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Outdoor High Voltage Non-Ceramic Insulators

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***Abstract*- Electrical insulation is a very important component in the electric power system such as substations and distribution and transmission lines. In depth knowledge on this subject is necessary for the electrical power field. This paper discusses selection and designing of high voltage polymeric insulators. Finite element method is adopted for this paper. Two dimensional 110kV polymeric insulators are modeled using ANSOFT. And also discusses the E-field distribution on polymeric insulators and corona ring which is used to reduce corona discharge on polymeric insulators due to E-field.**

***Index Terms*—Composite insulator, corona ring, SiR, E-field, Electric field, grading ring, FEM, Finite element method, Non-ceramic insulator (NCI), Polymer insulator.**

I. Introduction

Utilization of remotely located sustainable energy resources such as solar, wind and hydro calls for further developments of long-distance electric power transmissions operating at high voltage levels. It is also foreseen that insulation of such transmission systems is to be mainly based on polymeric materials [1] that can provide a number of technical benefits over the traditionally used glass and porcelain based insulation. Insulators are used to insulate the overhead line conductors from supporting poles and towers, and also must provide the necessary supports for the conductor against the worst likely mechanical loading condition. Insulators are divided into CI and NCI. Ceramic materials (CI) are made from organic material such as porcelain and glass. Non-ceramic insulators (NCI) are made up of inorganic materials. It has central core covered by the outer insulating coating, central core provides the mechanical support to the conductor, and protective coating is used to protect the central core from external agents. The fiber glass core affords protection against the environment through encapsulation in rubber housing. The metal end fittings are attached to the fiber glass rod to give the mechanical strength.

Early advantages of non-ceramic insulators claimed that they achieved up to 90% of weight reduction when compared to the ceramic equivalent, they also had a superior resistance to shock loads due to conductor or hardware failure on adjacent spans. Non ceramic insulators withstand vandalism. Significant portions of ceramic insulator failures are due to the vandalism involving shooting. When a bullet hits a ceramic unit, it breaks or shatters. Non ceramic insulators do not fail immediately when shot, because their components are not brittle. There are instances where non- ceramic insulators have remained in service without problems for many years after being shot.

II. Polymeric Insulator Component Terminology

The components associated in the polymeric insulator are relatively higher than conventional insulator. Following terms will give better information to analysis the insulator. This can be shown from Fig. 1 to Fig. 3.

1) *Fiberglass rod:* The fiberglass rod is the internal strength member of the polymer insulator. It must never be exposed. 2
2) *Polymer rubber:* The polymer insulators used by FPL have had material composed of silicone rubber, ethylene propylene rubber (EPR), or an "alloy" (EPR with silicone oils added). The sheds and sheath are made of polymer rubber. Test results and experience have shown that silicone rubbers generally perform much better than EPR in contamination. We use only silicone within 1 mile of saltwater bodies.
3) *Shed:* The sheds are the discs or skirts on the insulator. They may be flat, concave or cone shaped. Sometimes they are installed with alternating diameters. The shed function is to increase contamination performance of the insulator.
4) *Sheath:* The sheath is the covering for the rod. Its primary function is to keep water out of the rod and protect it from ultraviolet Radiation (UV).
5) *End fittings:* End fittings have the mechanical function of transferring mechanical load from the fiberglass rod to the structure, and the fiberglass rod to the conductor. They are generally galvanized steel, but sometimes aluminum is used.
6) *End fitting seal:* At the junction of end fitting at the polymer rubber there must be a tight seal to keep water out. In most insulators a silicone sealant is applied after the insulator is manufactured.
7) *Anchor:* The anchor is the metal part compressed onto the rod of a post insulator. The anchor is then bolted onto the base plate.
8) *Base plate:* Sometime just called the "base", the base plate attaches the line post insulator to the structure.
9) *Grading ring:* The purpose of grading rings is to reduce the electrical field stress at the end fittings. They are required at the line end of all 230kV suspension insulators and at both ends of all 500kV polymer suspension insulators. Grading

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rings are designed for each manufacturer insulators. They are not inter-changeable.

