World Congress & Exhibition
on Insulators, Arresters & Bushings
Rio de Janeiro, Brazil
May 13-16,2007

HVDC TOUGHENED GLASS INSULATORS

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Abstract

HVDC applications around the world have been in service now for quite many years, and a great number of toughened glass insulators have been used on these very strategic power lines. This paper will review some key properties that insulators have to comply with when used under DC stresses, as well as field cases with actual service experience.

Summary

While more than two million toughened glass insulators from Sediver have been used on most of the HVDC lines in use around the world, the excellent performance of these insulators has been largely acknowledged. Some old insulators were removed from HVDC lines in the United States and in Brazil after decades (25 and more than 35 years) of field service in order to verify their performance. The test results found in the evaluation program show an outstanding electrical and mechanical behaviour, proof of no ageing of toughened glass even under DC stresses.

1. The specific stress conditions of HVDC on insulators

HVDC by nature is creating a set of conditions quite remarkable and different from traditional AC lines (5). The unidirectional E field is a main source of ionic effects on dielectric materials. While IEC (1) is describing in detail the testing parameters and performance expectations of ceramic DC insulators (either glass or porcelain) it is not so the case for composite DC application which is not covered by any standard. The question needs to be asked, however, if highly strategic lines such as DC can afford to take the risk of unknown performance, with organic inherently ageing materials, compared to the safety net provided by stable and inert products, such as toughened glass, largely supported by decades of service.

Over the years, manufacturers' have set up special materials and designs for HVDC, from the dielectric itself to the end fittings. For toughened glass, the current design has largely integrated the evolutions of the last 50 years field experience as can be seen in figure 1 and 2.

