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Głogów pollution test station, a review of 30-years research

***Abstract**. Insulators made of different materials were tested: porcelain, glass, hydrophobic glazes, silicone rubber, hydrophobic epoxy resin and polymer concrete. Special attention was paid for tests of insulators that have a different specific leakage distance. The leakage current and flashovers were monitored and the degree of pollution on the insulator surfaces was sampled on different insulators with the same profile but made of different materials. It was found that a shorter specific leakage distance than that recommended by the IEC 60815 standard is possible.*

Streszczenie.** Testowano izolatory wyprodukowane z różnych materiałów: z porcelany, szkła, szkliw półprzewodzących, kauczuku silikonowego, żywicy epoksydowej, i betonu polimerowego. Szczególną uwagę poświęcono próbom izolatorów mających różną drogę upływu. Rejestrowano prąd upływu i przeskoki oraz wyznaczano ESDD na izolatorach o tym samym profilu lecz wykonanych z różnych materiałów. Wykazano, że jednostkowa droga upływu może być krótsza niż ta zalecana przez normę IEC 60815. **(Stacja prób izolatorów w Hucie Miedzi Głogów, przegląd z 30—letnich badań)

Keywords: Flashover, industrial pollution, leakage currents, surface discharges.
Słowa kluczowe: przeskok, zabrudzenie przemysłowe, prąd upływu, wyładowania powierzchniowe.

Introduction

Laboratory investigations of polluted insulators started before WW I. However, the theoretical pollution flashover model was not proposed until 1958. The classical Obenaus model was later modified and enhanced by many scientists. There is a widely known opinion that either the model calculations or laboratory pollution tests are not able to eliminate the pollution field tests. Therefore, new pollution test stations are still being built all over the world, and the guide for the establishment of naturally polluted insulator testing stations was published ten years ago [1].

The first pollution test station was probably the Redondo station situated south of Los Angeles, which was commissioned in 1927. The second was Croydon station in Surrey, Great Britain [2]. Similar outdoor insulator testing facilities were built in many countries, e.g. Frieseninsel and Boxberg in Germany, Anneberg and Ludvika in Sweden, Martigues in France, Shiobara and Noto in Japan, Koeberg in South Africa, and Beijing in China.

Blackouts initiated by pollution flashovers were noticed in Upper Silesia (Poland) – three in 1954 and two in 1955. That is why the first Polish station in Walbrzych, situated close to Victoria coal mine, was commissioned in 1957. The next two stations were built in 1963: near Czechnica power plant near Wroclaw, and in Zabrze (Upper Silesia). Five smaller stations connected directly with a 110 kV lines (without own transformer) were established in Upper Silesia in Swietochlowice, Groszowice, Bukowno, Dwory and Kedzierzyn. Two set ups were also built in 2003 near the Baltic coast in Swinoujscie-Karsiborz and in Dzwirzyno on 15 kV poles [2].

Pollution severity changes

The development in industry caused rapid dust emission and its deposition on outdoor insulators. Therefore, the first pollution test stations were located near factories that emitted a lot of pollution (Croydon, Zabrze) or near the coast (Redondo in USA, Dungeness in UK). In the second half of the XX century HV power lines and substations were built in salt sand deserts. Therefore, pollution test stations were established in deserts in Tunisia, Egypt, Israel, Saudi Arabia, Iran and Pakistan.

Natural contamination like sea salt or salt sands cannot be limited. However, industrial pollution emission in Western countries began to decrease in the 1970s, and in Poland after 1985 [3]. A very good example illustrating this process is the dust deposition decrease at Glogow test station: 1980 - 9.1 g/m^2 a day, in 1987 – 3,8 g/m^2 and in 2003 only 0,4 g/m^2 a day (Figure 1a). The dust emission from the neighbouring smelting plant was reduced 80 times between 1980-2005 (Figure 1b). As a result, this site pollution class was classified as being heavy pollution in 1980, but after 2003 as only light pollution.

Atmospheric precipitation conductivity in Upper Silesia in the 1960s reached even 1000 μS/cm [5]. The values measured at present are much smaller and usually amount to less than 50 μS/cm. The chemical analysis and conductivity measurement of rainwater collected in many different spots are carried out in the frame of environmental monitoring by state agencies. The measurements of monthly water samples collected in 25 spots in 2009 showed that the minimum value of 10 μS/cm was found in Raciborz, and the maximum value of 250 μS/cm – in Torun [6, 7].