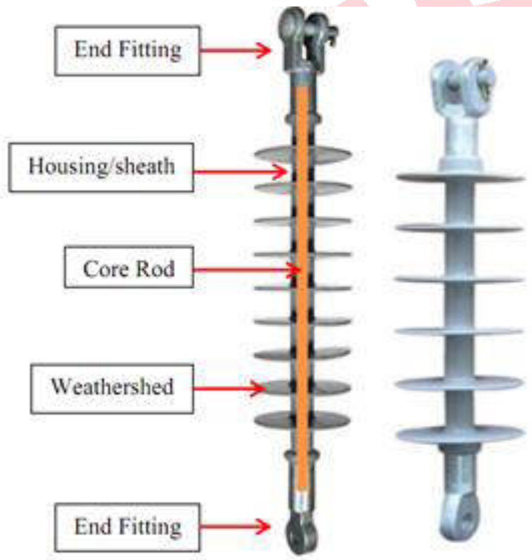

Fig. 1. Cross sectional view of Polymeric Insulators

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III. Design of Polymeric Insulators

The modeling of the insulator is the essential basic step for design procedure. Usually mathematical modeling gives us approximate values due to complexity of higher order equations and approximations are taken. Accurate modeling is achieved by using Finite element method. The design procedure for polymeric insulators is given below.

IV. Factors Considered for Design

The design procedures have its own imitations while designing for various voltages due to its dimensional factors. The height, the diameter of the insulators core and the number of units are important design factors.

A. Height of the insulators: The variations of the height of the insulators for the various voltage levels are tabulated and it indicates almost a linear relationship between the height and the voltage ratings.

B. Diameter of the insulators core: The variation of the diameter of the insulators core for the various voltage levels are tabulated and it indicates is almost constant for the entire voltage ranges.

TABLE I
Height and Diameter of the Insulators Core for Different Voltage Ratings [5]-[8]

S. No	Voltage ratings (kV)	Height of Insulators core (mm)	Diameter of Insulators core (mm)
1.	34.5	800	25
2.	110	1365	26
3.	220	1976	20
4.	500	3641	28
5.	765	4700	22

Fig. 2. Fiber rod and Metal end fittings

Fig. 3. Methods for producing the Polymer Fiber

C. Number of units in the insulator: Depending upon the voltage ratings, we can choose the number of units. It will increase the creepage distance. It also increases linearly with increasing voltages.

V. E-Field Distribution on Polymeric Insulators

The electric field distribution on transmission line composite non-ceramic insulators (NCI), affects both the long and short term performance. In order to design and apply composite insulators effectively, a fundamental understanding of the Electric field distribution and its effect on the insulator performance is needed. In general, the E-field magnitudes are

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more close to the energized and grounded ends of a composite insulator.

TABLE II
NO OF UNITS FOR DIFFERENT VOLTAGE RATINGS [4]

S. No	Voltage ratings (kV)	Number of units (mm)
1.	33	3-4
2.	66	5-7
3.	132	9-11
4.	230	14-20
5.	400	18-21
6.	750	30-35

For voltage levels below 345kV the grading rings are installed near the line end side alone but 345kV and above rings are installed at both the ends. It also reduces corona discharges as well as associated electromagnetic interference levels [2].

The electric field strength on composite insulators needed to be controlled for two reasons [3]:

1. To prevent significant discharge activity on the surface material of composite insulators under dry condition. This may result in the degradation of the polymer material.
2. To avoid internal discharge activity inside the fiberglass rod and the sheath rubber material that could result in mechanical and electrical failure.
   Fig. 5 is an example of corona discharge on Polymeric Outdoor Insulators.

There are three major regions to be considered while designing the insulators [3]

1. Within the fiberglass rod and polymer rubber weather-shed material, as well as at the interfaces between these materials and the metal end fitting.
2. On the surface and in the air surrounding the polymer weather-shed surface and surrounding the end-fitting seal.
3. On the surface of, and in the air surrounding the metallic end fittings and attached grading rings.

VI. NEED FOR CORONA RING

Corona rings are used to improve the performance of the insulator strings. They reduce corona discharges as well as associated audible noise level and radio and television interference levels. Corona rings do also improve the voltage distribution along the insulator string by reducing the percentage of the voltage on the unit nearest to the power transmission line. More importantly, they can eliminate the corona degradation. Fig. 4 shown is an example of corona ring for 230kV Polymeric Insulator.

