On Electric Fields in Belted Cables and 3-Phase Gas Insulated Cables

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Abstract—**The electric field distribution in Belted Cables and 3-phase gas insulated cables (GIC) enclosed in a common ground enclosure is analyzed and presented in this paper. The electric fields in this type of GIC are analogous to those of 3-phase belted cables. Unlike 3-phase screened cables, the stress distribution in belted cables is not radial. With time varying voltages (power frequency voltage variations; quasi-static voltages) the stress distribution in the cable insulation changes, not being radial. The electric stress distribution is expected to show systematic, revolving effect. This revolving effect is important as the location of maximum stresses keep on shifting. Also, as a secondary effect, the revolving e-field results into electric-field-winds which can add to the particle movements in the gas insulated cables. The literature acknowledges that particle movements in the gas insulated system can have deleterious effect on the over all system insulation strength; which partly get impetus from e-field-winds. The stresses in such a cable are analyzed using open source software Finite Element Method Magnetics (FEMM). The results presented show that the field distribution over a cycle (of 50 Hz) at discrete time intervals are thought to be having a great educational value, giving a feel of electric field variation in (i) belted cables and (ii) GIC with common enclosure. The computed results of electric stress and potential distribution using FEMM are compared with available results based on CSM models to validate the present results where ever possible.**

Keywords-Belted Cable, Electric Stress, FEM, GIC, Revolving eletric field;

I. INTRODUCTION

The upgrading of the voltage and current ratings of power cables in the light of the public request to limit overhead transmission lines (due to their environmental effects) particularly in suburban and urban areas necessitates a continuous improvement of power cables. [1]

Knowledge of the electric field in three-core cables is of great importance for the proper design and the safe operation of power cables. For the optimization of the insulation design both for three-core belted power cables and for three phase enclosed compressed gas insulated cables (CGIC), it is fundamental to know the location and the magnitude of the maximum field stress as a function of the cable dimensional parameter. [2, 3].

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A serious difficulty that occurs with belted cables is due to the electric field distribution throughout the insulation. The [Type text]

electric field is no longer radial to the conductor as in the case of single-core cables. The calculation of the electric field requires the solution of the Laplace's equation, which must satisfy the cable boundary conditions. This can be done either by analytical or numerical methods [4, 5]. However, for a more complicated system such as insulated three-phase cylindrical conductors surrounded by a metallic sheath which is held at a ground zero potential (three-core cable) the finite elements or the charge simulation techniques are often used to calculate the electric field between the conductors and the grounded cylindrical sheath [2].

In the present work an open source finite element analysis software package for solving electromagnetic problem, (Finite Element Method Magnetics; FEMM) [6] is used to calculate the electric field in a three-core belted cable surrounded by a grounded sheath and gas insulated cable with common enclosure. The results are compared with those of Charge Simulation Method (CSM) of field computation, available in the literature. This not only compares the two methods, namely CSM and FEM, but also validates the FEM model. Through these simulation efforts, a re-look at the stress in the belted cable and parameters influencing is attempted. This Finite Element Method (FEM) model is further used to compute the electric field distribution over a cycle (of 50 Hz) at discrete time intervals showing systematic, revolving effect. These results are thought to be having a great educational value, giving a feel of electric field variation in 3-phase cables of the kind being discussed.

II. ELETRIC STRESS IN BELTED CABLES

The electric stresses in belted 3-core cables are not radial. Understanding of the stress distribution in such cables is of importance and quite a few attempts to model the field distribution can be seen in the literature [7-12]. Earlier attempts were to determine the stress distribution by experimental or by analytical means. The results of experimental method have more errors. On the contrary, analytical solutions are not always possible and hence involve approximation. There are quite a few attempts to model these cables using Charge

Simulation Method (CSM). For close boundary problems, FEM is more suited than CSM and hence it is used as the tool to model and understand the stress distribution.

A. Modeling details

The typical 3-core cable cross-section is as shown in the figure 1. The electric stress distribution in the core-insulation, belt-insulation and filler-insulation are of importance. The magnitude of electric stress depends on the cable dimensional and material parameters. The dimensional parameters of importance are b (= belt thickness), d (diameter of the core), r (radius of the conductor or core = d/2), R (radius of the cable; inner radius of the metallic sheath) and T (insulation thickness). With symmetrical arrangement of the cores there will be a definite distance between the centers of the conductor to the center of the cable, termed L. This term is given by following equation:

$L = (2T + d)/\sqrt{3}$.

