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STUDY OF THE HEAT EQUATION AND THE EFFECT OF TEMPERATURE INSIDE AN ELECTRIC CABLE CONSISTING OF ALUMINUM AND COPPER METALS

* Dalal Adnan Maturi [1]

[1]Departement of Mathematics, Faculty of Science, King Abdulaziz University, Saudi Arabia

*Corresponding Author, Received: 15 June 2022, Revised: 23 Feb. 2023, Accepted: 19 March 2023

ABSTRACT: In this paper, we study the mathematical physics model; partial discharge (PD) mapping and power cable fault location are approaches based on the principle of time domain reflection (TDR) measurement, influenced by the power cable's height Frequency wave propagation properties. Furthermore, power cables. They're increasingly being used to transmit electrical energy and communication signals simultaneously. Smart grids are an example of such technology. Power cables are exposed to a variety of temperatures when in use. Changes in the load current flowing through the cable cause differences. As a result, it is essential to Recognize how temperature affects the high-frequency characteristics of power wires. Temperature changes advance Errors in TDR measurements, according to simulations, and result in numerical solutions undertaken in this study. It's also shown that when the cable's temperature rises from25°C to 60°C, the attenuation increases by 1° and the propagation velocity rises by 1°.a 4-percentage-point average The phase constant, on the other hand, drops by order of magnitude on average. The findings imply that temperature effects must be considered while making decisions. Communication channels in power cables are designed.

Keywords: Heat Equation, Electric Cable, Aluminum, Copper, MATLAB.

1. INTRODUCTION

In the eighteenth century, the idea of electrical conductivity was developed, as were the first investigations on its temperature dependence. Although the German physicist Paul Karl Ludwig Drude (1863-1906) made the first serious theoretical advances on electrical conductivity of metals, The discovery of electricity as an imponderable elastic fluid transferable from one body to another by British scientist Stephen Gray (1666-1736) around one hundred and eighty years before, sweeping away the old idea of an electrical effluvia inseparably attached to a body in which they were excited [1-4]. Gray, a dyer by trade and an amateur naturalist by inclination, carried out a series of experiments using a hemp thread in 1720, inspired by the accounts of his physicist and compatriot Francis Hawksbee (1666-1713) [5,6], and after some related experiences as an assistant to the also British natural philosopher Jean Theophilus Desaguliers (1683-1744), Gray, a dyer by trade and an amateur naturalist by inclination, carried out a series. The early Gray's theories on electrical communication were practically ignored at first, but nine years later, they returned to the fore and gained public domain with a new publication in 1731 [7,8]. No significant progress was made on this subject until 1734, when Charles Fran cisde Cisternay du Fay (1698-1739), a French scientist and Superintendant of the Jardins du Roi, proposed the existence of two types of electric fluid, vitreous and resinous, which could be separated by friction and neutralized each other when combined [9]. The "two-fluid" theory of electricity proposed by du Fay, which was based on experiments with the attraction and repulsion of different electrified substances, was later contrasted with the "one-fluid" theory proposed by American scientist Benjamin Franklin (1706-1790), which assumed only one fluid was present, either positively or negatively charged [10-22]. The basis for the behavior of the new property was established with the classification of substances as conductors or insulators and the establishment of the electrical flow direction from positive to negative. Because they are outside and exposed to the elements, power lines and cables reinforced in the upper portion of transmission line support for the protection of wires from atmospheric over-voltages and direct lightning strikes [23–27] must function under challenging circumstances.

Several meteorological events (wind, rain, ice, and temperature variations) and chemical contaminants in the air[28-33]. In this sense, the wires must have electrical solid conductivity and adequate mechanical strength to withstand the impacts of atmospheric phenomena and chemical contaminants, consequently, in recent years. Bimetallic materials, made from a combination of metals that are distinct in their layered structure, have received a lot of attention during the construction of power lines [34-36]. Therefore, combining a bimetallic wire or rod's strength and plastic characteristics serves as the primary quality indication. In addition, the primary attributes of bimetallic materials are structurally sensitive, meaning that deliberate modifications in the structure can regulate them when it undergoes pressure processing [37-40].

Bimetal wire, commonly used in the industry, has a steel core and a variety of sheaths, including copper, aluminum, and brass.These wires typically have superior electrical conductivity and increased corrosion resistance, great strength, and conductivity. Copper continues to be the primary metal used in the cable business, despite its price continuously fluctuating at the moment. A copper shell provides low electrical resistance, while high structural strength is provided by a steel core, which can be altered by carbon content and heat treatment [41,42].

