20 µS and 70 µS) were applied. The layer conductivity was measured three minutes after the contamination of the arrester housing. The suspension used for thin pollution layers consisted of 40 g Kaolin per liter of water. For thicker pollution layers the suspension consisted of 100 g Kaolin and 10 g Perfil 250 per liter of water. This thicker layer was not so easily washed off during the tests. The filter agent Perfil 250 manufactured by Köszig, Budapest, was also used earlier to produce a thin pollution layer on silicon rubber insulators by dipping on method [6].

To measure the highest temperatures at different points on the varistor column small adhesive thermostrips were used. The measurement error resulting from thermostrips stuck on the coating surface and not on the varistor surface was estimated to be about 4°C. Immediately after the test the arrester was opened and the maximum temperature was evaluated. If it was lower than 37°C (lowest measurable temperature with the strips) the temperature at this moment was measured using an electronic thermocouple.

In addition internal and external charges were measured using a current pulse integrator CPI–2 manufactured by TransiNor AS which provides the possibility to use different threshold levels for internal and external currents. In order not to integrate any capacitive current the threshold level for the external current was adjusted to 0.5 mA and to 1.5 mA for the internal current. With a non polluted arrester and an applied AC voltage of 77 kV the crest value of the internal current was 0.8 mA.

III. TEST RESULTS

After the fog is applied the external charge in most cases increases almost linearly with time. Typical test results obtained with salt fog and solid layer tests are shown in Fig. 1 and Fig. 2. The registered internal charges are usually very small because the internal current can exceed the adjusted threshold level of 1.5 mA only if a dry zone is formed at the bottom flange. If a dry zone occurs at the top flange the current integrator which is mounted at the bottom will not be triggered although the varistor currents are the same

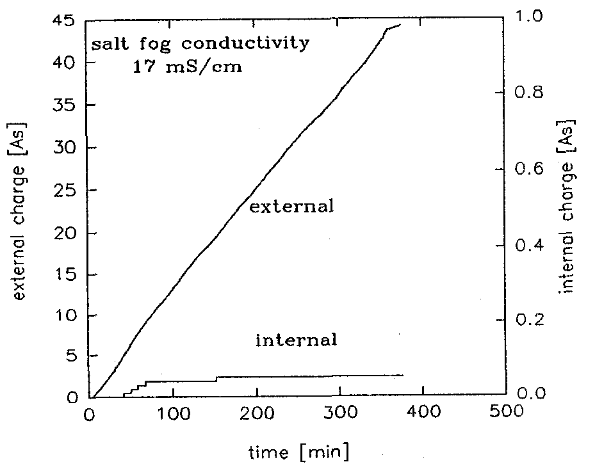

Fig. 1 External and internal charge measured during tests according to the salt fog method

as with the dry zone at the bottom. Therefore, it is generally not possible to predict the temperatures inside of single unit arresters by internal charge measurement.

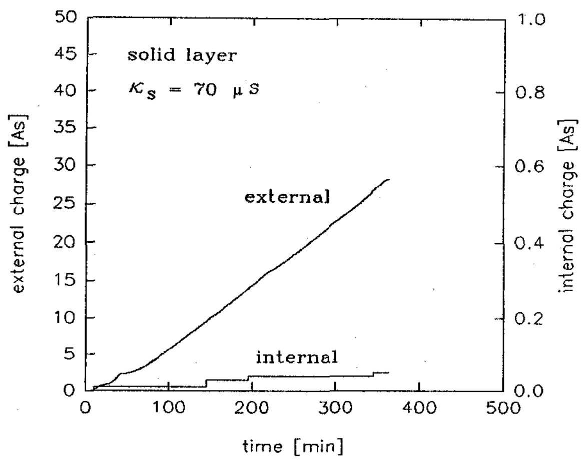

Fig. 2 External and internal charges measured during tests according to the solid layer method

The most important results of the pollution tests are shown in Table 1 where Q_e/h is the mean external charge per hour, $\Delta\vartheta$ is the maximum temperature increase above ambient with measurement error correction (to the measured values 4°C were added).

