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A new generation of Composite Support Insulators for UHV DC and AC systems

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SUMMARY

For High Voltage substation support functions the only standardized solution available until recently were solid core porcelain or solid core composite insulators. The requirements for UHV installations in terms of length, mechanical strength , permissible deflection, creepage distance and pollution resistance provided a challenge for the existing technology. Based on the positive experience with hollow core equipment insulators used for breakers, bushings, instrument transformers and cable terminations the fundamental concept of the hollow core composite insulator was used to develop this new type. The challenge in this development was to provide a reliable and economical solution to water vapor permeation. A solution was found based on closed cell hard foam which allowed hollow composite support insulators up to 250mm diameter. However for larger diameters necessary to cover the needs for high strength , low deflection needs of e.g. disconnectors in UHV systems gas filling of the hollow core was chosen. Along with fundamental research on water permeation of hollow core insulators, new test methods were developed to prove the long term stability of this solution. This type of insulator was chosen for the disconnector design for the first commercial 800kV DC system in China. As part of a retrofit program a Canadian utility replaced 500kV DC busbar insulators to this new type

KEYWORDS

Composite hollow core insulator – UHV– HVDC – water vapor permeation – disconnector – support insulator.

1 Composite Hollow Core Station Post Insulators

The aim of this project was to establish a solution which enables engineers to use High Voltage Composite Station Post Insulators as an alternative for porcelain types providing advantages in terms of pollution resistance, size, weight and mechanical strength.

The superior properties of fiber reinforced, resin impregnated tubes versus solid fiber reinforced pultruded rods in terms of weight, bending strength and deflection were well known and used in practice for High Voltage apparatus insulators for bushings, terminations, breakers, instrument transformers etc. The use of pultruded rods (solid core types) as strength members for support insulators is however limited by manufacturing process issues as core diameters above 100mm present difficulties in terms of porosity. It is known that these problems were bypassed by adding wound layers on top of solid pultruded rods. However the fundamental issue of adding material with declining benefit for minimum deflection could not be solved. In practice the use of solid core composite insulators is limited to voltages up to 220kV. Some multi stack / column units set up in the same way as porcelain units were made to extend this limit. Table. I illustrates the issue comparing solid rod and hollow core with a standard porcelain C16 insulator. In short : Today's solid core composite support insulator for 220kV application will not achieve the required mechanical cantilever strength and low deflection of a porcelain C16 type.

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Table I Comparison of different type support insulators based on requirements for traditional porcelain type C16, BIL 1050kV

		Solid Core Porcelain	Solid core Composite	Hollow Core Composite
Core diameter	mm	120	80	257
Break @	kN	16	6	31
Routine Test	kN	8 -10	n.a.	n.a.
Deflection	mm / kN	10 @ 12	165 @ 4	14 @ 12
Weight	kg	260	55	120

1.1 Standards

Hollow core insulators are covered by IEC 61462 Composite hollow insulators – “Pressurized and unpressurized insulators for use in electrical equipment with rated voltage greater than 1 000 V “ –. This standard however does not cover support insulators. Composite solid core support insulators are covered by IEC 62231-1, Ed. 1.0: “Composite station post insulators for substations with ac voltages greater than 1 000 V up to 245 kV” . This means that a hollow core support insulator would be a new type which is not covered by any of the existing international standards.

1.2 Filler options

The biggest challenge of this project was to identify a filler material for hollow core support insulators. Several options were investigated. Both porcelain and composite hollow core insulators were installed many years ago using air as filling materials. However, catastrophic failures caused by moisture ingress and inner flashover raised questions about the reliability of this type. A solid insulating filler material would be a great way to deal with any issues regarding inner electrical strength, leakage currents etc. However high cost and weight would not allow solid materials for an economic solution . A liquid insulation material provides a similar situation but requires special attention to solve issues like thermal expansion and leakage. Pressurized gas filling is well known for equipment insulators and has been common practice for HV breakers and Gas Insulated Switchgear (GIS) since the mid sixties. A support insulator follows the ambient temperature unlike applications where the insulator is frequently heated from the inside because of the resistive losses in the conductor due to load. Considering the mechanics of water vapor transmission this phenomena must be taken into consideration when dehydrating fillers are applied.

1.3 Foam

Foam looked attractive to solve the issues as explained above. However little experience was available in the world of high voltage power products to answer some of the questions associated with foams like electrical strength, water / vapor absorption , mechanical behaviour during temperature cycling , application, long term stability etc. Polyurethane based closed cell foams appeared to be a good potential candidate. Studies carried out at the University of Darmstadt , published in 1989 [1] indicated the potential suitability of this material as a filler. The selected PU foam provides a good thermal stability at high and low temperatures. Samples of the foam selected were tested to prove that the AC breakdown voltage would consistently be above the maximum to be expected stress. Electric field calculations showed that the electric stresses in the foam would not exceed the stresses in air on the outside.