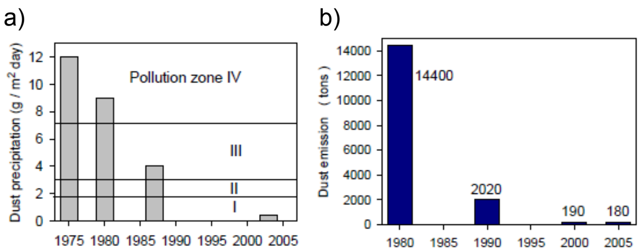

Fig.1. Dust deposit density at test station (a), dust emission of Glogow Smelting Plant (b), [4]

According to Polish standard PN-E-06303, the main criterion for the evaluation of site pollution class is the maximum daily indicator of distilled water conductivity increase $\Delta\gamma_{max}$. This parameter is given in μS/cm per day and related to the 3 cm water level in a measuring container. The author has proposed a change in procedure for calculating measuring results. It is possible to calculate the equivalent salt deposit density (ESDD) given in mg/cm^2 or in μg/cm^2 for the same data set. ESDD calculation results for 10 locations in the Lower Silesia Region are shown in Table 1. The data of the Institute for Meteorology and Water Management was used [6].

The decrease in environmental contamination caused by industry in developed countries resulted in a shrinking of the pollution flashover number to nearly zero. The insulators installed 30 years ago in industrial regions are usually over-dimensioned. Very often the new installed hydrophobic composite insulators have an even longer leakage distance than the old porcelain insulators at the same location. This "philosophy" does not take into account that the site heavy pollution in the past can now be classified as "light pollution" [8].

Table 1. Arranged maximum and minimum ESDD values (in μg/cm^2 a day) of dry and wet precipitation collected in 10 locations in Lower Silesia in 2010.

Spot number	1	2	3	4	5	6	7	8	9	10
Maximum	135	119	82	80	60	58	45	46	35	33
Minimum	18	5	13	12	5	6	3	12	3	3

1-Przesieka, 2-Głogów, 3-Gryfów, 4-Karpacz, 5-Ścinawa, 6-Brzezie, 7-Rudna, 8-Żmigród, 9-Kłodzko, 10-Legnica

Głogów pollution test station

Severe contamination in the Legnica-Glogow Copper Region caused pollution flashovers on outdoor insulation in the winter of 1978/1979. As a result, the new modern pollution test station was built in 1980 at the so-called Glogow I Copper Smelting Plant. The station was supplied through a 2 MVA power transformer manufactured by TUR Dresden, which delivered the adjustable voltage from 0 to 200 kV. The main source parameters are as follows: nominal current 10 A, voltage 6/200 kV, power 2 MVA, short circuit voltage 8.5%, and short current 150 A. The power is delivered through three transformers: the symmetry transformer ESDOM 6/1 kV (supplied by three 6 kV phases), the regulation transformer FT/D/EO 1000/10 AL, and the high voltage transformer 6/200 kV. The insulator field and the three transformers are shown in Figures 2 and Figure 3.

Fig.2. Insulator field, the small (yellow) building contained a 6 kV substation and the command room, the white cubic room housed the pollution chamber.

Fig. 3. Supply transformers. From left to right: the symmetry transformer (supplied by three 6 kV phases), regulation transformer and high voltage transformer 6/200 kV.

Experimental procedure and measuring equipment

The capacitive voltage divider TUR200 with a 138 pF compressed gas capacitor, and the peak voltmeter MUT7 was used for AC voltage measurement. A very useful device was the rotating-type disconnector installed in 1998. Its main task was disconnection of the insulator field and the supply of high voltage to the pollution chamber. This disconnector was also applied for testing insulators installed outdoors on the rack according to the modified up and down method [9].

