



## Design and testing of polymer-housed surge arresters with special emphasize on seismic stresses and selection of specific creepage in costal areas.

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### SUMMARY

Results from pollution withstand tests on polymer-housed metal-oxide surge arresters are given. The test results are used to calculate the risk for flashover of arrester insulators at different pollution levels and for different selection of creepage distance. The calculations are calibrated against long term field test results at two heavily polluted test sites in UK and South Africa. The outcome of the calculations indicates that it is possible to significantly decrease the required creepage for arresters in coastal areas with the use of polymer-housings with silicone rubber as external insulation.

*Keywords:* Surge arrester, pollution test, risk analysis, probability

### 1. INTRODUCTION

Polymer-housed surge arresters have been used in service for twenty years and have shown significant advantages compared to porcelain-housed arresters especially with respect to performances under polluted conditions, seismic stresses and short-circuit currents. However, in the standards still test procedures and acceptance criteria are mainly adapted to porcelain-housed arresters only and not considering the special features of polymer-housed arresters, but focusing on the weaknesses of porcelain insulators instead.

In a number of CIGRÉ papers e.g. [1] [2] recently presented excellent field experiences from the use of polymer-housed surge arresters with silicone rubber insulators have been reported. Long-term field tests at a number of environments i.e. inland, coastal and semi-desert have indicated that a significantly shorter specific creepage is useable for silicone rubber insulators compared to porcelain insulators. In particular this seems to be possible for surge arresters with their excellent self-protection against overvoltages.

The data collected from the field tests in coastal environments could be used to evaluate the site severity on a statistically bases i.e. the pollution environment stress as function of the ESDD level. For a complete statistical approach [4] the statistical flashover strength as function of ESDD level and specific creepage is needed as well to be able to calculate the statistical risk of flashover in different environments for different choice of creepage. To establish the flashover strength distribution an artificial pollution test method is necessary and a suitable method found to determine the flashover strength of polymer-housed surge arresters for coastal areas is the Dry Salt Layer test method (DSL) [3]. This test simulates the coastal environment with negligible level of non-soluble pollution component NSDD, i.e. pollution by sea salts. Knowing the stress and strength distributions the risk of pollution flashovers for a 275 kV polymer-housed arrester has been evaluated as function of ESDD

level. In particular the risk of flashovers of the arrester for the highest pollution classes given in the Japanese standard, JEC [8] has been estimated. As a comparison deterministic pollution tests as per the JEC [8] have been performed and the outcomes of the statistical approach and the results from the deterministic methods have been compared. The field experience has also been compared with the calculated risk of flashovers based on the statistical method.

Mechanical strength and design for severe pollution is to some extent coupled since a longer arrester means a weaker design. In particular for areas with high seismic activity therefore the possibility to reduce the creepage length by use of polymer-housings will result in higher safety with respect to mechanical strength under earthquakes.

## 2. POLLUTION TESTS PERFORMED

### 2.1 Dry-Salt-Layer (DSL) Tests

The arrester tested was of polymer-housed design with silicone rubber as external insulation. The polymer housing is directly moulded (vulcanised) on the internal structure under high temperature and vacuum. The process is known as high-temperature vulcanising (HTV). This design ensures e.g. excellent thermal performance due to the lack of a gas channel between the ZnO blocks and the external insulator. Data for the arrester tested are given in Table I.

**Table I: Data for arrester tested with Dry-Salt-Layer test method**

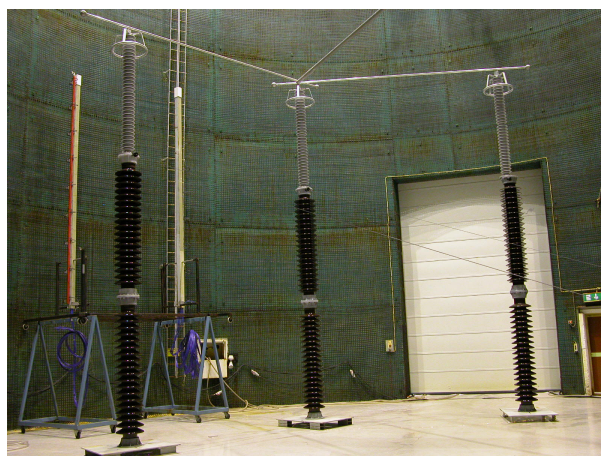
Rated voltage as per IEC	Japanese standard	Continuous operating voltage	Creepage distance
kVrms	kVrms	kVrms	mm
240	266	166	7250
Protection level at 10kA	Line Discharge Class-IEC	High current impulse	Flashover distance along insulator
kVpeak		kApeak	m
564	3	100	2.0

With the ZnO blocks mounted in the arrester it would only be possible to apply a voltage slightly in excess of the rated voltage for a very short period of time. Since the expected withstand voltage was well above the rated voltage the ZnO blocks had to be replaced by insulating material. Glassfibre reinforced epoxy rods with the same diameter as the ZnO blocks were used. This made it possible, if necessary, to increase the test voltage

to approximately 450 kVrms maximum. No special conditioning of the test samples was made before the DSL test, which is in line with the approach adopted by CIGRÉ [7].

