American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-8, Issue-12, pp-138-145
www.ajer.org
Research Paper Open Access

Analysis of Insulators for Distribution and Transmision Networks

Nzenwa, E. C.[1], Adebayo, A. D.[2]
[1]*Department of Electrical and Electronic Engineering, University of Port Harcourt, Rivers State, Nigeria*
[2]*Department of Electrical and Electronic Engineering, University of Otuoke, Bayelsa State, Nigeria*
Corresponding Author; Nzenwa, E. C

ABSTRACT: *This work made an analysis of analysis of insulators for distribution and transmission networks. Electrical insulator is a very important component in the electric power systems such as sub-stations and distribution & transmission lines. In-depth study and practical knowledge on this subject is necessary for the electrical professionals in the electrical power field. In the early days, insulators were made of ceramic and glass materials. But in 1963, polymeric insulators were developed and its improvements in design and manufacturing in the recent years have made them attractive to utilities. It is consist of a fiberglass core rod covered by weather sheds of skirts of polymer such as silicone rubber, polytetrafluoroethylene, EPDM (ethylene propylene diene monomer) and equipped with metal end fittings. It is also called composite insulators, which means made of at least two insulating parts, a core and housing equipped with end fittings. Polymeric insulators have many advantages over the ceramic and glass insulators such as good performance in contaminated environment, light weight, easy handling, maintenance free, and considerably low cost etc. Because of these properties it is gaining popularity worldwide and replacing the conventional ceramic and glass insulators. The scope of this technical paper is to discuss about construction, types, designing, testing, and selection of polymeric high voltage insulators. Based on the findings of the study, necessary recommendations were made.*

KEYWORDS: *Analysis, Analysis of Insulators, Insulators, Distributors and Transmission Networks.*

Date of Submission: 15-12-2019 Date of acceptance: 27-12-2019

I. INTRODUCTION

High voltage transmission lines are used for efficient transmission of electrical energy over long distances. Today, the insulation of overhead transmission lines with composite insulators is common practice world-wide. The electric insulators are used in transmission lines to support the cables and isolating them of the ground (Kakani,2010). Consequently, the insulators individually or grouped in a chain, must present enough mechanical resistance to maintain the weight other insulator, effect wind, temperature and forces of the short circuit . The insulators string reduces the mechanical vibration transmitted to the tower and facilitates their maintenance. Although the use of silicone rubber composite insulators has been increased significantly in recent years, porcelain and glass insulators are still manufactured and remain predominant in distribution and transmission lines. Except for hydrophilic property, porcelain and glass insulators are widely used because they offer many advantages: low cost, flexible maintenance and high strength. When energized in polluted area such as coal industry zone and coastal area, the insulators are easily contaminated , dry band will be formed and leading to flashover. Control of electric field around high voltage equipment such as transmission line conductors, insulators and associated line hardware, surge arresters and switchgears is a very important aspect of the design of such equipment. Forecasting the flashover voltage, and select the appropriate quantity of insulators in the insulator chain according to the forecasting voltage, can avoid the flashover effectively and then increase the reliability and security of transmission line and then ensure safety and stability of power system (Adrian,2013) . The electric field calculation is one of the essential factors in the design and development of high voltage insulators. The calculation of the electric-field distribution is very important for the design of high-voltage transmission lines. High electric-field strength can cause strong corona around the conductor surface, audible noise, radio interference, partial discharge, premature aging of insulation, and other electromagnetic (EM) pollution. These days, composite insulators are being increasingly used to replace porcelain and glass insulators because of the advantages obtained from good performance against pollution, lower weight, reduced installation and maintenance cost. At the same time, compact transmission lines are also being widely used which have a lot of advantages over the traditional transmission lines. However, the composite insulators are very sensitive to the magnitude of the electric-field strength and may be eroded when subjected to sustained electrical discharges. Manufacturers provide special grading devices with the high-voltage (HV) insulators to reduce the electric-field strength at the insulator ends. Because the phase spacing of the compact transmission lines is reduced significantly, the towers, the transmission lines, and the ground wires will greatly affect the electric field in the vicinity around the insulators. Thus, it is necessary to investigate the electric-field distribution around the composite insulators and the heads of transmission towers. For 1000kV ac transmission lines, the field distribution is quite non-uniform because of the high voltage and the long insulator string. High electric field intensity may cause strong corona, partial discharge, and premature aging of insulation (Grigsby,2011). High voltage distribution ratio may breakdown insulators, so that the operation safety of lines cannot be ensured . Thus, it has important significance to calculate and improve the field distribution along the insulator string through well grading rings design. Because of the distributed capacitance between the insulators and the iron tower, the voltage distribution is quite non-uniform along the insulator string. Various methods have been proposed.