Although technologies for solid-phase joining of various dissimilar metals continue to advance each year [43-46], it is practically impossible to improve steel metal's strength properties because of various technological aspects. These characteristics include the development of chemical compounds on the copper sheath's surface after heating and bimetallic wires' embrittlement after being heated and passing through an alcohol solution. Most importantly, utilizing more expensive steel causes the entire production process less economically efficient. The creation of ultrafine-grained wire in such wires employing pressure metal treatment (PMT) technologies is one of the most promising areas in improving steel-copper wire's plasticity and tensile properties [47–52] as a result of heating a steel-copper. It is difficult to use a wire made of two metals with distinct physical and mechanical properties in the future because diffusion processes can generate brittle intermetallic inclusions at the steel-copper bond's border. In this regard, approaches for severe plastic deformation (SPD) that employ a straightforward shear scheme under multicyclic processing circumstances are actively being explored. Furthermore, the ability to increase the strength and flexible characteristics of the corresponding metallic materials is made possible by obtaining ultrafine-grained structures in such metals [53-75]. Based on the previous, we may conclude that the most crucial task is to find innovative and effective methods for creating ultrafine-grained structures in metals and alloys using existing conventional PMT techniques. Phase for the advancement of all rigid plastic deformation-related processes. A promising technique for reaching the requisite high degree of strain is equal-channel angular pressing (ECAP), perhaps the most used SPD technology [58–61]. This technology has recently undergone many improvements [62,63], some of which make it feasible to produce long-lasting goods [64,65]. ECAP and Conform were coupled by Raab et al. [66] to create aluminum compounds with ultrafine grains constantly. The process yields long semi-finished products with a high level of physical and mechanical qualities while achieving significant material usage. It does not, however, rule out the requirement for multicyclic processing, which increases the process's complexity and raises energy costs. Hwang et al. [67] recently developed a shear drawing (S.D.) procedure with a cone-shaped channel and corner radius at the intersection to address these shortcomings of earlier studies. The continuous S.D. technique imposed substantial plastic deformation on the material while ensuring stable flow. Nevertheless, their studies indicated that a smaller intersecting. Due to tension, angle may reduce flow stability and cannot easily guarantee the diameter's dimensional correctness, which results in unfavorable reductions in the deformed sample's surface area. By 1976, Avitzur had proposed the extruding method [68]. This approach combines pressing and rolling motions at a single point of tension. Lower power loss from reactive friction and a more complete filling of the reservoir is the critical differences between this method and others metal components from the workpiece used to gauge the cavity. The biggest flaw in this method is the modest draft and short length of the finished product. This technology has not been used in other industrial settings because it cannot produce the pressure needed for extrusion and cannot supply a constant flow of metal. Western Electric Co experts in the USA suggested a technique called Lainex. This technique uses active friction forces to press continuously. The dynamic friction forces are present in the rectangular workpiece's upper and lower planes. Chain links' smooth surfaces and cross-section. The difference between the frictional forces on the workpiece's unlubricated and lubricated planes determines the pressing force in this instance. At Wenski factories, this technique is applied to producing aluminum tires and processing wire. The fundamental drawback of this technique is that, compared to the Conform approach, the maximum value of the elongation coefficient in this method is an order lower. Modernization of the extraction procedure led to developing the combined rolling and pressing (CRP) technique. The strain of a long workpiece with a rectangular cross-section in a closed gauge of the two-roll type that is blocked at the end is used to develop this method the result of a die[69].

2. RESEARCH SIGNIFICANCE

Many electrical engineers are switching to aluminum as a cost-saving measure. Copper and aluminum cables can be used interchangeably, but copper is more commonly used in communications and control. While aluminum is able to carry a lower current than copper and has a higher resistance, it can be used by increasing the wire size by two American Wire Gage sizes. However, aluminum requires more space, is more difficult to work with, and needs a special compound or lug type for termination to prevent corrosion. Ultimately, the decision to use aluminum or copper will depend on cost and the intended application.

