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# ASSESSMENT OF ELECTRICAL AND MECHANICAL PERFORMANCE OF TOUGHENED GLASS INSULATORS REMOVED FROM EXISTING HV LINES

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This paper presents the results of actual field experience and laboratory tests results performed on toughened glass insulators from HV lines located in various parts of the world and in service up to 40 years. Mechanical and electrical test results clearly indicate that, unlike any other material used for HV line insulators, toughened glass does not age under normal ambient and in-service conditions. The performance review of toughened glass insulators removed from service also helps understand some of the key design features required to ensure long term performance and reliability of HV lines.
Today most utilities are facing pressing urgency to assess the condition and reliability level of their existing transmission assets. At the same time a growing number of new HV transmission projects are being planned. This review of the in-service performance of toughened glass insulators can provide useful guidance in the selection of appropriate insulation technologies to be considered for future HV projects over the next 40 years;

Overhead line - Old insulator - Glass insulator - Ageing - AC - DC - Reliability

## Introduction

Whatever technology is being used for overhead line insulators, a major topic of discussion among the scientific community and utilities, is the ability of laboratories to predict the possible lifetime of these products (4). This is especially true for polymeric insulators which, by their organic nature are particularly prone to ageing. For ceramics, on the other hand, there is a clear understanding today that the crystalline heterogeneous structure of porcelain is the main factor affecting time related degradation in performance (3). This is clearly demonstrated through mechanical and electrical evaluation of old porcelain removed from service (1), as well as the increasing quantity of punctured old porcelain retrieved by maintenance crews whenever taken down from service.

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Insulators made of toughened glass are generally known to be less susceptible to ageing compared to polymer or porcelain insulators. This is largely due to the amorphous nature of glass and the properties imparted to it by the toughening process. As a result, relatively few studies are actually dealing with the ageing of toughened glass, even with about half a billion units installed all over the world on HV lines located in the most extreme climatic and environmental conditions.

This paper presents a series of test results carried out at Sediver laboratory as well as other independent laboratories, on glass insulator samples in service for up to 40 years. The test results confirm that toughened glass insulators are largely immune to time related degradation.

## 1. Insulator performance in AC conditions

Insulators sampled for laboratory evaluation have been in service under the conditions described in table 1.

| TYPE Ref . | RATING (kN) | LINE (KV) | COUNTRY | SERVICE YEARS | FIELD CONDITIONS |
|---|---|---|---|---|---|
| U300 | 300 | 400 | Iran | >20 | coastal/ desertic climate |
| 1502 | 75 | 150 | Netherland | >40 | coastal/ humid |
| F12/146 | 120 | 150 | Netherland | 30 | coastal/ humid |
| BS1513/140 | 114 | | | 25-27 | Power plant/ cement plan |
| BS12/140 | 114 | 132 | Malaysia | 20 | extreme pollution |
| BS1501/140 | 70 | | | 25 | tropical climate |
| N8R2 | 89 | 138 | United States | 30 | North East US climate |
| N14R2 | 133 | 138 | United States | 30 | North East US climate |

**Table 1:** Description of samples and relative field conditions of insulators tested.

Pictures of typical samples can be found in **appendix B**.

A variety of tests were performed on these field samples. Given the availability of samples in limited quantity, some tests have not been performed with exact quantities required by standards. However, in most cases, results are totally relevant and in line with test requirements. This evaluation includes the following tests:

- mechanical strength tests
- residual mechanical strength test
- thermo mechanical test
- dry and wet power frequency test
- lightning impulse test
- Steep front impulse test

Mechanical evaluation

- Mechanical strength test.

These tests were performed according to IEC 60383. The mechanical failing load was determined on about 40 samples from the different field cases as shown in appendix A. Given the fact that all insulators are not rated at the same value, the summary presented in figure 1 shows a normalized presentation of the test results compared to their ratings. It is clearly established here that all the values are above rating and that there is no evidence of time dependence.