Aims and Objectives

The main aim of the study is to analysis insulators for distribution and transmission networks. It specific objectives are:

1. To evaluate the various insulators sizes suitable for distribution and transmission lines
2. To identify the criteria in the determination of good insulators.
3. To develop a valuable guide to assist with the selection of insulator size for overhead transmission and distribution lines.
4. To highlight the significance of incorporating planning and load forecast considerations, power quality constraints, voltage collapse in selecting insulators.
5. To make necessary recommendations based on the findings of the study

II. HYBRID POWER SYSTEMS

Historical Development of insulators

The first polymers used for electrical insulators were bisphenol and cycloaliphatic epoxy resins. Introduced commercially in the mid 1940s, bisphenol epoxy resins were the first polymers used for electrical insulators, and are still used to make electrical insulators for indoor and outdoor applications. Cyloaliphatic epoxys (CE) were introduced in 1957(Bernhard,& Bernhard,2011). They are superior to bisphenol because of their greater resistance to carbon formation. However, the first commercial CE insulators failed shortly after installation in outdoor environments. Since then, new CE formations have resulted in improved electrical performance. In the early 1960s, distribution class (CE) insulators were first sold commercially in the U.S. under the name GEPOL. These units failed due to surface damage and puncture. CE was used later in experimental 500 kV station breaker bushings, and in 115 kV bushings in the 1970s, and for suspension insulators by Transmission Development Limited (TDL) of England. The TDL suspension insulators used slant sheds to provide natural washing of contamination. From the mid-1960s on, CE insulators were tested at up to 400 kV service voltage as suspension / strain insulators and cross-arm in the United Kingdom. For various reasons, including poor cold temperature performance and insufficient weight reduction, CE did not gain acceptance in the US for outdoor high voltage suspension insulators. But today, CE is widely used in indoor and even semi-enclosed power systems. In the 1960s an insulator having porcelain sheds supported by an epoxy resin fiberglass rod was developed. It was not widely used because of further developments in lighter-weight polymeric insulating materials. Polymeric outdoor insulators for transmission lines were developed as early as 1964 in Germany, and by other manufacturers in England, France, Italy, and the U.S. In Germany, units for field-testing were provided in 1967(Klein, & Gafni, 2006). In the late 1960s and early 1970s, manufactures introduced the first generation of commercial polymeric transmission line insulators. A large number of utilities started to experiment with the first generation composite insulators manufactured before the mid-1980s. The early experience was disappointing. Utilities initially installed these insulators in short sections of lines and at trouble spots, mostly for experimentation and data gathering. As a consequence of reported failures some manufacturers stopped producing high voltage units and others started an intensive research effort, which led to the second generation of composite transmission line insulators. These improved units have tracking free sheds, better corona resistance, and slip-free end fitting.

Insulators

An electrical insulator is a material whose internal electric charges do not flow freely; very little electric current will flow through it under the influence of an electric field. This contrasts with other materials, semiconductors and conductors, which conduct electric current more easily. The property that distinguishes an insulator is its resistivity; insulators have higher resistivity than semiconductors or conductors.

Benefits of insulations

A properly designed and installed insulation system offers immediate and long-term benefits. Insulation protects your personnel, your equipment, your system, and your budget. The following are the benefits:

1. Reduces energy costs
2. Prevents moisture condensation
3. Reduces capacity and size of new mechanical equipment
4. Enhances process performance
5. Reduces emissions of pollutants
6. Safety and protection of personnel
7. Acoustical performance: reduces noise levels
8. Maximizes return on investment (ROI)
9. Improves Appearance
10. Fire Protection

II BASIC DESIGN CONCEPTS

The basic designs of polymer insulators evolve around three essential components. These are, a core, a sheath or weather sheds and metal end fittings. The end fittings are attached to the core in various ways to develop the required mechanical strength for the intended application. The core consists of axially aligned glass fibers bonded together by means of an organic resin. The unprotected core with end fittings by itself is not suitable for outdoor high voltage application, as moisture, ultraviolet rays, contamination, acid, rain, ozone and voltage are conducive to the degradation of the core material and leading to electrical and mechanical failure. Hence, a protective sheath or weather sheds made from various polymer materials that have been compounded for outdoor electrical applications are applied over the core in various ways to protect the core and to provide maximum electrical insulation between the attachment ends. It is quite clear that with such a diversity of possible constructions, the performance of polymer insulators depends on the selection of materials and on the design and construction of the insulators.