3. RATING FOR DYNAMIC CABLES

Due to the fluctuation of the conductor temperature during the useful life of the cable according to the inputs of the thermal models, the application of the steady-state current rating of cables may be cautious in some circumstances. As a result, throughout time, the assessment of a line's thermal stress has shifted from a steady-state thermal rating to a more general Dynamic Line Rating (DLR) or Dynamic Thermal Rating (DTR), which may better characterize thermal transients and their implications. The DLR is used to determine the line's actual current rating based on continuous measurements or the solution of the cable's thermal model. Assumptions on input variables that are conservative, such as those used in the steady-state model**.**

4. THERMAL ANALYSIS OF POWER CABLES USING HEAT TRANSFER CONCEPTS

The current traveling through a power cable generates heat, which is released into the environment through the cable's metallic layers and insulation. In the presence of a temperature gradient, heat is an energy form that is transmitted from one system to another. Conduction, convection, and radiation are the three heat transfer mechanisms involved in this process. If the cable is buried, exposed to the air, or submerged in water, the conduction phenomena happens through the cable's metallic layers and insulation. From the cable surface to the outside world, convection and radiation occur. Convection is classified as natural convection or forced convection depending on the nature of the heat movement. Natural convection occurs when the flow is produced by buoyant forces caused by density differences in the air caused by temperature gradients. Forced convection is caused by external factors such as a pump, a fan, or the wind. In comparison to cables buried underground, heat transmission processes for cables deployed in open air or water are more complex due to interactions with the ambient environment. Electromagnetic waves, or photons, are referred to as radiation. Radiation does not require a medium and is greatly influenced by temperature [8]. Only for electrical cables located in air, heat is transported from the cable surface to its surroundings by convection and radiation. If the power wire in the air is exposed to solar radiation, it is considered an extra energy source [9].

5. TEMPERATURE WITHIN AN ELECTRICAL CABLE

The temperature achieved within an electrical cable as a function of current and other parameters is required in the design of cable systems. Let us solve the nonhomogeneous heat equation in cylindrical coordinates with a radiation boundary condition to do this. The heat equation is derived from the law of conservation of energy.

Heat generated=heat dissipated + heat stored

$$\begin{aligned} I^2RNdt = -k\left[2\pi r\left.\frac{\partial u}{\partial r}\right|_r \right. \\ \left. - 2\pi(r+\Delta r)\left.\frac{\partial u}{\partial r}\right|_{r+\Delta r}\right]dt \\ + 2\pi r\Delta r c\rho du, \end{aligned} \tag{1}$$

where I is the current through each wire, R is the resistance of each conductor, N is the number of conductors in the shell between radii r and $r + \Delta r = 2\pi m\Delta r/(\pi b^2)$, b is the cable radius, m is the total number of conductors in the cable,κ is the thermal conductivity, c is the average specific heat, and u is the temperature. Equation (1)becomes in the limit of $\Delta r \rightarrow 0$

$$\frac{\partial u}{\partial t} = A + \frac{a^2}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right), \quad 0 \leq r < b, \quad 0 < t \tag{2}$$

where $A = I^2Rm/((\pi b^2 c\rho)$,

The nonhomogeneous heat equation for an infinitely long, axisymmetric cylinder is 8.3.139. We know that we must write the temperature as the sum of a steady-state and transient solution because of $u(r,t) = w(r) + v(r,t)$.

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right) = -\frac{A}{a^2} \tag{3}$$

or

$$w(r) = T_c - \frac{Ar^2}{4a^2}, \tag{4}$$

The steady-state solution $w(r)$ meets the requirements. T_c is the (as-yet-unknown) temperature in the cable's center $v(r,t)$ is a transient solution governed by

$$\frac{\partial v}{\partial t} = a^2\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v}{\partial r}\right), \quad 0 \leq r < b, \quad 0 < t, \tag{5}$$

$u(r,0) = T_c - Ar^2/(Aa^2) + v(0,t) = 0$ is the initial condition. $r = b$ at the surface