These dimensional parameters are interrelated by the equation given below:

$R = L + (d/2) + T + b$.

The material parameter of importance is the relative permittivity of the insulating materials. The numeric value of this in the present study is assumed to be 3.5 (similar for belt, filler and core insulation; although their dielectric strength would be different, depending the type of the material). With 3-phase ac supply (power frequency), the potential of the cores (A,B and C) are assumed to be

$V_A = \sin(\omega t)$

$V_B = \sin(\omega t + 120°)$

$V_C = \sin(\omega t + 240°)$

with peak value of sinusoidal wave as unity; ω being angular velocity.

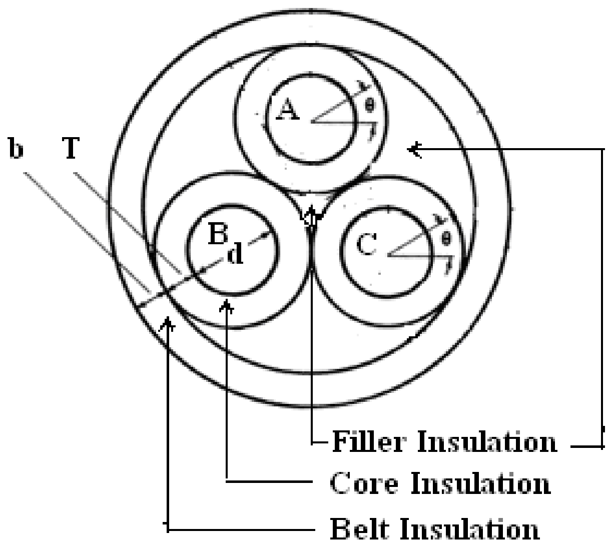


Figure 1. Schematic of three core cable.

B. Stresses at the core surface

Simulations are carried out using FEMM [4]. The variation of electric stresses at the core surfaces of the three conductors is as shown in figure 2.

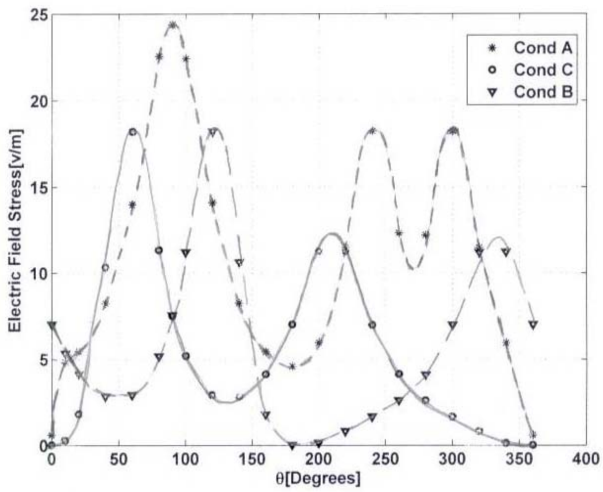


Figure 2. Resultant electric stress around conductors of cores A, B and C for `T/d' = 0.05 at ωt=90º.

For each conductor, angle Θ is measured from its centre in counterclockwise direction. These typical results correspond to ωt=90º for a T/d of 0.05, with d as unity (per unit). At this time instant the potential of core A will be 1 p.u., being at the positive crest of the 50 Hz cycle. The computed stress magnitudes given in figure 2 are in V/m, normalized with respect to peak voltage. Practical T/d values for the cables will be in the range of 0.05 to 1.5 [2,8].

The trend shown in figure 2 match with those of results published elsewhere using CSM as the simulation technique [8]. With the FEM model a number of numerical experiments have been carried out to understand the effect of various dimensional parameters (and also with respect to time over a cycle).

