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Mathematical model for evaluation of overhead transmission lines temperatures

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ABSTRACT

The problem of determining the temperature distribution in radial direction of composite overhead transmission lines in steady state is formulated. A mathematical model has been developed, when the heat supplied to the transmission line is balanced by the heat dissipated, to obtain the temperature of each layer of the line.

To obtain the change of the transmission line temperature with time the line can be treated as a lumped body, subjected to convective and radiative boundary conditions.

A test rig was constructed to supply and control a current to the test section of a transmission line, in addition to measure the temperature of each layer of this section. Comparison between the results obtained by the experimental work and by the mathematical analysis shows satisfactory agreement.

The maximum current capacity of each standard transmission line should be decreased by a factor, which can be called the derating factor, to obtain an actual current capacity in order to that the temperature of the transmission line does not exceed the maximum permissible temperature.

1. INTRODUCTION

The maximum load current that can be carried by a conductor is designated as the conductor ampacity and is normally determined from a single set of weather conditions in addition to an assumed maximum temperature [1]. A steady-state thermal rating procedure, which includes forced convection heat transfer equations taking into account the effect of wind turbulence, wind direction, conductor height above ground, the proximity of conductors in a bundle, and conductor pitch, has been investigated before [2].

The transient current capacity of thick aluminum-clad As strands used as overhead ground wires for extra-high voltage transmission

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lines was discussed previously [3].

Laboratory results indicate that the tested line hard-ware can operate with conductor temperatures up to 200 °c [4]. In another investigation an on-line method for transmission ampacity evaluation was studied [5]. The thermal rating of overhead line conductors can be determined by either deterministic or a probabilistic methods. The second method is the preferred one, although it is more complicated [6].

The main object of this work is, therefore, to investigate the temperature distribution in the radial direction of a composite overhead transmission line at steady-state condition, to calculate the difference between temperatures of different layers at steady state. Also a transient study to calculate the transmission line temperature at each time interval is presented.

2. EXPERIMENTAL WORK

The test rig is constructed to supply and control the current to the test section of the transmission line and in addition to measure the temperatures of different layers of the line [10].

The main parts of the test rig, as shown in Fig.(1), are :-

1. Test section :- A section of considerable length from an overhead transmission line (Cardinal line) is suspended in the laboratory. It consists of 7 steel strands surrounded by 54 aluminum strands, as shown in Fig.(2). Thermocouples are inserted at various distances from the center line of the transmission line to measure the temperature distribution in the radial direction.

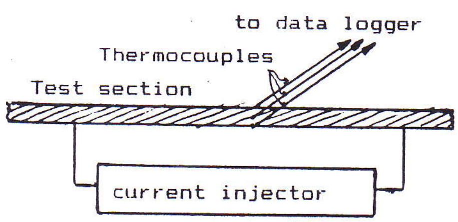

Fig.(1) Experimental set up.

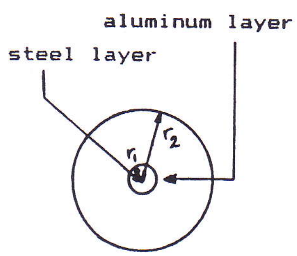

Fig.(2) Transmission line cross-section.

2. Current injector :- The constant current used is supplied from a current injector and it can be controlled by using a variac.

3. Connections :- The test section is connected to the current injector leads by two clamps, one at each section end.

The instruments used are :-

1. Clamp ammeter, to measure the energized current.
2. Thermocouples, to measure the temperature as a voltage difference at their terminals.
3. Data logger, to translate the voltage differences at the terminals of the thermocouples to corresponding temperatures.

After the test rig is prepared, the current can be injected to the test section and the corresponding temperature of each layer can be recorded at each time interval.