The equipment used at the pollution test station is very unique and sometimes has to be built by the operating staff. The first registrations of leakage current were carried out by means of electromechanical counters that were designed and manufactured at the High Voltage Laboratory of Wroclaw University of Technology [2]. The fuse indicator was designed and tested in the laboratory and then again in the field to record the pollution flashovers (Figure 4a) [10]. Rod probes and strip probes designed by Juergen Pilling for spot measurements of surface conductivity on the polluted insulators were applied (Figure 4b) [11]. A new Equivalent Contamination Deposit Density (ECDD) was measured by means of Besztercey's probe [11]. The most expensive measuring equipment was the Current Pulse Integrator (CPI) from the Norway Company TransiNor, used for the pollution test of metal oxide surge arresters (Figure 4c) [12], and also the Leakage Current Monitor (LCM) from FGH Mannheim used for long–term leakage current measurements on the polluted insulators (Figure 5a) [13, 14]. The varistor temperature inside metal oxide surge arresters were measured by means of TINYTALK probes from the British company Gemini Data Loggers (Figure 5b) [15], and the temperature of their housing was assessed using a thermovision camera [16]. The diagnostics of the surge arresters were carried out using the relatively simple Leakage Current Recorder MPU-1 made in the Institute of Power Engineering in Warsaw (Figure 5c), or the more advanced system Leakage Current Monitor LCM-1 from TransiNor [17, 18]. The meteorology station WMR200 from the American company Oregon recorded the ambient temperature, air humidity, atmospheric precipitation and wind speed/direction.

a) b) c)

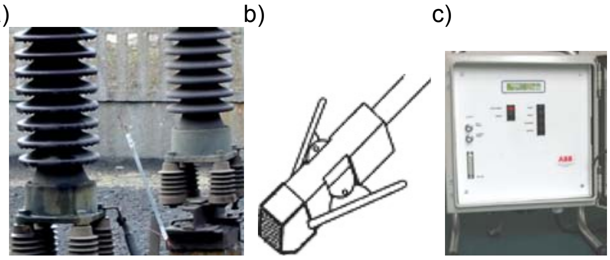

Fig.4. SWZP post insulator with 8 sheds short circuited by the fuse indicator of the pollution flashover (a), strip probe for surface conductivity measurement (b), Current Pulse Integrator CPI (c).

a) b) c)

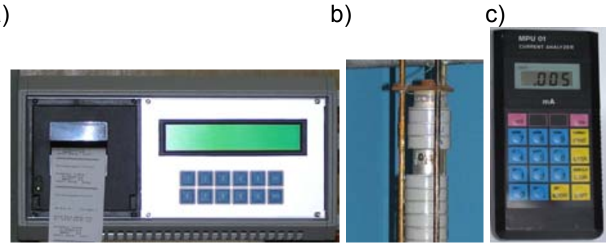

Fig.5. Leakage Current Monitor LCM (a), TINYTALK temperature probe mounted in a ZnO varistor column (b), current analyser MPU 01 (c).

Today, there are technical possibilities that allow the application of modern inductive contact-less probes for current measurement (Pearson probes), or probes based on the Hall effect. The measuring data and pictures from video-, thermovision- or special UV-cameras in digital form can be transmitted by the Internet and used for real-time monitoring.

Research in the period 1980-2000

The research on the test station can be divided into three subjects. First, the physical and chemical properties of pollutants and different pollution severity parameters were studied. Then, different porcelain and composite insulators were tested, and finally, the behavior of surge arresters under pollution were examined.

The surface conductivity on different insulators [19], the dust deposit density (DDD), and also the conductivity of soluble contaminant solutions were measured. The aim of the program was focused on the modification of the standard PN/E-79/E-06303 “Exposure of outdoor insulation to pollution and the selection of insulators under polluted conditions”. As a result, the new method for pollution severity measurement and calculation was proposed [20]. It was found that industrial dust (including that from the copper smelting plant in Glogow) contains salts with limited solubility, e.g. $CaSO_4$. Consequently, the relation between the surface conductivity and ESDD could be a non-linear function [21]. It was also found that dust is deposited uniformly on silicone rubber insulators and that it absorbs UV radiation, which can eventually inhibit the material degradation [22].

The electrical strength of the SWP porcelain post under natural pollution and climatic conditions was estimated. The experiment, described in detail in [23], confirmed the usefulness of fuse flashover indicators and electromagnetic leakage impulse counters.