1.4 Water vapor permeation

The Silicone housing does not provide a sufficient water vapor barrier. The glassfiber reinforced resin impregnated tube consists of 70vol % glass fiber. This high content of glass is the main reason for its potential low water vapor transmission rate. The PU foam itself will absorb water up to 3% of its volume. At the time of the development of the support insulator a governmental funded research program (AIF) to investigate the true water permeation of glass fiber reinforced tubes was conducted in close collaboration with the University of Darmstadt [2]. To deal with the uncertainty until the reliable data became available it was decided to develop short, medium and long term tests to prove the reliability of the concept.

1.5 Short term – artificial gap test

As it is impossible to guarantee either the filling being completely uniform or the foam adhering to the inside of the tube along the entire interface of the insulator. The stability of the system in a worst case scenario was simulated:

- No adhesion of the foam to the inside of the tube
- A gap between the tube and foam of 1 -2mm throughout the insulator
- Water inside the tube to 100% relative humidity of the gap space at room temperature

The basic idea was to create a layer of condensed water along the inside of the tube to trigger an internal flashover. The amount of water used in this tests was above the calculated amount which might accumulate due to the water vapor transmission rate of the tube (using Fickians law).
Samples were left in an oven for 24h to vaporize the water. The parts were then quickly cooled below dew point and immediately exposed to an AC withstand test. In none of the tests an internal flashover happened. All flashovers occurred on the outside of the insulator in air. It should be noted that complete filling of the insulator and firm adhesion of the foam to the inside of the tube is still needed to provide sufficient additional safety margin.

1.6 Medium term – no flange test

Foamed tube samples of different lengths without flanges at either end were used to simulate a defect of the sealing between the flange and tube were exposed to 40ºC @ 90%rH for a total of 4000h. During the test the samples were taken periodically to the High Voltage lab for AC flashover test. Weight increase due to the humidity was monitored. All flashovers occurred on the outside of the insulator in air during all electrical tests.

1.7 Long term- 50.000hrs humidity test

Special samples were produced with 4mm fiber glass reinforced tubes to increase the water vapor transmission rate of the glass fiber reinforced tube. It should be noted that none of the serial products features such a thin wall – the smallest wall thickness for serial products is 8mm . Samples were tested in accordance with IEC 61462 part 7.2 - “ Interface and connection of end fittings “ - which consists of a combined mechanical, and temperature stress preconditioning . Pass criteria is outer flashover during impulse test after boiling in salt water of the sample for 42h. All three samples passed this test. One unit was then exposed to the salt fog test in accordance with IEC 61227 and afterwards stored at 100% relative humidity for a total of more than 50 000 h as of today. During this storage period the sample was impulse tested infrequently. No flashover occurred inside the insulator.

2. Support insulators for 800 kV DC disconnector

Table II Summary of mechanical requirements

Total height	11397mm	Specified Mechanical Load (SML)*	25 000 N
Units / column	2	Max. Service Pressure (MSP)*	0.1 MPa
Max weight	1200 kg	Max. Deflection @MML	167 mm
Service Temperature	-40…+80 ºC	Creepage distance min	38700 mm
Maximum Mechanical Load (MML)*	10 000 N	Min. Arcing distance	10600 mm

To achieve a low deflection and to maintain a single column unit the largest available diameter had to be chosen using an optimized winding scheme . One insulator consists of 2 units , each about half of the total length. The top and bottom flange are made of gastight Al alloy castings. The lower flange was designed using finite element calculations to withstand the high bending moment. Foam filling of the insulating tube has shown process limitations for diameters above 250 mm. It has been decided to use a mixture of SF_6 and N_2 as a filling medium. The filler gas is kept under pressure of only 0.1MPa during service. This allows monitoring the tightness of the insulators during service. To avoid any accumulation of water inside the tube due to water vapor transmission a special cassette, filled with desiccant was designed to provide sufficient absorption capacity for a service life of more than 40 years.

2.1 Mechanical Type testing

Since there is no existing standard it has been decided to test the mechanical properties in accordance with IEC 61462. The insulator passed all tests. The requirement for very low deflection in the tube design resulted in the true SML value being exceeded by more than 80%. The insulator broke at 46 kN.