The DSL test method comprises firstly a deposit phase during which the arresters were individually exposed to wind-borne salt particles, blown at a speed 4-7 m/s simulating strong wind from the sea.

The duration and salt content were adjusted to obtain a predetermined average ESDD level on the insulators. During the deposit phase the voltage was kept constant equal to 166 kVrms, i.e. the continuous operating voltage of the arresters. After the completions of the deposit phase three identical test objects were simultaneously exposed to wetting by steam fog gently blown -at a speed of about 0,2 to 0,5 m/s- towards the test objects. During the wetting phase a progressive stress method [3] was used to determine the 50% flashover voltage,  $U_{50}$ , -of the arrester insulators. The initial voltage level is decided based on earlier experience and the number of voltage steps is planned to obtain flashover between 30-60 minutes after the steam application. Since the



*Figure 1: The 3 surge arresters in the test chamber*

wetting procedure to some extent causes washing of the insulators, the total duration of progressive

voltage application was limited to obtain a flashover within maximum 100 minutes from start of wetting. Three test objects were simultaneously tested as shown in Figure 1. When a flashover of a test object occurred this object was automatically disconnected (special fuse blown) and the test thereafter continued on the remaining test samples. The test procedure was repeated three times to obtain the  $U_{50}$  at three test severities, 0.43, 1.0 and 1.57 mg/cm<sup>2</sup>. The test result is summarized in Table II.

The standard deviation,  $\sigma$ , could not be calculated from the test results due to too few flashovers. Therefore, 10% is further used for the risk for flashover calculations as a typical value based on standard laboratory practice in pollution testing.

**Table II. Results from DSL test** (\* No flashovers occurred below 412 kV and the test was interrupted)

Test No.	Pollution level mg/cm <sup>2</sup>	$U_{50}$ kV <sub>rms</sub>
1	0.43	>412 *
2	1.0	430
3	1.57	405.5

## 2.2 Tests as per JEC

A complete 275 kV arrester as per Table I but with an additional module in series to obtain a total creepage distance of 8613 mm was tested as per JEC [8] for the highest pollution class i.e.

an ESDD level of 0.35 mg/cm<sup>2</sup>. The pollution test procedure comprised 4 sequences of pollution and voltage application where each sequence consisted of 8 cycles during which the arrester was energized at continuous operating voltage of 166 kV for one minute followed by an increased voltage of 207 kV for 2 s. The JEC [8] does not specify if a polymeric surface must be made hydrophilic prior to the application of the pollutant. Two series of tests therefore were performed both with and without removal of the hydrophobicity prior to the test. In none of the cases flashover occurred across the arrester. In addition measurement of leakage currents did not indicate any high internal temperatures of the ZnO-discs.

## 3. ENVIRONMENTAL STRESS AT COASTAL AREAS

In [1] field test experiences from coastal areas are given. In particular arresters have been tested at Dungeness test station in UK and Kelso test station in South Africa, which are considered as two heavily polluted sites. The pollution severities expressed in 50% value and 2% values are given for the two test sites in Table III. The 2% value is taken as the maximum registered value during the test period, which was between 2 and 3.5 years.

**Table III. Pollution severity at test sites with surge arresters.**

Test site	Pollution severity	
	50% value mg/cm <sup>2</sup>	2 % value (Max. value) mg/cm <sup>2</sup>
Kelso (South Africa)	0.09	0.39
Dungeness (UK)	0.05	0.15

The ESDD values were directly measured on cap-and-pin glass insulators according to the recommended procedure by CIGRÉ/IEC.

To describe the pollution severity a lognormal distribution is used. This gives the pollution severity per pollution event. Thus, for the calculation of total risk for flashover also the number of events foreseen at a particular site is important. The number of pollution events observed at Kelso and Dungeness were in the order of 3 to 10 per years (typical number of storms).

## 4. CALCULATION OF RISK-FOR-FLASHOVER

A statistical method to calculate the risk for flashover under polluted conditions as per [4] [6] was used. The method is similar to the statistical insulation co-ordination procedure for slow-front overvoltages as per IEC 60071. Knowing the probability density function for the pollution stress at a particular site and the cumulative distribution describing the strength of the insulator, considering the

number of simultaneously stressed insulators, the risk per pollution event is calculated as the integral of the product of the two functions.

