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Numerical Analysis of High Temperature Low Sag Conductor for publications of IEI

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Abstract – The conductors that can embrace high temperature low sag characteristics are known as HTLS conductors. The coefficient of thermal expansion of High temperature low sag conductor is lesser than that of conventional conductors. This thereby results in reduced sag with a high rating. Among some HTLS conductor accessible, the Aluminium Conductor Composite Core (ACCC) conductor has a lightweight inner composite core. The geometric model of the ACCC/TW conductor is modeled and analyzed using finite element analysis. The ACC/TW conductor is composed of an inner composite core surrounded by two aluminium layers wound in a clockwise and anti-clockwise direction. The inner composite core is made of glass carbon composite material. The core is surrounded by the first layer consisting of 8 individual strands wound in a clockwise direction. The second layer consists of 14 individual aluminium strands wound in an anticlockwise direction. In this paper, the individual core and assembled conductor are analyzed using FEA software to predict the behavior under loading conditions. The attained outcomes are validated with the experimental work reported in the literature.

Keywords – Numerical analysis; ACCC/TW conductor; friction; cable mechanics; wire rope.

Introduction

High temperature low sag (HTLS) conductors are used in a variety of engineering applications for their high strength and very efficient use of the material. The thermal rating in HTLS conductors is improved with a low sag effect comparatively with the existing conductor [1] [2]. The HTLS conductors that are commercially available are Aluminium Conductor, Steel Supported (ACSS), Gap Type Ultra Thermal Resistant Aluminium Alloy Conductor, Steel Reinforced (G(Z)TACSR), Thermal (High Strength) (Ultra) Resistant Aluminium Alloy Conductor, Steel Reinforced (T(K)(Z)ACSR), Extra (Ultra) Thermal Resistant Aluminium Alloy Conductor, Invar Reinforced (X(Z)TACIR), Aluminium Conductor Composite Reinforced (ACCR) and Aluminium Conductor Composite Core (ACCC) [3]. Conventional conductors, such as the ACSR conductor, usually work, 90°C, because the aluminium anneals, are above this temperature. The ACSR is the oldest overhead cable built before 1950 [4]. The inner steel core is subject to corrosion and can be prevented using a corrosion detector [4]. The inner core steel of ACSR conductor permeability depends on the tensile stress and temperature [5]. The use of composite materials for the cores of overhead conductors is fairly recent and more noticeable [6]. The selection of conductors is critical since wind, ice, tension loads, and other environmental effects accounts that make the process tedious for designing. Structure height is also largely dependent on the conductors selected since the maximum sag of phase conductors under maximum ice or maximum temperature conditions is governed by certain physical, mechanical, and dimensional properties of the conductor.

The strength of the conductor is affected due to matrix softening and loss of fiber-matrix adhesion [7]. The conductor strength can be improved by studying both the internal and external factors affecting it. The various internal factors affecting the conductor incl tension, shear, bending torsion, contact force, friction [8]. The external factors affecting the conductor include climate changes and external load applied. The external loads like the wind will induce the conductor to vibrate. Aeolian vibration, galloping, and sub-span oscillation are the three forms of wind acting on the conductor [9]. The heavy loads causing

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vibration will lead the conductor to a high risk of line breakage [10].

The ACCC/TW conductor yield a low thermal expansion coefficient [11] that holds good for reduced sag and improved creep resistance [12] [13]. Obtaining a higher rating with a reduced sag in the existing conductor [14] is the main challenge considered. The low sag behavior can be measured by using the theoretical technique [15] [16]. The ACCC/TW conductor possesses higher tensile strength compared to the conventional conductor. The ACCC/HW conductor holds good mechanical behavior and current capacity [18].

A. Geometrical Parameters

A wire rope is an assembly of aluminium wires or other materials. They are helically wound around the core which results in flexible metallic cord cable resisting high tensile loads. The core length, wire pitch of the first, second layers are calculated using the basic formula. The design parameters presented in table 1 are taken as a reference [17]. The geometric model is developed using modeling software for modeling the strands of ACCC/TW conductors.

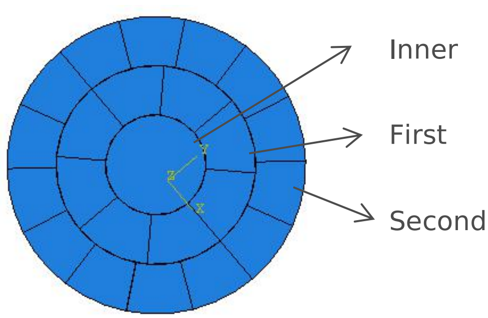

Fig. 1 Cross-section of Aluminum conductor Carbon composite (ACCC/TW)

A computer geometric model of the multilayered strand with the construction of the 1 + 8 + 14 wires is created using 3D modeling software. The cross-section of the ACCC/TW conductor formed is shown in Fig.1. The ACCC/TW conductor consists of 24 concentrically arranged compact strands of aluminium trapezoidal wires around a composite core. The outer layer of the trapezoidal aluminium wires consists of 14 wires, while the inner layer consists of 8 wires with the opposite lay angle. The outer diameter of the conductor is 28.14 mm while the inner layer constitutes 18.84 mm. The composite core of diameter 9.53 is comprised of continuous glass and carbon fibers in an epoxy matrix [17]. The 3D representation of the whole conductor arrangement is shown in Fig.2