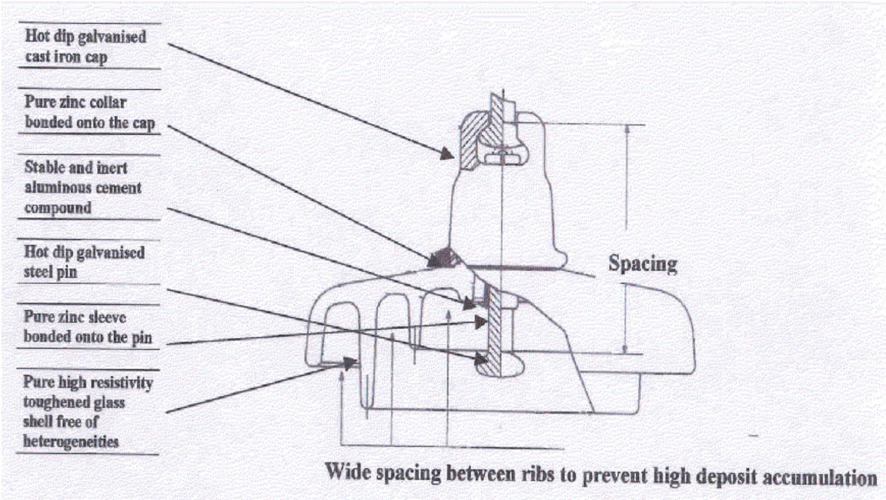


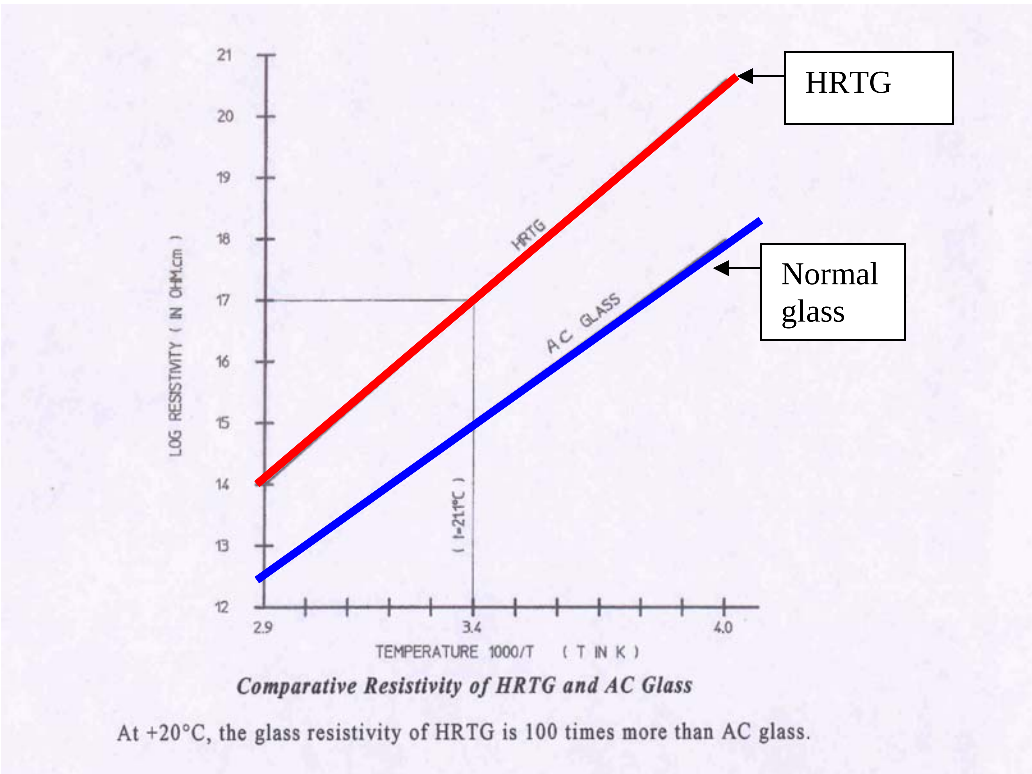
Figure 1 : Typical toughened glass insulator for HVDC application

Figure 2 : Current DC toughened glass insulator with corrosion protection features on cap and pin end fittings

Originally, standard glass or porcelain was used for HVDC. As a result of ionic migration and the associated specific stress effect, several problems occurred leading to punctures and outages on lines with standard porcelain (like for example in (2)), or shattering of glass shells at levels higher than expected during the first years (3), (4). Toughened glass, however, never led to the magnitude of problems encountered with porcelain since a shattered unit does not generate any operational interruption or disturbance.

The specific action of ionic migration corresponds to the migration of ions in the glassy phase of the dielectric material under the unidirectional DC voltage. This glassy phase exist in both glass and porcelain. Under the ionic effect of DC voltage, there is a formation of a depletion layer where Na+ alkali cations have moved. This migration through the silica network which forms the frame of glassy materials depends on the resistivity of the material itself. Ionic conductivity depends mainly on temperature, but is also a function of the amount and type of alkali present in the dielectric (5).
A second effect of this migration, is a possible ionic accumulation in areas of structural heterogeneity.

The second generation of DC glass, HRTG special glass composition has been designed (6) around a better protection against corrosion (figure 2) and above all, a much higher resistivity as shown in figure 3. This special chemistry of glass is locking the ions through a much lower ionic conductivity in order to stop the migration under DC voltage. Given this “immunity” against ionic stress, the adverse effects described above and seen in the earlier applications have been eliminated. Additionally, special process treatments in the glass moulding have led to a much higher purity of glass, and therefore a lower impact to DC ionic accumulation.



Comparative Resistivity of HRTG and AC Glass

At +20°C, the glass resistivity of HRTG is 100 times more than AC glass.

Figure 3: difference of resistivity of HRTG versus normal glass

2. Worldwide experience of toughened glass insulators for DC applications

Sediver has supplied more than 2 million toughened glass insulators worldwide over the last 40 years for a variety of applications under the most diverse climatic and environmental conditions (Table 1). All these insulators are still in operation with the exception of a few cases such as Mozambique where war damage has required replacement of some sections of line.