For the stress distribution a lognormal distribution is used and for the strength a truncated Weibull distribution with parameters calculated from test results [4]. A truncation point set 4 standard deviations below the 50% value was used in this report. The distributions are illustrated in Figure 2.

The total risk on a yearly base is obtained by multiplying the risk per pollution event by the number of foreseen pollution events.

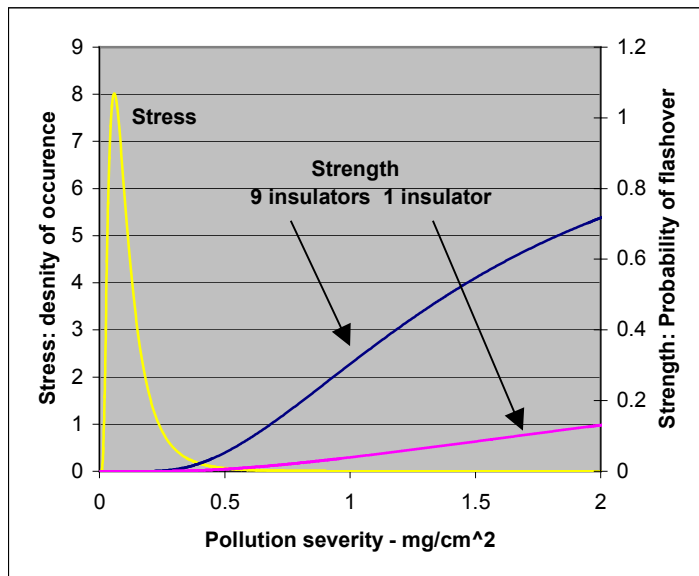


Figure 2: Stress-strength concept for calculation of flashover with respect to polluted conditions

obtained in the DSL test would have been 22% lower. Thus, as a very conservative approach and as a basis for further estimations of necessary creepage and risk of flashover a reduction in withstand voltage of maximum 22 % from the test result is considered as well.

Thus, the risk calculated based on tests results by the DSL method probably gives a realistic estimation. However, assuming a reduction in withstand voltage of 22% from test results gives certainly a result on the safe side.

#### 4.2 Calculation of necessary creepage distance for Japanese environments

The required creepage distances for the 2 highest pollution classes in Japan are based on pollution severities of 0.12 and 0.35 mg/cm<sup>2</sup>.

According to the existing JEC [8] the required creepage for surge arresters of these classes is calculated by a formula based on the arrester average diameter, the pollution severity and the arrester rated voltage. The same formula is used irrespectively of the housing material i.e. the same creepage is required for polymer-housed as well as porcelain-housed arresters. The required creepage for 275 kV arresters of the type tested is given in Table IV. As seen from Tables I and IV the arrester tested by the DSL method has a creepage which does not fulfil any of the two pollutant classes. The arrester tested as per the JEC [8] only fulfils the requirements for the lower class.

It is considered that the pollution in Japan is mainly of marine type like for the coastal sites at Kelso and Dungeness. Therefore the shape of the statistical distributions describing the pollutant severity in Japan is assumed to be similar as the shape of the distributions found in Kelso and Dungeness. The standard deviation for the highest class is set equal to the standard deviation for Kelso. The 50% values of the lognormal distributions thereafter are adjusted to obtain 2% values equal to the classifying values i.e. 0.35 and 0.12 mg/cm<sup>2</sup> respectively.

Furthermore 3 pollution events per year are considered since in average 3 storms per year have been observed in Japan during the years 1971-2000. In addition a medium size substation is taken into account by assuming 9 simultaneously stressed arresters.

#### 4.1 Comparison with field test results

In spite of only 12 mm per kV in specific creepage no flashovers occurred on an arrester at Kelso [1] during a test period of 3 years. For the 275 kV arrester tested by the DSL method 12 mm per kV corresponds to a continuous operating voltage of 349 kV. With in average 6 pollution events per year and a pollution stress distribution as per Kelso the calculated risk for flashover of one insulator is 0.04 i.e. once in 25 years. The statistical material from the field is however limited but to obtain a risk of 50% for 3 years in service the 50% withstand voltage

**Table IV: Required creepage distance for 275 kV arresters rated 266 kV and with an average insulator diameter of 150 mm as per JEC [8]**

Pollution severity mg/cm <sup>2</sup>	Required creepage mm	Required specific creepage (275 kV system) mm/kV
0.35	9783	35.6
0.12	8009	29.1

In Table V the calculated risks are given both based on actual test result in the DSL method and, conservatively, assuming a 22% reduction with

time due to e.g. some decrease of hydrophobicity and as also calibrated against field test results as a maximum statistical decrease. The continuous operating voltage of 166 kV of the 275 kV arresters is used for the calculations. The obtained result was further confirmed by using the Insulator Selection Tool (IST) software [6] developed based on the principles described in [4] [5]. Comparing the required specific creepage distances as per existing JEC [8] in Table IV with the calculated required creepage in Table V yields that a reduction of 50% would be possible with the use of polymer-housed surge arresters.

