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INFLUENCE OF AIR-BORNE VOLCANO ASHES ON OUTDOOR INSULATION

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Abstract: The 2010 eruption of Eyjafjallajökull volcano in Iceland caused enormous disruption to air travel across western and northern Europe. At the same time power companies in Scandinavia were worried that in the worst case one should be prepared for washing of some insulators in overhead lines and substations. A comprehensive investigation using a collection of existing experience and laboratory testing of samples of volcano ashes from Eyjafjallajökull volcano was performed for evaluation of possible influence of ashes on the dielectric strength of polluted outdoor insulation including glass/porcelain and silicone rubber insulators. Criteria for critical pollution levels of ashes were established and compared with typical dimensioning criteria for Scandinavian overhead lines. No issues for polluted outdoor insulation were expected for Norway and Sweden during the eruption in Iceland. However, insulation may be affected in the vicinity of a volcano.

1 INTRODUCTION

STRI has been approached by four Scandinavian power companies for investigation of possible influence of eruptions of the Eyjafjallajökull volcano on outdoor insulation i.e. influence of long-distance transport of ashes. The 2010 eruptions of Eyjafjallajökull (Figure 1) were a sequence of volcanic events in Iceland which, although relatively small for volcanic eruptions, caused enormous disruption to air travel across western and northern Europe over an initial period of six days in April 2010. One of the authors of this report had to cancel his flight in Europe during this time.

Figure 1: Example of the eruption and its consequences.

Immediate concern of Scandinavian power companies in the middle of April was that in the worst case they should be prepared for washing of some overhead lines and substations. Based on evaluation of existing experience it was decided that this might be needed only in the vicinity of the eruption, thus no actions were recommended. However, the physical and chemical properties of ashes may be different for each of the eruptions in the world, and the same is valid for meteorological conditions. Thus, a comprehensive investigation was decided on, using collection and analysis of already existing experience and new laboratory investigations with samples of ashes taken from the Eyjafjallajökull volcano. The main goal was to evaluate possible influence of ashes on the dielectric strength of polluted outdoor insulation and to recommend some countermeasures if needed. Possible reduction of flashover strength was considered for ceramic insulators, while for composite insulators possible reduction of ability for hydrophobicity recovery was investigated.

2 LITERATURE AND EXPERT EXPERIENCE

There is not much information about experience with outdoor insulation during volcanic eruptions; however in the frame of present investigations we combined literature research with interviews with carefully selected specialists in the field of outdoor insulation. The most comprehensive of all sources is the IEEE paper published in 1981 [1]. Generally speaking each and every eruption is different and may cause different troubles for insulation based on specific weather conditions as shown in Figure 2. It is clearly seen however that only wet ashes with very high thickness may create insulation troubles (Figure 3-Figure 5). This conclusion is backed by a number of statements from experts summarized in Table 1. Some general findings from the literature and experts communication are as follows:

- To get a flashover of an insulator, it should be covered by ashes to 100%

- Only wet ashes are of danger for the insulation, dry ashes are non-conductive enough and are rather easily removed naturally by wind and artificially by cleaning and washing
- Fine ash is more dangerous because the surface area is larger and its resistivity is reduced because of more soluble salts attached to ashes
- Only very high amount of ashes would be dangerous, a few mm in thickness.
- Strong wind and strong rain have very good natural cleaning effect, while light rain (1-2 mm/h) is the worst case.

