IJIREEICE

ISSN (Online) 2278-1021
ISSN (Print) 2319-5940

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

REPSE-17

National Conference on Sustainable Development in Renewable Energy Sources and Power System Engineering

Sri Venkateshwara College of Engineering, Bengaluru

Vol. 5, Special Issue 3, May 2017

Design and Manufacturing of Porcelain Longrod Insulator for Improved Performance of National (U) HVDC Grid

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Abstract: Insulators for ultra-high voltage direct current (±800 kV UHVDC) transmission line should meet the dual requirement of withstanding a peak high voltage defined by the nominal system voltage without flashover as well as sustain the mechanical load derived from the conductor. Generally the insulator suffers damage due to simultaneous action of mechanical load arising out of heavy wind, lightning, power arc and electrical switching surge current. Although the line losses are minimized while the transmission cost goes down in ±800 kV DC line, pollution performance of the insulator assumes a decisive role due to fixed grid polarity. It is overcome by improvement in the shed profile, shape and size of insulator. Based on the experience of ±500 kV DC grid, state-owned Powergrid used ball and socket type porcelain insulator for ±800 kV Chiriapalli – Agra, India (U)HVDC line. Cigre however recommends composite insulator made with epoxy-glass core with silicone rubber sheds which is found to have superior pollution performance initially due to intrinsic hydrophobicity that diminished in field over a period of time. In contrast puncture-proof porcelain longrod insulators provide an excellent hassle-free service with 3-5 fold increase in life. Additionally hydrophobic glaze can provide superior pollution performance over the entire life period. In this study we propose our design concepts and discuss the controls required on material and processing so as to prevent early aging of the porcelain longrod insulator in (U)HVDC.

Keywords: HVDC, Insulator, porcelain, polymer, longrod, Pollution, Electro-mechanical, Strength, Vibration, Aging.

I. INTRODUCTION

Brics countries particularly India, South Aftica and Brazil became hub for infrastructure growth in the last 5 years. Power is an infrastructure on growth trajectory in tandem with the thematic value, Make-in-India. The Economic Survey[1] projection published by the Ministry of Power indicated that the country required an addition of more than 100,000 MW capacity in the 11th plan period. This translates in annual capacity addition of around 18,000 MW by the end of 11th plan in 2012[1]. Actual capacity addition is reported as 21,080 MW and 54,964 MW in the 10th and 11th plan periods[1-2]. In the 12th plan period additionally 88,537 MW was planned. A lion share was to be met from hydroelectric sources available in the north-eastern region of our country towards sustainability.

Bulk power evacuation from generation point at far off distance prompted switch over from Extra High Voltage (EHV) to Ultra High Voltage (UHV). As transmission voltage rises the tower height also increases for providing ground clearance and required air-braking distance. As the tower goes taller lightning chances increase. Hence there is a need to optimally design the grid and use appropriate components based on the regional power demand.

In UHV a.c. nominal system voltage of 765 kV is now in practical operation[3]. The next voltage level is 1200 kV a.c. undergoing trials at Bina (India) since 2013. High Voltage Direct Current Transmission concept made in-road into India in around 1990s with ±500 kV d.c. from the R&D house of ABB Sweden and a transmission line got commissioned in 2000. In 2006, ABB further mooted that ±800 kV d.c. (UHVDC) is the most economical option for power block of over 6000 MW through the distance of 2000 km and hence popularly said as 'super power highway' first introduced in Xiangjiaba hydropower plant to Shanghai in 2012[3-5]. State-owned Power Grid Corporation of India Ltd., (Powergrid) commissioned a similar line connecting the north-east corridor to the capital by ±800 kV d.c. bipole Chiriapalli–Agra transmission line for evacuating hydro-electric power over a distance of 3000 km.

1. Requirements of D.C. Insulator and Present Practice

The configuration of insulation string is seen in Table 1. It shows that the number of insulators in d.c. transmission are higher than that of the a.c. with similar transmission voltage (400 kV a.c. requires only 23 Nos.) and individual insulators are also having higher creepage. This is to prevent high flashover risk associated with d.c. transmission in comparison with that of the a.c. The behaviour is further influenced by local climate change, rain fall and air pollution level in the region.

