Study Committee B3

Substations and Electrical Installations

Paper ID: 11078

EHV and DC Station Substation Post Insulators with Integrated Monitoring System

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Motivation

The societal and economic demands of a HVDC system dictates the need for the utmost reliability of all its components. This paper reviews the fulfilment of that reliability expectation with regards to the smoother reactor insulators used in a 500kV converter station for an American federal agency operating in the Pacific Northwest. While reliability is a multi-faceted, this paper will focus on three major aspects which dictated the insulator design:

- The novel application of a "smart" insulator whereby the utility can use the self-diagnostic capabilities of the insulator to monitor the reliability of an insulator
- The seismic reliability
- The pollution withstand reliability

Concept

- Catastrophic failures (when overstressed) are normally immediately visually apparent for porcelain post insulators
- In contrast, the failure/damage of composite hollow core insulator are often not easily detectable, i.e., cracking of the composite tube or the unbonding of insulator bolting flanges.
- In addition, there may be the failure of the fittings, which normally can be seen.
- Such above-mentioned failures are all integral to the gas pressurization of a hollow core composite station post insulator
- Thus, the mechanical integrity of the insulator can be extrapolated by monitoring the gas pressure

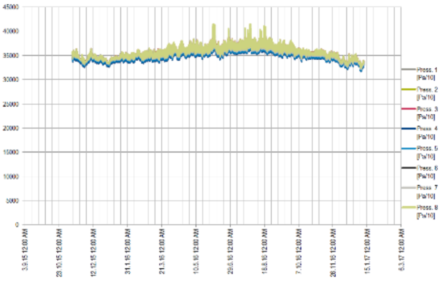
Examples of gas filled hollow station post insulators: On the left is the arrangement used on a 800 kV HVDC smoother reactor and on the right is that used for a 1200 kV UHVAC disconnector

Purpose of the Gas Filling

- Inert
- Relatively safe (78% of air is nitrogen)
- Cost effective
- Environmentally non-intrusive

Gas Pressure Monitoring

Philosophically any pressurized vessel is subject leakage and since the presence of a filling gas is an important of aspect of the hollow core composite station post insulator performance, it is considered prudent to monitor pressures. As an enclosed volume of gas, the pressure of the gas in a hollow core station post insulator is subject to Boyle's Law and is temperature dependent. Pressure readings must therefore be correlated to temperature for comparison purposes.



An example of a pressure vs. time plot of several insulators that illustrates the change of pressure with temperature over a period exceeding a year

Integrated Monitoring System (ISM®)

The Integrated Monitoring System is a multifaceted data acquisition system developed specifically for substation applications.

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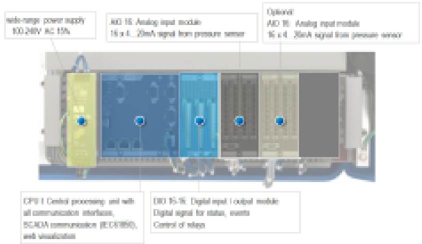
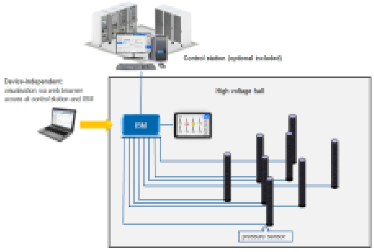


For the Smart Insulator application, the system is configured with the following major components:

- A pressure transducer at each hollow core composite insulator
- An Integrated Monitoring System housed in a weatherproof cabinet in close proximity to the hollow core composite insulators (up to sixteen) being monitored
- A conduit system linking the aforementioned components
- Optionally, a dedicated communication line from the Integrated Monitoring System to any remote monitoring station within the substation



Integrated Monitoring System Communication Methods

Reactor 1

Insulator 1: 3.5 bar
Insulator 2: 1.5 bar
Insulator 3: 2.5 bar
Insulator 4: 3.5 bar
Insulator 5: 3.5 bar
Insulator 6: 3.5 bar
Insulator 7: 3.5 bar
Insulator 8: 3.5 bar

Screen shot giving an example of all three possibilities of insulator status

Seismic Reliability

- The reactors are supported on insulators
- The resulting seismic loads generated typically produced large bending
- The length of the required insulator is over 6 m due to the creepage and impulse requirements, leading to great influence on the overturning moments
- Seismic loads are proportional to mass
- The earthquake loads of a smoother reactor with the weight of 32000 kg are significant relative to the lateral (or cantilever) resistance of station post insulator technology.

