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B2 - OVERHEAD LINES
PS1 / CHALLENGES & NEW SOLUTIONS IN DESIGN AND CONSTRUCTION OF NEW OHL

Selection of Porcelain Cap and Pin Insulator Components for Transmission Lines in High Altitude and Exposure to Ice and Snow

Subramanian SAKTHIVELU* and Harleen MINHAS
Grasim Industries Ltd (Unit: Aditya Birla Insulators)
India.
sakthivelu.s@adityabirla.com

SUMMARY

Ladakh region of Jammu and Kashmir in India is one of the highest inhabitation and difficult terrains in the world. A project was envisaged for implementing 220/66kV transmission system. The transmission lines of this project need to be built at a height of around 3,000-4,000 meters above sea level. At high altitude, changes in air pressure, temperature and humidity will exert influence on performance of insulators. Therefore, it is imperative to know the effects of the atmospheric conditions on the specific components, otherwise it may result in premature aging, reduction of operation performance or even failure. This paper describes the important characteristics that need to be considered for various components of insulator for applications in high altitude and environmental exposure to ice and snow. This selection process is very important for better performance of power system in cold, hostile climates that experience ice and snow conditions. The important characteristics that were considered in this pare are:

(1) The adverse ambient temperature ranges of +35 °C to -45 °C in the region, which may affect the thermal shock resistance of porcelain body in long run, is one of the major factors that affects the long term performance of insulators. The microstructural phase analysis was used on a High Alumina body, to ensure increased mechanical and electrical performances when subjected to freezing conditions.

(2) The grade of metals used for cap, pin & security clips to mitigate the adverse effects that low temperatures cause on these components.

(3) The cement properties are very important for performance of porcelain insulators that are exposed to ice and snow.

(4) Improvement in design of porcelain insulator by optimization of design parameters.

The insulators supplied to this transmission line were performing satisfactorily for more than three years.

KEYWORDS

Porcelain Insulator, High Altitude, Icing, Fog, Snow, High Voltage, Transmission Line.

INTRODUCTION

Ladakh region of Jammu and Kashmir in India is one of the highest inhabitation and difficult terrains in the world. A project was envisaged for implementing 220/66kV transmission system from Alusteng (Srinagar) to Leh via Drass, Kargil, Khalsti in order to connect Kargil and Leh regions with the Northern Grid. The transmission lines of this project need to be built at a height of around 3,000-4,000 meters above sea level. The project includes an approximately 335 km long transmission line. At high altitude, changes in air pressure, temperature and humidity will exert influence on performance of insulators. Due to the high altitude, overhead transmission lines and their substations are subject to ice accumulation for an extended period (nearly six months) each year due to freezing rain or drizzle, in-cloud icing, icing fog, wet snow, or frost. In addition to mechanical damage due to excessive ice accumulation and dynamic loads caused by wind, the presence of ice and snow on insulators may lead to flashover faults that result in power network outages. In recent years, several incidents related to the flashover of iced insulators have been reported worldwide [1–3]. Therefore, it is imperative to know the effects of the atmospheric conditions on the specific components, otherwise it may result in premature aging, reduction of operation performance or even failure [4].

One of the major negative effects of accumulated ice or snow on insulators is excessive mechanical loading on transmission line hardware that can either lead to impeding proper operation of apparatus or, in extreme cases, to major collapsing of the lines with dramatic consequences. The second obvious negative effect is electrical failures on account of the fundamental changes in electrical insulation such as air gap discharge voltage, corona inception voltage and pollution flashover voltage. These factors, including high fault currents and equipment stresses, are prime reason for electrical flashovers that are more severely associated with high altitude transmission lines [5].

The external insulation design, under these severe atmospheric conditions, with regard to pollution and icing performance is a critical factor for the reliability of overhead electrical lines [6]. Several mathematical models were proposed to predict ice-covered insulator critical flashover voltage [7–9], they are of two types. Both static [8] and dynamic [9] models have been used to simulate flashovers on insulators that are fully bridged by ice accumulation. However, these models lacked as they do not take into account the physical mechanisms involved during the arc propagation, which is a complex phenomenon.
Internationally, IEEE and IEC have provided guidance with respect to icing test methods [10], selection of transmission line and sub-station insulators for ice and snow [11] conditions. However, international guidelines for selecting individual components of insulators with respect to ice and snow remain to be established. This paper describes the important characteristics that need to be considered for various components of insulator such as porcelain body, metal components, cement and design of insulator for applications in high altitude and environmental exposure to ice and snow.