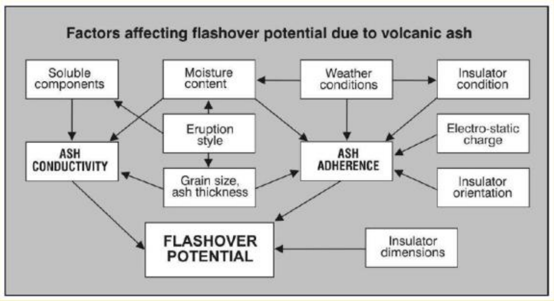
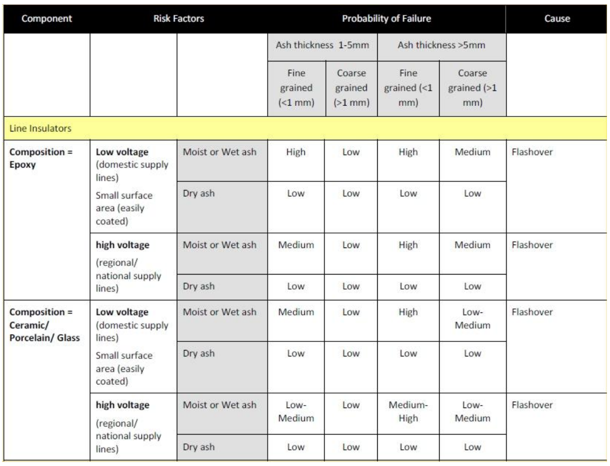


Figure 2: Factors that may affect flashover performance of outdoor insulation (adopted from [1]).



Component	Risk Factors		Probability of Failure				Cause
			Ash thickness 1-5mm		Ash thickness >5mm		
			Fine grained (<1 mm)	Coarse grained (>1 mm)	Fine grained (<1 mm)	Coarse grained (>1 mm)	
Line Insulators							
Composition = Epoxy	**Low voltage** (domestic supply lines)	Moist or Wet ash	High	Low	High	Medium	Flashover
	Small surface area (easily coated)	Dry ash	Low	Low	Low	Low	
	high voltage (regional/ national supply lines)	Moist or Wet ash	Medium	Low	High	Medium	Flashover
		Dry ash	Low	Low	Low	Low	
Composition = Ceramic/ Porcelain/ Glass	**Low voltage** (domestic supply lines)	Moist or Wet ash	Medium	Low	High	Low-Medium	Flashover
	Small surface area (easily coated)	Dry ash	Low	Low	Low	Low	
	high voltage (regional/ national supply lines)	Moist or Wet ash	Low-Medium	Low	Medium-High	Low-Medium	Flashover
		Dry ash	Low	Low	Low	Low	

Figure 3: Evaluation of risk for flashover (adapted from [2], note boxes with "high" risk). It is clearly seen that the ashes have to be wet to create insulation troubles.

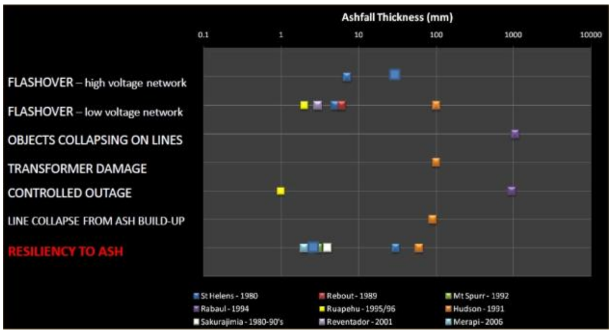
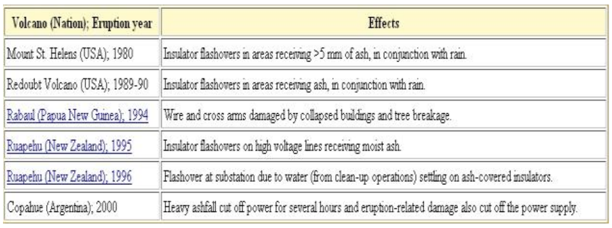


Figure 4: Evaluation of risk for flashover depending on ash fall thickness (adopted from [3]).

It is clearly seen that the thickness of ashes have to be higher than a few mm to create insulation troubles.