Material Selection Core

The mechanical strength member of polymer insulator is a fiberglass rod. The rod, normally referred to as the core of the insulator, consists of between 70 and 75% by weight of axially aligned glass fibers bonded by an organic resin. The resin system can be either polyester or epoxy and the rod either cast or pultruded. Today’s core is pultruded in various diameters with electrical grade E-type glass fibers and polyester resin. Two critical process parameters in the pultrusion of fiberglass rod for insulators are pulling speed and temperature of the forming die. An axial crack develops when the outside of the rod cures more quickly than the center of the rod. This occurs when either the die temperature is too high for the pulling speed or outside of the rod sets, shrinkage during curing of the bulk of the rod and produces an axial crack in the center of the rod. Bonding of glass fibers to the polyester resin is affected by process parameters as well. In pulling glass fiber, the fiber is sized or treated chemically for protection against mechanical damage during handling.

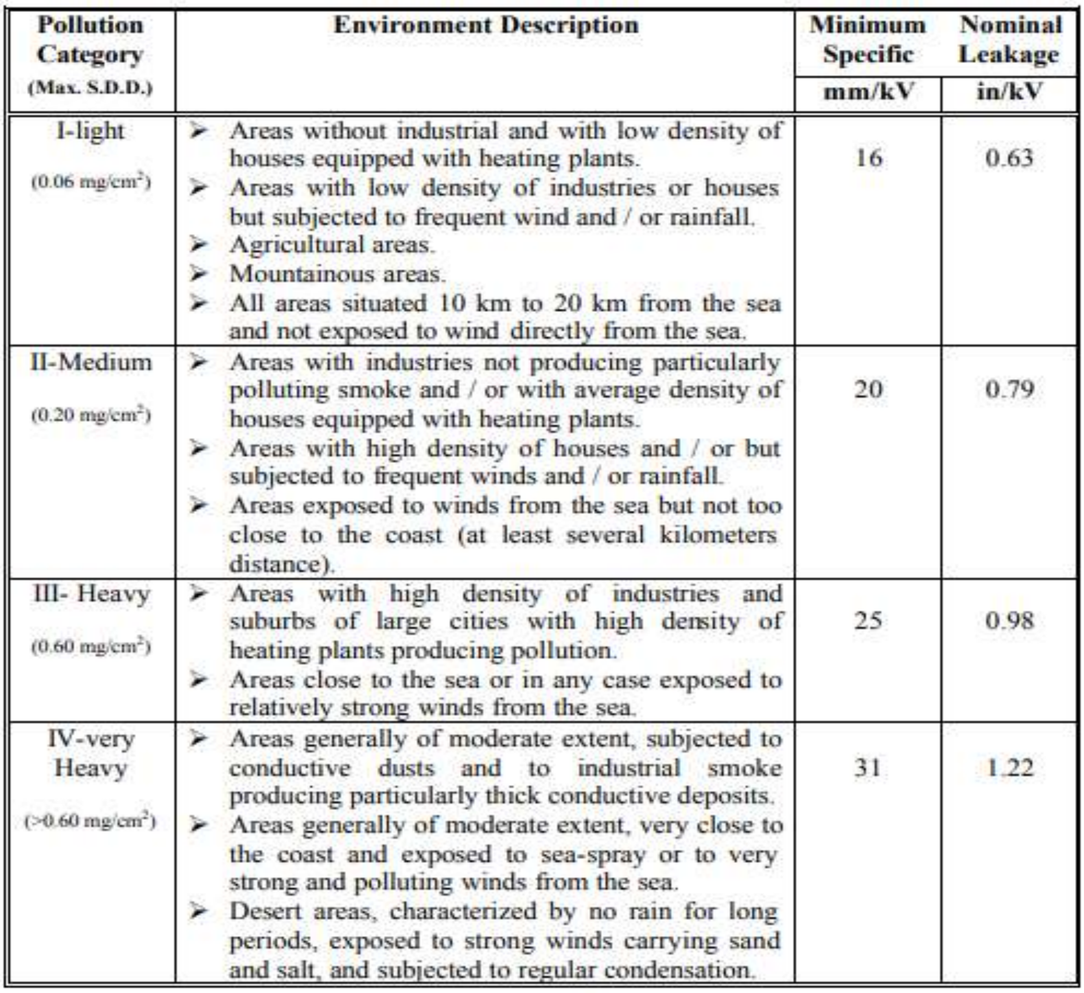
Insulator Design

Elastomeric weathersheds in first generation insulators are individually molded and glued to the core and to each other by an epoxy adhesive. In some designs, silicone gel or silicone caulking sealant is applied. In other designs, silicone gel or grease is used to fill the air space between the sheds and the core. Although epoxy glue provides some measure of protection against water entry, there is some uncertainty in the lifetime of such a seal. Insulators constructed from individual sheds are known to permit water reaching the core and have failed during hot line high-pressure water washing. Most of the insulators are molded from either EPDM or silicone elastomers, in one-piece having an aerodynamic design, that is fully vulcanized to the core.

Pollution severity levels

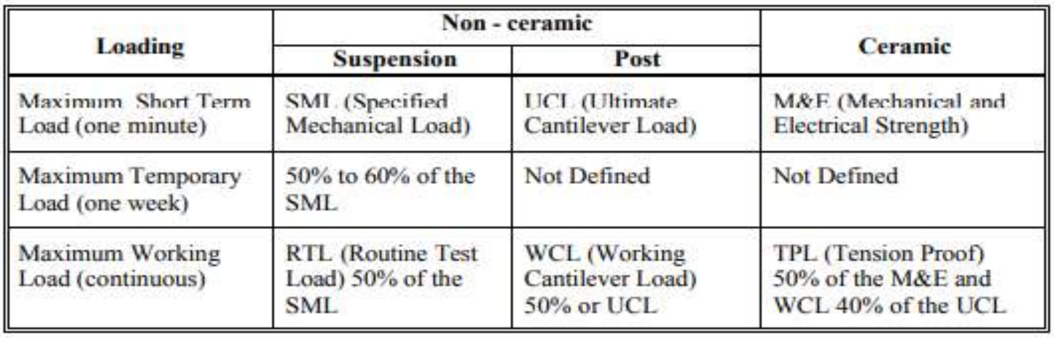