SELECTION OF INSULATOR COMPONENTS

Insulator Type

Porcelain as an insulating material has more than one century of proven service history in terms of electrical, mechanical, thermal and environmental stress withstanding capability. The chemical stability of porcelain offers environmental and ageing resistance, thus making it suitable for long term use [12]. At high altitude, the main negative effect is accumulated ice or snow on insulators resulting in excessive mechanical loading, transmission lines and substations hardware that can either lead to impeding proper operation of apparatus or, in extreme cases, to major collapsing of the lines with dramatic consequences. The fully vitrified porcelain insulator, due to firing at temperature above 1250 °C, imply satisfactory mechanical performance under these conditions.

The standard cap-and-pin disc insulators of ball and socket type, having rated mechanical technical strength of 120 kN (diameter 255 mm, spacing 145 mm and creepage distance 380 mm) and 160 kN (diameter 280 mm, spacing 170 mm and creepage distance 380 mm) were supplied for this project. Figure 1 shows the details of individual components that are part of porcelain insulator.

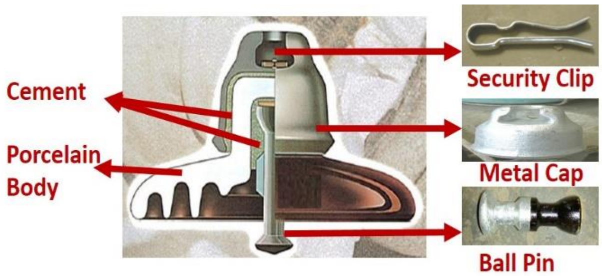

Figure 1 Components of Porcelain Insulator

Porcelain Body

These insulators were manufactured using Alumina Porcelain body considering the adverse ambient temperature range of +35 °C to -45 °C in the region, which may affect the thermal shock resistance of porcelain body in long run. The thermal shock resistance could be improved by reducing the amorphous content and increasing the crystalline content in the microstructure of fired porcelain body. It is evident from Table 1 that High Alumina Body used for manufacturing these insulators contains 44% crystalline content (Mullite, Corundum and Quartz). Moreover, the decrease of glass phase (amorphous) in High Alumina Body lead to increase in electrical strength in these materials. In silicate based porcelains, presence of undissolved quartz lead to initiation of non-coherent interface in structure, micro crack formation and decrease of mechanical properties [13]. This is avoided in insulators manufactured using High Alumina Body and they offer dual advantages of ensuring increased mechanical and electrical performances when subjected to freezing conditions.

Table 1 Microstructural Phase Analysis Porcelain Body

Phase Content	Amount Present (wt %)
Amorphous (Glass Phase)	56
Mullite (Crystalline)	12
Corundum (Crystalline)	23
Quartz (Crystalline)	9

Metal Components

The CIGRE Work Group B2-03 report [14] revealed that 55% of mechanical failures were due to hardware breakage. Most of the hardware failure were caused by no-fatigue. Hence, the primary adverse effects that low temperatures cause are loss of ductility, increasing brittleness, and making the metals to be more sensitive to impacts. To increase the ductility (elongation) and impact toughness of metal parts [15], metal caps were manufactured with Grade 400/18 of IS:1865 grade iron instead of 450/10 of IS:1865 for these insulators. Generally, 450/10 grade iron metals parts are used for porcelain insulators used in transmission lines.

The mechanical properties of 400/18 and 450/10 are provided in Table 2. There is around 10% decrease in tensile strength of 400/18 grade at 20 °C when compared to 450/10 but, this is not significant as the tensile strength of metals increases at low temperatures [16]. Table 2 also provides the minimum temperature at which the elongation of iron is maintained similar to elongation at 20 °C [16]. The ductility of 450/10 decrease below -25 °C, whereas the ductility of 400/18 is stable up to -75 °C. This is very critical to withstand loads caused by snow combined with wind.