The maximum stress in the cable occurs at the conductor surfaces. This location of maximum stress occurs at a point in the core insulation (i) along the line joining the cable center and core center for that core which is at its peak potential, either being towards the belt or towards the cable center (ii) along the line joining the centers of the two cores with third core potential being zero at that instant. But one of these situations (specific one) will prevail depend on the magnitudes of rations T/d and T/b. The interesting observation is that the cable center will not experience the maximum stress and as expected will be of constant magnitude. The stresses in the cable insulations go highly no uniform as the ratio of T/d decreases. Analogous to single core cable (1-phase or one core of 3-phase screened cables) which has maximum stress in the cable which is minimum at a fixed ratio of R/r (=e; for a fixed over dimension R of the cable), an optimal range of T/d has been identified for 3-phase belted cables at which the maximum stress in the cable is minimum.

III. Belted Cables Versus GIC

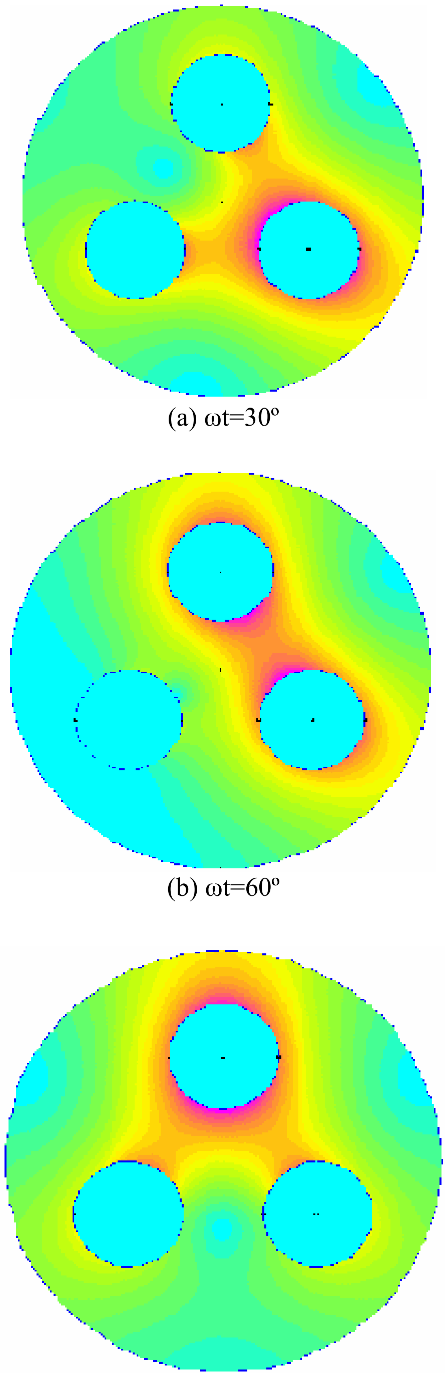
Gas Insulated Cables have inherent advantages are becoming popular, although they are more expensive [13-14]. GICs with common enclosure with symmetrical spatial disposition of three cores are similar to the belted cables with two major differences. They are (i) GICs use gaseous insulation (ii) The outer metallic enclosure will be equivalent to the metallic screening outside the belt insulation present in the belted cables (with no equivalent of belt in the GICs). Hence above simulation results are applicable to the GICs with all 3-phases housed in a common enclosure. The dielectric constant of the insulating material will be unity (relative), in case of GICs.

GICs have a problem of floating metallic particles (as impurities), which can drastically reduced the overall strength of the insulation [13]. The problem of floating impurities (dust/ metallic particles) is aggravated in the case of GIC's with common three phase enclosures due to the rotating magnetic fields and the associate electric winds.

The typical electric stress distribution at three different time intervals namely (i) at ωt=30º (ii) at ωt=60º and at (iii) ωt=90º are as given figure 3. These three successive computations show how the maximums stress at core C has shifted to core A. By series of computed results of electric stress distribution at successive interval of ωt (at 10º interval), the effect of changing electric field resulting into rotating electric field will be presented/demonstrated. Although this aspect is not new is worth a demonstration, which is specific to the belted cables and GICs (with common ground enclosure).

IV. Conclusions

The belted 3-phase cable has been modeled using the FEMM freeware and some of the key parameters of the belted cables on the stress distribution have been re-looked at. The commonality between 3-phase cable and the GICs with common ground enclosure have been discussed with special reference to the rotating electric fields.



(a) ωt=30º

(b) ωt=60º

(c) ωt=90º

Figure 3. Typical electric stress distributions in the 3- core cable at three different time interval on a power frequency cycle.

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