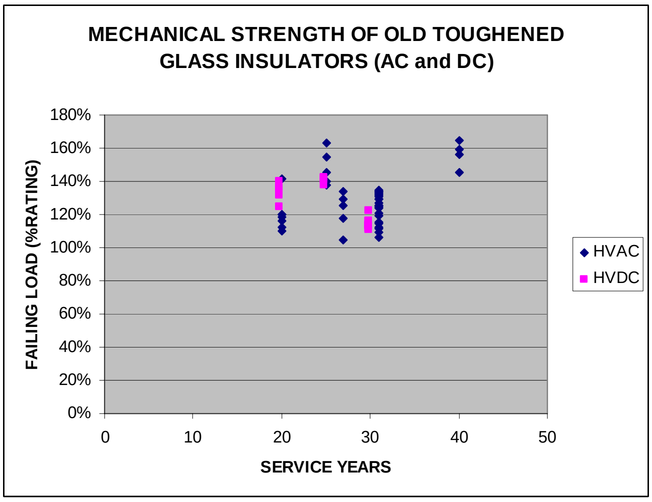


**Figure 1**: Normalized test results as a percentage of the insulator nominal rating (Initial rating of the new insulator is 100%)

Some insulators had severe corrosion on the shank of the pin. Those correspond to some of the lowest (but still above rating) test values found during this evaluation. These were units in service in extreme contamination conditions as shown in figure 2. This phenomena is known as a major contributor to the end of life of cap and pin insulators. Over the last 25 years, however, major manufacturers started supplying the insulators intended to be installed in corrosive or highly polluted conditions with a pin protected by a zinc sleeve on the shank (shown in figure 3) which eliminates completely such degradation with time.

**Figure 2:** Pin corrosion after more than 20 years in service in severe condition (Iran)

**Figure 3:** Zinc sleeve protection preventing and eliminating pin corrosion

The understanding of pin corrosion phenomena has removed this possible source of ageing of hardware and end fittings. As far as the dielectric is concerned, no change of performance can be found between new and old insulators. This is attributed to the amorphous structure (non crystalline) of glass and the toughening process used to manufacture such insulators. More detailed explanation is given in section 4.

- Residual strength test : Data collected from tests performed in Arizona State University (3) demonstrate on a specific case of glass insulators removed from a line in the North East of the USA that all the values are above 97% of the initial rating. Twenty five (25) units of each type were tested. Average failing loads under residual test conditions on these units, after more than 30 years remain above the initial rated value, when tested as per ANSI C 29-2. Table 2 gives the results of these tests.

| Type | Age years | Initial rating kN | Residual strength Average kN | Sdt deviation kN |
|---|---|---|---|---|
| N8R2 | >30 | 89 | 104,4 | 10,2 |
| N14R2 | >30 | 133 | 165,7 | 8,4 |

**Table 2** : Residual strength test on insulators removed from service in the USA after 30 years in the field. (tests as per ANSI C29 2)

According to ANSI C29-2, the acceptance criteria would require compliance to the following rule:

$$\textit{Average failing load} \geq (1.2\ \textit{Tension proof load}) + 1.645\ \textit{Stdt deviation}$$

The calculation with the test results for both cases provide an extremely comfortable safety margin, respectively 48% and 76% above ANSI normal acceptance criteria for new insulators.

High quality toughened glass insulators would typically provide at least 80% of their initial rating when tested under more stringent conditions such as IEC 60797. Also, when tested under simple mechanical failing load conditions, residual values will remain above rating.

Residual electrical strength of stubs have been evaluated under dry power frequency conditions, and a withstand value around 12kV to 20kV was established. As shown in figure4, the arc is always outside the stub, eliminating the risk of internal arc.

**Figure 4**: arc remains outside on a broken glass insulator (also called "stub")

These results demonstrate that a broken glass insulator does not represent a threat to the line, because it maintains a high mechanical strength with no risk of internal electrical puncture. This is an essential difference compared to porcelain which, once damaged can lead to all types of erratic behaviours (including string separation) and therefore requires quick intervention of maintenance.

### ➢ Thermo mechanical test

As an additional evaluation procedure, some units have been subjected to thermal cycle tests based on IEC 60575. The tests were performed on 5 insulators installed in Malaysia on a 132 kV after 27 years in service. Insulators' rating was 114kN.

Applied load is 60% of rating
Temperature cycles from -30°C to +40°C

The results are the following:
Average failing load after the thermo mechanical cycles: $\overline{X}$ = 146.1 kN
Standard deviation: S = 10.4 kN
The calculation of the criteria Qs= 3.08 > 1.4 (actual acceptance criteria as per IEC)
These insulators are in full compliance with the requirements on new insulators, and do not show any sign of ageing.