Table 2 Mechanical Properties Metal Grades of Cap

Property	Grade 450/10	Grade 400/18
Tensile Strength (N/mm^2)	Min. 450	Min. 400
0.2% Proof Strength (MPa)	Min. 310	Min. 250
Elongation (%)	10	18
Min. Temperature to maintain +20 °C tensile elongation (°C)	-25	-75

The security clips were manufactured with Phosphor Bronze (Gade 1 of IS:7814), having mechanical strength along with desirable ductility, instead of austenitic stainless steel (AISI-304).

Cement for Assembling Metal Parts

As detailed in Figure 1, the porcelain insulator includes ceramic body, iron, and cement, which are three different components, with a bitumen coating and grog band between them. The cement part acts as a bridge connecting all the constituents of the porcelain insulator. The mechanical property of cement is very important, especially when the insulators are exposed to ice and snow.

Generally, Ordinary Portland Cement (OPC) grade 53S is used for cap-and-pin insulators manufacturing. But, for this application a special grade cement was developed using special additives. The special additives helped the cement to gain high-early-strength, reduce shrinkage and expansion during curing. The severe exposure condition of insulators was considered as exposure to cycles of freezing and thawing. The accumulative effect of successive freeze-thaw cycles and disruption of concrete can eventually cause cracking. Hence, the autoclave expansion of cement was controlled to minimum level and the mechanical strength of the cement was increased to withstand pressure developed due to expansion of water when it freezes.

Modification in Design

The disc insulators were taken for improving the surface characteristics by optimizing the design. The existing design has been modified by considering various aspects such as Form Factor (FF), Creepage Factor (CF) and String Factor (SF) to develop the new design. This is to get better pollution performance of these insulators.

The optimization of FF has been done on full creepage distance (CD), which is divided in to Short Creepage Distance (SCD) with 15 or 20 mm each and the FF calculation has been done using Equation (1).

$$\text{Form Factor} = \frac{\text{Short Creepage Distance (SCD)}}{\text{Diameter of each SCD X } \pi} \qquad \text{Eq (1)}$$

To derive the CF, the linear portion of porcelain shed length has taken as d1 and from rib side, where the go-No go gauge is touching has taken as d2. The details are given in Fig.2 and Equation (2) is the formula used for calculating CF.

CF = CD / (d1+d2) Eq (2)

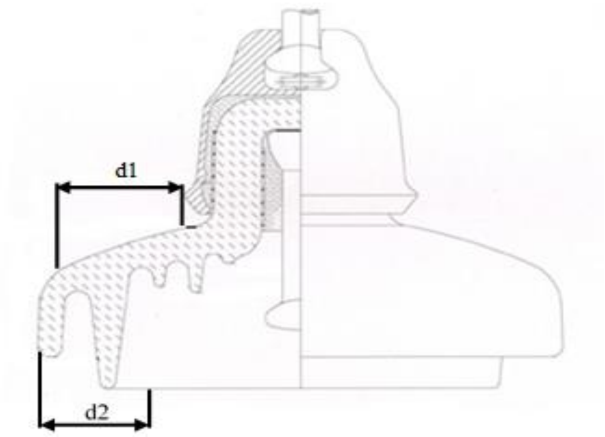

Figure 2 Details of Creepage Factor of Porcelain Insulator

The SF is determined using the vertical gap (VG) between outer shed and head of two consecutive disc insulators, in a string as detailed in Fig.3, and perpendicular distance (PD) between previous outer shed and next disc outer surface. The SF has been calculated using Equation (3).

