Tomsk Polytechnic University

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**Development of Composite Insulators for Overhead Lines**

Made by

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**1. INTRODUCTION**

Overhead power transmission lines require both cables to conduct the electricity and insulators to isolate the cables from the steel towers by which they are supported. The insulators have conventionally been made of ceramics or glass. These materials have outstanding insulating properties and weather resistance, but have the disadvantages of being heavy, easily fractured, and subject to degradation of their withstand voltage properties when polluted. There was therefore a desire to develop insulators of a new structure using new materials that would overcome

these drawbacks.

The 1930s and '40s saw the appearance of the first insulators to replace inorganic materials with organic, but these suffered problems of weather resistance, and their characteristics were unsatisfactory for outdoor use. In the 1950s epoxy resin insulators were developed, but they were heavy, suffered from UV degradation and tracking, and were never put into actual service. By the mid-1970s a number of new insulating materials had been developed, and the concept of a composite structure was advanced, with an insulator housing made of ethylene propylene rubber (EPR), ethylene propylene diene methylene (EPDM) linkage, polytetrofluoro ethylene (PTFE), silicone rubber (SR) or the like, and a core of fiber-reinforced plastic (FRP) to bear the tensile load.

Since these materials were new, however, there were many technical difficulties that had to be remedied, such as adhesion between materials and penetration of moisture, and the end-fittings, which transmit the load, had to be improved. Since the 1980s, greater use has been made of silicone rubber due to its weather resistance, which is virtually permanent, and its hydrophobic properties, which allow improvement in the maximum withstand voltage of pollution, and this had led to an explosive increase in the use of composite insulators.

In 1980, Furukawa Electric was engaged in the development of inter-phase spacers to prevent galloping in power transmission lines, and at that time developed composite insulators that had the required light weight and flexibility. In 1991 the first composite insulators having a silicone rubber housing were used as inter-phase spacers for 66-kV duty, and in 1994 their use was extended to 275-kV service with a unit 7 m in length--the world's largest.

Thus as composite insulators have established a track record in phase spacer applications and their advantages have been recognized, greater consideration has been given to using them as suspension insulators with a view to cutting transportation costs, simplifying construction work and reducing the cost of insulators in order to lower the costs of laying and maintaining power transmission lines.

Recently Furukawa Electric developed composite insulators for suspension and delivered, for the first time in Japan, 154-kV tension insulators and V-type suspension insulator strings. Subsequently they were also used on a trial basis as tension-suspension devices in 77-kV applications. Work is also under way on the development of composite insulators for 1500-V DC and 30-kV AC railway service.

**2. DESIGN OF COMPOSITE INSULATORS**

**2.1 Structure of Composite Insulators**

*Figure 1. Structure of composite insulator.*

Typically a composite insulator comprises a core material, end-fitting, and a rubber insulating housing. The core is of FRP to distribute the tensile load. The reinforcing fibers used in FRP are glass (E or ECR) and epoxy resin is used for the matrix. The portions of the end-fitting that transmit tension to the cable and towers are of forged steel, malleable cast iron, aluminum, etc. The rubber housing provides electrical insulation and protects the FRP from the elements. For this reason we at Furukawa Electric have adopted silicone rubber, which has superior electrical characteristics and weather resistance, for use in the housing. Figure 1 shows the structure of a composite insulator.

**2.2 Designing Composite Insulators**

An important feature of the composite insulators developed here is that the design of the shed configuration is extremely free, owing to the use of silicone rubber for the housing. Based on past experience, IEC 60815 "Guide for the selection of insulators in respect of polluted conditions" was adopted. Electrical and mechanical characteristics were designed to satisfy the requirements set forth in IEC 61109 "Composite insulators for a.c. overhead lines with a nominal voltage greater than 1000 V: Definitions, test methods and acceptance criteria".

With regard to pollution design, it has been suggested that because of the hydrophobic properties of silicone rubber, composite insulators can be designed more compactly than in the past, but because of the absence of adequate data it was decided in principle to provide as great or greater surface leakage distances. The design value for leakage distance was referenced to the value per unit electrical stress as determined in IEC 60815, adjusted upward or downward according to customer requirements.

Tensile breakdown strength was determined by applying a safety factor to the long-term degradation in tensile breakdown strength.

The rubber and FRP of the housing were required not only to have sufficient mechanical adhesion but to be chemically bonded, so as to prevent penetration of water at the interface. And because in general a large number of interfaces may result in electrical weak points, Furukawa Electric has adopted a composite insulator design in which the sheds and the shank are molded as a unit, resulting in higher reliability.

The end-fittings comprise three elements, and have the greatest effect on insulator reliability. Specifically the penetration of moisture at this point raises the danger of brittle fracturing of the FRP and the electrical field becomes stronger. For this reason the hardware is of field relaxing structure and the silicone rubber of the housing is extended to the end-fitting to form a hermetic seal. The end-fitting is connected to the FRP core by a compression method that maintains long-term mechanical characteristics.

The design requirements for composite insulators for 154-kV service are set forth below.