Table 1: Results of Pollution Tests

	test method	Qe / h As / h	$\Delta\vartheta$ °C	fog/surface conductivity	dry band(s) position
1	SF	1.45	9	0.5 mS/cm	without dry bands
2	SF	4.2	14	1.3 mS/cm	one at the bottom
3	SF	7.3	21	5 mS/cm	one in the middle
4	SF	4.3	20	15 mS/cm	one in the middle
5	SF	7.5	27	15 mS/cm	one at the top
6	SF	7.2	47	17 mS/cm	one at the top
7	SL	3.0	12	20 µS	2 dry bands
8	SL	5.2	14	20 µS	two dry bands
9	SL	3.6	9	20 µS	2 and 3 bands
10	SL	4.7	49	70 µS	1 dry band on top
11	SL	4.8	19	70 µS	1 dry band on top

SF: salt fog method SL: solid layer method

The most critical situation, especially for the single unit arrester, is the formation of stable dry bands on the housing. Without dry band formation even the performance of very severely polluted arresters is not significantly affected. In our experiments no dry band formation occurred in only two cases: during arrester testing with unconditioned (hydrophobic) housing at a fog conductivity of 15 mS/cm and during tests with a very small fog conductivity of 0.5 mS/cm. During salt fog tests the time instant of single dry band formation can be very different. This stochastic phenomenon is influenced by fog conductivity, preconditioning of the housing surface (hydrophobic or hydrophilic), and by the electrical stress and wetting rate. In three cases the single dry band was formed after 1.5 hours (position 3, 5, 6 in Table I). During a test with a small fog conductivity (position 2 in the Table 1) this happened only after 6.5 hours of testing. When a single dry band is formed it can exist for a long time at the same position (stable dry band). Due to uneven voltage distribution the varistors near the dry zone are overstressed and heated up [1]. The radial heat transfer increases additionally the temperature of the dry zone, which is also warmed up due to nearby surface discharges. As a result the water evaporates and a certain salt accumulation occurs in this region. The remaining part of the housing is steadily wetted by salt fog with an equilibrium between wetting and dropping off of pollutant. This stable condition can last very long. After the test the accumulation of salt crystals in the dry zone is visible. The surface conductivity measured locally after wetting by deionized water reached 200 to 350 µS. On the other parts of the housing it was only 10 to 20 µS.

The most critical situation occurs if there is a single, stable dry zone close to one the flanges [1]. In tests where the temperature increase was about 45°C (position 6 and 10 in Table 1) such a state lasted for more than 4 hours up to the end of the test. This leads to a very non–linear temperature distribution along the varistor column (Fig. 3).

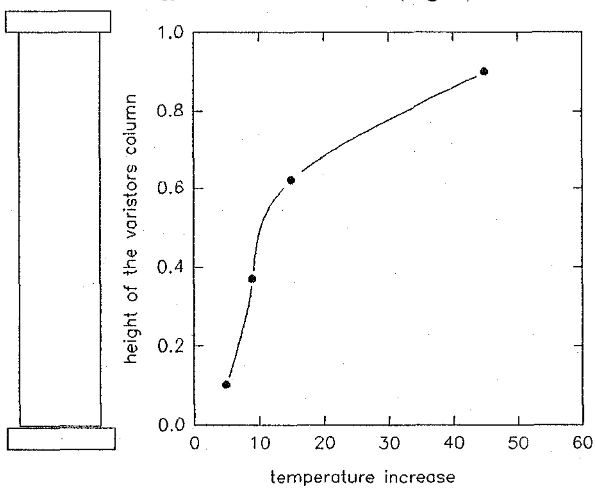

Fig. 3. Temperature distribution along varistor column during test according to solid layer method (position 10 in Table 1)

In general, there is no distinct correlation between the external charge and the temperature rise of the varistors inside the arresters. From the test results in Fig. 4, it can be seen that there seems to be a certain correlation between the external charge and the maximum temperature rise only if the two measuring points with the highest temperatures (most important cases) are neglected. So, in the case of severely polluted arresters, the probability of a high temperature increase is higher than normally polluted arresters; but more important than the degree of pollution is the number, position and duration of stable dry bands on the arrester housing.