SF = VG / PD Eq (3)

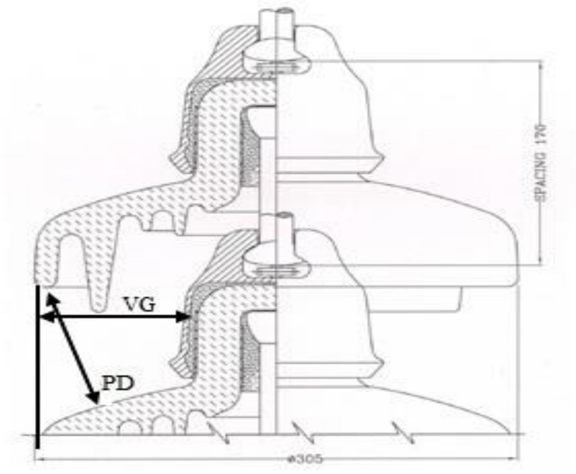

Figure 3 Details for String Factor Determination

The summary of design parameters that were obtained after optimization are given in Table. 3. The pollution performance test was carried out artificially, as per IEC 60507 [17], on these insulators showed remarkable improvement. The improvement in pollution performance of new design (ND) samples over existing design (ED) is evident from Figure 4. The design optimization helped to achieve 100% increase in performance level. This is because of the improved geometrical parameters i.e. FF, CF and SF.

Table 3 Design parameters after optimization

S.No	Design Parameter	Result after optimization
1	Form Factor	1.56 (0.01 to 0.06 for 34 segments)
2	Creepage Factor	3.35
3	String Factor	0.84

The pollution flashover of iced insulators is mainly influenced by the conductivity of the water film on the ice-surface. The mechanisms of flashover of iced insulators are not yet fully understood. However, some explanations have been advanced [18-19]. In operation, a wetted and polluted insulator generates and dissipates heat under the influence of voltage. The surface of disc insulator's heating power depends on FF. Therefore, an area with high heating power has a high temperature. Heat conducts from high- to low-temperature areas and transfers to the outside environment through radiation and convection [20]. The uniform FF (34 segments of SCD), along the surface of insulator, ensures uniform distribution of temperature fields. Hence, the conditions for the formation of dry bands or dry band arcs are reduced. This has resulted in improved pollution performance of ND insulators in Figure 4.

The CF, also known as creepage distance density, is a parameter that indicates how tightly the sheds are arranged or in other words how dense is the creepage distance per unit length. It has been shown that as the overall diameter of the insulator increases, the contamination flashover voltage decreases [21]. Therefore, a creepage distance increase is desirable as the diameter of the insulator increases. The IEC Technical Standard 60815-2 [22] categorises the values of this parameter in three classes (none, minor, major deviation) based on how much they can reduce the performance of the insulator. From Table 3, it is noted that the CF of 3.35 lies below the minor deviation category (3.5 to 4.0). The rest of the parameters SF will influence on the voltage [23].