3. STEADY-STATE MATHEMATICAL MODEL

The thermal state of a transmission line will depend on the load current, the electrical characteristics of the conductor and the atmospheric parameters, which include the solar radiation, the mean wind velocity (direction and turbulence) and ambient temperature. When the heat supplied to the transmission line is balanced by the heat dissipated, the thermal state of the line is defined as steady state. The heat balance equation can be given by , [6],

$$q_j + q_m + q_i + q_s = q_{con} + q_{rad} + q_{eva} \qquad (1)$$

Where q_j , q_m , q_i and q_s are joule, magnetic, corona and solar heating, while q_{con} , q_{rad} and q_{eva} are convective, radiative and evaporative cooling, respectively.

The heating of the conductor due to the load current includes the joule and magnetic heating. The magnetic heating is due to cyclic magnetic flux which causes heating by eddy currents, hysteresis and magnetic viscosity. Corona heating is only significant with high surface voltage gradients and can be calculated from an empirical formula. The solar heating using global solar radiation can be written as, [6, 9],

$$q_s = \alpha_s S D \qquad (2)$$

where α_s is the absorptivity of transmission line surface, ($0.27 \le \alpha_s \le 0.95$ or $\alpha_s \cong 0.50$), S is the global solar radiation and D is the outer diameter of the transmission line.

The heat transmitted by convection from the transmission line surface q_{con} is given by, [6 to 9],

$$q_{con} = \pi \; Nu \; K_f \; (T_s - T_a) \tag{3}$$

Where Nu is the Nusselt number, $Nu = h \; D \; / \; K_f$, K_f is the air thermal conductivity (watt/m °k), T_s is the transmission line surface temperature, T_a is the ambient temperature and h is the heat transfer coefficient (watt/m^2 °k).

Substitute Nu in eqn.(3), q_{con} can be rewritten as follows :

$$q_{con} = h \; A_s \; (T_s - T_a) \tag{4}$$

Where A_s is the transmission line surface area (m^2).

Nusselt number is given by, [7],

$$Nu = \left[0.6 + \frac{0.387 \; R_a^{1/6}}{[\; 1 + (\; 0.559 \; / \; Pr \;)^{9/16} \;]^{8/27}} \right]^2 \tag{5}$$

Where Pr is Pramdtl number, $Pr = c_a \; \mu \; / \; K_f$, c_a is the specific heat of air at constant pressure (J / kg °k), μ is the dynamic viscosity of air (kg / m s), and R_a is Rayligh number,

$$R_a = [\; g \; B \; (\; T_s - T_a \;) \; D^3 \;] \; / \; \upsilon \; \alpha \tag{6}$$

Where g is the gravitational acceleration (m/s^2), B is the coefficient of thermal expansion of air, $B = 1 \; / \; [0.5 \; (T_s + T_a)]$, υ and α are the kinematic viscosity and the thermal diffusivity of air (m^2/s).

The heat radiated from the conductor surface q_{rad} is given by the following equation, [6 to 8],

$$q_{rad} = \varepsilon \; \sigma \; A_s \; (\; T_s^4 - T_a^4 \;) \tag{7}$$

Where ε is the transmission line surface emissivity, it depends on the conductor surface, ($0.27 \le \varepsilon \le 0.95$ or $\varepsilon \cong 0.6$), and σ is

Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8}$ watt/m^2 $°K^4$.

The radiation loss is usually a small fraction of the total heat loss, especially with forced convection [8]. The evaporative cooling effects can be generally neglected. As an approximation, the joule heating of the conductor due to its resistance will be considered only. Therefore, the heat balance equation, in eqn.(1), can be modified to

$$q_j = q_{con} + q_{rad} \tag{8}$$

The composite transmission line can be considered as two concentric layers. The joule heating q_j in the transmission line equals the power delivered in the steel layer plus that delivered in the aluminum layer. The power in each layer can be obtained by calculating the current in each layer and the layer resistance, where the two resistances are connected in parallel. Each resistance can be calculated from the length of the transmission line, the cross sectional area of each layer and from the corresponding resistivity of each material. The cross sectional area of each layer equals to the cross sectional area of one strand multiplied by the total number of strands in the layer.