Fig. 1 Bending Test set up

3 Disconnector for the worldwide first 800 kV UHV DC transmission system

The first 800 kV high-voltage direct-current link in China started with power transmission in December 2009. For this application disconnectors and earthing switches had to be developed. Double-side break disconnector was chosen due to the outstanding operational performance for 500 kV DC and 800 kV AC. The double-side break disconnector features three support insulators fixed to a steel structure (Fig.3 & 4).. The current path is mounted on the top of the central support insulator. A rotating unit transfers the movement from the drive to the current path via the support insulator in the centre. The outer support insulators are fixed. Gas filled hollow core composite insulators have been used. The fixed contacts are equipped with contact fingers. In this design, the current path performs a combined swinging and rotary movement. After completion of the swinging movement, the contact force is generated by the rotation of the current path around its own axis. [3]

3.1 Application

Disconnectors and earthing switches and the bypass circuit breakers are the only mechanical switches in an Ultra High-Voltage DC system. Within these substations the 800 kV DC disconnectors can be grouped according to their tasks and locations:

- Bypass disconnector : in parallel with upper 12-pulse valve group
- Group disconnector : between upper 12-pulse valve group and pole bus (± 800 kV DC)
- Bus disconnector: between transmission line and pole bus (± 800 kV DC) as well as between transmission line and neutral bus
- Filter disconnector: between filter and pole bus (± 800 kV DC)

The earthing switches ensure a safe connection to earth for parts of the system that are switched off. All earthing switches were designed as build-on earthing switches at disconnectors as a result of the layout of the 800 kV UHVDC substations. [4]

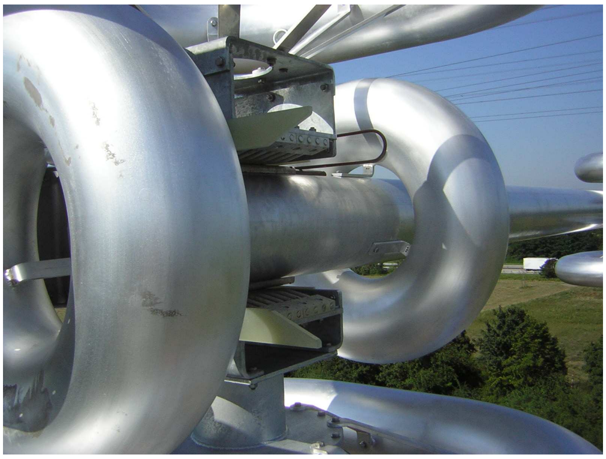

Fig. 2 Close-up view of the mating contact with commutating contact system of the disconnector.

3.2 Requirements

The 800 kV DC disconnector and earthing switch were developed based on the customers specification. The main ratings and technical data are listed in Table III. These requirements lead to a ground breaking product development. The focus of the design process was the dimensioning of the key components such as current conducting parts including moving and fixed contacts, insulators and kinematic chain. In the absence of standards for UHVDC disconnectors and earthing switches, the development and type tests are based on analogies with AC equipment standards and on client specifications. [4]

3.3 Dielectric investigations

A series of dielectric pretests have been performed to determine the necessary flash over distances across the isolating distance, earth and corona protection.
In cooperation with technical universities in Germany the dielectric behaviour, DC withstand voltage of 1200 kV for 60 minutes during artificial raining, erection altitude up to 2000 m above sea level, creepage distance of 47 mm/kV, thread measure of the insulator of 13.5 mm/kV have been investigated.

Table III : Requirements for 800 kV UHVDC disconnectors and earthing switches

High voltage requirements		Mechanical requirements	
Rated DC voltage		Mechanical endurance	2000 CO
terminal - earth	800 kV	Seismic withstand capability for ground acceleration	0.3 g
between terminals	800 kV		
DC withstand voltage		High current requirements	
terminal - earth	1200 kV	Peak and short time withstand current	50kA peak / 20 kA rms – 1 s
between terminals	1200 kV	Transfer current @ 80 V peak recovery voltage	2500 A rms
Switching impulse withstand level		Making and breaking current capability @ 56 kV peak recovery voltage	100 A rms
terminal - earth	1790 kV		
between terminals	1790 kV	Temperature rise requirements	
Lightning impulse withstand level		Temperature rise	5000 A
terminal - earth	2205 kV		
between terminals	2205 kV		
RIV level @ 1040 kV DC	< 2500 µV		

In these studies particular attention has been given to understand the behavior of the insulator and the disconnector arcing distances under switching impulse voltage stress as well as to understand corona effects under dry and wet conditions.
It was necessary to define the diameter D of the toroids necessary to limiting the corona effect to the permitted RIV level of <2500µV@1040kV. A specific tube diameter of the toroids of 1.2xD is expedient for the high switching impulse withstand voltage under wet conditions over the arcing distances given in Fig. 3.