## 1.1 Electrical evaluation

### ➢ Electric type tests

As can be seen in figure 5, type tests have been performed on a variety of those insulators, and results are in line with specified values. The particularity of the toughened glass dielectric is that cracks cannot propagate inside the glass given the toughening condition of the glass (see section 4). Therefore, there is no possibility to find a punctured unit made of toughened glass, and subsequently results are all in line with the electrical ratings (dry/ wet power frequency and lighting impulse).

**Figure 5** : Electrical type tests on BS1513 insulators after 27 years of service on a 132kV line in Malaysia.

## Steep front tests

Steep front impulse was performed on a sampling of 10 units from Malaysia which were 27 years old. Test parameters were steepness greater then 2500kV/µs, alternating polarity every five shots. No failure occurred. Unlike porcelain which micro crack propagation and growth can, at some point in time, lead to puncture, toughened glass shells do not evolve with time. Therefore, no change in puncture strength over time should be expected from toughened glass.

- Pollution test

In addition to these type test verifications, an additional pollution test was performed on a string which also came back from Malaysia (line Rawang-Who). As can be seen in figure 6, the level of pollution was extraordinary high. Table 3 give the contamination measured on these units:

| | ESDD mg/cm² | NSDD mg/cm² |
|---|---|---|
| Top surface | 0,077 | 24 |
| Bottom surface | 0,06 | 29 |

**Table 3**: Contamination level of 27 year old insulators removed from Malaysia 132kV line

A pollution test according to IEC 60507 was performed (figure 7). A withstand value of 15kV/unit (phase-ground) was determined. This value confirms that after 27 years in service on a 132kV line, the string was still capable to operate normally despite the extreme level of NSDD covering the surface.

**Figure 6**: Pollution condition of a 27 year old glass in Malaysia. (near cement plant)

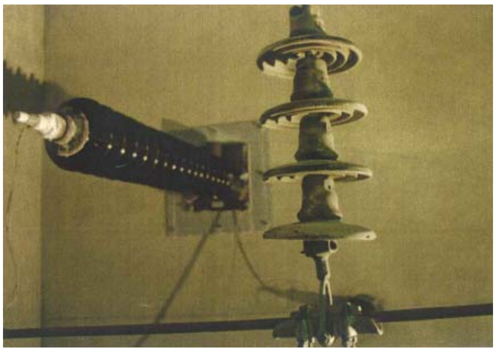


**Figure 7:** view of fog chamber insulator during the pollution test

## 2. Insulator perfomance in DC conditions

HVDC requires a specific set of design features described under IEC61325. This standard was published in 1995, and quite many HVDC lines had been built prior to this date. Manufacturers have since adapted their designs to fit these requirements. The following section shows the performance of toughened glass insulators removed from HVDC lines after decades of field conditions (2). Table 4 gives details of the test samples.

| TYPE | RATING (kN) | LINE KV | COUNTRY | SERVICE YEARS | FIELD CONDITIONS |
|---|---|---|---|---|---|
| F16P | 160 | 500 | BRAZIL | >20 and >25 | Tropical Itaipu area |
| F18P and N18P | 180 | 600 | USA | 30 | North West USA |

**Table 4:** Description of HVDC field returned insulators used for the tests (2)

The particularity of the evaluation of old HVDC insulators resides in the specificity of direct current to generate structural depletion of the dielectric material. This aspect will help to better understand the amorphous structure of glass.

### 2.1 Ionic migration

The main attribute of a dielectric material under DC stresses is the ability of the dielectric to sustain over time the ionic migration flow generated by the unidirectional current. This is described in IEC 61325 section 18.

After about 30 years in service, these insulators were tested according to this procedure which is set to describe a 50 year ionic activity. After measuring the body resistance, test parameters were adjusted to set the conditions as if the test was performed on new insulators. (Figures 8 and 9). Test conditions were 70kVDC and 90°C