The boundary condition is $u_r = -hu$, where h is the surface conductance, because heat radiates to free space. Because after all transient effects pass away, the temperature equals the steady-state solution, $w(r)$ must fulfill this radiation boundary condition independent of the temporary solution. This necessitates that

$$T_c = \frac{A}{a^2}\left(\frac{b^2}{4} + \frac{b}{2h}\right) \tag{6}$$

As a result, at $r = b, v(r,t)$ must satisfy

$$v_r(b,t) = -hv(b,t)$$

By separating the variables $v(r,t) = R(r)T(t)$, we can get the transient solution $v(r,t)$Using Equation (5) as a starting point

$$\frac{1}{rR}\frac{d}{dr}\left(r\frac{dR}{dr}\right) = \frac{1}{a^2T}\frac{dT}{dt} = -k^2, \tag{7}$$

or

$$\frac{d}{dr}\left(r\frac{dR}{dr}\right) + k^2rR = 0, \tag{8}$$

$$\frac{dT}{dt} + k^2a^2T = 0, \tag{9}$$

with $R'(b) = -hR(b). J_0(kr) where\ J_0$ is the zero-order Bessel function of the first kind, is the only solution to Equation (8) that stays finite at $r = 0$ and satisfies the boundary condition. The transcendental equation I is obtained by substituting $J_0(kr)$ into the boundary condition

$$kbJ_1(kb) - hbJ_0(kb) = 0 \tag{10}$$

Equation (10) gives an infinite number of unique zeros k_n for a given value of h and b.
The problem's associated temporal solution

$$T_n(t) = A_n \exp(-a^2k_n^2t), \tag{11}$$

as a result, the total number of product solutions

$$v(r,t) = \sum_{n=1}^{\infty} A_n J_0(k_nr)\exp(-a^2k_n^2t). \tag{12}$$

The final challenge is to calculate An. Equation (12) is evaluated at $t = 0$

$$v(r,0) = \frac{Ar^2}{4a^2} - T_c = \sum_{n=1}^{\infty} A_n J_0(k_nr), \tag{13}$$

In J_0, there is a Fourier-Bessel series (k_nr). We demonstrated how to compute the coefficient of a Fourier-Bessel series expanded in $J_0(k_nr)$ with a boundary condition of the type we've arrived to the following conclusion

$$A_n = \frac{2k_n^2}{(k_n^2b^2+h^2b^2)J_0^2(k_nb)}\int_0^b r\left(\frac{Ar^2}{4a^2} - T_c\right) J_0(k_nr)dr \tag{14}$$

Performing the integrations that have been specified

$$A_n = \frac{2}{(k_n^2+h^2)J_0^2(k_nb)} \cdot \left[\left(\frac{Ak_nb}{4a^2} - \frac{A}{k_nba^2} - \frac{T_ck_n}{b}\right)J_1(k_nb) + \frac{A}{2a^2}J_0(k_nb)\right] \tag{15}$$

consider the following values:

$b = 4\,cm,\ hb = 1, a^2 = 1.14\,cm^2/s,\ A = 2.2747\,C/s,$ and $T_c = 23.94\,C.$ A represents 37 wires of #6 AWG copper wire in a cable providing a 22 amp current.

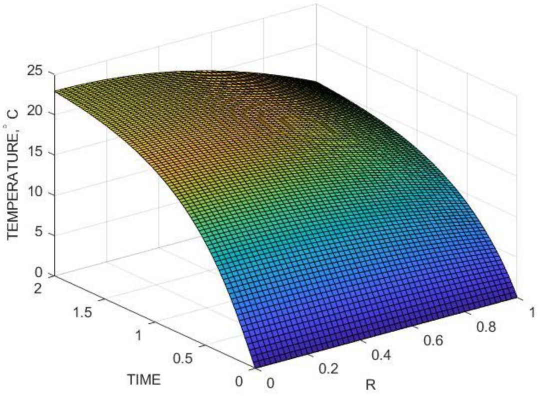

Fig.1 At various points r/b and times a^2t/b^2 the temperature field (in degrees Celsius) within an electric copper cable with 37 wires and a current of 22 amperes.The temperature was initially set to zero, and then the cable was allowed to cool naturally as it was heated $hb = 1$ is the value of the parameter, and the value of the parameter is the value of the parameter. The cable's radius is $b = 4\,cm.$

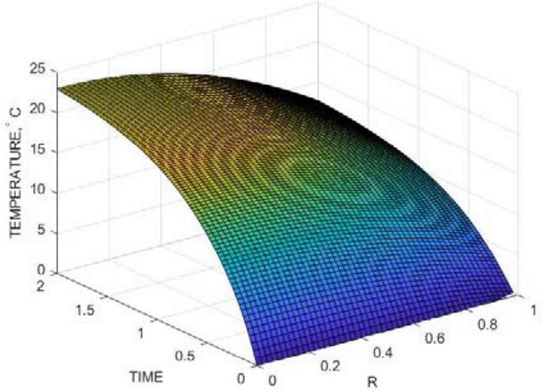

Fig.2 At various points r/b and times a^2t/b^2 the temperature field (in degrees Celsius) within an electric aluminum cable with 37 wires and a current of 22 amperes. The temperature was initially set to zero, and then the cable was allowed to cool naturally as it was heated $hb = 1$ is the value of the parameter, and the value of the parameter is the value of the parameter. The cable's radius is $b = 4\,cm.$