Volcano (Nation); Eruption year	Effects
Mount St. Helens (USA); 1980	Insulator flashovers in areas receiving >5 mm of ash, in conjunction with rain.
Redoubt Volcano (USA); 1989-90	Insulator flashovers in areas receiving ash, in conjunction with rain.
Rabaul (Papua New Guinea); 1994	Wire and cross arms damaged by collapsed buildings and tree breakage.
Ruapehu (New Zealand); 1995	Insulator flashovers on high voltage lines receiving moist ash.
Ruapehu (New Zealand); 1996	Flashover at substation due to water (from clean-up operations) settling on ash-covered insulators.
Copahue (Argentina); 2000	Heavy ashfall cut off power for several hours and eruption-related damage also cut off the power supply.

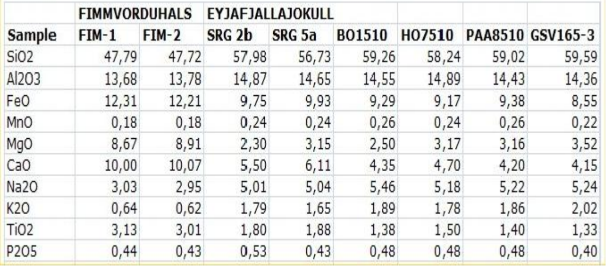
Figure 5: Examples of eruptions influencing the insulators performance (adopted from [4]). It is evident that heavy and well-wetted ashes may create insulation troubles.

Table 1: Summary of statements of different experts

Expert from	Most important in the statement
Japan-1	Breakdown close to volcano
Japan-2	Only wet ashes are dangerous
Japan-3	NSDD about 50 mg/cm^2 is critical
Russia-1	Volcano ashes chemically are similar to industrial pollution
Italy-1	Problems only in the vicinity of volcano
Italy-2	No problems with Etna ashes, but clean before cementing

3 ANALYSIS OF CHEMICAL ELEMENTS

Analysis of chemical elements from Eyjafjallajökull is shown for the main formulations in Figure 6. Each abbreviation like "SRG 2b" shows different places and time, when the samples were taken. The samples were at the distances 1-60 km from the volcano and for the period from 15th of April to the 16th of May. It is obvious that there is no significant difference in basic chemical composition depending on distance from the crater (with a reservation that only distances 1-60 km were investigated) and depending on the date of collection, thus it is possible to use some average figures for comparison purposes.



	FIMMVORDUHALS		EYJAFJALLAJOKULL					
Sample	**FIM-1**	**FIM-2**	**SRG 2b**	**SRG 5a**	**BO1510**	**HO7510**	**PAA8510**	**GSV165-3**
SiO2	47,79	47,72	57,98	56,73	59,26	58,24	59,02	59,59
Al2O3	13,68	13,78	14,87	14,65	14,55	14,89	14,43	14,36
FeO	12,31	12,21	9,75	9,93	9,29	9,17	9,38	8,55
MnO	0,18	0,18	0,24	0,24	0,26	0,24	0,26	0,22
MgO	8,67	8,91	2,30	3,15	2,50	3,17	3,16	3,52
CaO	10,00	10,07	5,50	6,11	4,35	4,70	4,20	4,15
Na2O	3,03	2,95	5,01	5,04	5,46	5,18	5,22	5,24
K2O	0,64	0,62	1,79	1,65	1,89	1,78	1,86	2,02
TiO2	3,13	3,01	1,80	1,88	1,38	1,50	1,40	1,33
P2O5	0,44	0,43	0,53	0,43	0,48	0,48	0,48	0,40

Figure 6: Chemical analysis of the ashes from Eyafjallajokull taken from different distances and in different time.

According to recently published IEC TS 60815-1 related to dimensioning of insulators in polluted conditions, types of pollution or environment are divided into: desert, coastal, industrial, agricultural and inland. Looking into main chemical formulation in Figure 6, one should try to relate volcano ashes to industrial pollution as the first choice. Such data was provided from Russia (14 samples taken from insulators close to different chemical and metallurgical plants) and Iran [5]. These were complemented by data from Japan taken close to three different volcanoes [6]. A summary is presented in Table 2. It can be concluded that in general based on analysis of distribution of main oxides, one can consider ashes as industrial pollution. Thus, general insulator knowledge is applicable for analysis of possible influence of ashes on dielectric strength.

