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Characterization of charge distribution on the high voltage glass insulator string

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ABSTRACT

Irregularity in charge distribution of an insulator may lead to accelerated aging and electrical breakdown. However, knowledge of charge distribution on the insulation surface is still insufficient albeit has gained worldwide attention. The insufficiency is particularly on the charge profile along the string insulator under AC excitation. Therefore, charges distributions on the surfaces of glass insulators without installed grading ring are investigated in this paper. Simulation and experimental results were found in good agreement when studying the charge distribution pattern along glass insulator string where the polarity of charge swinging occurs at the center of suspension string insulator of I-type.

1. Introduction

The reliability of a transmission network is partly dependent on the performance of insulators available in the electric power transmission system. These insulator strings provide insulation (and mechanical support) between the transmission line and the poles/tower that are often exposed to the atmosphere. Therefore, the performance of insulators strings is strongly affected by environment conditions in which it is exposed, shape and the material properties of the insulator [1].

Materials used in high voltage insulation are usually made of organic and inorganic [2]. Inorganic materials are widely used particularly in glass and porcelain insulators, while the organic materials used in insulating polymers. Glass and porcelain insulators are the earliest insulators used in power system transmission lines. Glass and porcelain insulators offer many advantages such as very high mechanical strength under pressure and hardness, thus capable to operate under adverse conditions also suitable for environments with dust, salt and high moisture, or for combination of all aforementioned. Due to these advantages, inorganic insulators especially glass are still used even today around the world, including Malaysia, as shown in Fig. 1. Meanwhile, organic insulators use polymers instead of porcelain as weather sheds and built with mechanical load-bearing fiberglass rods.

The insulator strings are designed to minimize the buildup of electrical charges around the insulator surfaces because charge buildup causes current leakages, arcs and flashovers that can accelerate insulation breakdown. Studies have shown that the leakage current (LC) around string insulators can provide information about the insulators surface condition and indeed a promising technique to study the performance of the insulator [3,4]. Thus charge distribution on the insulator surfaces has received considerable attention for decades. It is now accepted fact that breakdown of the insulator is correlated with the presence of space charges [5,6]. Where significant positive charge propagation was observed in [5] immediately before breakdown while in [6] breakdown process was initiated by space charge nature at the interfaces of LDPE.

It is established that the flow of LC is definitely due to the flow of charges [7]. All insulators that are made of the same shape and materials that operates in same normal conditions are expected to contain equal number of positive and negative charges; no net charge. However, these charges become imbalanced in the presence of space charge and leads to the formation of static electricity effects. When these electrical effects move from one surface onto another, electrostatic discharges (ESD) occurs. The formation of electrostatic field on the surface of insulators will create electrical pathways that may allow relatively under-rated

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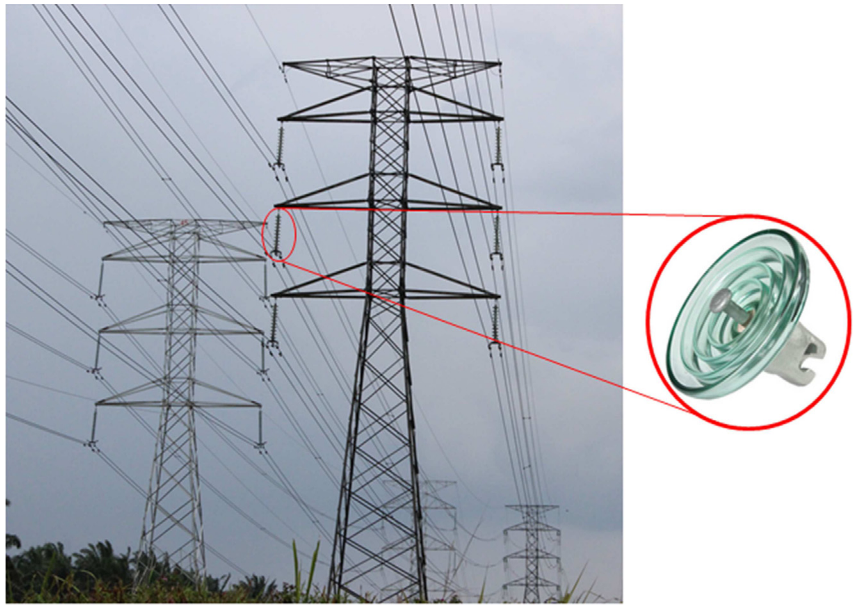