Country	Utility	Project	Year	Voltage (kV)
Brazil	Furnas Centrais	Foz Do Iguaçu-Sao Roque I HVDC Itaipu Transmission System	1984	600
	Furnas Centrais	Itaipu II	1987	600
Canada	BC Hydro Vancouver	Saltspring-Stratford / Vancouver Island	1968	260
	Atomic Energy of Canada	Kettle-Winnipeg / Nelson River	1973	450
	Hydro Québec	6TH James Bay	1988	450
China	Shanghai Super High Voltage	Gezhouba Shanghai	1999	500
	Southern Power Grids Co.	Tianshengqiao-Guangdong	2001	500
	Anhui Wuhu		2001	500
	State Power Grids Co.	3 Gorges-Longta-Qinghai	2002	500
	Southern Power Grid	Guizhou-Guangdong	2003	500
	Anhui Transmission Power Co.		2003	500
Denmark	Elsam	Skagerrak / Bulbjerg-Tjele	1987	250
Sweden + Denmark	SSPB + Elsam	Billdal-Kungsbacka-Gothenburg Aalborg-LaesoIsland Konti Skan Project	1965	250
Denmark + Norway	Elsam + NSPB	Bulbjerg-Tjele Stoelen-Kristiansand Skagerrak Project	1976	250
Finland	IVO International Ltd.	Fenno Skan / Rihtniemi-Rauma	1988	400
India	Power Grid Corp.	Rihand Dadri	1987	500
	M.S.E.B.	Chandrapur-Padghe	1997	500
Italy	ENEL	Corsican section – Italian section / Carbo Sarda	1968	200
Mozambique	Hidroelectrica de Cahora Bassa	Songo-Apollo / Cahora Bassa	1977	533
	Hidroelectrica de Cahora Bassa	Cahora Bassa	1995	533
New Zealand	Transpower	North South Island	1990	350
Norway	Statnett	Skagerrak	1993	350
	Statnett	Skagerrak	1993	350
	Statnett	Skagerrak	1993	350
USA	BPA – PDWP - City of Los Angeles	Celilo-Oregon Border Oregon Border-Sylmar / Pacific Intertie	1970	500
	United Power Association Elk River	Dickinson-Coal Creek / CU Project	1979	400
	Vermont Electric	Norton-Comerford Quebec-New England Intertie	1987	450

Table 1: Toughened glass HVDC applications

3. **Performance evaluation of old insulators returned from BPA, USA**

Out of many lines built over the last decades with toughened glass, some interesting feedback was provided through utilities interested in testing old insulators removed from DC lines. As an example, after more than 35 years in service, (insulators made in 1967) insulators from BPA (Bonneville Power Administration, USA) have been removed from a 500kV DC line to be tested. The goal of these tests was to make an assessment of their condition and evaluate the possible modifications of their performance after more than 35 years on a DC line. Several tests were performed:

a) Dielectric test on the material

- ionic migration

b) Insulator testing

- mechanical strength test
- residual strength test
- thermo mechanical test

These tests were performed in CEB Laboratory, France and Saint Yorre laboratory France. The overall condition of these insulators, as can be seen in figure 4 is excellent. There was a zinc sleeve on the pin, and the fittings do not show any significant damage.

Figure 4: BPA 500kV DC insulators after more than 35 years in service.
Mechanical rating is 180kN

3.1 Ionic migration test

To verify the integrity of the dielectric under ionic migration conditions, 50 insulators were tested as per IEC 61325 section 18. The Q50 conditions were evaluated as per this method, after determination of the body resistance (figure 5 and 6). The test was performed as shown in figure 7.