For the purposes of standardization, four levels of pollution are qualitatively defined, from light pollution to very heavy pollution. Table-3.1 gives, for each level of pollution, an approximate description of some typical corresponding environments. Other extreme environmental conditions exist which merit further consideration, e.g. snow and ice in heavy pollution, heavy rain, and arid areas. 2. Relation between the pollution level and the specific creepage distance For each level of pollution described in Table3.1, the corresponding minimum nominal specific creepage distance, in millimeters per kilovolt (phase-to phase) of the highest voltage for insulator is also given. 3. Application of the "Specific Creepage Distance" concept In order to successfully apply the "specific creepage distance" concept, certain dimensional parameters characterizing the insulator shall be taken into account.

Pollution Consideration



Pollution Category (Max. S.D.D.)	**Environment Description**	**Minimum Specific** mm/kV	**Nominal Leakage** in/kV
I-light (0.06 mg/cm²)	➢ Areas without industrial and with low density of houses equipped with heating plants. ➢ Areas with low density of industries or houses but subjected to frequent wind and / or rainfall. ➢ Agricultural areas. ➢ Mountainous areas. ➢ All areas situated 10 km to 20 km from the sea and not exposed to wind directly from the sea.	16	0.63
II-Medium (0.20 mg/cm²)	➢ Areas with industries not producing particularly polluting smoke and / or with average density of houses equipped with heating plants. ➢ Areas with high density of houses and / or but subjected to frequent winds and / or rainfall. ➢ Areas exposed to winds from the sea but not too close to the coast (at least several kilometers distance).	20	0.79
III- Heavy (0.60 mg/cm²)	➢ Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution. ➢ Areas close to the sea or in any case exposed to relatively strong winds from the sea.	25	0.98
IV-very Heavy (>0.60 mg/cm²)	➢ Areas generally of moderate extent, subjected to conductive dusts and to industrial smoke producing particularly thick conductive deposits. ➢ Areas generally of moderate extent, very close to the coast and exposed to sea-spray or to very strong and polluting winds from the sea. ➢ Desert areas, characterized by no rain for long periods, exposed to strong winds carrying sand and salt, and subjected to regular condensation.	31	1.22