3.4 Mechanical investigation

In parallel to the dielectric studies mechanical tests and design concept works have been carried out. The activities focused on the selection of a suiTable insulator arrangement and of the adjustment of the current path travel characteristic. Using the first results of the dielectric dimensioning an insulator height of 11 m has been defined. Calculations of the disconnector behavior during seismic loads have shown that composite insulators compared to porcelain insulators have advantages due to their lower weight. In the early stage of the investigations foam filled composite hollow core insulators have been used. In free oscillation and bending tests on single, double and triple column composite insulator arrangements the mechanical characteristics, like deflection and bending stiffness have been determinated. This was important to ensure the proper function of the disconnector during wind and seismic load. In cooperation with the manufacturer of composite insulators a single column insulator design became possible by using a gas filled hollow core type with a tube diameter of 600 mm. This design fulfills the required maximum deflection of 167mm@10kN.

3.5 Type tests

The type tests of the 800 kV DC disconnector and earthing switch have been carried out in accredited test laboratories in Germany. The dimensions of the test object, the 800 kV DC ratings and dielectric test levels placed high demand on the test laboratories. During the dielectric type test the insulator was filled with 100% Nitrogen at a pressure of 0.1 MPa (gauge). The type tests of the 800 kV DC disconnector and earthing switch have been successfully completed in 2008.

3.6 Summary

The development and type tests of the 800 kV DC disconnectors and earthing switches were completed in April 2008 and lead to a design using single column composite insulators (Fig.3 & 4).

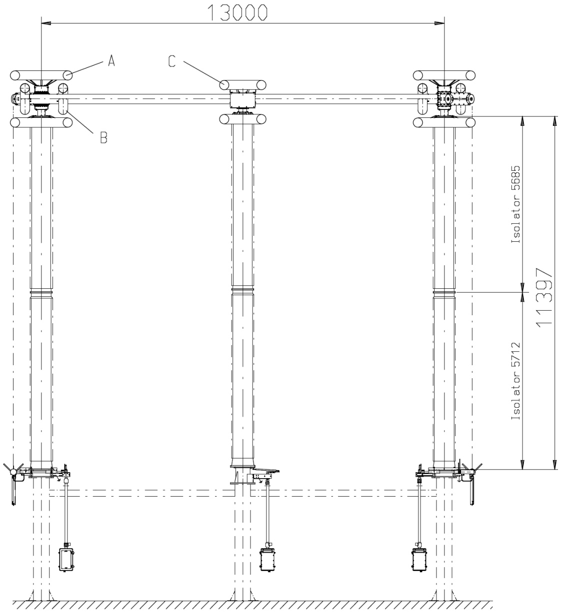

Fig. 3 Main dimensions of the 800 kV DC disconnector with built-on earthing switch for Suidong Substation

Fig. 4 Bypass Disconnector for the world's first commercial 800kV DC transmission system energized in December 2009.

In July 2008 the disconnectors and earthing switches for the first UHVC system in the world were delivered to the customer. Since December 2009, Pole 1 of the first 800 kV high-voltage DC link in China is in operation at nominal power of 2500 megawatts (MW) without any interruptions.
In June 2010 the transmission capacity has been doubled to 5000 MW by putting in operation Pole 2. With one pole operating at plus 800 kV and the other at minus 800 kV, the voltage difference between the poles reaches the world record of 1600 kV DC. [5]

4 Busbar Support Insulator for 500kV DC System

The Nelson River Bipole 1 and 2 HVDC scheme supplies power from isolated hydroelectric generation in northern Manitoba to a large load center in the south. The Bipole 1 system operates at 1854MW at the rectifier at ±463.5kVand 2000A capacity. The Bipole 2 system operates at 2000MW at the rectifier at ±500kV and 2000A nominal. The Bipole 1 system was first commissioned in September 1973 and the Bipole 2 system was commissioned in various stages from October 3, 1978 to June 17, 1985. No power reversal is required but voltage reversal is applied during line faults. The system is run on a varying daily load cycle.