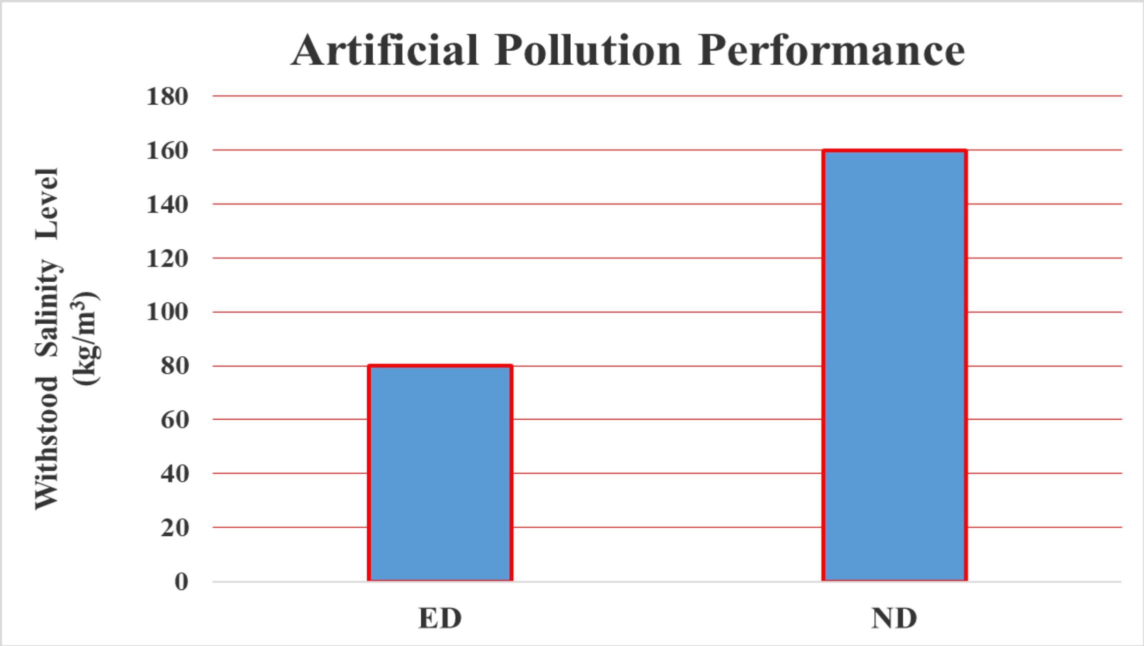

Figure 4 Effect of design optimization in pollution test

CONCLUSION

Insulator and its components used in transmission lines and substations, to be built at high altitude, should be selected with regard to the expected severe cold, hostile climates changes occurring during the normal operation of power system. The important characteristics with respect to porcelain body, metal parts, cement and design parameters were selected and applied successfully to mitigate the negative effects in high altitude. Porcelain cap and pin insulators supplied for such a project were performing satisfactorily for the past 3 years. The important characteristics that need to be considered are: -

1) High Alumina Porcelain body to be used. Because, it offers dual advantages of ensuring increased mechanical and electrical performances when subjected to freezing conditions.

2) The metal components having higher ductility (elongation) shall be used to mitigate the primary adverse effects that low temperatures cause are loss of ductility, increasing brittleness, and making the metals to be more sensitive to impacts.

3) Cement with lower autoclave expansion and having high-early-strength gain properties to be used for assembly of metal components. This will reduce shrinkage and expansion during curing. The accumulative effect of successive freeze-thaw cycles that causes cracking are avoided.

4) Improvement in design of porcelain insulator by optimization of imporant parameters of creepage factor, form factor and string factor to improve the surface characteristics of porcelain insulator. This is to get better pollution performance of these insulators.

BIBLIOGRAPHY

[1] Farzaneh, M., Kiernicki, J., “Flashover problems caused by ice build-up on insulators”, IEEE Elec. Insul. Mag., Vol.11, pp. 5–17, 1995.

[2] Kannus, K., Lahti, K., “Electrical behaviour of high voltage insulator strings under rime ice”, In Proceedings of the 9th International Workshop on Atmospheric Icing of Structures, Chester, UK, p. 8, 2000.

[3] Jiang, X.L., Shu, L.C., Sima, W.X., Xie, S.J., Hu, J.L., Zhang, Z.J., “Chinese transmission lines’ icing characteristics and analysis of severe ice accidents”, Int. J. Offshore Polar Eng., Vol. 14, pp.196–201, 2004.

[4] Nelson, J.P., “High-Altitude Considerations for Electrical Power Systems and Components”, IEEE Trans. Ind. Appl., IA-20, pp. 407–412, 1984.

[5] Farzaneh, M., Baker, T., Bernstorf, A., Burnham, J. T., Carreira, T., Cherney, E., Chisholm, W. A. , Christman, R., Cole, R. , Cortinas, J., de Tourreil, Drapeau, J. F., Farzaneh-Dehkordi, J., Fikke, S., Gorur, R., Grisham, T., Gutman, I., Kuffel, J., Phillips, A., Powell, G., Rolfseng, L., Roy, M., Rozek, T., Ruff, D. L., Schwalm, A., Sklenicka, V., Stewart, G., Sundararajan, R., Szeto, M., Tay, R.., and Zhang, J., “Selection of station insulators with respect to ice or snow—Part II: Methods of selection and options for mitigation,” IEEE Trans. Power Del.,Vol. 20, pp. 271–277, 2005.

[6] Farzaneh, M., and Chisholm,W.A., “Insulators for Icing and Polluted Environments”, John Wiley & Sons: Hoboken, NJ, USA, 2009.

[7] Farzaneh, M., Zhang, J.,”and Chen, X., “Modeling of the AC arc discharge on ice surfaces”, IEEE Trans., Power Deliv., Vol. 12, pp. 325–338, 1997.