Consider the following values:

$b = 4\,cm,\ hb = 1, a^2 = 0.86\,cm^2/s,\ A = 2.2747\,C/s,$ and $T_c = 23.94\,C.$ A represents 37 wires of #6 AWG aluminum wire in a cable providing a 22 amp current.

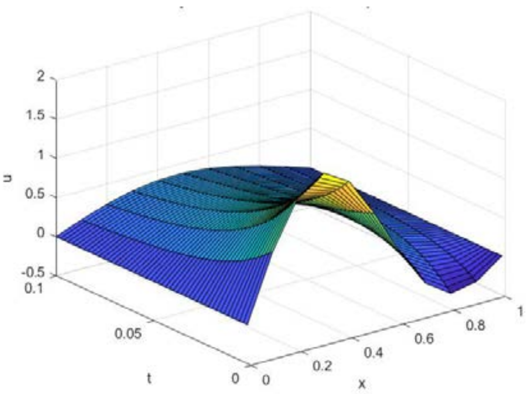

Fig.3 Analytic solution of Electric Equation

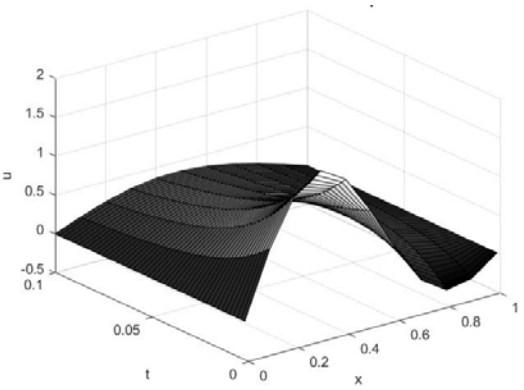

Fig.4 Numerical solution of Electric Equation

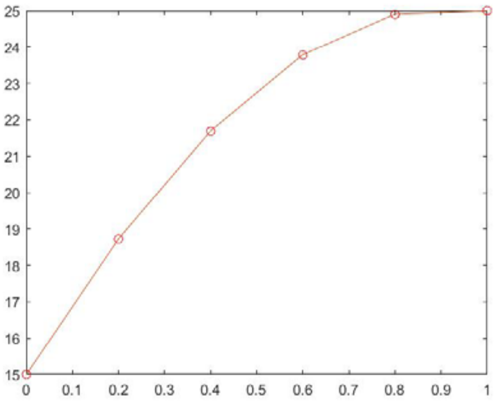

Fig.5 Finite Element Method of Electric Equation

6. CONCLUSIONS

The thermal models of subterranean cables were discussed in this study, starting with simple models with general hypotheses and progressing to more comprehensive specifications to meet practical instances. The heat transport concepts needed to derive an underground cable's thermal model have been summarized, and applications to specific scenarios have been defined (e.g., the non-infinite dimension of the soil, cable with a finite length). Furthermore, because the cable thermal model is commonly utilized in the sphere of power systems, the electrothermal analogy has been applied to it. To provide an overview of the primary contributions, the methodologies utilized to model heat transfer in the cables and in the external medium have been summarized. Finally, the cable thermal models have been used to calculate the cable current rating. Underground power cables have been widely investigated and modelled for decades, and as a result, there are several contributions in the literature. The historical components of this review paper have been presented, and the latest evolutions have been delineated. According to the literature assessment, there are a number of ongoing advancements that need to be improved. Due to the processing speed available, detailed FEM models of cables with the surrounding soil and ambient, including in 3D, are becoming feasible in non–uniform circumstances. However, there has been a fascinating development of improved and simplified models that can produce results that are comparable to FEM. The application of realistic thermal models of cables in the field of dynamic line rating, recognized as an activity that allows greater utilization of cable lines in various scenarios and is also useful for deferring expenditures to upgrade the installed cables, is a topic that is becoming more appealing.

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