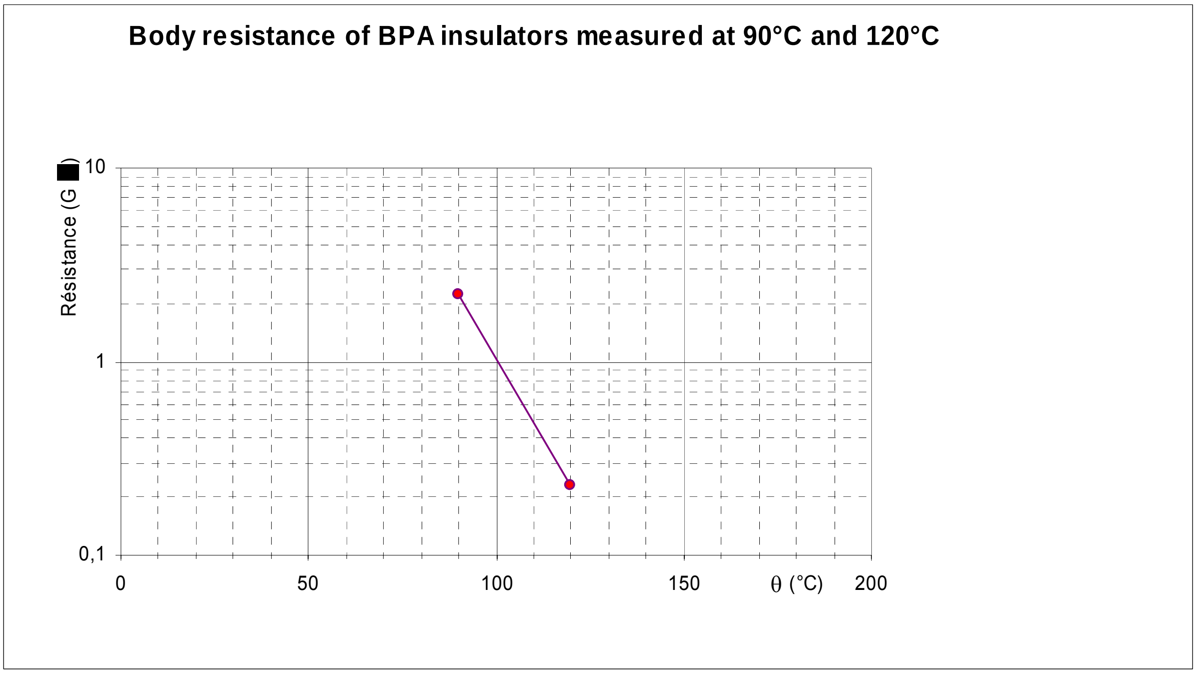


Figure 5: Body resistance of the tested insulators

Figure 6 : body resistance tests (CEB laboratory, France)

Figure 7: Ionic migration test. (CEB laboratory, France)

Test conditions were 70kV, and 90° C. The charge quantity calculated for the test to achieve under these conditions the Q50 was 153C. A shattering occurred after 258C, equivalent to a service time of **86 years**. The test was stopped after 525C with no further evolution, which is above **100 years** of equivalent service time.

At this stage, we can conclude that the dielectric material itself is not modified, with a result pointing out very clearly that the **glass shell has not aged** and kept its structure intact.

3.2 Mechanical strength

Ten insulators taken after they passed the ionic migration test were tested. The test was performed as per IEC 60383 in Saint Yorre laboratory, France. The rating of the insulators is 180kN. The set up is shown in figure 8.

Figure 8 : set up of the tensile test

Figure 9: Pin breakage typical of mechanical failure

All the insulators broke at the pin (figure9). The values are:
Average failing load: $\overline{X}$ = 204.1 kN
Standard deviation : σ = 2.9 kN

All the values were found above rating, and **identical to those of new insulators.**

$\overline{X}$ -3σ = 195.4kN > 180kN (rating)

3.3. Residual strength test

This test was performed as per IEC 60797 on 15 insulators, using a preconditioning thermal cycle (figure 10). All these insulators had previously passed the ionic migration test.

Figure 10: residual strength test with preliminary thermal cycles (IEC 60797)

Out of the 15 units tested, 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: σ = 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* σ) = 196.7 kN
k= 0.99

After more than 35 years in service, the residual strength of these insulators is above standard requirement, and quite **equal to the rated value of new and intact insulators.**

3.4. Thermo mechanical tests

This test was performed as per IEC 60575 with temperature variations from **-50°C to +50°C**. The set up is shown in figure 11. All 10 insulators were taken from the samples which had passed previously the ionic migration test.