[8] Farzaneh, M., and Zhang, J. A., “Multi-arc model for predicting AC critical flashover voltage of ice-covered insulators”, IEEE Trans., Dielectr. Electr. Insul., Vol. 14, pp. 1401–1409, 2007.

[9] Taheri, S., Farzaneh, M., and Fofana, I., “Dynamic modeling of AC multiple arcs of EHV post station insulators covered with ice”, IEEE Trans., Dielectr. Electr. Insul., Vol. 22, pp. 2214–2223, 2015.

[10] Farzaneh, M., Baker, T., Bernstorf, A., Brown, K., Chisholm, W. A., de Tourreil, C., Drapeau, J. F., Fikke, S., George, J. M., Gnandt, E., Grisham, T., Gutman, I., Hartings, R., Kremer, R., Powell, G., Rolfseng, L., Rozek, T., Ruff, D. L., Shaffner, D., Sklenicka, V., Sundararajan, R., and Yu, J., “Insulator icing test methods and procedures,” IEEE Trans. Power Del., Vol. 18, no. 4, pp. 1503–1515, 2003.

[11] Farzaneh, M., Baker, A.C., Bernstorf, A., Burnhan, J. T., Cherney, E.A., Chisholm, W.A., Fofana, I., Gorur, R. S., Grisham, T., Gutman, I., Rolfseng, L., and Stewart, G.A., "Selection of Line Insulators With Respect to Ice and Snow—Part II: Selection Methods and Mitigation Options", IEEE Transactions on Power Delivery, Vol. 22, NO. 4, pp. 2297-2304, 2007.

[12] Khan A. A., and Husain, E., "Porcelain Insulator Performance under Different Condition of Installation around Aligarh," International Journal of Electrical and Computer Engineering, Vol. 7, pp. 933-937, 2013.

[13] Jose M. Amigo, Francisco J. Serranoa, Marek A. Kojdeckib, Joaquin Bastidaa, Vicente Estevec, Maria Mercedes Reventosa, Francisco Martid, "X-ray diffraction microstructure analysis of mullite, quartz and corundum in porcelain insulators", Journal of the European Ceramic Society, Vol. 25, pp. 1479 -1486, 2005.

[14] Yoshida, S., and Naito, K., "Survey of electrical and mechanical failures of insulators caused by iceand/or snow", CIGRE, Work Group document WG-B2-03, pp.22-26, 2005.

[15] Hafiz, M., "Mechanical properties of SG-iron with different matrix structure ", Journal of Materials Science, Vol. 36, pp. 1293-1300, 2001.

[16] British Cast Iron Research Association, "Guide to the use of ductile cast irons at sub-zero temperatures", Broadsheet 73-2, UK.

[17] IEC 60507, "Artificial Pollution Tests on High-Voltage Ceramic and Glass Insulators to be Used on A.C. Systems," International Electrotechnical Commission, 2013.

[18] Farzaneh M., and Kiernicki J., "Flashover problems caused by Ice build-up on insulators," IEEE Electrical Insulation Magazine, pp. 5-7, March/April, 1995.[19] Farzaneh M., Zhang J., and Chen X., "Modelling of the AC arc discharge on iced surface," IEEE/PES Winter meeting, Paper No. 96 WM 078-6 PWRD, 1996.

[20] Zhang D., and Meng, F., "Research on the Interrelation between Temperature Distribution and Dry Band on Wet Contaminated Insulators," Energies, Vol. 12, doi:10.3390/en12224289, 2019.

[21] Matsuoka R., Sakanishi S. Ito, K., and Naito K., "Flashover on contaminated insulators with different diameters," Electrical Insulation, IEEE Transactions, Vol. 26, pp. 1140-1146, 1991.

[22] IEC 60815-2, "Selection and dimensioning of high-voltage insulators intended for use in polluted conditions - Part 2: Ceramic and glass insulators for a.c. systems," International Electrotechnical Commission, 2008.

[23] Priyanka S., Kantharaj B., Mohan K.R., and Poshitha, "Studies on Pollution Performance of Outdoor Porcelain Disc Insulators," International Journal of Scientific Development and Research, Vol.1, pp. 296-301, 2016.