Table 1 Cap and pin type insulator assembled to form string in Chiriapalli–Agra ±800 kV d.c. line compared to 170 mm spacing, 160 kN and 210 kN rating in ±500 kV d.c. line and 160 kN and 120 kN rating in 400 kV a.c. line

Configuration	Triple Tension	Single Y-suspension
Number of insulator	3 set of 67 No. = 201	2 set of 45 No. = 90
Electro-mechanical strength, kN	420	320
Min. Creepage, mm	590	590
Unit Spacing, mm	205	195

As in the case of HV a.c., conductor is isolated by a long string of cap and ball pin disc insulator that eliminates surface flashover under defined pollution level. In the case of 160 kN cap and pin disc insulator for normal a.c., the creepage is 370 mm while it increases for anti-pollution requirement such as anti-fog variety used in coastal area, highest being 640 mm for d.c. The design of profile is patented by individual manufacturer but almost all the manufacturers have a projected second rib from the outer edge so as to cut the free run of flash over the surface of the insulator. In recent times the profile of insulator has undergone substantial change in terms of shape with introduction of open profile for the benefit of improved pollution performance as well as self-cleaning advantage by the action of natural wind and rain. At an initial stage of development, to prove the design concept, the pollution performance is tested on units by coating the surface of the insulator with a standard pollutant in salt solution and apply specified voltage for three hour. Result is expressed in terms of equivalent salt deposit density (ESDD) which can be compared for different profiles. Full string is required to be tested for certification purposes.

Disc insulators made out of glass often fail in both EHV and UHV line due to dielectric puncture or shattering of assemblage holding the live conductor that disrupt the power supply. Poor quality of porcelain disc with even trace amount porosity as detected by die-penetration test was found to have similar type of bursting soon after rainy season. Although the increase in line voltage (a.c.) did not show significant rise in the failure rate of non-porous high strength insulators and initially if one of the disc insulator fail within a string, conductor still remains in position unaffected electrically. But once it looses it's mechanical strength then the conductor comes down. Due to fixed polarity in d.c., 'ion migration' by electrolysis occurs in the case of rattling cations (Na) in the dielectric medium in between metal cap and ball pin of disc insulator. There is a potential risk of puncture in disc insulator. This deficiency can be totally avoided with the puncture proof long rod insulators made out of different dielectric materials such as composite or monolithic porcelain.

National railway corridor for interconnecting the four metros opened yet another opportunity for the 25 kV porcelain insulator for traction. A very high order of reliability is necessary for traction insulator because the failure of porcelain insulator halts electric locomotive movement. Poor quality of porcelain insulators (porous) supplied by the manufacturers paved the way for composite insulators into railways with epoxy-glass (EG) core and silicone rubber (SR) shed. It is understood that Powergrid has been floating exclusive tenders for composite insulators even for HVDC and deserted disc insulators completely.

2. Composite Insulator with Polymer Shed

The light weight composite insulator made with EG core and polymeric shed are used in place of conventional disc insulators. Additional advantage is improved pollution performance due to hydrophobicity of silicone rubber and therefore claimed to have superior anti-pollution performance due to hydrophobic nature of the rubber material[5]. The polymer-EG insulators are mechanically failure proof provided the crimping of end fitting is properly done. Simplicity in erection is an additional advantage.

However, the designers are sceptical about the sustenance of properties even in its 'short life span' besides reasons such as higher cost of silicone rubber material if procured from reputed sources, numerous failure reports in joints, flashover due to improper insulator length, power-arc susceptibility, erosion, UV-ray degradation of polymeric shed, handling damage, bird-pecking, tearing of sheds in desert area and so on as also reported by CIGRE WG 22-03 in 1986. Loss of hydrophobicity due to pollutant settling over the polymer shed in field is another deterrent factor[6]. Besides it is difficult to detect the defective composite insulator by proof testing. Interestingly, many porcelain insulator manufacturer also manufacture composite insulators side by side to meet the market demand. In 400 kV composite insulator creepage distance is 13250 mm even though the length of 3910 mm is same with 23 nos of 170 mm spacing disc with total creepage of 8510 mm. Alternate shed design and higher creepage accounts for better pollution performance.