Table 2: Summary of chemical analysis (in Wt%) of major elements (oxides) for samples collected both from volcano ashes and industrial pollution from the surface of insulators

Sample	SiO_2	Fe_2O_3	Al_2O_3	SO_3	CaO	Na_2O	MgO
Average industrial, Russia	30	20-30	20	>10	>10	<10	<10
Industrial, Iran	8	73			4		3
Average volcano,	55	10	16	-	7	-	-
Average, Eyafjallajokull	59	9	15	-	5	5	3

4 MEASUREMENT OF POLLUTION DURING VOLCANO ERUPTION

Both Statnett in Norway and SvK in Sweden have been performing Directional Dust Deposit Gauge (DDDG) measurements according to the IEC 60815-1 in the frame of pollution monitoring projects. These results were used to evaluate any influence in additional pollution accumulation during April-May 2010 in comparison to other months (the measurements are taken once per month). Two DDDG measurement sites, Ringhals and Horred at the west coast of Sweden have been used; their location is shown in Figure 7. The DDDG levels in terms of conductivity at each station in 2009 and 2010 are shown in Figure 8-Figure 9.

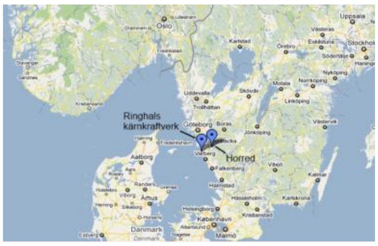


Figure 7: Map showing location of DDDG measurement stations.

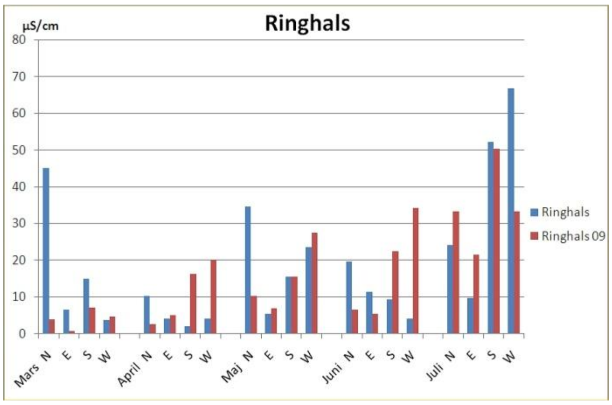


Figure 8: DDDG measurements at Ringhals (red colour in 2009; blue colour in 2010).

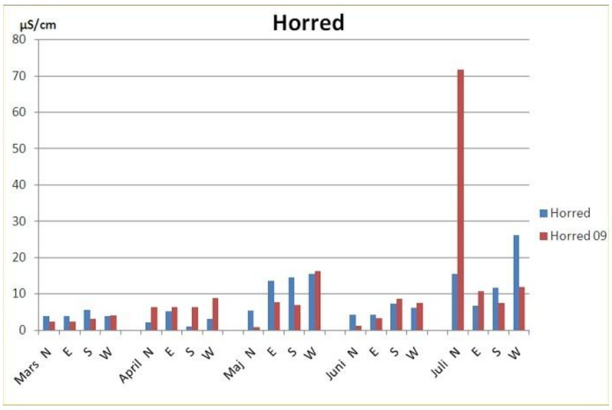


Figure 9: DDDG measurements at Horred (red colour in 2009; blue colour in 2010).