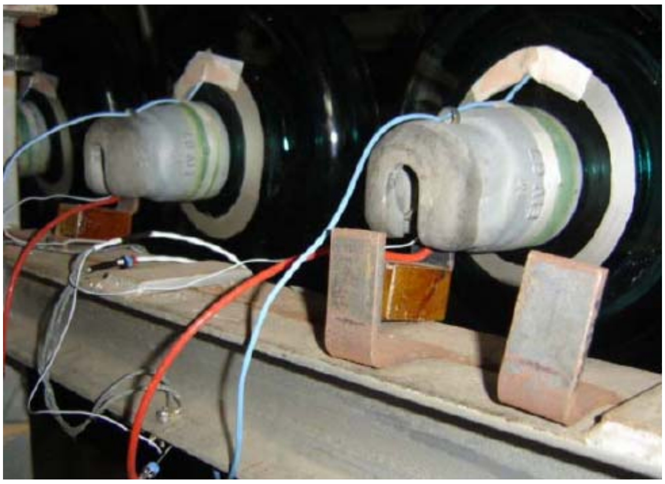


**Figure 8**: ionic migration set up

**Figure 9** : Ionic migration test chamber

The equivalent to 50 years would correspond to an accumulated charge of 153C. At this point nothing happened during the test, and all the insulators were still intact. The test was continued until an accumulated charge level reaching an equivalent of 100 years with only one shattering occurring around the 86 year mark. This, with the already 30 years of field service demonstrates the reliable performance of glass, far beyond the normal expected lifetime of the transmission line and under especially harsh conditions such as DC operation.

## 2.2 Mechanical evaluation

Like for AC, several mechanical tests were performed on these DC insulators including mechanical strength test, residual strength test as per IEC 60797, and thermo mechanical tests as per IEC 60575 with reinforced temperature cycle.

Appendix A and figure 1 describe the mechanical normalized results as a percentage of the rating. It appears clearly that, like for AC, there is no degradation over time.

To support the explanation made earlier on the pin corrosion phenomena and the protection sleeve effect, it is interesting to see the effectiveness of such method for DC, which is even more prone to such corrosion phenomena. The samples taken from Brazil (Itaipu) show an excellent protection on the pin side, even after more than 20 years in tropical conditions.(see appropriate figures in appendix B). The corrosion seen on the cap on some samples had no influence to the mechanical performance. (DC insulators today have also a zinc collar on the cap for prevention of corrosion. Like for the pin, this feature was not used 20 years back).

## 2.3 Thermo mechanical evaluation

The performance of old toughened glass insulators removed from HVDC lines was evaluated under reinforced conditions of thermal cycles.(temperature variations from -50°C to +50°C). The thermo mechanical test (figure 10) demonstrates full compliance with the standards applicable to new insulators.

**Figure 10 :** thermo mechanical test on HVDC Insulators removed after 30 years in service

- All values above rating
- Average failing load 209.1kN
- Standard deviation : 10.8 kN
- Acceptance criteria :1.2x10.8 +180 = 193
- $\overline{X}$ > 193 kN

### 2.4 Residual strength test

This test was performed on 15 insulators (rated 180kN) which had been in service for 30 years. The test conditions were according to IEC, therefore more severe than ANSI (see previous section for AC tests). 9 insulators broke at the pin. The lowest value of the pin breakage is 200 kN. For the others, 6 pins were pulled out, the lowest value being 176.1 kN. For these one, the calculation of the acceptance criteria is:

Average failing load: $\overline{X}$ = 192.4 kN
Standard deviation: $\sigma$ = 8.5 kN

The lowest value is at 97.7 % of the rating, far above any standard requirement for this type of test. The IEC calculation method on the pin pull outs would give the following result:

$(0.65*180+1.645*\sigma) = 196.7$ kN
k= 0.99
The residual strength of these old insulators tested as per IEC 60797 (figure 11) is above standard requirement, and quite equal to the rated value of new and intact insulators.

**Figure 11 :** Residual strength test after thermal cycles on 30 year old HVDC insulators

## 3. Discussion

The observations summarized below apply to both AC and DC toughened glass insulators:

- Under extreme corrosion conditions, old insulators can have suffered of pin corrosion. A mechanical strength reduction may result under extreme conditions. This particular point of performance has been solved more than 20 years ago by the addition of a sacrificial pure zinc sleeve attached to the shank of the pin. This protection has completely eliminated the occurrence of such pin corrosion.
- The dielectric itself has shown no sign of ageing. Neither mechanical nor electrical weakening has occurred up to an excess of 40 years. These insulators have been exposed to harsh pollution, including particular stresses such as DC ionic migration conditions.

The following section will describe the main factors explaining why toughened glass does not age.