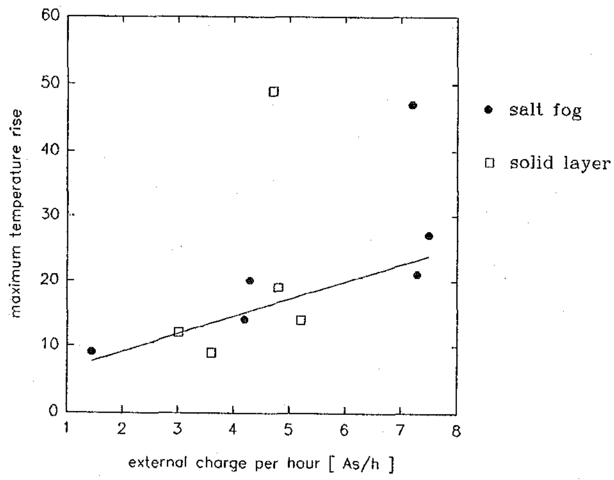

Fig. 4. Relationship between external charge and temperature increase of internal elements

After single dry band formation on the housing current spikes on both the internal and external current signals were often observed. These spikes are caused by internal discharges inside the arrester [1]. When the housing was opened the ionization phenomena could be easily detected by intensive odor. In spite of this no varistor degradation was detected. The voltage/current characteristic was not changed.

IV. ELECTRICAL MODEL OF THE ARRESTER

To model the behavior of polluted MOA a PSPICE model of a polluted arrester was developed. The arrester was divided into 8 parts each consisting of a varistor block with a coupling capacitance between the pollution layer and the varistor column C_{1i} (where i = 1...8) and the pollution layer resistance R_{1i}. The MO varistors were considered as a non linear resistance (two Zener diodes) in parallel with a capacitance C_i and a series resistance R_i. The resistances R_{21} and R_{22} represent the shunts used for the charge (current) measurement (Fig. 5).

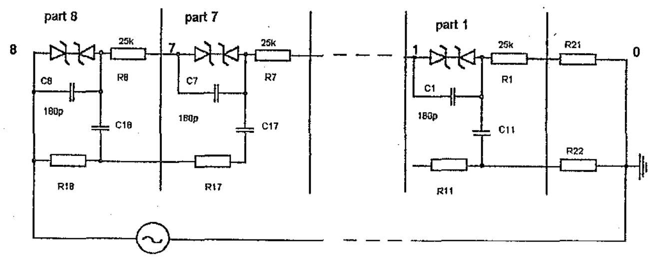

Fig. 5. PSPICE model of arrester

The arrester used for simulation has the following specifications:

max. continuous operating voltage	77	kV
diameter of varistors element	75	mm

length of varistor column	1100	mm
core diameter of porcelain	150	mm
inner diameter of porcelain	110	mm
form factor of the housing	7	

Simplifying the shape of the housing to a cylinder, the coupling capacitance between the pollution layer and the varistor column was estimated. The varistor capacitance was calculated from a current measurement at 77 kV AC voltage. Resistance values of the pollution layer were calculated using the surface conductivity and the form factor of the porcelain housing. Finally, the zener voltage of the varistors and its serial resistances were estimated using the voltage/current characteristic of the arrester.

V. RESULT OF COMPUTER SIMULATION

The most severe condition for a polluted MOA is a single dry band close to one of the flanges at maximum continuous operating voltage. This was simulated with an appropriate PSPICE model. It was considered a dry zone at the upper flange with a resistance of 1 TΩ having a length of 1/8 of the total arrester height. For the remaining part of the housing a surface conductivity of 50 μS was used. Due to the extremely non linear pollution on the porcelain the voltage distribution along the varistor column is non linear too. The voltage at the top varistor blocks reaches a value of 20 kV (varistor breakdown voltage), whereas the varistor block at the bottom flange has the smallest electrical stress (about 7 kV, see Fig. 6). There is a significant phase shift between the voltages of the upper and bottom varistor blocks (section 8 and 7).