Figure 11: Thermo mechanical test -50/+50°C
(Saint Yorre laboratory, France)

After the 96h cycle test, the insulators were pulled to mechanical destruction. All the values were above rating. (7 broken pins, 3 broken caps)
The results are:

Average failing load: $\overline{X}$ = 209.1 kN
Standard deviation: σ = 10.8 kN
Acceptance criteria: $\overline{X}$ = **209.1 kN** > (1.2*10.8 + 180) = 187.8 kN

These insulators pass **successfully** the thermo mechanical tests as per IEC 60575 with reinforced thermal cycle criteria.

As can be seen from all these tests, the insulators which have spent more than 35 years on a 500kV DC line show **no sign of ageing** either from an electric, mechanical or thermo mechanical point of view. (It is important to note that all the insulators used in these mechanical tests had previously been used for a ionic migration test). Thanks to the homogeneity of glass and complete inertia to time, these insulators did not age and perform like new insulators.

4. Insulators returned from ITAIPU, Brazil

Some insulators have been removed by FURNAS from the +/-600KV DC lines in Itaipu (figure 12). The main difference with the previous case is the climatic conditions, tropical, warm and highly humid with natural pollution conditions (fungus…).

Figure12: Itaipu I and Itaipu II +/-600 KV DC equipped with SEDIVER toughened glass insulators

4.1 General comments and observations

These insulators were produced in 1981 and 1986 respectively fro Bipôle I and II. The visual observations show insulators in very good conditions. Some insulators have rust spots at the base of the cap, but overall their aspect is excellent. It appears also that the pollution (when present) is not evenly distributed. Some units are very clean others have a biological type of pollution located mainly between the outer edge of the under skirt and the large rib under the skirt as shown in figure 13. A close up (figure 14) of the pollution deposit shows fungus in this region.

Figure 13: pollution concentration in external section of the bottom of the insulator outside the large rib while the rest of the insulator remains clean

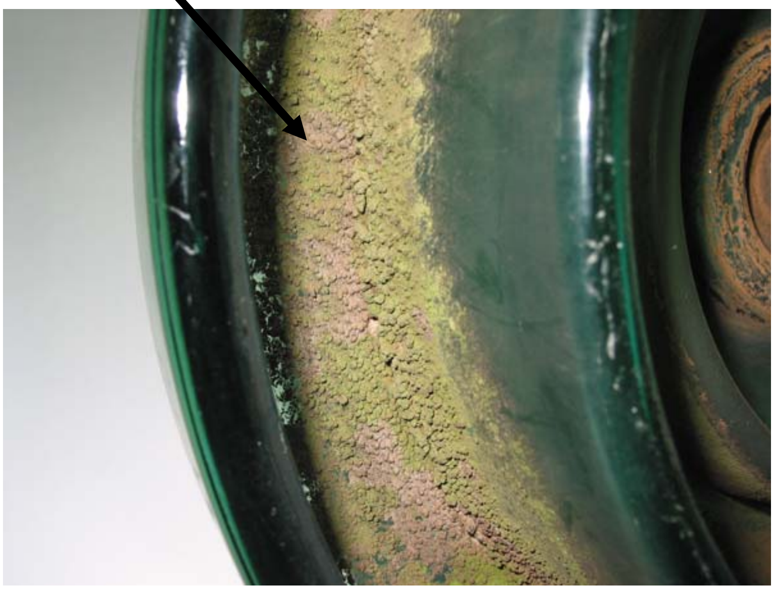


Figure 14: close up of biological pollution built up

The insulators removed from these lines do not show any major sign of corrosion on the pin. The pins are in excellent condition (figure 15), In a few cases the base of the cap of some units was rusted as shown in figure 16. Furnas Engineers had spotted these cases, and did not report any particular damaging behaviour.