## 4. Toughened glass material structure

Toughened glass is an amorphous material with no crystallographic structure. In fact, glass remains “liquid like” even at ambient temperature. This fundamental characteristic of the dielectric explains why glass does not age,(5) (6).

While micro cracks are inherent to porcelain (3), as time goes, these tend to grow , under the influence of mechanical or thermo mechanical stresses, to the point where they become critical with consequences on electrical or mechanical performances.

Toughened glass on the other hand does not contain such cracks. Crack formation or propagation is prevented by the toughening process.

Once the glass liquid being moulded has the shape of a dielectric shell, the glass will be cooled down rapidly in a forced cold air jet process. Temperature gradient across the volume of glass will generate an equivalent gradient of internal forces (7), being compressive forces along the surface while balanced by tensile forces in the inside volume of the glass shell (see figure 12).

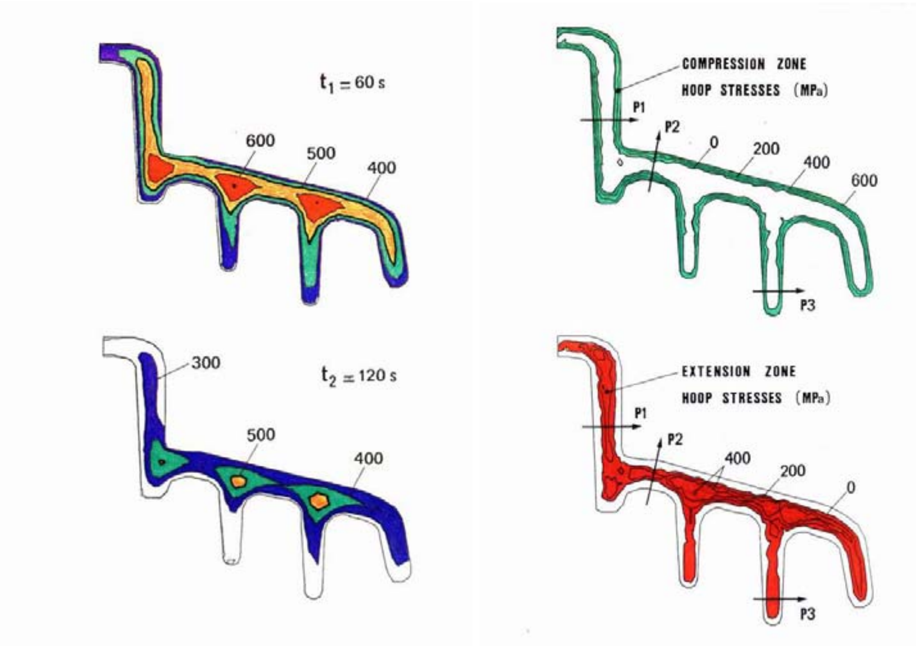


**Figure12:** Thermal profile of toughening of a glass shell establishing a balance between compressive force (surface layer) and tensile forces (inside)

Once the glass shell is cold, there is a permanent compressive force shield reinforcing the material achieving high mechanical strength, but more importantly, this compressive shield will inhibit any crack generation. Since ageing is directly related to micro crack propagation, it is therefore a natural consequence for glass not to be prone to ageing once it is toughened.

Any situation where an excessive impact would impose a local stress level above the “compressive shield protection” would result in a shattering of the glass shell, leaving a “stub” which performance was explained in section 1. This “binary behaviour” of toughened glass is a feature that provides unique advantage to maintenance crews when it comes to inspection.

## 5. Conclusion

During this investigation, old toughened glass insulators sampled from HV lines located in different countries and climates after up to 40 years of service under a large diversity of climatic and environmental conditions have been tested. The findings show that:

1. Mechanical strength of toughened glass insulators remains above rating and similar to new units even after more than 40 years in service. Despite corrosion on the pin on a few units (limited to vintages prior to the addition of the zinc sleeve systematically used today for polluted areas), the samples have demonstrated mechanical strength above their initial rating.
2. No degradation was observed on the electrical performance even for samples that were 40 years old.
3. These results are the normal consequences of the glass material structure associated to the toughening process which will inhibit any generation or propagation of micro cracks in the dielectric shell. This immunity to degradation is the reason for toughened glass to sustain initial performance over time.
4. The performance over time of old toughened glass insulators sampled from HVDC lines was found to be similar to those from AC lines.
5. Test results clearly indicate that for toughened glass insulators in service for up to 40 years, there is no sign of ageing affecting either their electrical or mechanical performance.