• Overall performance

(1) To have satisfactory electrical characteristics in outdoor use, and to be free of degradation and cracking of the housing.

(2) To be free of the penetration of moisture into the interfaces of the end-fitting during long-term outdoor use.

(3) To possess long-term tensile withstand load characteristics.

(4) To be free of voids and other defects in the core material.

(5) To be non-igniting and non-flammable when exposed to flame for short periods.

• Electrical performance (insulator alone)

(1) To have a power-frequency wet withstand voltage of 365 kV or greater.

(2) To have a lightning impulse withstand voltage of 830 kV or greater.

(3) To have a switching impulse withstand voltage of 625 kV or greater.

(4) To have a withstand voltage of 161 kV or greater when polluted with an equivalent salt deposition density of 0.03 mg/cm2.

(5) To have satisfactory arc withstand characteristics when exposed to a 25kA short-circuit current arc for 0.34 sec.

(6) Not to produce a corona discharge when dry and under service voltage, and not to generate harmful noise (insulator string).

• Mechanical performance (insulator alone)

(1) To have a tensile breakdown load of 120 kN or greater.

(2) To have a bending breakdown stress of 294 MPa or greater.

(3) To show no abnormality at any point after being subjected to a compressive load equivalent to a bending moment of 117 N**.**m for 1 min.

(4) To show no insulator abnormality with respect to torsional force producing a twist in the cable of 180°.

(5) To be for practical purposes free of harmful defects with respect to repetitive strain caused by oscillation of the cable.

Table 1 shows the characteristics of an insulator

designed to satisfy these specifications.

**3. PREDICTING SERVICE LIFE**

The service life of a composite insulator involves both electrical and mechanical aspects. Electrical aging involves damage from erosion or tracking due to the thermal or chemical effects of discharge occurring when the insulation material is polluted or wet, and may even result in flashover.

Mechanical aging includes long-term drop in the strength of the core material or in the holding force of the end-fittings, as well as brittle fractures of the core material, and can on occasion result in breakage of the insulator string. A drop in core strength or holding force of end-fitting can be countered by adopting an appropriate safety factor and using a reliable method of compression.

Brittle fractures, on the other hand, occur mostly near the interface between the insulation material and the end-fitting, and provided this area has been properly manufactured, the probability of their occurrence will be lower than that of electrical aging. To estimate service life from the electrical aspect, actual-scale composite insulators were exposed to electrical stress, and were subjected to an exposure test under a natural environment. A test chamber simulating environmental stress was also constructed, and accelerated tests were carried out according to international standards (IEC 61109 Annex C). Further, by comparing leakage current waveform and cumulative charge, which may be characterized as electrical aging, evaluation of composite insulator service life was carried out. Furthermore, since in Japan, a drop in insulation performance due to rapid pollution during typhoons is a familiar henomenon, an investigation was made based on the characteristics of leakage current obtained during a typhoon into the effect of rapid pollution on electrical aging in composite insulators.

**4. CONCLUSION**

Composite insulators are light in weight and have demonstrated outstanding levels of pollution withstand voltage characteristics and impact resistance, and have been widely used as inter-phase spacers to prevent galloping.

They have as yet, however, been infrequently used as suspension insulators. The composite insulators for suspension use that were developed in this work have been proven, in a series of performance tests, to be free of problems with regard to commercial service, and in 1997 were adopted for the first time in Japan for use as V-suspension and insulators for a 154-kV transmission line. To investigate long-term degradation due to the use of organic insulation material, outdoor loading exposure tests and indoor accelerated aging tests are continuing, and based on the additional results that will become available, work will continue to improve characteristics and rationalize production processes in an effort to reduce costs and improve reliability.

**5. WORLD LIST**

Conventionally

Outstanding

The Disadvantages

Fractured

To Degradation

Withstand

Polluted

a desire

overcome

drawbacks

appearance

suffered

outdoor

epoxy

tracking

concept

ethylene propylene rubber

ethylene propylene diene methylene

polytetrofluoro ethylene

silicone rubber

a core of fiber-reinforced plastic

to bear the tensile load

remedied

adhesion

penetration of moisture

the end-fittings

silicone rubber

permanent

hydrophobic

engaged

inter-phase spacers

galloping

housing

established

track record

consideration

transportation costs

delivered

Subsequently

trial basis

AC railway service

reinforcing fibers

forged steel

malleable cast iron

adopted

shed

extremely free

acceptance criteria

absence of adequate data

leakage distance

electrical stress

upward(downward)

adhesion

chemically bonded

penetration

electrical weak points

shank

molded

brittle fracturing

raises

hardware

hermetic seal

forth below

Overall performance

Voids

To possess long-term tensile

non-igniting

satisfactory arc

dry

harmful

compressive load

torsional force

leakage

predicting

Involves

Erosion

Occurring

Wet

Flashover

holding force

occasion

electrical aging

To estimate

actual-scale

exposure

environment

chamber simulating

Further

cumulative charge

evaluation

typhoons

familiar henomenon

investigation

obtained

proven

regard

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