Ringhals site is located very close to the sea. The Horred measurement station is located more inland (about 10-15 km) and therefore is not affected by the pollution from the sea to the same extent as Ringhals. It is important to note that the data presented in Figure 8-Figure 9 as March 2010 was actually collected on the 20th of April 2010, for both measurement stations. Thus this is the data most relevant for the evaluation of volcano influence. The DDDG measurement devices are constructed as four tubes and thus pollution is captured from four directions, namely: North, South, West and East. At the Ringhals graph one can see an increase in March 2010 from the Northerly direction. This is very important since the sea is located to the North and West of the measurement station. One can also see that in May 2010 there is another increase from the Northern direction and in July 2010 there is an increase from the Westerly direction. The peaks in May and July cannot be connected to the eruption of Eyjafjallajökull. Even though Iceland is also located North West from the measurement sites these later increase in pollution accumulation can be most probably attributed to the pollution transport from the sea.

Another confirmation of this conclusion is that during the months of March 2010 and May 2010 there are no increases in the pollution measurements from the northerly and westerly directions at the Horred measurement site. Also, the level of Horred DDDG is constantly lower than for Ringhals. If the pollution from the volcano travelled hundreds of kilometers, this would almost equally influence both of measurement sites, which are located rather close. Instead, some increase was observed only at Ringhals site confirming that this increase in pollution can be attributed to pollution carried from the sea, since the Horred station is located further inland and is not directly on the coast. Thus, no increase of conductive part of pollution captured from the air was observed at the West coast of Sweden during the peak of eruption in April 2010.

5 LABORATORY INVESTIGATIONS

5.1 Test samples

Two different ash samples were tested. These samples were taken from the same location in Iceland (the Seljavellir farm approximately 8 km from the Eyjafjallajökull volcano crater), but at different times. Ash sample 1 was taken on the 24th of April 2010 and ash sample 2 was taken on the 15th of May of the same year. Since the eruption started in April it is assumed that ash sample 1 contains ashes taken immediately after the eruption and ash sample 2 contains ashes taken some time after the eruption. These two samples are clearly different visually (even in colour) see Figure 10-Figure 11.

Ash sample 1 is “sandier” in nature; it is very dry and appears to have finer particles. Ash sample 2 is more clay-like and appears to contain some moisture; it seems to be heavier and contains bigger particles. The density of ash sample 1 was 1,5 g/cm^3 and the density of ash sample 2 was 1,2 g/cm^3. This difference may be explained by a larger volume of air bubbles inside ash sample 2 with larger particles.

Figure 10: Ash sample 1, collected in April 2010.

Figure 11: Ash sample 2, collected in May 2010

5.2 Conductivity of volcano ashes and its “translation” in standard insulation pollution parameter Equivalent Salt Deposit Density (ESDD)

The goal of this part of the report was to evaluate possible contribution of volcano ashes in standard pollution severity parameter Equivalent Salt Deposit Density (ESDD) defined by IEC 60815-1. In comparison with two samples of ashes kaolin was used. This is standard neutral (almost non-conductive) pollutant used for artificial pollution tests according to IEC 60507. The first step consisted of mixing the kaolin and distilled water in order to get a solution of 40 g/l of kaolin and measure its conductivity. This is a standard solution prescribed by IEC 60507. The conductivity of each of the three solutions was measured at 20 minute intervals over a period of 120 minutes. The results are shown in Figure 12. The obtained results are summarized as follows. “Fresh” samples of ashes (sample 1) are about two times more conductive than kaolin. This is, however, still an indication of low conductivity, because kaolin is a neutral (non-conductive) material specially used for this purpose in standard artificial pollution tests. “Aged” samples of ashes (sample 2) are characterized by lower conductivity than sample 1 and even kaolin. Possible explanation is that salts are partially washed away from this sample. In general, ashes are characterized by low soluble salts, which may give an increase of about 30% in conductivity after 24 hours (was specially checked). The process of dissolving seems to be saturated at this stage.