Heat generated from the flow of the electric current through resistive conductor is transferred by combined convection and radiation to the surrounding environment. Generally, the temperature distribution through the conductor material is given by the general conduction equation, [7], as follows

$$\frac{\partial}{\partial r} \left(K \frac{\partial T}{\partial r} \right) + \dot{q} = \rho c \frac{\partial T}{\partial t} \tag{9}$$

Where K is the material thermal conductivity, T is the temperature and $\dot{q}$ is the rate of heat generated per unit volume (watt/m^3), ρ is the conductor material density (kg/m^3), c is the specific heat of conductor material, t is the time and r is the radial distance measured from the geometric center of the conductor (m).

The temperature distribution will be in the radial direction considering infinite conductor length and no variation in the axial direction. If the thermo-physical properties of the conductor material is constant and with approximation to one-dimensional steady-state conduction, eqn.(9) can be simplified to

$$\frac{1}{r}\frac{d}{dr}\left(r \frac{dT}{dr} \right) + \frac{\dot{q}}{K} = 0 \qquad (10)$$

When a transmission line is composed of strands of two different materials, two layers of uniform sections can be assumed to overcome the discontinuity of eqn.(10). Then the transmission line can be considered as two-concentric cylinders closed to each other or separated by an air gap. The temperature distribution through both the steel layer and the aluminum layer of the transmission line can be obtained by integrating eqn.(10) taking into consideration the appropriate boundary conditions for each layer. The following equation can be obtained for the steel layer :

$$T_{st} = (- \dot{q}_{st} r^2 / 4 K_{st}) + C_1 \ln r + C_2 \qquad (11)$$

Where T_{st} is the temperature of the steel layer at a radius r, $(0 \le r \le r_1)$, $\dot{q}$ is the rate of heat generated per unit volume and C_1 , C_2 are the integration constants.

At $r = 0$, $T_{st} = T_o$, $C_1 = 0$ then $T_o = C_2$ and at $r = r_1$, $T_{st} = T_1$ then

$$T_1 = (- \dot{q}_{st} r_1^2 / 4 K_{st}) + C_2 \quad , \text{or} \quad C_2 = T_1 - (- \dot{q}_{st} r_1^2 / 4 K_{st})$$

Therefore, eqn.(12) gives the temperature at geometric center of the transmission line T_o,

$$T_o = T_1 + (\dot{q}_{st} r_1^2 / 4 K_{st}) \qquad (12)$$

Substituting the values of C_1 and C_2 in eqn.(11), the temperature distribution in the steel layer of the transmission line is obtained as follows

$$T_{st} = T_1 + (\dot{q}_{st} (r_1^2 - r^2) / 4 K_{st}) \qquad (13)$$

Integrating eqn.(10), the temperature distribution in the aluminum layer of the transmission line is obtained as

$$r \, (d T_{al} / d r) = (- \dot{q}_{al} r^2 / 2 K_{al}) + C_3 \qquad (14)$$

Then at $r = r_1$

$$(d\,T_{al} / d\,r) = (- \dot{q}_{al}\, r_1 / 2\,K_{al}) + (C_3 / r_1) \qquad (15)$$

The flow of heat q_{st} between the steel layer and aluminum layer results in a direction opposite to the temperature gradient. This heat flow can be obtained from the rate of heat generated per unit volume, $\dot{q}_{st}$, as follows

$$q_{st} = \dot{q}_{st}\, \pi\, r_1^2\, 1 / 2\,\pi\, r_1\, 1 = \dot{q}_{st}\, r_1 / 2 \qquad \text{but} \quad q_{st} = - K_{al} \frac{d\,T_{al}}{d\,r}$$

then
$$(d\,T_{al} / d\,r) = - \dot{q}_{st}\, r_1 / 2\,K_{al} \qquad (16)$$

From eqns.(15) and (16), C_3 can be obtained as

$$C_3 = - r_1^2\,(\dot{q}_{st} - \dot{q}_{al}) / 2\,K_{al} \qquad (17)$$

Integrating eqn.(14) to obtain the temperature distribution in the aluminum layer, we get

$$T_{al} = (- \dot{q}_{al}\, r^2 / 4\,K_{al}) + C_3 \ln r + C_4 \qquad (18)$$

Substituting the boundary condition, $r = r_2$, $T_{al} = T_s$ (surface temperature), in eqn.(18) the temperature of the transmission line surface is obtained as

$$T_s = (- \dot{q}_{al}\, r_2^2 / 4\,K_{al}) + C_3 \ln r_2 + C_4 \qquad (19)$$

From eqns.(17) and (19), C_4 can be written as follows

$$C_4 = T_s + (\dot{q}_{al}\, r_2^2 / 4\,K_{al}) + (r_1^2 / 2\,K_{al})\,(\dot{q}_{st} - \dot{q}_{al}) \ln r_2 \qquad (20)$$