**Table V: Calculated risks of flashover and estimated necessary specific creepage for 275 kV arrester with rated voltage 266 kV for different pollution classes in Japan. (9 arresters and 3 pollution events per year considered)**

Pollution severity 2% value mg/cm <sup>2</sup>	No reduction from test result		22% reduction from test result	
	Risk of flashover for tested arrester type *10 <sup>-6</sup>	Specific creepage for a risk of 0.001 (once in 100 years) mm/kV	Risk of flashover for tested arrester type *10 <sup>-6</sup>	Specific creepage for a risk of 0.001 (once in 100 years) mm/kV
0.35	<0.00001	12.1	0.09	17.2
0.12	<0.00001	10.0	<0.00001	13.8

## 5. TESTS TO VERIFY PERFORMANCE UNDER SEISMIC STRESSES

Today's arrester standards for mechanical testing like seismic stresses are adapted to porcelain designs. As porcelain is a brittle rigid ceramic very large safety margins are required between the maximum usable bending moments to the actual breaking load. Typically porcelains can be mechanically stressed continuously in service only up to 33% of the guaranteed average value of the breaking load, tested as a sample test on porcelains acc. to DIN 48113. If the porcelain breaks, automatically the whole arrester collapses and falls down, which justify large safety margins for porcelain-housed arresters.

Polymer-housed surge arresters get their mechanical strength from composite material like glass fibre. The insulation material of silicon- or EPDM-rubber, only contributes marginally to the mechanical strength. The composites on the other hand, are built up from individual fibres joined together by means of epoxy or other polymeric materials. Up to a certain mechanical load no fibres of the composite material will break, which is the maximum usable bending moment that can be applied continuously in service. This load is preferably verified by cyclic tests with 500-1000 cycles. For higher dynamic loads above this limit some fibres will start to break causing a slightly changed mechanical performance of the arrester if it is stressed up to or above this limit once more. The more fibres that are damaged the more its mechanical performance is changed. Obviously this also means that fibres can break without that the arrester will collapse and that for short dynamic mechanical stresses slightly above the maximum usable bending moment the change has no significant influence. This load, defined as the maximum dynamic load will still be below the irreversible plastic phase. At even higher loads irreversible changes will occur and finally the arrester will break. Hence polymer-housed arresters will not have fixed ratios between breaking load, maximum dynamic load, and the maximum continuous load as this will depend on fibre-material, winding angle, shape of glass fibre structure and so on.

Due to that composites are flexible the arresters will somewhat deflect under application of mechanical loads, which also means that polymer-housed arresters in general show a better damping

against seismic stresses. The risk of a total collapse of the arrester structure is very low and hence the risk of arresters falling down damaging other insulators/equipment is negligible. This feature of polymer-housed arresters in addition to their low weight can also be used to avoid seismic stresses with for example hanging installations.

### **5.1 Seismic tests performed**

A seismic test was performed on a complete 275 kV arrester as per clause 2.2. As required in [8] the arrester was subjected to a 3 sine-wave test at resonant frequency with the acceleration of 3 m/sec<sup>2</sup>. During the test the mechanical load was measured to 2,300 Nm, which was below the maximum usable bending moment of 2,500 Nm, and gave a safety factor of 2.6 with respect to the breaking load of 6000 Nm. However, this arrester would pass dynamic loads up to at least 4,000 Nm without irreversible changes which means that a safety factor of 1.5 to the breaking load would have been sufficient in this case. Also actual earthquake waves of “Sanriku-minami great earthquake” and “Hyougoken-nanbu great earthquake” were applied to the arrester. Visual inspection and tests revealed no mechanical or electrical changes.

## **6. CONCLUSIONS**

Based on field and artificial pollution tests the risk of pollution flashover has been calculated for different pollution severities applying a statistical procedure. The procedure is calibrated against field test results and shown to give a realistic result. Furthermore, assuming a 22% reduction in withstand voltage from test results ensures a conservative result. In particular applied to pollution levels specified in Japan calculations show that it would be possible to significantly reduce the existing required creepage distances, which are based on porcelain insulators, for polymer-housed arresters with silicone rubber. This would be beneficial from several aspects. In particular the possibility to use a shorter creepage distance in highly polluted areas also leads to that shorter arresters could be used, which in turn significantly reduces possible mechanical stresses under e.g. seismic activity. In seismic verifications the now standardized and huge safety margins required for porcelain-housed designs are not relevant for polymer-housed arresters with their non-brittle material.

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