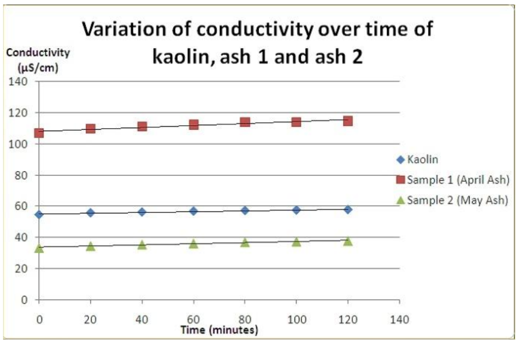


Figure 12: Conductivity of kaolin and ash sample solutions over 120 minutes.

The next step was to pollute glass plates using the same water solutions for kaolin and ashes and to measure both ESDD and Non-Soluble Deposit Density (NSDD). By knowing the relation between ESDD and NSDD for ashes, if any data on NSDD would be available in the future, actual increase in ESDD could be easily calculated. Four glass plate samples were prepared to be polluted by each of three types of pollutants (kaolin, ash sample 1, ash sample 2). The glass plates were 6 x 6 cm in size and so the area of pollution measurement was 36 cm^2. Three glass plates were dipped into each of the volcanic ash solutions (40 g/l) and dried by titling. No salt was added to any of the solutions. After drying the measurements of ESDD and NSDD were taken and the results are presented in Table 3. The ESDD measurements were taken over 120 min. to ensure that all natural salts in ashes would dissolve. Measurements of ESDD/NSDD are summarized as follows. For further discussions we will concentrate only on ash sample 1, which is higher in conductivity and ESDD, as shown in Table 3 and Figure 12. This sample represents “fresh” ashes from volcano. Taking a conservative average of ESDD after 120 min. it is assumed that NSDD of about 1,0 mg/cm^2 corresponds to ESDD of about 0,008 mg/cm^2. This relation will be used further for the estimation of dielectric strength.

Table 3: ESDD/NSDD measurements at glass plates

Sample	ESDD/NSDD, mg/cm^2		
	Test 1	Test 2	Test 3
Ash1	0,011/1,16	0,006/1,10	0,006/1,34
Ash 2	0,04/0,92	0,04/0,47	0,03/0,98

5.3 Possible influence on hydrophobicity recovery

The goal of this part of the report was to evaluate possible influence of volcano ashes on the process of hydrophobicity recovery of silicone rubber insulators. Normally, in Scandinavian conditions, the surface of composite insulators is hydrophobic and thus very high flashover voltages are obtained for these insulators in polluted and wet conditions.

The tests were performed on plates of “standard” High Temperature Vulcanized (HTV) silicone rubber; the same plates were used in [7]. Firstly the slurry was prepared with some salt with the aim of producing an ESDD of 0,1 mg/cm^2 when polluting a silicone rubber sample. The silicone rubber plates were firstly pre-conditioned; a brush was used to apply dry kaolin powder to the plates, see Figure 13. Four silicone rubber plates were then polluted using each of volcanic ash sample as well as kaolin. The resistance across the plate in time during gentle spraying was then calculated. This was done by applying the voltage 500 V across the plate and measuring the leakage current, see set-up in Figure 14. The resistance was re-measured every 24 hours over the following 15 days. The main results are shown in Figure 15. The results are summarized as follows. A special check of ESDD on a reference plate showed that after repeated wetting ESDD values decreased only 2-4 times in comparison to initial reference values and NSDD was not influenced at all. Thus the increase of resistance obtained as more than an order of magnitude can be explained only by the recovery process (low molecular weight components penetration of pollution layer). The speed of recovery process is slightly lower for ashes in the long run (especially for “old” ashes, sample 2) than for kaolin. However, for the first 3-4 days, recovery speed is almost the same for kaolin and for “fresh” ashes.

Figure 13: Pre-conditioning of the silicone rubber samples.