General field arrangement: an overview of the installation (left) and the conduit leading to the Integrated Monitoring System (right)

Smart Insulator details: a cross-sectional view of the pressure transducer housing (left) and a cabinet housing of the Integrated Monitoring System (right)

These challenges were overcome by using a patented device which promotes a low frequency response:

- The resulting seismic spectral response may be reduced at a sufficiently low frequency
- For hollow core composite insulators, the dimensions and material characteristics of the core's fiberglass material properties can be selected so as obtain a relatively low modulus of elasticity (contributes to a low frequency response)
- Hollow core composite station post insulators can achieve relatively large strength to weight ratios (contributes to seismic loading)

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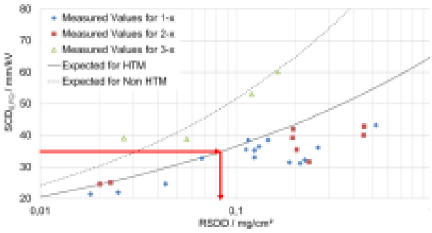
Overview of Pollution Design

- Partial loss of hydrophobicity was considered and the related correction factor was applied
- The empirical design approach in accordance with IEC TS 60815-4 was followed and utilized existing experience data with DC insulation at the site.
- A DC housing profile made of LSR was selected and the applied material is of the HTM type according to IEC 60815-4.
- After all site correction factors are applied, the final specific creepage distance was 45.8 mm/kV.

Parameter	Variable	Unit	IEC Recommendation	Design
Nominal Voltage	U	kV	-	500
Maximum Voltage	Umax	kV	-	560
Hydrophobic Transfer Material	HTM		-	Yes
Partial Loss|				Yes
Alternating Profile			-	Yes
	s/p		≥ 1 (never below 0,85)	1,4
	p1		-	65
	p2		-	50
	p1-p2		≥ 15	15
Shed spacing	c	mm	typical min. 45	70
Arcing Distance		mm	-	5770
	CF		typical below 4,4	3,97
Creepage Distance	CD	mm	17500	18830
Creepage Distance per kV [	CD’	mm/kV	35 (agency spec.)	37,7
Altitude	H	m	600	600
Altitude Correction	C_a		Ca=exp(n H / 8150) n=0,35	1,026
Average Diameter	D_a	mm	-	681
Diameter Correction	C_D		$C_D=(D_a/D_0)^{0,17}$ D_0 = 250mm	1,186
Corrected Creepage Distance	CDcorrected	mm	-	22910
Corrected Creepage Dist. per kV	CD’corrected	mm/kV	-	45,8
Top Shed Angle		°	0…25	11
Bottom Shed Angle		°	-	5

The profile parameters for the pollution design

	Type A pollution (solid layer)	Type B pollution (salt fog)
HTM	$SCD = 65 \cdot RSDD^{0,25} \cdot C_d$	$SCD = 15 \cdot SES^{0,33} \cdot C_d$
Non-HTM	$SCD = 110 \cdot RSDD^{0,33} \cdot C_d$	$SCD = 15 \cdot SES^{0,25} \cdot C_d$



Measured and Calculates RSDD (solid layer tests)

Long Term Ageing Performance

- The short-term pollution performance of the insulation can be verified with the test methods and procedures supporting the economic design process
- The long-term performance of the housing is affected mainly by tracking and erosion as well as combined ageing effects
- Today’s experience for HTV and LSR housings is very positive if the recommendations of IEC 60815 are followed
- This is confirmed by laboratory testing, field and test station experience
- The equipment has been in service for approximately 5 years and has proven its pollution withstand capability

Conclusion

The reliability of the equipment, with regards to the specified requirements, has been successfully met for the station post insulators for the smoother reactors.

This was achieved via:

- The utilization of customized insulator core properties in conjunction with the use of a specialized seismic protective device
- An investigation program, coupled with established engineering guidelines, and the careful selection of materials/geometry resulted in a design that has exceeded the pollution withstand requirements.

Furthermore:

- The reliability of the equipment has been further extended to envelop non-specified events through the novel application of an Integrated Monitoring System.
- This new capability, which allows to digitally monitor and assess equipment after an extreme or unexpected event, is a powerful tool contributing greatly to power system reliability.