3. Porcelain Longrod Insulator

Siemens Germany introduced puncture-proof long-rod insulator (LRI) using high strength alumina porcelain (C130) for superior mechanical performance. Alumina is chemically inert, thermally stable, electrically nonconductor and possesses high dielectric strength of 9.9-15.8 kV/mm. As a filler material in porcelain it provides superior mechanical properties. Quartz on the other hand undergoes inversions at 573ºC associated with sudden volume change during cooling that results in microcracking, the performance of quartz porcelain is lower in terms of flexural strength and fatigue, hence is not be admissible technically[3].

At present alumina costs as high as $1 a kg compared to $0.05. Customers other than RDSO does not specify alumina content in their purchase tender. A high life-span reliability of quartz-free longrod is a long term gain over the polymer insulator with EG core[6]. There is however no known field experience or data with LRI in HVDC above ±500 kV. A developmental work was initiated by the author in 2006 based on the experience gained on HVDC disc with NGK, Japan and BHEL, Bangalore.

4. Performance Analysis

Transmission loss in d.c. is projected to be less by 25%. In 2015-16 about 282,000 MW power was generated in the country and transmission loss could be restricted within 3000 MW out of 150 tripping in the transmission line spread over 3,15,1000 circuit km with bundle conductor and other improvements in the transmission sector such as selection of appropriate creepage using a pollution map prepared by Central Power Research of India, Bangalore[7]. Overall efficiency of transmission is calculated from the power lost in the process of transmission and is a serious concern. Because of fixed polarity in d.c. the charge piles up at the poles, discharges intermittently creating surface flashover and accounts for the transmission loss primarily.

In the previous presentation[4-5], we discussed the issues related to the manufacturing technology and raw material for good quality of porcelain disc insulators[8-10].

Furthermore, it was suggested that the electrical design, testing standards and specification should be objectively determined so that the services of insulator manufacturing industry is effectively used towards achieving the national objective of developing sound infrastructure[8]. It is again emphasised that the onus for ‘uninterrupted power supply’ grossly rests with the insulator quality although it constitutes a meagre 5% of the entire cost in a trnsmission line. The biggest consumer of insulators is the Powergrid who develops and owns majority EHV/UHV transmission system network. Nearly 1000 Crores of porcelain insulators were sold by three major amnufacturer, Aditya Birla Insulators, Modern Insulators and BHEL with sales of 505, 274, 201 Crores respectively in FY13-14 employing about 6000 people directly[2,10-11]. In the year 2007-08, manufacturers added large capacity in domestic insulator industry in existing EHV insulator production line as well as developed new insulators for 765 kV a.c. Several new entrepreneurs in the small-scale sector ventured in the scenario by setting up plants for 11-33 kV range at Morvi, Gujrat and at Bikaneer, Rajasthan.

While the small-scale sectors cater to 11-132 kV range, Rishra Plant (Aditya Nuvo), BHEL’s two plants in Bangalore and Jagadishpur mostly cater to EHV/UHV transmission line insulators with the conventional disc insulator. In order to meet the growth rate import was allowed and import from China soared in FY12-13. It hit the domestic manufacturer badly. Indian electrical industry was growing at an average rate of around 30% however some of the profit making industries like BHEL suffered loss in FY12-13 and FY13-14. In order to cope with the market competition country’s private manufacturers resorted in cost cutting by replacing costly raw materials[11-12]. State authorities presumably may not be geared up to ensure incoming quality from import due to required technical skill. Government funded R&D expenditure is nil for technology development in this sector and country still depends on age old syndromes.

In this presentation, we shall discuss the knowledge acquired via failure analysis on porcelain insulators and polymer insulators, and suggest remedies for UHV application.

