Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10500

Recommendations for IEC 60815-2 based on Functional Performance of Optimized HVCB Porcelain Insulators in Very Highly Polluted Environments

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Motivation

- Limited research on HVCBs for High Pollution environments (PM2.5 and High SO_2 Concentrations)
- High Rate of Pollution Flashovers in 765kV HVCBs
- Opportunity to Re-Work and Enhance Profile parameters guidelines in IEC_60815-1
- Expensive and Time-Consuming Testing Methods and Arduous Setup Procedure for each iteration of the Artificial Pollution Test
- Optimization of Yield Output of Porcelain insulators and Material usage in production
- Reduced Carbon footprint by decreasing porcelain base materials

Method/Approach

- Review of existing studies on
  - Pollution Performance of Porcelain Insulators (IEC Standards)
  - Air Pollution in India / Pollution Conditions PM2.5 and PM10
  - Manufacturing Constraints – Pug Baking, Glazing (Indian Insulator Mfg. companies)
  - Artificial Pollution – Salt Fog Test at UHVRL
- Analytical methods were used to estimate
  - Peak Performance of 765kV Insulators and threshold limit (w.r.t. IEC standards) for High Creepage insulators.
  - Areas for further research in design optimization of EHV CBs
  - Safety tolerance to adjust profile parameters for increased material optimization and design value.

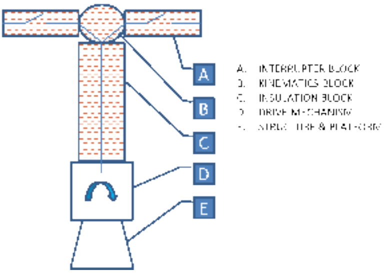
Objects of Investigation

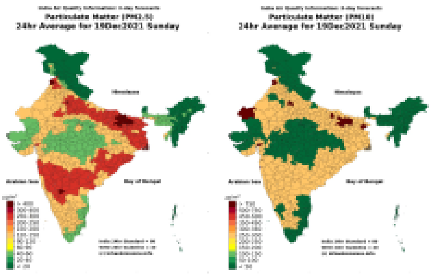
- This paper aims to prove that “Hollow Type Porcelain Insulators” designed for the insulation block, with multiple profile parameters falling in the Major deviation zone of section 6.1 as per IEC 60815-2, will perform satisfactorily in severe pollution conditions
- The Salt fog test method is selected for the successful simulation of real-life pollution environments for this qualification at salinity 160 kg/m³ as per IEC 60507.

Experimental setup & test results

- Level of Everyday Pollution at site: Very Heavy with PM2.5 range between 90-300 µg/m³, PM10 ranging normally between 100-300 µg/m³

Shed Profile	Alternating Shed
USCD (Very High Creepage)	53.7
#Sheds	Lesser than IEC guidelines
Shed spacing to projection ratio	> 0.65 (without under ribs)
Min. distance between sheds	$C_{selected} >> C_{criterion}=30$
L/s Ratio	< 4 (MINOR Deviation Zone)





- The 765 kV transmission lines of India are predominantly situated along the very highly polluted coastal environments. Thus, HVCBs are subjected to high di-electric stress.
- Pollution flashover in outdoor porcelain insulators is influenced by profile parameters in insulator design.

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Insulator Design Parameters

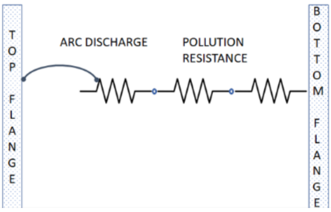
- The Indian Standard recommends designing outdoor porcelain insulators for 31mm/kV (in millimetres per unit of Rated Voltage) for very heavily polluted atmospheres.
- The specifications for selection of unified specific creepage distance are listed in IEC:60815-1 as in the table below:
- Creepage Correlation b/w SCD and USCD:

Level of Pollution	SCD (mm/kV)	Unified Specific creepage distance USCD (mm/kV)
Very light	12.7	22
Light	16	27.8
Medium	20	34.7
Heavy	25	43.3
Very Heavy	31	53.7

- The specific creepage distance (SCD) for Very Heavy level of pollution of 31mm/kV corresponds to USCD of 53,7mm/kV as recommended in Annex J of IEC 60815-1 for three-phase A.C. system. The phase-to-earth voltage $U_s/\sqrt{3}$ is considered to compute the USCD.

Shed profile design for polluted environments

- The pollution performance of insulators is characterized by the shed profile parameters used in the design of the CB with deviation recommendations from IEC 60815-2.
- Guidelines on the design parameters stated, have a positive correlation on the pollution performance of the insulator, in the salt fog test as per IEC 60507.
- A partial arc formed by dry band activity in series with the contaminated region of the insulator is given by a series resistance.
- An increase in contamination causes the leakage current to increase, creating more intensive discharges. Increased thermal ionization caused by high temperature arcs, would promote flashover.
- Dry Band Phenomenon:

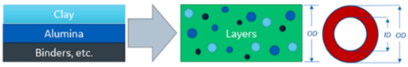


Significance of Deviations in design

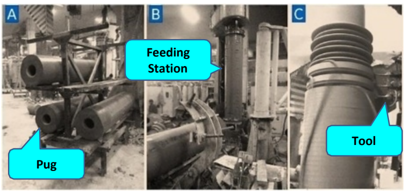
#	Deviation	Criterion	Deviation Region	Significance	Ref. in 60815-2
1	Shed Overhang	P1-P2 for alternating sheds ≥ 15mm	Higher Value selected w.r.t. criterion	Increased performance in ice, snow and heavy rain conditions.	Clause 9.2
2	S/P Ratio	s/p ≥ 0.65 for shed without under ribs	Higher Value selected w.r.t. criterion	Decreased chance of "Shorting out" creepage distance bridged by a shed-to-shed arc.	Clause 9.3
3	Min. Distance "c" b/w sheds	c=30 for Insulator Length > 550mm	Very High Value selected w.r.t. criterion	Negates the need to increase creepage distance	Clause 9.4
4	l/d Ratio	l/d < 5	For alternating sheds, l1/d1 is in the MINOR Deviation Zone (l/d > 6) l2/d2 is in the MINOR Deviation Zone (l/d > 6)	Susceptible to risk of bridging by arcs because of Dry Bands. Comparatively Less avoidance of localized pollution as per 60815-2	Clause 9.5
5	Shed Top angle	5° < α < 25°	α within 5°-25° range	Efficient water run-off in Natural washing	Clause 9.6
6	l/S Ratio	l/S < 4	l/S > 4 in the MINOR Deviation zone		Clause 9.7

Challenges in Insulator Design & Mfg

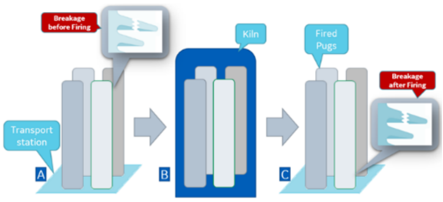
- The design of such AIS – EHV CB for very high pollution levels, remains complex with respect to Material and Strength. Raw materials are compressed to dense sheets removing excess moisture as shown.



- Special tool on a VMC control creepage factor by maintaining the shed angle and overhang as per design in second phase as seen in Figure 5. In the third phase, Insulator are solidified in Isothermal kiln furnaces.



- Lack of shed thickness optimisation, pug interference during feeding into kiln, cracking of overhangs after firing reduces yield of insulators, thereby decreasing quality repeatability of the process.



- In fourth Phase, Sheds are glazed as required which determines dust deposit and rainwater bridging.
- In the fifth Phase, flanges and Insulator are bonded together with cement to withstand service loads and seismic level of the Circuit breaker

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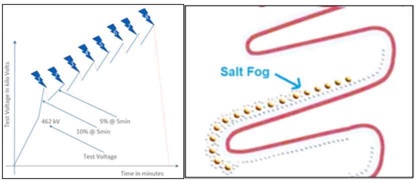
Pre-Conditioning Process

- The test specimen is conditioned as per IEC 60507. Designed specimen withstood eight spells. The moisture and fog particles on the insulator shed prior to pre-conditioning.



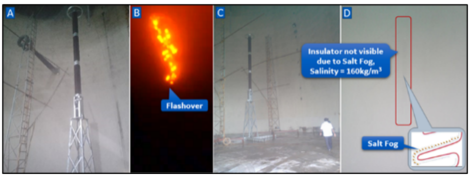
Type Test as per IEC 60507

- The USCD and I_{hmax} were calculated. The value of the ratio of minimum value of short circuit current to the maximum highest leakage current pulse amplitude met the standard IEC 60507.

$$I_{sc\ min} = USCD/\sqrt{3} - 10 = 21\ A_{rms}$$

$$\frac{I_{sc}}{I_{h\ max}} \geq 11 \Rightarrow \frac{21}{1.7167} = 12.233 > 11$$

SCD (mm/kV)	USCD (mm/kV)	I_{hmax} (A)
16	27.71281	0.55
20	34.64102	0.85
25	43.30127	1.35
31	53.69358	1.7167

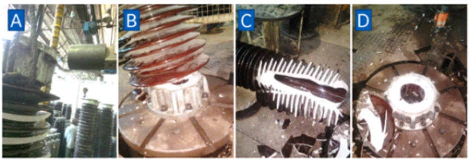


Parametric Design Methodology and Mathematical Modelling of ST

- A mathematically modelled was developed comparing validated design with lenient design using parametric approach. The interpolation of % of change in profile parameters [l/S and l/d] for lenient and optimized design, for 31mm/kV SCD requirements has grown as a workable reference for designing high creepage insulators in future. The standard error S_T is the ratio of standard deviation of the sampling range to the square root of total number of samples i.e. 4.363%.

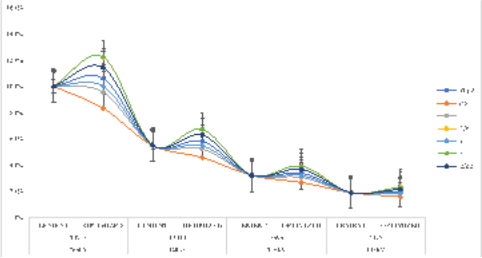
$$\text{Safety Tolerance } (S_T) = \frac{\sqrt[2]{\frac{\sum(x_i-\mu)^2}{N}}}{N} = 4.362616\%$$

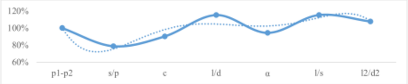
N = Size of parameter population;
x_i = Value of parameters;
μ = mean of parameters



Safety Tolerance for New Designs

- The fifth order polynomial equation derived for the optimized insulator can be compared with its reference curve as shown below.





$$y = -0.005x^5 + 0.1044x^4 - 0.8298x^3 + 3.0541x^2 - 5.0179x + 3.6994$$

Functional Performance of Designed Insulator in Current Site Situatione

- The designed circuit breaker is proven to successfully function and perform to above expectations in very highly polluted site conditions for more than 7 years without any complaints from the customer site.

Conclusion

- IEC recommends achieving a higher Creepage Factor to qualify the salt fog test. This research paper proposes to IEC to significantly relook the range of minor deviations recommended in Clause 9.5 and 9.7 of IEC 60815-2

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