TABLE I
GEOMETRIC PARAMETERS OF ACCC/TW CONDUCTOR

Specification	ACCC/TW
Outside Diameter, mm	28.14
Diameter of composite in the core, mm	9.53
Diameter of Al layer, mm	18.84
The total cross-section area of the conductor, mm^2	588.1
Actual Aluminum area, mm^2	517
Total area, mm^2	588.1

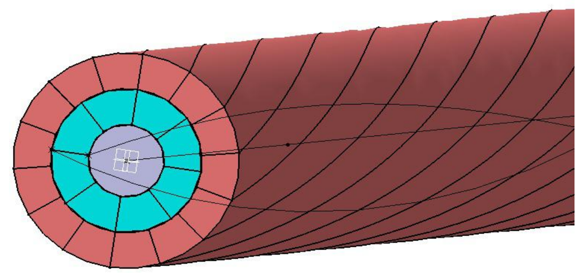

Fig.2 3D representation of the ACCC/TW conductor

B. Theoretical study

In the following analysis, each strand, core, and whole conductor are analyzed for predicting the behavior. The material properties, boundary conditions, and interaction properties are considered as the imperative constraints in the complete study. The axial force and torque acting on the stand is given as [19] in equation (1) and (2).

[illegible] (1)

[illegible] (2)

The interfacial contact forces acting between each strand are considered as an important factor in determining the strand behavior [20] [21]. To predict the interfacial contact force in radial and lateral contact wire, Gnanavel et.al developed a new mathematical model [22]. The maximum contact stress is expressed using Hertzian theory as given in equation (3) [23]

[illegible] (3)

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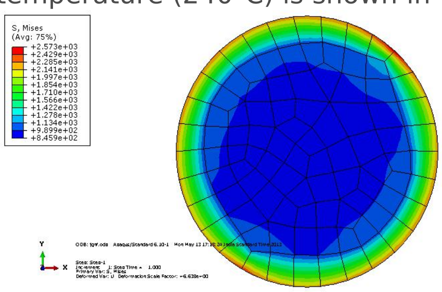
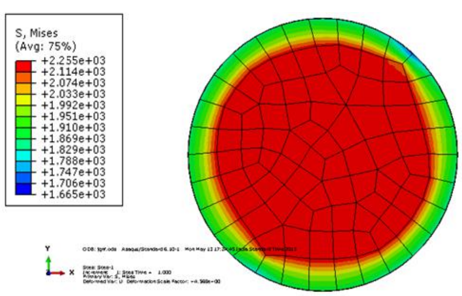
C. Numerical Analysis

The 3D model is fine-meshed using C3D20R, a 20-node quadratic brick, reduced integration mesh element. The core is kept as the base and the aluminium wires is considered as the supporting strands. The interaction between the core to stand and strand to strand is assigned as a surface to surface contact with friction case. The coefficient of friction between composite to aluminium and aluminium to aluminium is assigned as 0.4 and 1.4. The effect of the conductor is measured by arresting one end and applying a load of 174KN at the other end. Also effect at successive loads of 30%, 50%, and 70% of RTS is also noted for conductor performance. The conductor is analyzed under two cases. In the first case, the load is applied on the center composite core without including the aluminium strands. The stress exerted on the center core at room temperature and working temperature (240^{0}C) is shown in Fig.3.



a) Room temperature



b) Working temperature, 240^{0}C

Fig.3 Stress distribution observed in the inner composite core of ACCC/TW conductor

At room temperature, the maximum stress exerted on the center core is 2573N/mm^2. At a working temperature of 240^{0}C, the maximum stress exerted on the center core is 2255N/mm^2. In the second case, the whole conductor including the aluminium strands is analyzed with the same loading condition. The stress distribution for the whole conductor is shown in Fig.4. The results are compared with the experimental work and deviation is found to be 5.3% and 7.6% at room temperature and working temperature. It is observed that the load is distributed evenly over the conductor and the major stress is taken by the center core.

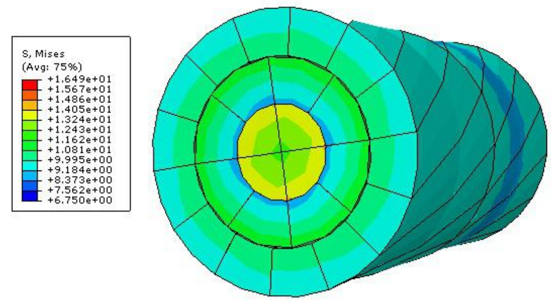


Fig. 4 Stress distribution of ACCC/TW conductor

CONCLUSION

The geometrical model of a multilayered conductor composed of 1+8+18 strands is presented in this paper. The present work can be used to study the conductor behavior at loading conditions. This process helps to study the interfacial contact force exerted between the core to aluminium strands and aluminium to aluminium strands. Using this method, the cable structure and mechanical properties can be simulated, thereby predicting the conductor behavior at different environmental conditions. This method holds promise in solving more complex analyses of strands and ropes behavior.

Nomenclature

F axial force
E young's modulus
ƀ2 area of cross section
ܿ axial strain
m helical wire numbers
ߙ helix angle
G shear modulus
J polar moment of inertia
T tensile force
N(binormal shearing force
G(Bending moment
߬ twist angle/unit length
H twisting moment
r wire helical radius
ߪ normal contact stress
ܾ1 undeformed radius of helical wire
v poisson's ratio

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