Insulator Strength Rating Definition



Loading	**Non - ceramic**		**Ceramic**
	Suspension	**Post**	
Maximum Short Term Load (one minute)	SML (Specified Mechanical Load)	UCL (Ultimate Cantilever Load)	M&E (Mechanical and Electrical Strength)
Maximum Temporary Load (one week)	50% to 60% of the SML	Not Defined	Not Defined
Maximum Working Load (continuous)	RTL (Routine Test Load) 50% of the SML	WCL (Working Cantilever Load) 50% or UCL	TPL (Tension Proof) 50% of the M&E and WCL 40% of the UCL

Loading Considerations

Ice and Wind Establishing the everyday working load of an insulator requires that ice and wind conditions for the area of application be considered. Ice and wind can add considerable load to the conductor and insulators, resulting in greater loads. Table-3.2 lists parameters to use for calculating ice and wind loads for each region.

Insulation Consideration

There are basically three factors to consider when designing the insulators. · The 60-Hz power voltage. · Surge voltages caused by lightning. · Surge voltage caused by switching. Surge voltages provide the most stringent test and the rationale for the standard impulse voltage wave form; that is, if the insulator is properly insulated to withstand surges, it can usually accommodate the highest expected 60 Hz voltage. Insulators are more tolerant of short-duration overvoltage than sustained values. The waveform is referred to as T1 X T2, where both values are conventionally given in microseconds. The crest value of the waveform V.

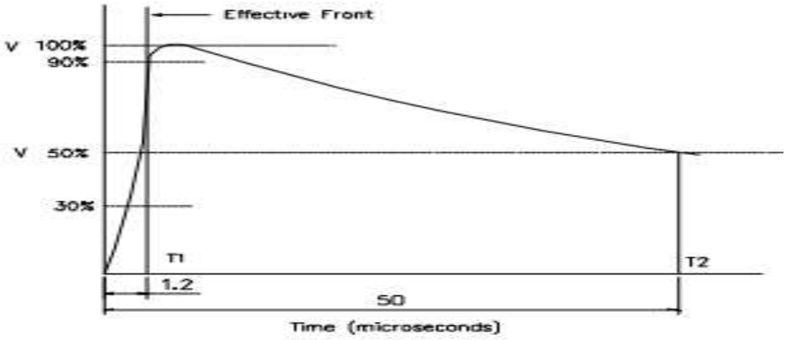
The value T1 is the rise time to crest, whereas the value T2 is the fall time to 0.5 V. A convenient analytical representation of the pulse waveform is the double-exponential expression

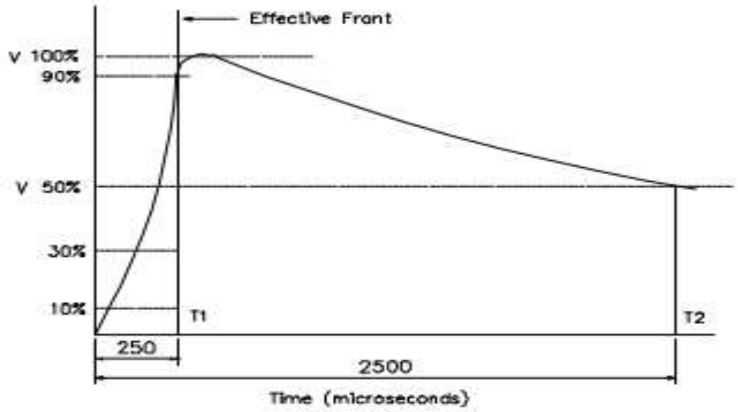
$V(t) = V1[\exp(-t / t2) - \exp(-t / t1)]$