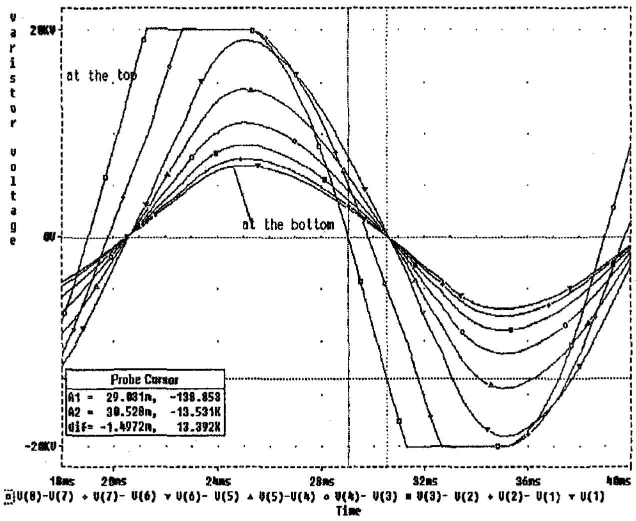

Fig. 6. The voltages at varistor blocks under critical pollution condition (dry band resistance R_{18} = 1 TΩ, surface conductivity 50 μS, coupling capacitance C_{1i} = 17 pF)

The non–linear voltage and current distributions cause a non uniform power dissipation on the varistor blocks resulting in different temperatures.

Fig. 7 shows the crest voltages and the product of the RMS values of voltages and currents of the single varistor blocks. The curves are similar to the curves evaluated on the basis of the measurements published in [7]. This confirms the accuracy of the above computer simulation results.

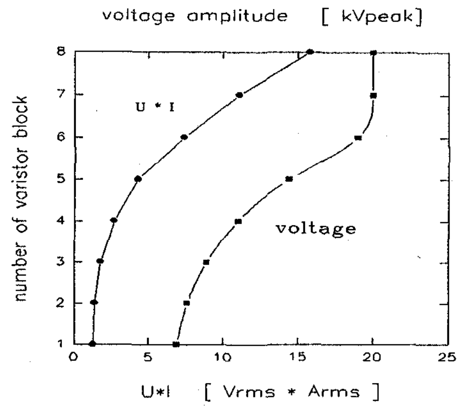

Fig. 7. Power dissipation and crest voltage on particular varistor blocks

The coupling capacitance is an important design parameter and has an essential influence on arrester pollution performance. To prove this the calculations were carried out for different outer diameters of the porcelain housing, in the range from 11.5 cm (no spacing between varistor column and inner surface of housing) to 25 cm. Fig. 8 shows the influence of the outer diameter of porcelain housing on coupling capacitance and power dissipation of the upper varistor block (element no. 8). Due to the similar shape of both curves it can be concluded that the power dissipation of the varistors close to a single dry band is proportional to the coupling capacitance.

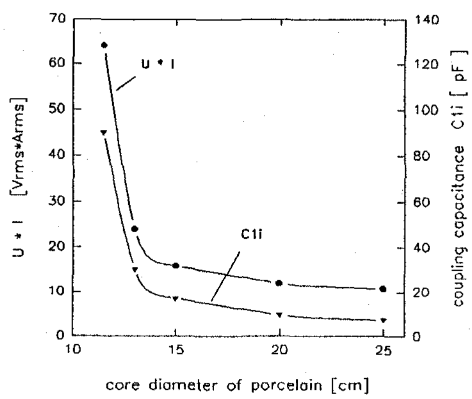

Fig. 8. Influence of outer diameter of porcelain housing on power dissipation and coupling capacitance for a varistor block close to a single dry zone

The minimum distance between the varistor column and the inner housing surface should be more than 1 cm (corresponding to 13.5 cm outer diameter of housing). There is a steep increase of coupling capacitance and power dissipation for small diameters of the porcelain housing.

In case of a high resistance of the dry band (1 TΩ), the voltage distribution is very non linear even at a small surface conductivity of 0.05 μS (Fig. 9).

