Electric Power Systems Research 144 (2017) 72–80

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Calculation of electric field and partial discharge activity reduction for covered conductor/high voltage insulator systems

Mohamed E. Ibrahim*, Amr M. Abd-Elhady

High Voltage and Dielectric Materials Lab., Electrical Engineering Department, Faculty of Engineering, Menoufia University, Shebin El_Kom 32511, Egypt

ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form 12 October 2016
Accepted 20 November 2016
Available online 28 November 2016

Keywords:
Covered conductor (CC)
Electric field calculation
High voltage insulator
Partial discharge

ABSTRACT

In this paper, a proposed covered conductor (CC) sheath design is presented. The proposed design is theoretically evaluated based on calculations of electric field strength at different regions using finite element analysis. These calculations are carried out considering the conventional as well as the proposed CC designs. The evaluation is done concerning two different insulator types such as porcelain and polyethylene insulators. The proposed design aims at reducing the electric field strength at sheath/high voltage insulator interface as well as at the dry bands formed over the wet polluted or ice covered insulator. Therefore, activity reduction in partial discharge at the sheath surface and dry band arcing over the high voltage insulator surface can be achieved. The proposed design is experimentally evaluated based on partial discharge inception voltage (PDIV) measurements considering dry and polluted conditions. Also, the experimental evaluation is carried out considering leakage current measurements under wet polluted condition. The obtained results either theoretical or experimental give an evidence for an efficient proposed design in electric field, partial discharge, and dry band arcing reduction for CC/insulator system.

1. Introduction

In fact, covered conductors find a great spread in medium voltage distribution systems in Europe, Japan, Ghana, Australia, North and South America, and in a lot of countries [1]. The reason behind this spread is the increased reliability of these conductor types as compared to bare wire [1–3] especially in forested countries as it reduces the accidental contact problem resulting from leaning trees [4]. Regarding research works in Refs. [5–9], field experiences around the world are introduced considering the different types of overhead lines that use insulated conductors. These types can be classified to spacer cable, covered conductor/high voltage insulator, and aerial bundled cable systems [10]. In fact, the present study is focused on the second type that is used in medium voltage distribution systems.

For 33 kV distribution systems, a single sheathed XLPE covered conductor is commonly used. The sheath thickness of these conductors can reach 3.63 mm according to the standard PrEN 50397-1 which published by the European standards organization CENELEC [11]. In a lot of countries such as Ghana, Australia, and others, this covered conductor is fixed in a tower through a pin type high voltage insulator as shown in Fig. 1. This insulator is widely made of porcelain. Due to the large difference in dielectric constants of the covered conductor sheath and the insulator material, sharp points (points with excessive electric field intensities) appear at sheath/insulator interface [1,12]. These sharp points can lead to partial discharges at the conductor surface, even if the insulator surface is dry, which can result in surface tracking of conductor insulation [12,13], see Fig. 2. Accordingly, partial discharge (PD) is measured for covered conductor/high voltage insulator system for porcelain and glass insulators [13]. It is found that an increase by 20% in PD is obtained with porcelain insulators. This comes due to the higher permittivity of porcelain as compared to glass that results in a higher difference in permittivities between insulator and the insulation of covered conductor.

Therefore, polymeric insulators, especially high density polyethylene based compound, are suggested as it has a dielectric constant of a value close to the covered conductor sheath [1]. This close value of insulator permittivity results in a decrease in sharp points in electric field. But, this is only achieved in dry conditions. So that, studying its performance in wet polluted conditions is presented in this paper. Also, it is well known that the lifetime of high voltage polymeric insulators is much lower than porcelain high voltage insulators as the polymeric insulators suffer from aging

* Corresponding author.
E-mail address: en.ezzat@yahoo.com (M.E. Ibrahim).

http://dx.doi.org/10.1016/j.epsr.2016.11.015
0378-7796/

Fig. 1. Covered conductor with pin type porcelain insulator [17].

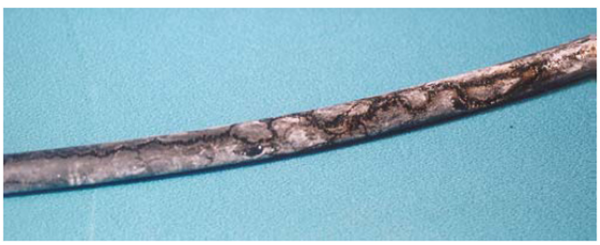


Fig. 2. Surface tracked covered conductor [12].

[14–16]. In addition to the lower mechanical stresses withstand of polymeric insulators as compared to porcelain ones. In the case of wet polluted or ice covered insulators, polymeric insulators cannot solve the PD problem as sharp points can appear near the conductor surface as well as in the dry bands over the insulator surface. Therefore, the solution of this problem is introduced based on suggesting a design for covered conductor sheath.