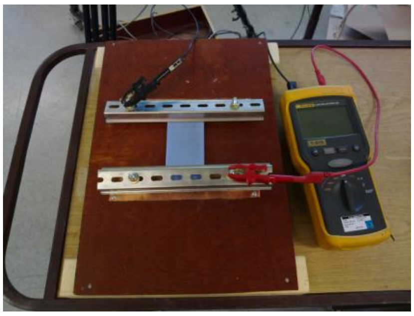


Figure 14: Set-up for evaluation of recovery (resistance measurements of polluted layer over time).

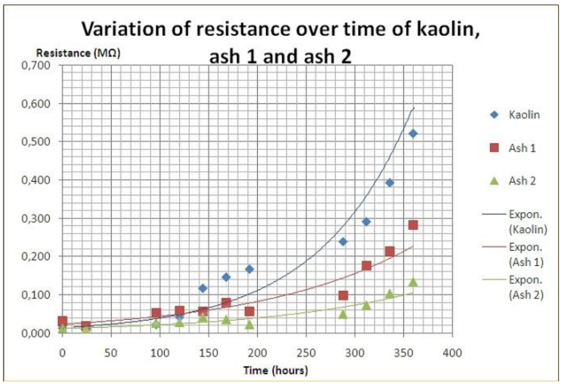


Figure 15: Time dependent variation of resistance for kaolin, ash 1 and ash 2.

6 DISCUSSION

6.1 Influence of ashes on ceramic insulators

Using a conservative approach NSDD of ashes of about 1,0 mg/cm^2 corresponds to ESDD of about 0,008 mg/cm^2. Maximum ESDD levels in Scandinavia are estimated as 0,1 mg/cm^2 [8], however they were not measured properly and most probably are lower, e.g. 0,04 mg/cm^2. Thus to reach such levels in terms of NSDD insulators should be polluted 5-10 times higher than at present. It is also important to note that according to service experience in the world actual NSDD levels for the flashed insulators were in the range 50 mg/cm^2 (Japan) to 600 mg/cm^2 (USA), which are much higher than 5-10 mg/cm^2 estimated above for Scandinavia. To obtain actual flashover performance of insulation covered by ashes, laboratory pollution tests are needed.

6.2 Influence of ashes on composite insulators

The speed of recovery process of hydrophobicity is slightly lower for ashes in the long run (especially for “old” ashes, sample 2) than for reference kaolin. However, line composite insulators are much better in flashover performance than strings of cap-and-pin insulators, even during the complete loss of hydrophobicity. This is due to better profile parameters, i.e. much lower average diameter. Thus no insulation issues are expected for silicone rubber insulators, even with temporarily loss of hydrophobicity.

6.3 Important note

All above is valid for the investigated case, i.e. eruption of volcano Eyjafjallajökull in Iceland and the influence of its specific ashes on the distant insulation (in the first hand in Sweden and Norway). Obviously, volcano ashes can influence electrical insulation in the vicinity of the eruption and thus some monitoring systems based on i.e. leakage current measurements may be recommended to evaluate this. Such systems, however, should be calibrated via laboratory pollution test of insulators covered by actual ashes.

7 CONCLUSIONS

Volcano ashes can be an issue only close to the volcano and this might also depend on the specific chemical composition of ashes. This is a common conclusion of a number of international experts from Japan, Russia and Italy, backed by literature research. Volcano ashes contamination is similar to industrial contamination, but with very low conductivity. No noticeable additional pollution accumulation in terms of conductive particles was observed during eruption of Eyjafjallajökull volcano in Iceland using standard Directional Dust Deposit Gauges (recommended by IEC 60815-1) installed in two different sites in Sweden. Higher pollution observed at one of the sites was brought as usual from the sea, not from the volcano. Very high pollution severity parameter Non-Soluble Deposit Density (NSDD) is needed for flashover of insulation covered by ashes. Criteria for critical pollution levels of ashes were established and compared with typical dimensioning criteria for Scandinavian overhead lines. In order to reach critical values of conductivity for flashover in the Scandinavian environment, insulators should be covered by ashes with NSDD 5-10 times higher than normal service level estimated at present.

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