Where $t2 = T2 / \ln(2) = 1.443T2$ $t1 = T1 / 5 = 0.2T1$ $V1 = V \exp(T1 / 1.443T2)$

For a given well-defined voltage waveform, under specified test conditions, the following terminology is defined:

- Critical Flashover Voltage (CFO) - The crest (maximum) voltage for which the probability of flashover is 0.50
- Withstand Voltage - The crest voltage 3s below the CFO
- Basic (lightning) Impulse Insulation Level (BIL) - The crest voltage for which the probability of flashover is 0.10, using a 1.2/50 ms test pulse.
- Basic (switching) Surge Impulse Insulation Level (BSL) - The crest voltage for which the probability of flashover is 0.10, using a 250/2500 ms test pulse.





Waveform — Switching Impulse

Consideration of Interference and Corona Generating processes

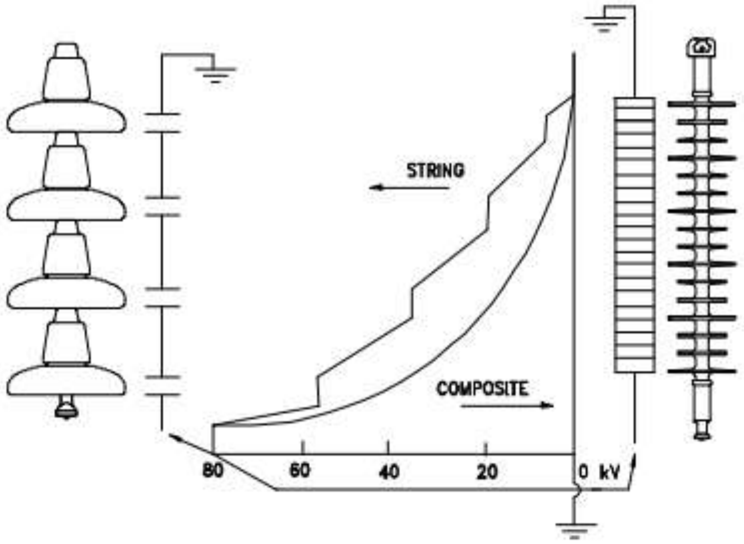
Interference with radio and television (RI and TVI) may arise when electrical discharges run on insulators and inject high-frequency currents into associated conductors, which radiate electromagnetic waves. The types of discharge which generate interference are: micro sparks between water drops or metal fittings, the latter especially in cases of corrosion; discharges across dry bands on leaky surfaces; surface corona discharges around highly stressed electrodes. Surface corona discharges are again relatively slow phenomena, incapable of heavy generation at VHF, but principal sources at lower frequencies. Surface discharges may be prevented by hydrophobic treatment. This not only inhibits dry-band formation but also gives good voltage grading, thus removing the over voltages, which cause other types of discharge. It might appear that the installation of a corona ring would smother capacitive over voltages, while avoiding the usual power loss, which follow installation of a corona ring. Both the above-mentioned types of discharge are, to some extent, weather dependent. Water may cause droplet discharges while suppressing contact discharges by virtue of its high conductivity and permittivity; dry bands do not a fair-weather phenomenon, the existence of which depends on the design of the insulator and the geometry of the insulators of fittings. Surface corona, if in fair weather, for which reason it has long been the practice to specify higher than normal voltages for corona inception on insulator.

Consideration of Capacitance Effects

The distribution of capacitance along an insulator, and their size, govern the electric stresses, which excite generation of interference, and the coupling of the generator to the radiating antenna. A composite insulators like a cylinder of dielectric having a relative permittivity about 6. The field intensity falls away rapidly with increasing distance from the live terminal . The generating discharges occur at or near the live terminal, and the capacitance, which couples the high-frequency currents into the radiating circuit, i.e. the line and tower, is small. Composite insulators are thus significantly quieter as interfering sources than string of discs. In a string of discs, quite large capacitance – of the order of 30 pF – are connected in cascade through the fittings.