Bibliographic references

[1] A. Mishra, R. Gorur, S. Venkataraman, D. Kingsbury Condition assessment of porcelain and toughened glass insulators from residual strength tests (CEIDP 2006)

[2] L. F. Ferreira, J.M. George HVDC toughened glass insulators (World Conference & Exhibition on Insulators Rio de Janeiro May 2007)

[3] NGK Technical Guide (Cat N° 91R)

[4] CIGRE WG B2-03 Guide for the assessment of old cap and pin and long rod transmission line insulators made of porcelain and glass : what to check and when to replace (CIGRE Brochure Thématique 2006 N° 206)

[5] R. Parraud, H. Pekly Long term performance of toughened glass insulators on AC and DC transmission lines improvement field experience and recommendation (CIGRE International Workshop Rio June 1998)

[6] R. Parraud, D. Dumora Long term reliability of toughened glass insulators for overhead lines (1st Magarebi Symposium Tripoli April 1995)

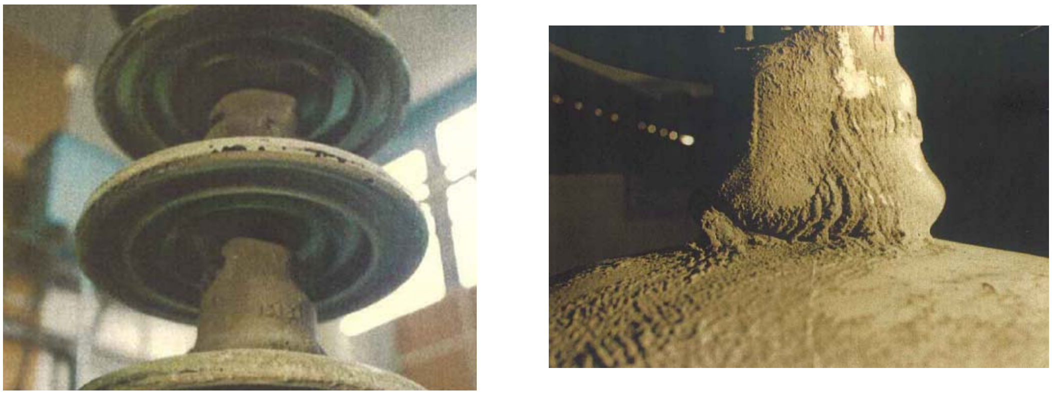
[7] D. Dumora, H. Saisse, B. Knosp, J. Goudeau, C. Licht Thermal tempering study of glass insulators by means of a finite element modellization.(14th International Congress on Glass India 1986

**APPENDIX A** : **Summary of mechanical test results on old toughened glass insulators**

| COUNTRY | SERV. YEARS | RATING | FAIL. LOAD | RATE FACT. | Type of failure |
|---|---|---|---|---|---|
| IRAN | 20 | 300 | 425 | 142% | cap broken |
| IRAN | 20 | 300 | 355 | 118% | pin broken |
| USA | 30 | 90 | 101 | 112% | cap broken |
| USA | 30 | 90 | 119 | 132% | cap broken |
| USA | 30 | 90 | 109 | 121% | cap broken |
| USA | 30 | 90 | 116,5 | 129% | cap broken |
| USA | 30 | 90 | 118 | 131% | cap broken |
| USA | 30 | 90 | 121,4 | 135% | cap broken |
| USA | 30 | 90 | 114,3 | 127% | cap broken |
| USA | 30 | 90 | 113 | 126% | cap broken |
| USA | 30 | 90 | 118,3 | 131% | cap broken |
| USA | 30 | 90 | 103,6 | 115% | cap broken |
| USA | 30 | 133 | 171,7 | 129% | pin broken |
| USA | 30 | 133 | 141,4 | 106% | pin broken |
| USA | 30 | 133 | 177,9 | 134% | pin broken |
| USA | 30 | 133 | 165 | 124% | pin broken |
| USA | 30 | 133 | 165,9 | 125% | glass shattered |
| USA | 30 | 133 | 166,8 | 125% | glass shattered |
| USA | 30 | 133 | 158,8 | 119% | pin broken |
| USA | 30 | 133 | 177,9 | 134% | pin broken |
| USA | 30 | 133 | 177,5 | 133% | pin broken |
| USA | 30 | 133 | 152,6 | 115% | glass shattered |
| Malaysia | 25 | 70 | 96,5 | 138% | cap broken |
| Malaysia | 25 | 70 | 108 | 154% | cap broken |
| Malaysia | 25 | 70 | 114 | 163% | cap broken |
| Malaysia | 25 | 70 | 98 | 140% | cap broken |
| Malaysia | 25 | 70 | 102 | 146% | cap broken |
| Malaysia | 20 | 114 | 137 | 120% | cap broken |
| Malaysia | 20 | 114 | 128 | 112% | cap broken |
| Malaysia | 20 | 114 | 132 | 116% | cap broken |
| Malaysia | 20 | 114 | 125 | 110% | cap broken |
| Malaysia | 20 | 114 | 137 | 120% | cap broken |
| Malaysia | 27 | 114 | 134 | 118% | cap broken |
| Malaysia | 27 | 114 | 147 | 129% | cap broken |
| Malaysia | 27 | 114 | 143 | 125% | cap broken |
| Malaysia | 27 | 114 | 119 | 104% | cap broken |
| Malaysia | 27 | 114 | 152,5 | 134% | cap broken |