Fig. 1. Glass Insulator used in transmission line at Skudai, Malaysia (April 2014).

voltages to flow across the insulator surface and eventually lead to breakdown [8].

To the best of authors' knowledge, space charge measurement has become a common tool to investigate the internal behavior of solid insulating material under high electric field. Many methods, either direct or indirect, have been developed for investigating space charge distribution in solid dielectrics and are explained deeply in Ref. [9]. However, the most popular methods that have been used widely are pressure wave propagation and pulsed electro-acoustic methods that are described thoroughly in Ref. [10]. Though a lot of studies have been done on the accumulation of space charge inside the polymeric insulation material [11] as well as in insulator surfaces [12,13], the exploration of space charge in glass as insulating material is still limited despite the apparent possibility space charge accumulation on the surface of the material [14]. Therefore, in this paper, the charge distribution on the glass insulator surfaces was investigated both for simulation and experimental-based studies. A string of four cap-and-pin glass insulator without installed grading ring, is taken as main research object. In the simulation study, the voltage and electric field distributions that are indeed closely linked to charge distribution were simulated using available commercial software namely QuickField™ Professional. Meanwhile, an attempt to capture charge distribution on glass insulators surface by using stainless steel mesh is also introduced in this paper. This study is expected to present and compare both the simulation and experimental study of the effect of charge distribution on glass insulator surface.

2. Simulation parameters

A string of four cap-and-pin suspension glass insulator particularly U100BL [15] type is selected in this study. Technical parameters of the modeled insulator is shown in Fig. 2 where five different regions are depicted as cap (G_1), cement between cap and glass (G_2), glass (G_3), cement between glass and pin (G_4), and insulator pin (G_5). The shed diameter, D is 255 mm; while the insulator height, H is 146 mm. The nominal creepage distance of each insulator is 320 mm.

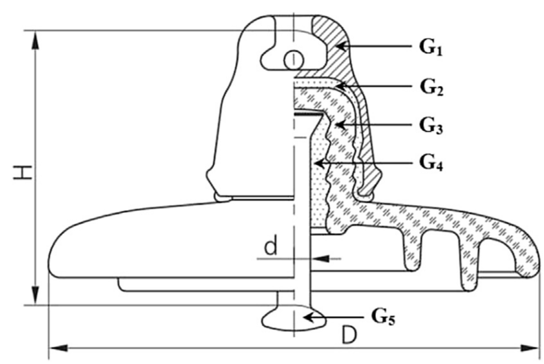

Fig. 2. Schematic of the U100BL insulator model adopted for study [15].

The simulation is modeled in free space, indeed according to the size of chamber (50 cm × 50 cm × 75 cm) used in the experiment. AC stress of 33 kV is applied to the pin at the bottom of string insulator while top insulator cap is grounded. The actual profile data of the insulator in Table 1 is transferred manually to the computer for simulation purpose. Considering that the insulator has a symmetrical shape, this simulation works was performed in an axisymmetric 2D model class. In this class, cross-section of the insulator that shown in Fig. 2 is adequate to represent the 3D modeling model in QuickField™ professional software [16]. It is worth noting that the supporting structures, conductors and other accessories are to be neglected in this study.

Table 1
Material properties [17,18].

Types of material	Relative electric permittivity, ε_r
Glass (G_3)	4.2
Cement grout (G_2 and G_4)	15
Cast iron (G_1 and G_5)	1000
Air	1