Research in the period 2000-2010

The metal oxide surge arresters GXA96 (one unit) and 2GXA48 (two units), housed in porcelain, have been tested since 1996. The initial results were reported in [9, 12]. The maximum temperature of 56°C was recorded inside surge arrester GXA96 during the hot June of 2005. The ambient temperature was close to 40°C. The temperature of 56°C is considerably lower than the critical temperature (more or less 100°C) that can initiate the thermal run away.

RTV silicone coating Sylgard was applied on post insulators SWZP (Figure 4a) and on long rods LP 75/27W (Figure 10c) in 1995. The same type of insulators were covered by fluorourethane coatings in 1996. The flashover voltage of these three post insulator types was measured in the years 2001-2003. The modified up and down method was described in [8]. From the experimentally estimated withstand voltage, the specific withstand leakage distance for three post types was calculated and is shown in Figure 6. The specific leakage distance is given in cm divided by the kV of the phase-to-phase voltage (the test voltage of 100 kV was multiplied by $\sqrt{3}$). The specific leakage distance for the post with bare glazes was determined as 13 mm/kV and was shorter by 0,5 cm/kV than that calculated in 1987 under heavy pollution [23]. This parameter was also about 30% lower for insulators with silicone coatings. However, the application of silicone coatings is only justified under heavy pollution. The porcelain insulators with bare glazes or glass insulators with an even shorter leakage distance perform well under light pollution [24] (Table 2).

It is important to note that the lowest flashover voltages (longest specific creeping distance) were measured in winter under light frost when there was the appearance of a thin ice layer after spraying of the insulator. Table 2 shows the withstand specific creepage distances in the years 2001-2003 on the post SWZP4 with bare glazes. The maximum value of 1,3 cm/kV measured in December 2002 is lower than the maximum 1,8 cm/kV measured in 1987. The big increase of electrical strength of about 40% is caused by the huge environmental improvement. Dust precipitation Q in the year 2002 decreased nearly 10 times when compared to 1987 (Figure 1a). Note that the highest electrical strength, which occurred in March 2002, is two times greater than the lowest one in December 2002.

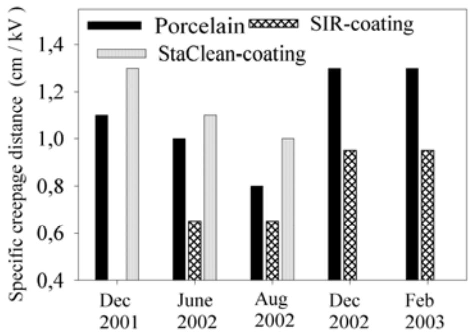

Fig. 6. . Flow on test results (spray wetting of natural pollution). The specific withstand leakage distance of post SWZP with bare glaze (porcelain), with silicone coating (SIR) and with fluorourethane coating (StaClean coating).

Table 2. Withstand specific creepage distance Lw (phase to phase voltage) measured on post insulators SWZP with bare glazes in 2001 – 2003 [9].

Month, year	Lw cm/kV	Ambient temperature °C
Oct 2001	0,9	+5
Dec 2001	1,1	-4
Feb 2002	1,0	+2
March 2002	0,6	+4
Jun 2002	1,0	+28
Aug 2002	0,8	+20
Dec 2002	1,3	-5
Feb 2003	1,3	-2

a) b) c) d)

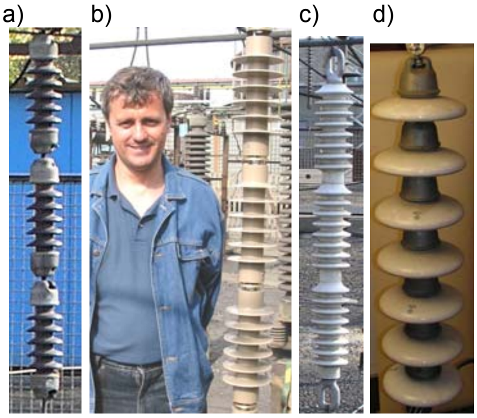

Fig.7. Insulators with the special hydrophobic glazes (a), insulators with hydrophobic epoxy resin (b), Insulators made of polymer concrete (c), cap and pin insulators with semi conductive glazes (d)

The study of hydrophobic glazes on porcelain insulators (Figure 7a) and insulators made of hydrophobic epoxy resin (Figure 7b) has shown that these surfaces, when contaminated by a very thin dust layer, become hydrophilic [24]. Therefore, the leakage currents on insulators with standard glazes, and also on insulators with hydrophobic glazes, are practically the same. The insulators made of polymer concrete were tested from 1999 to 2010 (Figure 7c). Three or four 20 kV insulators were connected together by means of steel screws. Unfortunately, every insulator chain (from the three tested) was damaged after about two years. Figure 8 shows the typical breakdown channel from the surface to the steel screw.