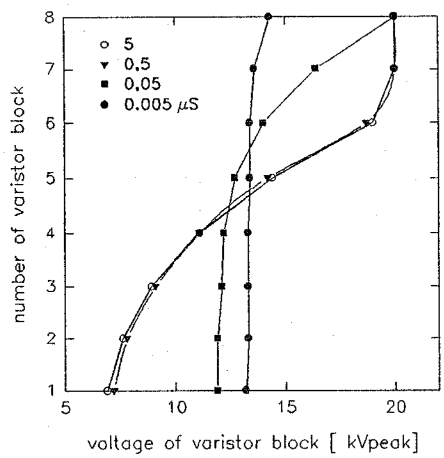

Fig. 9. Voltage distribution along the varistor column for different surface conductivities of wet pollution layer. (coupling capacitance C_{li} = 17 pF, dry band resistance R_{18} = 1 TΩ)

It is interesting that in the region from 0.5 to 50 μS the voltage distribution along the varistor column does not change significantly. It is almost linear at very small surface conductivities in the range of 0.005 μS. From the above results it can be concluded that after single dry band formation on the arrester housing the critical pollution condition (single dry zone) still can exist after washing off the solid pollution layer. To maintain this dangerous state only a wet layer with a very small surface conductivity is needed.

Fig. 10 shows the influence of dry band resistance on the power dissipation in the most stressed varistor block. The simulations were performed with a surface conductivity of wet contaminant of 5 μS and a coupling capacitance of 17 pF. For a dry band conductivity 10 times smaller than on the remaining wet part of the housing the power dissipation in the upper varistor block (element no. 8) increases considerably. Under natural conditions such non uniform pollution on the arrester housing is possible. When the dry band conductivity is about 100 times lower than the conductivity of the wet pollutant, the power dissipation in the upper block has almost reached its maximum value.

Fig. 11 shows the calculated internal and external currents at the bottom flange (flowing through the shunts R21 and R22) and the AC test voltage. The calculations were carried out with a dry band resistance of 170 MΩ (corresponding to 0.005 μS). The surface conductivity of the wet layer was 5 μS and the coupling capacitance C_{1i} amounted to 17 pF. Because of capacitive coupling between the varistor column and the pollution layer and the finite dry band resistance the external current is mixed

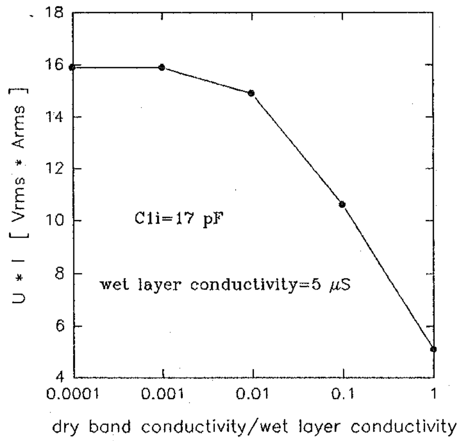

Fig. 10. Influence of dry band surface conductivity on the power dissipation of the varistor block close to the dry zone

capacitive/resistive. When the voltage of the upper varistor block reaches a value of 20 kV the currents rapidly increase. The next increase of currents occurs when the voltage of the 7th varistor block reaches the value of 20 kV (the varistor breakdown voltage). In our model the distributed coupling capacitance was replaced by lumped capacitors. The varistor column which has in reality about 30 single varistor elements was divided into only 8 varistor blocks. Therefore, for the real MOAs, the current changes are not so rapid.