| COUNTRY | SERV. YEARS | RATING | FAIL. LOAD | RATE FACT. | Type of failure |
|---|---|---|---|---|---|
| Netherlands | 40 | 75 | 119,5 | 159% | cap broken |
| Netherlands | 40 | 75 | 123,2 | 164% | cap broken |
| Netherlands | 40 | 75 | 109 | 145% | cap broken |
| Netherlands | 40 | 75 | 117 | 156% | cap broken |
| Netherlands | 30 | 120 | 133,7 | 111% | pin broken |
| Netherlands | 30 | 120 | 130,8 | 109% | pin broken |
| USA DC | 30 | 180 | 204,5 | 114% | pin broken |
| USA DC | 30 | 180 | 200,3 | 111% | pin broken |
| USA DC | 30 | 180 | 204,6 | 114% | pin broken |
| USA DC | 30 | 180 | 203,5 | 113% | pin broken |
| USA DC | 30 | 180 | 203,4 | 113% | pin broken |
| USA DC | 30 | 180 | 220,7 | 123% | pin broken |
| USA DC | 30 | 180 | 200 | 111% | pin broken |
| USA DC | 30 | 180 | 208,8 | 116% | pin broken |
| USA DC | 30 | 180 | 208,5 | 116% | pin broken |
| USA DC | 30 | 180 | 203,7 | 113% | pin broken |
| BRAZIL DC | 25 | 160 | 226 | 141% | pin broken |
| BRAZIL DC | 25 | 160 | 220,2 | 138% | cap broken |
| BRAZIL DC | 25 | 160 | 225 | 141% | pin broken |
| BRAZIL DC | 25 | 160 | 227,3 | 142% | cap broken |
| BRAZIL DC | 25 | 160 | 227,2 | 142% | cap broken |
| BRAZIL DC | 20 | 160 | 224,3 | 140% | cap broken |
| BRAZIL DC | 20 | 160 | 217,2 | 136% | pin broken |
| BRAZIL DC | 20 | 160 | 217,5 | 136% | cap broken |
| BRAZIL DC | 20 | 160 | 199,5 | 125% | cap broken |
| BRAZIL DC | 20 | 160 | 210,2 | 131% | cap broken |

## APPENDIX B: DESCRIPTION OF TYPICAL SAMPLES USED DURING THIS STUDY



Toughened glass insulator ref. BS1513 after 27 years in Malaysia.

Toughened glass insulators ref U300 after 30 years in Iran

Toughened glass insulators Ref 1502 after 40 years in The Netherlands

Toughened glass insulators Ref N14R2after 30 years in the USA

Toughened glass insulators Ref F18P after 30 years at 500kVDC in the USA

Toughened glass insulators Ref F16P after 25 years at 600kVDC in Itaipu Brazil. (second picture shows effective protection of zinc sleeve on a pin after being removed from an insulator.).

(pollution accumulation on Itaipu insulators was measured at ESDD of 0.4mg/cm² and NSDD above 2 mg/cm$^2$)