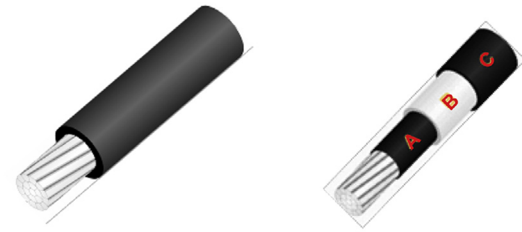
In this paper, a proposed sheath design for CC is presented. The proposed design is theoretically and experimentally evaluated. The theoretical evaluation is carried out based on electric field calculations using finite element analysis. This evaluation is done for the conventional as well as the proposed CC designs considering the insulator material types, porcelain and polyethylene, as well as dry and wet polluted conditions. The experimental evaluation is carried out for the conventional and proposed CC designs based on PDIV measurements at dry and wet polluted conditions. Also, the experimental evaluation is extended by measuring leakage current under wet polluted condition for CC/insulator system. The proposed design contributes in activity reduction of partial discharge and dry band arcing for CC/insulator system. Therefore, a better life time is expected with the proposed design as compared to the traditional one.

2. The proposed covered conductor sheath design

In this section, the conventional medium voltage covered conductor as well as the proposed sheath design are presented as follows:

2.1. Conventional medium voltage covered conductor design

Covered conductors can have one, two or three sheath layers at medium voltage. Fig. 3a and b shows two examples of single and multiple sheathed covered conductors. The single sheathed covered conductor uses cross linked polyethylene (XLPE) or high density polyethylene (HDPE) as an insulating material [1,12] whilst the three sheathed CC basically consists of a semi-conducting layer (A) close to the metal conductor to reduce the sharp points in electric field strength, an insulating polyethylene layer (B), and a



(a) Single Sheathed CC (b) Multiple Sheathed CC

Fig. 3. Single and multiple sheathed medium voltage covered conductors [1].

hard abrasion-resistant outside layer (C). The major advantage of using multiple sheathed CC design is to reduce the electric field at the interface between metallic conductor and its insulating sheath especially when the CC is in contact with another object such as tree or cross arm. This comes due to an increase in the effective radius of conductor strands that provides a lower electric field stress over the insulating sheath. Therefore, this design can lead to an enhanced life time. Also, the multiple layer design has higher impulse strength as compared to the single sheath one [1]. In despite of the advantages of the present design of multiple sheathes, the use of this present design suffers from sharp points in electric field at the interface with its holding insulator. Also, an increase in the electric field is obtained in the dry bands in the case of ice covered or wetted insulator. These high values in electric field either at the interface or in dry bands can cause damage in CC insulation as well as tracking in the holding insulator surface. Therefore, a modification in the multiple layer, three layer, design is suggested to improve its performance either in dry or wet conditions as will be illustrated in the next subsection.

2.2. Proposed medium voltage covered conductor design

In this paper, the same sheath configuration of a multiple sheathed covered conductor in Fig. 3b is used. Only, small amount of carbon black, about 0.5%, is added to the material of the outer layer (layer C). This addition results in a slight increase in layer conductivity and dielectric constant. The reason behind this addition is to provide a grading during the transition from the outer layer to high voltage insulator material. This grading is expected to reduce the electric field strength at the sharp points at the sheath/insulator interface. Therefore, a reduction in partial discharge and of course surface tracking can be achieved. For more illustration, consider a section of a covered conductor is placed over the surface of a porcelain specimen of 10^{-11} s/m conductivity, and a relative permittivity of 5.9. The covered conductor uses an aluminium stranded conductor that is energized by 5 kV at 50 Hz. A low voltage electrode, connected to ground, is attached at a distance of 5 cm from the contact point between the CC and the porcelain insulator along it surface. A continuous ice film of 1 µs/m conductivity, 0.01 cm thickness, and a relative permittivity of 10 is considered to be formed over the specimen surface as illustrated in Fig. 4.

In fact, two cases for the CC are considered as shown in Fig. 4a and b. The first case uses the conventional three sheath design. Hence, layer A has 10^{-10} s/m conductivity and a relative permittivity of 4. Layer B has a conductivity of 10^{-12} s/m and a permittivity of 2.3. Layer C is considered to have the same properties of layer B. However, the second case uses the same material properties of the first case except the layer C that has 10^{-10} s/m conductivity and a relative permittivity of 4.

The second case, proposed design, is expected to have a lower electric field intensity at the interface between the CC surface and the insulator. This comes as with the proposed design, the CC surface may be assumed to have the same voltage of the ice film