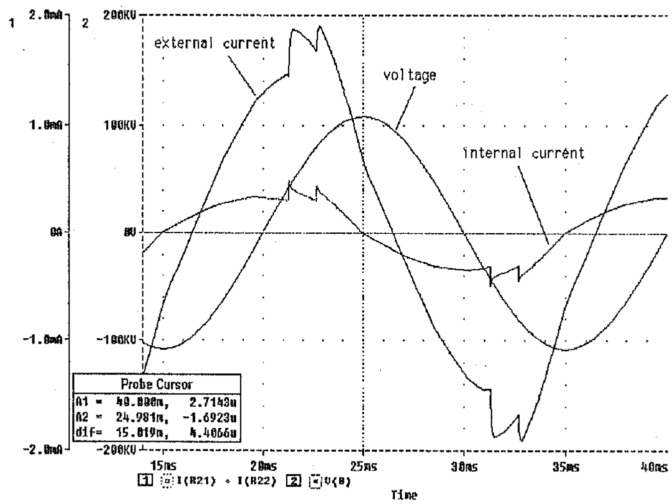

Fig. 11. Calculated external and internal currents at the bottom flange and AC test voltage (Dry band resistance R_{18} = 170 MΩ, surface conductivity 5 μS, coupling capacitance C_{1i} = 17 pF.

VI. CONCLUSIONS

The single, stable dry band formation was often observed during salt fog tests. In tests according to the solid layer method this phenomenon is possible too. Recently single dry band formation on polymer insulators under natural conditions was documented [4].

The temperature inside single unit arresters during pollution tests can reach a value of 70°C.

It is not possible to estimate the temperature rise inside single unit arresters by external or even internal charge measurements.

The presented simple electrical model can simulate the arrester performance under pollution. It is possible to evaluate the voltage distribution, power losses and currents as a function of pollution severity and arrester design, e.g. coupling capacitance and voltage/current characteristic of the arrester.

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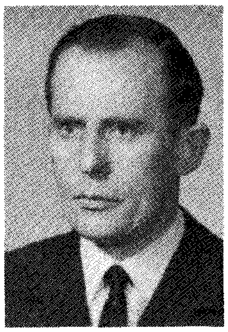
VIII. ACKNOWLEDGEMENT

The authors would like to thank the Polish Research Commission KBN for financial support.

IX. BIOGRAPHY

Krystian Chrzan was born in 1955, Odolanow, Poland. He studied Electrical Engineering at the Technical University of Wroclaw, Poland. Since 1983 he is with the Technical University of Wroclaw where he received his Ph.D. in 1987. From 1988 to 1989 he was a scholar of the Alexander von Humboldt Fellowship at the High Voltage Laboratory of the University of Stuttgart. From 1991 to 1993 he was with the High Voltage Laboratory of the Technical University of Zittau, Germany. He was visiting researcher to the University of Dresden in 1994 and to the High Voltage Laboratory FGH in Mannheim in 1995.



Zbigniew Pohl was born in 1929, Nowogrodek, Poland (now Belorussia). He received his M.Sc., Ph.D. and D.Sc. from the Technical University of Wroclaw all in Electrical Engineering in 1954, 1965 and 1975 respectively. Since 1991 he is a professor in the Institute of Electrical Engineering Fundamentals at the Technical University of Wroclaw. He was visiting researcher to the Technical University of Dresden and Leningrad. His major research interest concentrate on outdoor insulation for polluted conditions and development of polymeric insulators for outdoor high voltage insulation..

Stan Grzybowski was born in 1933, Poland. He received the M.Sc. and Ph.D. degrees in Electrical Engineering in 1956 and 1964, respectively, from the Technical University of Warsaw, Poland. In 1984 he obtained the D.Sc. (Dr. habilitated) degree from the Technical University of Wroclaw, Poland.

In 1956, he joined the faculty of Electrical Engineering at the Technical University of Poznan, Poland. From 1958 to 1981, he was Head of the High Voltage and Electrical Materials Division and served as Vice–Dean of Electrical Engineering Faculty in 1969 and from 1975 through 1977.

In 1987, he joined Mississippi State University, where he is now a Professor and Director of the High Voltage Laboratory in the Electrical and Computer Engineering Department.

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Wolfgang Köhler was born in 1956, Schwäbisch Hall, Germany. From 1976 to 1981 he studied Electrical Engineering at the University of Stuttgart finishing with the "Diplom Ingenieur" degree. Since 1981 he is with the Institute for Electrical Power and High Voltage Engineering at the University of Stuttgart, where he became chief of the high voltage laboratory in 1984. In 1988 he received his Dr.–Ing. degree from the University of Stuttgart. His current research work deals with high voltage test and measurement procedures, EMC tests and electric and magnetic field calculations and measurements.