The temperature distribution in the transmission line corresponding to a certain current can be evaluated from the mathematical model as follows :-

1. Read the input data (transmission line geometry, atmospheric parameters, ambient temperature, electrical characteristics, the current flows in the transmission line...).
2. Calculate the heat generated in the transmission line.
3. Assume an initial value of the surface temperature of the transmission line T_s.

4. Calculate the heat convected q_{con} and the heat radiated q_{rad} from the surface of the transmission line , eqns.(3) to (7).
5. Substitute from steps (2) and (4) above in the heat balance equation (eqn.(1) for exact solution or eqn.(8) for approximate one). The final corrected value of T_s can be obtained by using an iterative procedure.
6. Calculate C_3 , from eqn.(17), and C_4, from eqn.(20), then substitute their values in eqn.(18) to obtain the temperature distribution in the aluminum layer of the transmission line.
7. Substitute $r = r_1$ into eqn.(18) to obtain T_1.
8. Substitute T_1 into eqn.(13) to obtain the temperature distribution in the steel layer of the transmission line.
9. Substitute T_1 in eqn.(12) to obtain the temperature at the geometric center of the transmission line, T_o.
10. Go to step (2), if a new operating condition is occurred.

4. TRANSIENT MATHEMATICAL MODEL

The change of the temperature with time is the main objective of this section. The heat conduction equation, eqn.(9), shows that the temperature of the transmission line is a function of both radial distance r and time t, i.e. T = T (r, t). The following simplifying assumptions are considered to solve eqn.(9) :

1. The transmission line is composed of uniform material with mean properties between that of steel and aluminum.
2. The transmission line can be treated as a lumped body, T =T(t).
3. This body is subjected to convective boundary conditions.
4. A correction due to radiation effect from the transmission line surface is considered [7].

From eqn.(9) the stored heat q_{sd} within the lumped body, which represents the transmission line material, is given by

$$q_{sd} = \rho \, c \, v \, (\partial T / \partial t) \tag{21}$$

Where v is the volume of the transmission line.
This stored heat is the difference between the generated heat q_{gen} and the convicted heat q_{con} ,
i.e.

$$q_{sd} = q_{gen} - q_{con} \tag{22}$$

Where q_{con} was given in eqn.(4) and $q_{gen} = \dot{q}\ v$.

Substituting q_{sd} , q_{gen} and q_{con} in eqn.(22), the following equation is obtained

$$(dT/dt) = [\dot{q} - h(T - T_a)/D]/\rho c \qquad (23)$$

Assuming that $\theta = T - T_a$, then eqn.(23) can be rewritten as

$$(d\theta/dt) = (\dot{q}/\rho c) - (h/\rho c D)\,\theta \qquad (24)$$

The solution of this equation leads to, [7],

$$\theta = C_1\, e^{-ht/\rho c D} + \dot{q} D/h \qquad (25)$$

To obtain the integration constant C_1 , the initial values, $t = 0$, $T = T_i$ and $\theta_i = T_i - T_a$, are substituted in eqn.(25). Thus

$$C_1 = \theta_i - (\dot{q} D/h) \qquad (26)$$

Substituting C_1 and θ in eqn.(25), to obtain the surface temperature of the transmission line T, we get

$$T = T_a + [(T_i - T_a)\, e^{-ht/\rho c D}]$$
$$+ [\dot{q} D (1 - e^{-ht/\rho c D})/h] \qquad (27)$$

A correction to eqn.(27) due to radiation effect must be carried out to get more accurate value of the temperature. The corresponding heat balance equation is given by

$$q_{gen} = q_{con} + q_{sd} + q_{rad} \qquad (28)$$

Where q_{rad} was given in eqn.(7).