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II EXPERIMENTAL RESULTS & DISCUSSIONS

1. Design and Pollution Testing

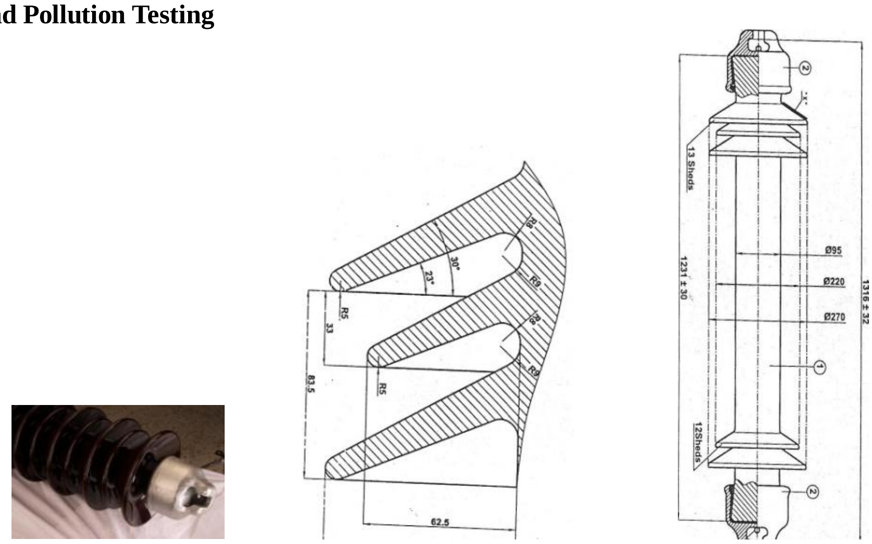
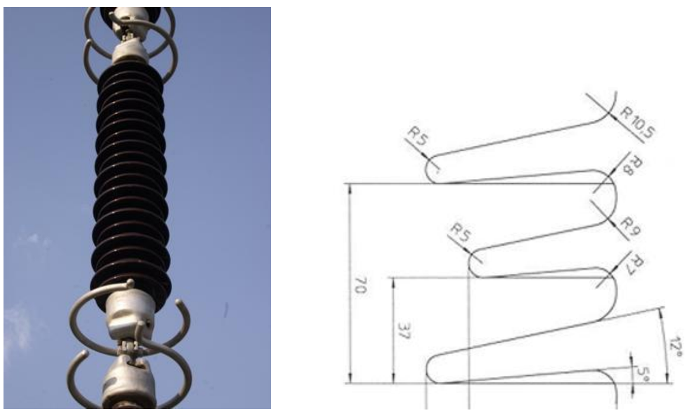


Fig.1: Longrod unit comprising of porcelain shell and MCI caps at either ends assembled with cement. Shed profile in top with inclination of 30º/23º, bottom-left with inclination of 12º/5º. Bottom right shows assembly of units with ball pin and hardware. Inset in the top shows glazed surface and socket.



Longrod insulators with 95 mm core diameter and 90 mm shed overhang were developed with different shed profile and tested in CPRI Bangalore with artificial pollution severity level of 0.045 mg/cm^2 equivalent salt deposit density, ESDD. Leakage current per second was measured. It was found that in the given test condition insulator with alternate shed design is better if the difference between the small and big shed is wide. Congested shed is to be avoided. Angle of inclination should be as low as possible, 12º/5º, to allow the free air passage for self-cleaning advantage. Thinner the outer edge better is the anti pollution performance.

2. Porcelain Manufacturing Process and Raw Materials

Most of the porcelain insulators contain quartz that diminishes the life and long term performance due to circumferential crack as seen in the Fig. 1. Instead of alumina porcelain which is preferred by the customers, quartz grain in porcelain is seen under microscope. Quartz is to be removed by washing the clay best by using hydro-cyclone separator. Microcrack associated aging behaviour is well known. If other impurities particularly metallic iron is present in the green body it affects the surrounding porcelain matrix as seen in Fig.3 during the firing process. Hence impurity are not tolerated at all in the raw material stage and Fe-parts in contact with the material are all to be replaced by stainless steel. Series of high power magnets of about 10,000 gauss are to be used for ferro-filtering and screens are to be used in series during wet seiving, last being 35µm size. Na-content in alumina and water to be checked thoroughly although the ion migration test is not required for LRI.