The voltage distribution is governed purely by these and by the stray capacitance to line and ground, in dry conditions. In such a voltage-dividing circuit the partition is independent of frequency: identical distributions therefore exist for the power-frequency and for the radio-frequency voltage. The units at the line end are more prone to surface corona than the rest. Because of the high unit capacitance the sources are closely coupled into the line, which presents load impedance equal to one-half of the line’s surge impedance. It is common practice to relieve the line end overvoltage by means of stress-grading fittings. Some of the devices which are used to minimize surface corona, in cases like these where ‘quiet’ insulators are essential. Tests showed those gradients between 10 and 14 kV/cm is sufficient to break down air in contact with insulator over gaps of a few centimeters.

VOLTAGE DISTRIBUTION ALONG STRING AND COMPOSITE INSULATORS



Insulator Testing

Definitions Tracking - Tracking is an irreversible deterioration by the formation of paths starting and developing on the surface of an insulating material. These paths are conductive even under dry condition. Tracking can occur on surface in contact with air and also on the interfaces between different insulating materials.

Treeing - Treeing is the formation of micro-channels within the material. The micro-channels can be either conducting or non-conducting and can progress through the bulk of the material until electrical failure occurs. Erosion - Erosion is an irreversible and non-conducting deterioration of the surface of the insulator that occurs by loss of material. This can be uniform, localized or tree-shaped.

Chalking - Chalking is a surface condition where in some particles of the filler become apparent during weathering, forming a powdery surface. Crazing - Crazing is the formation of surface micro-fractures of depths up to 0.1 mm.

Cracking - Cracking is any surface fracture of a depth greater than 0.1mm. Hydrolysis - Hydrolysis is a chemical process involving the reaction of a material with water in liquid or vapor form. It can lead to electrical or mechanical degradation.

Puncture - Puncture can be characterized by a disruptive discharge occurring through a solid dielectric (e.g., shed, housing, or core) causing permanent loss of dielectric strength. Specified

Mechanical Load (S.M.L) - The S.M.L. is a load specified by the manufacturing, used for mechanical tests in this specification. It forms the basis of the selection of composite insulators. Tensile Load - Tensile load is the load applied in-line with the longitudinal axis of the insulator rod and away from the end metal fitting Routine Test Load (R.T.L.) - The R.T.L. is the load applied to assembled composite insulators during Routine Tests. It is equal to 50% of the S.M.L.

Cantilever Load - Cantilever load is a load applied at the conductor position on the insulator, perpendicular to the conductor, and perpendicular to the rod of the insulator. This load is also called bending. Compressive Load - Compressive Load is applied in-line with the longitudinal axis of the insulator rod and towards the base end. Maximum Working Combined Loads The maximum working combined loads are the simultaneously applied cantilever and compression loads. They produce a bending moment that should not exceed the bending moment induced by the working cantilever load rating alone.

Working Cantilever Load (W.C. L.) - Working cantilever load is a load that must not be exceeded in service.

Maximum Design Rating (MDR) - The maximum mechanical load that the insulator is designed to withstand continuously for the life of the insulator.

Proof-Test Load - The routine mechanical load that is applied to an insulator at the time of its manufacture.

Delamination - Delamination is the loss of bonding of fibers to matrix.

Tests

Classification of Tests

Based on the purpose of testing, the tests to be performed on polymer insulators are classified in four categories as follows:

Design Tests - Design tests are performed to verify the suitability of the manufacturer's design, materials, manufacturing process and technology. When an insulator is submitted to the design tests, the results shall be considered valid for all insulators of the same design that are represented by the tested one. The design tests are performed once. Design tests shall include the following tests: q Material Tests i) Water Penetration Test ii) Tracking and Erosion Test iii) Aging or Accelerated Weathering Test iv) Dry Penetration Test v) Water Diffusion Test vi) Power Arc Test vii) Flammability Test q Mechanical Tests i) Tension Strength Tests ii) Torsion Strength Test iii) Working Cantilever Load iv) Thermal Mechanical

Test 2.

Type Tests - Type tests verify the main characteristics of the insulators, which depend mainly on its shape and size. They shall be repeated when the design, type, or size of the insulators changes. Three production line insulators of the relevant type shall meet the requirements. The following tests are recommended for this type of testing:

i) Low-Frequency Dry Flashover Test
ii) Low-Frequency Wet Flashover Test
iii) Critical Impulse Flashover Test
iv) Radio Influence Test

Sample Tests

Sample tests verify other characteristics of the insulator, including those which depend on the quality of the manufacture and on the material used. They are performed on insulators taken at random from a lot offered for acceptance. Sample shall include the following tests: i) Galvanizing Test ii) Tension Strength Test iii) Dye Penetration Test iv) Retest Procedure v) Verification of Dimensions, Markings, and Metal Fittings 4. Routine Tests - Routine tests are conducted to detect and discard insulators with manufacturing defects. They are made on every insulator produced. They include tensile load (50% of S.M.L.) and visual examination tests.