The Nelson River HVDC Scheme experienced first flashovers in the Bipole 1 oil fill porcelain shed wall bushings thus the creepage distance was increased on the Bipole 2 wall bushings, however they also flashed over. Extensive testing at IREQ revealed a dry and wet band on the wall bushing causing an unequal voltage distribution across the wall bushing. It also revealed that at various shed configurations and different materials such as silicone rubber could withstand higher HVDC withstand voltage than porcelain. Manitoba Hydro experimented with grease and “booster” sheds (these solutions still required a lot of maintenance and costly equipment outages) but gained very good performance with a silicone rubber shed air-to-air wall SF^6 filled wall bushing in about 1990. The porcelain air to air wall bushings used at the stations were experiencing problems with flashovers which resulted in more than one case of the porcelain splitting and the bushing catching on fire. It was decided to switch from porcelain air to air wall bushings to composite wall bushings to reduce the risk of flashovers, fire and reduce the risk of personal being injured in the event of a failure. Then all wall bushings in Bipole 1 were replaced with silicone rubber shed air-to-air SF6 filled wall bushing which led to considering using solid HVDC composite post insulators.

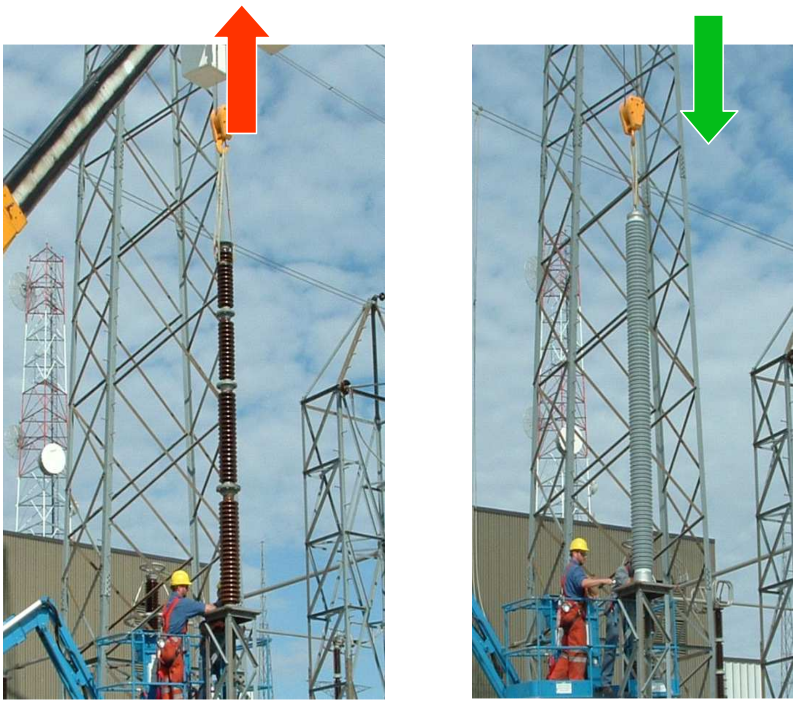

Fig 5. Replacement of porcelain support insulators at Dorsey substation

When a number of the porcelain HVDC post insulators fell down during a wind storm HVDC Engineering worked with the manufacturer who supplied the composite insulators to the air-to-air wall bushings manufacturer to determine whether it was possible to make a composite to replace the porcelain DC post insulator. Investigation reveal that if composite post insulators were used instead of porcelain there would be a better dry lightning impulse withstand, higher creepage distance, insulators would be substantially lighter in weight (one piece of composite weighs about the same as one of the four sections for the porcelain), higher tensile strength and would have a good bending strength.

Table IV Main data of the 500kV DC busbar support insulator

Total height	4520mm	Deflection @1,5 MML	<170 mm
Units / column	1	Lightning impulse withstand voltage, dry	1983kV
Max weight	150 kg	DC voltage polarity reversal, dry	625kV
Service Temperature	-40…+80 ºC	DC voltage withstand, dry	802kV
Maximum Mechanical Load @ 1.5MML	6 000 N	DC voltage withstand, wet	-603kV
Min. Break load	12 800 N	Switching impulse withstand	1273kV

Site personal have installed a number of these composite HVDC post insulators with very positive experience (Fig.5). There comments included easier and safer to handle because they are light with no risk of porcelain breakage, less man-hour to install, do not require washing to remove pollution, as they are less prone to flashovers. This has resulted in a cost saving due to lower assembly and less cleaning labor costs.

CONCLUSION

For the first time Composite Support Insulators are available to allow engineers to design HV and UHV air insulated substations using pollution resistant and maintenance free insulators without compromise vs traditional porcelain types. Depending on rated system voltage and mechanical needs foam filled or gas filled types are available. Special test procedures were developed to ensure the reliability. A new international standard to cover this type was accepted as a NWIP in TC36 . Examples of applications described in this report like disconnectors for 800kV DC and busbar support insulators for 500kV DC underline the advantages in practice of this technology.

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