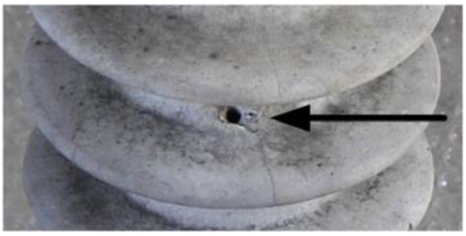

Fig.8. Breakdown channel through polymer concrete

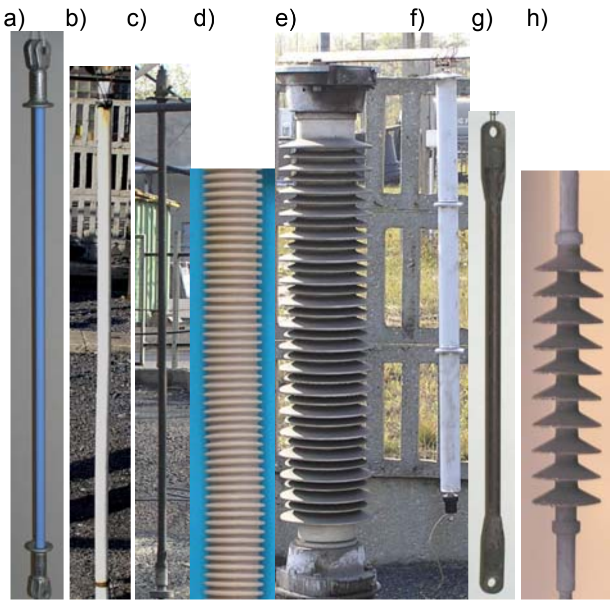

Fig.9. Silicone cylindrical insulator with a smooth surface (a), porcelain cylindrical insulator (b), silicone cylindrical insulator with a notched surface (c), the notched surface (d), metal oxide surge arrester GXA96 with porcelain housing (e), the prototype surge arrester assembled of three indoor surge arresters ASW with silicone housing (f), silicone insulator LTKC-25 with a 60 cm leakage distance (g), silicone insulator with a flange distance of 36 cm and a leakage distance of 90 cm (h).

Table 3. Long term tests without flashovers carried out under natural conditions and the parameters of the tested insulators

	insu-lator	L/1,73·U mm/kV	test time years	sheds number	shed diam cm	shank diam cm
1	SWZP	13	5	12	22	12
2	HEP	12	5	18	12,5	5,5
3	SIR	7	2	10	11	3
4	SIR rod	08	4,5	-	-	2,3
5	Porc rod	08	4,5	-	-	3,0
6	3·LP 60/5	11	9	15	12	6
7	LPZS 75/12	15	9	12	17,6	7,5

1-SWZP, porcelain post with bare glazes, Fig. 5a, 2-HEP, Hydrophobic epoxide insulator, Fig. 7b, 3-SIR, Silicone rubber insulator, Fig. 19h, 4-SIR rod, silicone rubber rod without sheds, Fig. 9a, 5-Porcelain rod without sheds, Fig. 9b, 6-3·LP60/5, three porcelain insulators, Fig. 7a, 7-LPZS75/12, porcelain insulator with stepped sheds with 12 unbridged sheds and with 3 bridged sheds, Fig. 10b

As was shown in section 2, the dust deposit density at the test station decreased gradually, and therefore this site could be determined as pollution class light after the year 2000. Taking this fact into account, the behaviour of insulators with a very short leakage distance was investigated.

Very valuable from the period 2001-2010, and not yet published, are the long-term test results given in Table 3. The insulators were tested under a 75 kV operating voltage. The specific leakage distance in the third column was calculated from the insulator leakage distance divided by the voltage (75 $\times$ 1,73) kV.