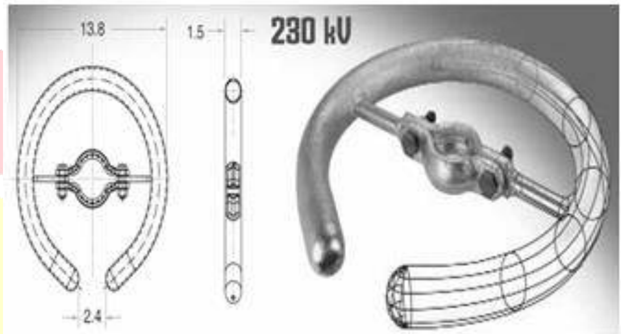

Fig. 4 Corona ring for 230kV Polymeric Insulator

Fig. 5. Corona discharge on Polymeric Outdoor Insulators

VII. POLYMERIC INSULATOR MODEL USING FEM

Polymeric Insulators are used to be modelled by using FEM. The 110kV,400kV and 500kV insulators are modelled with appropriate boundary conditions as shown in Fig. 6. The relative permittivity of FRP and SiR are taken as 5 and 3.7. The HV terminal with grading ring is energized with 63.5kV and the LV terminal at 0V. The electric field is computed using electrostatic 2D axis symmetry FEM field analysis. FEM is a numerical calculation technique for finding appropriate solution of partial differential equation as well as integral equations. The solution approaches based on eliminating the differential equation into an approximating system of ordinary differential equations which are numerically integrated using shed techniques such as Euler's method, Ring-kutta etc.

VII. SIMULATION RESULTS AND DISCUSSIONS

From the simulation results, the E-field distribution on polymeric insulator is high, nearest to the energized end and end fitting as shown in Fig. 7. After providing the corona ring,

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the value of E-field distribution along the 110kV polymeric insulator SiR sheath surface reduced to 2.5kV/cm (rms) which is measured at a radial distance of 0.5mm above the surface of the SiR sheath surface. This value is 50% lower than the maximum permissible limit of 4.5kV/cm (rms) [2].

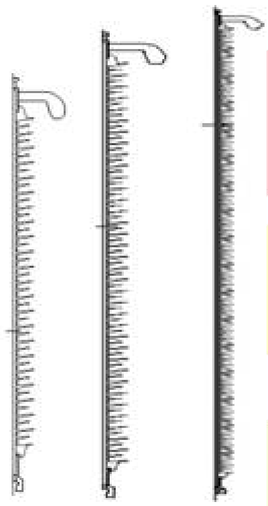

Fig.6 110kV, 420kV and 500kV polymeric insulator model with grading ring

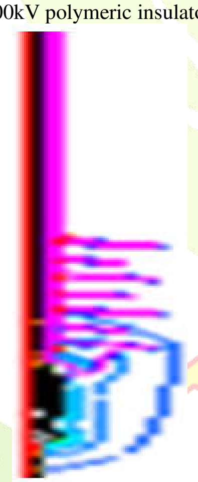

Fig. 7 E-field distribution on Polymeric Insulators

VIII. CONCLUSION

The design of polymeric insulators is considered three factors which are the height, the diameter of the insulators core and the number of units. The height and no of units of insulators are linearly varied with voltage ratings. The diameter of polymeric insulators is almost constant with variable voltage ratings. Two dimensional 110kV polymeric insulators are modelled using FEM which is useful to determine the E-field distribution on the polymeric insulators. The E-field distribution on the polymeric insulators is large closer to the high voltage end and metal end fitting. By using corona ring, the E-field distribution along SiR sheath surface of insulator is reduced below the 4.5kV/cm (rms).

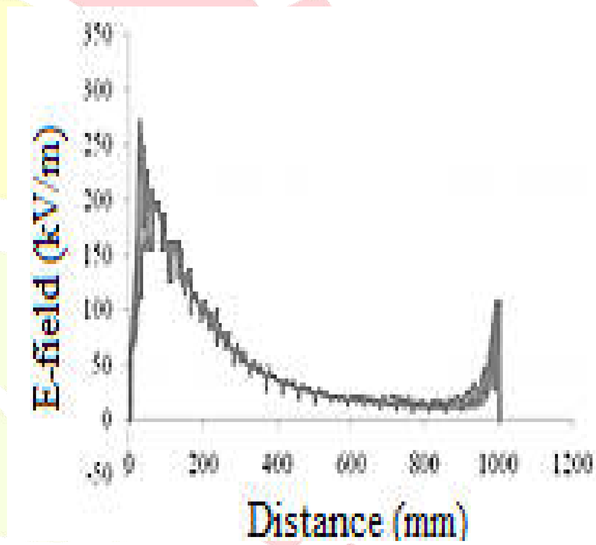

Fig. 8 E-field distribution inside SiR surface of 110kVPolymeric Insulators

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