Figure 15 : condition of the pin removed after mechanical test. No corrosion

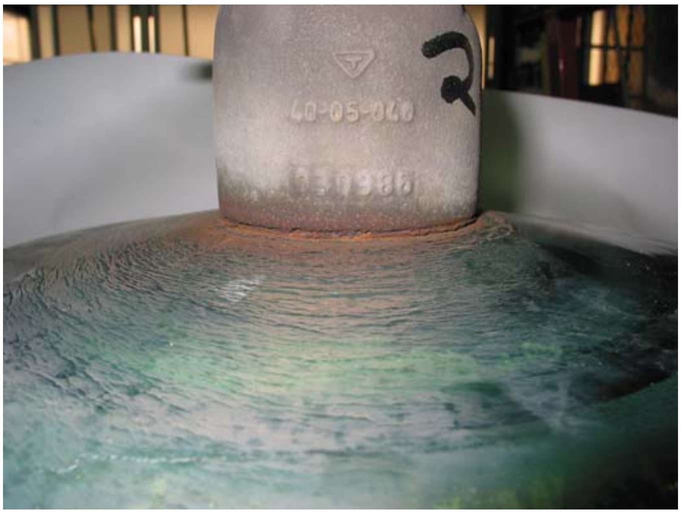


Figure16 : corrosion at the base of the cap on a few units

The risk of corrosion of the cap (even minor) has been completely eliminated in the new HRTG generation thanks to the addition of a pure zinc collar around the base of the cap as explained earlier in figures 1 and 2. Such additional protection to the cap has been used since on several major projects like in India or China.

4.2. Mechanical strength test

These insulators were rated at 160kN. A mechanical test (figure19) was performed on 10 insulators taken from both polarities:

Figure 19: Itaipu insulator during the mechanical test (polarity (-))

Average failing load: $\overline{X}$ = 216.2 kN
Standard deviation: σ = 12.1 kN
The review of these results is showing that
$\overline{X}$ -3xσ = **179.9 kN** > 160kN (rating)

The mechanical strength of the insulators removed after 20 to 25 years in service is **identical to the performance of new insulators.**

(The test program on these insulators is still in progress at the present time. More data will be available when the study is completed).

Conclusion :

The assessment of the condition of SEDIVER toughened glass insulators after 25 and more than 35 years in service under different climatic and environmental conditions on DC lines has shown that **high quality toughened glass does not age even under the specific conditions of DC voltage.**

The units tested for this purpose were removed from a +/- 500 kV DC line in the USA and a +/- 600 kV DC line in Brazil have shown excellent mechanical, electrical, and thermo mechanical results. The test results are **identical to those of new insulators, proof that toughened glass does not age even under DC stress.**

The technology in this field has evolved over the last 40 years, and today, the SEDIVER special DC toughened glass insulators (HRTG) are made with even higher purity, and resistivity and better fitting protection against corrosion.

Like always in the quite conservative field of the T&D industry, the experience gathered from the field has the unique advantage and characteristic to demonstrate beyond any possible doubt the reality of the performance of products used on overhead power lines. This study has established such answers for toughened glass insulators used for DC applications.

Bibliography:

(1): IEC 61325

(2): New Zealand +/-250kV 600MW HVDC link reliability, operating experience and improvements. M.T. O Brien, C. Burleigh, J.C. Gleadow. CIGRE 1991

(3): HVDC ITAIPU insulators performance A.I. Nigri, P.C.V Esmeraldo. FURNAS. CIGRE SC 33.93

(4): IEEE Transaction on Power delivery,1988, Vo l3, n 2 “Failure of transmission line cap and pin insulators under DC stresses”. C.A.O. Peixoto, G. Maronne, G. Carrara, L. Pargamin.

(5): State of the art concepts of insulator strings for HVDC lines. D Dumora, L. Pargamin, R. Parraud. CIGRE, New Delhi, India, 9-11th September 1991

(6): Improvement in the design and the reliability of toughened glass insulators for AC and DC transmission lines. R. Parraud, D. Dumora, R. Joulie, C. Lumb. 11th CEPSI 1996, Kuala Lumpur.

Acknowledgment:

BPA, (USA), and FURNAS (BRAZIL), for their kind assistance in providing samples for these tests.