The composite insulator designed for the 30 kV line had the shortest specific leakage distance of 0,7 cm/kV. This insulator has a leakage distance of only 90 cm. Next were the silicone and porcelain rods without sheds, with a leakage distance of 100 cm and specific leakage distance of 0,8 cm/kV. The shortest specific leakage distance for pollution class light according to the old IEC 60815: 1986 standard is 16 mm/kV. The new standard IEC 60815: 2008, part 2: Ceramic and glass insulators for AC systems, specifies the shortest so-called basic unified specific creepage distance of 22 mm/kV phase-ground voltage, which is equivalent to a 13 mm/kV phase –phase voltage.

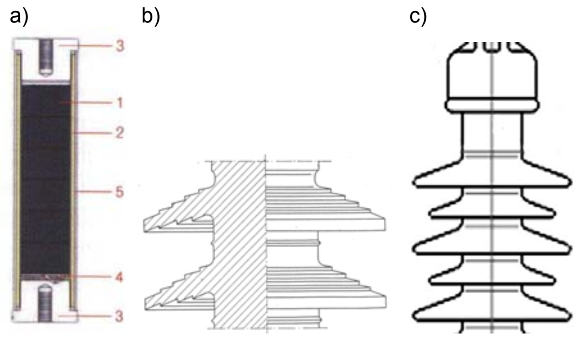

Fig.10. Cross section of surge arrester ASW18 (a), 1-varistor column, 2-glass-epoxy pipe, 3-electrodes, 4-spring washer, 5-silicone housing [29], Insulator with stepped sheds LPZS75/15 (b) [30], porcelain insulator LP75/27W with alternating sheds (c)

ESDD values on porcelain and silicone rubber insulators

In 1994**,** four long-rod porcelain insulators with bare glazed porcelain and with alternating sheds (Figure 10c) were hung 1 m above ground level and energized with a voltage of 75 kV at the top flange. Two of these insulators were coated with SIR RTV layers in 1995. Spot ESDD and DDD measurements were carried out on both insulator types in May 2006. The pollution layer on the insulator with the SIR coating is more uniform than that on the insulator with the bare glazes (Figure 11). The smallest ESDD value on the porcelain insulator was 9 times smaller than the highest value on the insulator with the SIR coating (appropriately 0,018 and 0,172 mg/cm^2). The minimum values were found close to the top of the high potential flange, and the maximum values were located near the bottom grounded flange. On the porcelain insulator with the bare glazes, the upper side of the shed at the top was very clean. The rain-washing effect on the same shed coated with SIR RTV is not so perfect. Therefore, the small concentrated discharges could be observed in the vicinity of the top flanges during the uniform wetting of the insulators (very high air humidity, dew or fog). This phenomenon was described in [13, 31].

The ESDD and DDD measurements revealed that the rain better washes the bare glazed upper surface of the sheds (exposed directly to droplets impact) than the silicone rubber surface. Additionally, the protected bottom silicone surface of the sheds also accumulates more pollutants than the glazed surface. The maximum ratio of the ESDD on the silicone rubber insulators to the ESDD on the porcelain insulators was found for the upper side of the top sheds of the SWZP post with the SIR coating, and the SWZP post with the bare glazes [28].

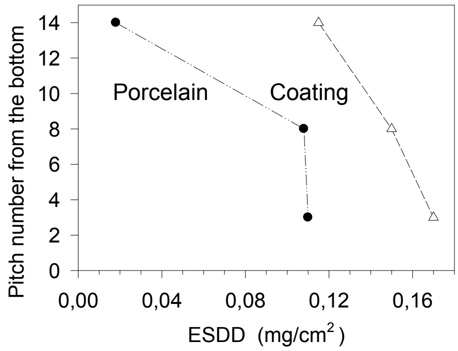

Fig.11. ESDD on the LP75/27W long-rod insulator with the SIR coating or on the insulator with the bare glazes. Measurements on smaller sheds below the greater sheds in May 2006 [32]

Colour changes of silicone rubber insulators

Silicone rubber insulators change their colour with operation time. They usually become darker and darker due to the deposition of black or brown dust. There is more dust on the silicone rubber surface than on the glazed porcelain surface. This process is caused by the Low Molecular Weight Components LMW of silicone rubber, which increase the hydrophobicity of the silicone rubber surface and cause the so-called transfer of hydrophobic properties to the pollutants. Additionally, LMW components increase the adhesiveness of a clean or polluted silicone rubber surface and decrease the ability of self-washing by rains.