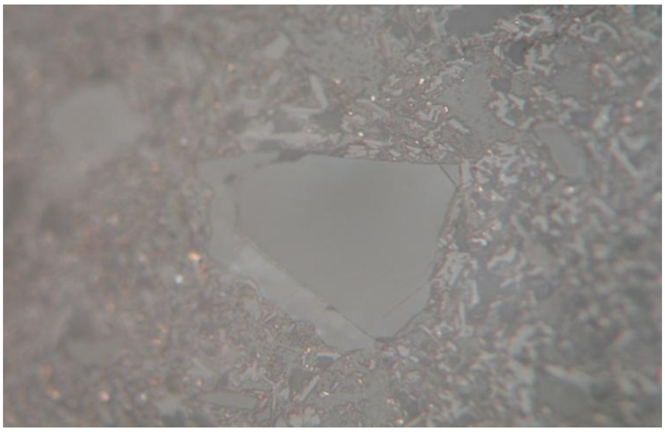


Fig. 2 Showing microcrack in the grain boundary region of large quartz gain of 45 µm size. Note microcracks are detected in the rim of 30 µm size quartz grain, PhD Thesis J. Liebermann

3. Hydrophobic Glazed Porcelain

A new glaze composition has been developed for hydrophobicity. Details will be presented elsewhere. Alternatively silicone grease or RTV coating can be employed[10].

Fig.3 Dark region of porcelain matrix in the insulator part retrieved from a low strength insulator after 15 years of life. Damage in the surrounding area is suspected due to contamination

4. Pb-alloy or Aramide FRC for Vibration Endurance

Fatigue endurance is reportedly improved by using a Pb-alloy as mortar for assembly of insulator shell with end metal cap[10]. The ductile nature of Pb-alloy takes care of any nonallignment of longitudinal tensile force applied through the end fittings. High tensile strength of aramide fibre dispersed in the normal cement mortar will provide the similar ductility while maintaining the rigidity. Pb-alloy requires high temperature for melting and poring into the narrow gap between the cone of the shell and inner cup of the metal cap.

III. CONCLUSION

Cap and pin type disc porcelain insulator or composite EG-polymer insulator presently used can have aging problem and replacement will become a necessity in the horizon 10-12 year timeline. Properly designed composite insulator with stress-free crimping technology and reliable source of polymeric material could have countered for sustaining another couple of years or so. A long term solution could be LRI. Needless to mention that a sound control over the starting material and a high order of process parameter conformity are essential for a long sustained life and strength. Customer and standardization body such as IEC. and CIGRE can change the standard to include the missing parameter brought in this communication. Hydrophobic glaze technology can be adopted by the manufacturers for the longterm benefit of porcelain insulator which is facing acute competition from the EG-polymer composite insulator. The customer should be able to carry out failure analysis objectively and insist on the standardization bodies like IEC and

CIGRE for revising the standard. Vendor development for quality insulator with latest know-how is the need of the hour for the sustainability of National Grid which are lifeline to society.

For each batch of production dielectric test should be performed carefully[13] and correlated with the change in raw material batch procedure. The possible changes in the material under high electrical and mechanical stress are to be captured with thorough study on microstructure to characterize the behavior of microcracks and other defects originally present. This was suggested to Powergrid[14].

ACKNOWLEDGMENT

Authors thank the Convener and National Organising Committee members of NCSRESPSE 2017 for extending the invitation. Thanks are due to management of Modern Insulators Limited for helpful support. Author is particularly grateful to Dr. J Liebermann, Retd. Technical Head, Siemens, Redwitz, Germany for figures mentioned in the caption.

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BIOGRAPHY

Dr. Amiya P. Goswami is a Professor at Sri Venkateshwara College of Engineering, Bangalore India. He took his doctorate degree from Jadapur University, Kolkata, India, served as Head of R&D in Aditya Birla Insulators, Modern Insulators and Allied Ceramics. During his early part of career he was trained in NGK Insulators, Japan by BHEL and later on exposed in Siemens Technology. His research interest includes electrical and mechanical properties of ceramic and composite materials including cement and concrete.