III. CONCLUSION

It is obvious that if overhead power lines are not properly insulated from their support poles/towers, the current will flow towards the ground through the poles/towers which also become hazardous. Of course, the power line won't even work in that case. Hence, overhead power lines are always supported on insulator.

Overhead line insulators should have the following properties:

- high mechanical strength in order to withstand the conductor load, wind load etc.
- high electrical resistance in order to minimize the leakage current
- high relative permittivity of insulating material so that the dielectric strength is high
- high ratio of puncture strength to flashover

Most commonly used material for overhead line insulators is porcelain. But glass, steatite and some other special composite material may also be used sometime. An insulator must be properly designed so as to withstand mechanical as well as electrical stresses. Electrical stress on insulator depends on the line voltage, and hence, proper insulators must be used according to the line voltage. Excess electrical stress can break-down the insulator either by flash-over or puncture.

The use of insulators in the electric power sub-stations and distribution & transmission lines is beneficial because of its many advantages such as contamination performance, reduced construction costs, light weight, easy handling, low or no maintenance, vandalism resistance and compact design.

REFERENCES

[1]. Kakani,L.(2010) . Electronics Theory and Applications. New Age International. p. 7. ISBN 978-81-224-1536-0.
[2]. Adrian W,(2013). An Introduction to Electrical Science. Routledge. p. 41. ISBN 1-135-07113-6.
[3]. Klein, N. & Gafni, H. (2006). "The maximum dielectric strength of thin silicon oxide films". IEEE Trans. Electron Devices. 13.
[4]. Inuishi, Y.& ; Powers,A. (2007). "Electric breakdown and conduction through Mylar films". J. Appl. Phys. 58. Bibcode:1957JAP....28.1017I. doi:10.1063/1.1722899.
[5]. Belkin,A (2017). "Recovery of Alumina Nanocapacitors after High Voltage Breakdown". Scientific Reports. 7. Bibcode:2017NatSR...7..932B. doi:10.1038/s41598-017-01007-9. PMC 5430567.
[6]. "Electrical Porcelain Insulators" (PDF). Product spec sheet. Universal Clay Products, Ltd. Retrieved 2008-10-19.
[7]. Cotton, H. (2008). The Transmission and Distribution of Electrical Energy. London: English Univ. Press. copied on Insulator Usage, A.C. Walker's Insulator Information page
[8]. Holtzhausen, J.P. "High Voltage Insulators" (PDF). IDC Technologies. Retrieved 2008-10-17.
[9]. IEC 60137:2003. 'Insulated bushings for alternating voltages above 1,000 V.' IEC, 2003.
[10]. Donald G. Fink, H. Wayne Beaty(2008)..,Standard Handbook for Electrical Engineers, 11th Edition,McGraw-Hill, 1978, ISBN 0-07-020974-X, pages 14-153, 14-154
[11]. Grigsby,L. (2001). The Electric Power Engineering Handbook. USA: CRC Press. ISBN 0-8493-8578-4.
[12]. Bakshi, M (2007). Electrical Power Transmission and Distribution. Technical Publications. ISBN 978-81-8431-271-3.
[13]. Diesendorf, W. (2004). Insulation Coordination in High Voltage Power Systems. UK: Butterworth & Co. ISBN 0-408-70464-0. reprinted on Overvoltage and flashovers, A. C. Walker's Insulator Information website
[14]. "Insulators : National Insulator Association Home Page". www.nia.org. Retrieved 2017-12-12.
[15]. Bernhard,F & Bernhard,H .(2011). EMF Electrical Year Book. Electrical Trade Pub. Co. p. 822.
[16]. "Understanding IEC Appliance Insulation Classes: I, II and III". Fidus Power. 6 July 2018.\

Nzenwa, E. C "Analysis of Insulators for Distribution and Transmision Networks" American Journal of Engineering Research (AJER), vol. 8, no. 12, 2019, pp 138-145