Figure 12 shows the colour change of the insulators at Glogow Pollution Test Station. It should be underlined that the hydrophobic properties of the 25 year old silicone rubber insulators, with a totally changed colour from their initial milky colour to dark gray, are very good. The wetting angle on a contaminated old insulator can be even greater than on a new clean insulator due to increased roughness.

a) b)

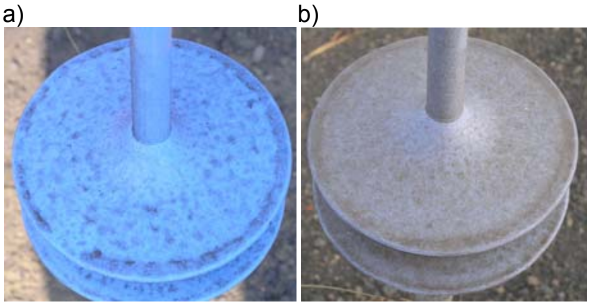

Fig.12. Colour change of the silicone rubber insulators with exposition time at Glogow Pollution Test Station. a – after one month, b – after 8 months

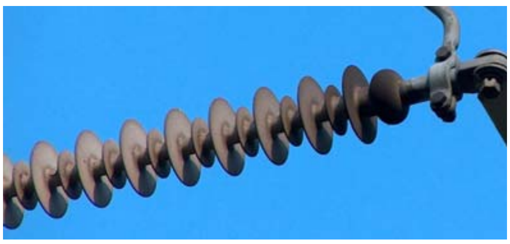

Fig.13. Pollution accumulation near the high voltage flange of the composite insulator [32]

A greater accumulation of pollutants near the high voltage flange can also be observed (Figure 13). The voltage distribution along the insulator is very non-uniform. The field close to the HV electrode is a few times higher than in the middle part of the insulator. The contamination particles in air have a dielectric permittivity greater than 1, and therefore move to the region with the highest electric field. The black sediments cannot usually be removed using only pure water. The black surface is technically clean because the surface conductivity measured by a strip probe can be very small e.g. 1 μS.

Research after 2010

The KGHM Company started construction of a new copper smelter in 2011. Unfortunately, the area where the station was located was intended for the expansion of the 110 kV switching substation. Therefore, at the end of 2010, the station was closed. Some of the tests performed at the station can be continued at HV switching substations on specially prepared stands. Measurements of the leakage currents on silicone housings and on the porcelain housing, made at the 110 kV substation in the Legnica copper smelter, confirmed the effect previously detected at the Koeberg and Głogów stations [33]. The energy losses on overhead insulators due to leakage current are estimated at 0,2-0,5 % of the total energy transmitted [34]. Unfortunately, the measurement of energy losses on overhead insulators is a very difficult task, especially when the measurement is to be performed at a HV switching substation rather than at a special testing station. There are further possibilities to modify the existing high voltage overhead insulation solutions [35]. However, new design and material solutions must be tested before they are used in power lines. The specific withstand leakage distances determined at the Glogow test station should also be verified by tests carried out at another station located in Central Europe.

Conclusions

Research carried out at Glogow Pollution Test Station has shown that in pollution class light, under the climate condition of Central Europe, it is possible to apply shorter specific leakage distances than those recommended by IEC 60815 standard.

The lowest flashover voltage was noted during winter frost when a thin ice layer appeared on the insulators.

Different insulator types were tested over a period of 30 years at the station. Some of them passed the tests (like silicone rubber insulators or silicone coatings), whereas some (like hydrophobic epoxy resin or fluorourethane coatings) did not.

The long term research collected at the station allowed (independently of Wallace Vosloo) an unexpected phenomenon to be found: under certain weather conditions the leakage current on silicone rubber insulators can be a little higher than on porcelain insulators that have the same profile.

Some test results collected at the station can be taken into account by CIGRE or the IEC Working Group in the future.

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