The correction was done by replacing $\dot{q}$ in eqn.(27) by a net value of the rate of the heat generated per unit volume $\dot{q}_{net}$, where

$$\dot{q}_{net} = \dot{q} - (q_{rad}/v) \qquad (29)$$

To obtain the temperature of the transmission line at a certain time, the previous mathematical model can be used as follows :

1. Read input data, as mentioned before in section 3.
2. Calculate the heat generated in the transmission line.
3. Specify the initial value of the temperature T_i , to calculate the transmission line temperature T from eqn.(27).
4. Calculate q_{rad} , from eqn.(7), and $\dot{q}_{net}$, from eqn.(29).
5. If $| \dot{q} - \dot{q}_{net} |$ is greater than the specified tolerance value, replace $\dot{q}$ by $\dot{q}_{net}$ and go to step (3) to obtain a corrected value of T.
6. IF $| \dot{q} - \dot{q}_{net} |$ is equal to or less than the tolerance value, increase the time by a time step and go to step (3) to obtain a new temperature value corresponding to the specified time.

5. RESULTS

The experiment was carried out in a closed room and the results give the temperature-time relation for the aluminum layer and for the steel layer of a transmission line, as shown in Fig.(3). The temperature was recorded every 5 minutes for injected current of 200 A. The temperature of each layer increases each time interval till it reaches a steady state value when the cooling rate is equal to the generating rate of heat in the transmission line. Also in Fig.(3), the difference between the temperature of the steel layer and the temperature of the aluminum layer is calculated and plotted each time interval.

Fig.(4) shows the steady-state temperatures of the core T_o, of the surface of the steel layer T_1 in addition to the temperature of the inner surface of the aluminum layer T_2 and of the surface of the line T_s at different values of transmission line current. The difference between the temperature of the core and the temperature of the surface of the transmission line increases with the increase of the current value, as shown also in Fig.(4).

Fig.(5) shows the steady-state temperatures of the core and of the surface of the line at different values of currents for various types of standard transmission lines (Waxwing, Cardinal and Bluebird).

Fig.(6) shows the difference between the core temperature and the surface temperature of each line of these transmission lines versus current. Fig.(7) shows the temperature of the Cardinal transmission line, which was calculated from the transient mathematical model, at different values of the transmission line current, versus time. When the current increases, the temperature of the line increases and when the current decreases, the temperature decreases but still higher than the corresponding values at the first part.

From the steady-state calculations it is noticed that the temperature gradient in the radial direction of a transmission line results in a temperature difference between the core and the surface of the line. This temperature difference should be taken as a base for determining the actual current capacity which can be carried by the transmission line.

A modified analysis is carried out to obtain a new factor to reduce the maximum current capacity of a transmission line to an actual one. The maximum current capacity of a line is corresponding to the maximum permissible surface temperature, but we have seen that the temperature of the core of the line is higher than the surface temperature, therefore the maximum current capacity of the line should be reduced until the core temperature will be equal to or less than the value of the maximum permissible temperature.

The rated current for each transmission line size can be found from standard tables. The core and surface temperatures can be calculated as mentioned before in the theoretical model of the steady-state condition. The difference between these two values equals ΔT. Eqn.(30) gives a new surface temperature $T_{s\ new}$, at which the core temperature of the line does not exceed the permissible temperature T_s.

$$T_{s\ new} = T_s - \Delta T \tag{30}$$

The convective and radiative heat corresponding to T_{snew} can be calculated from eqns.(4) and (7) and by substituting these values in the heat balance equation the corresponding value of the actual current capacity of the transmission line can be obtained by using an iterative procedure.

The transmission line should not be loaded more than this actual value to prevent the increase in the core temperature to be more than the permissible temperature of the line and to increase the life time of the line.

The ratio between the calculated current capacity and the maximum current capacity can be called the derating factor.

The same procedure is repeated for different sizes of transmission lines and the corresponding derating factor for each line can be calculated, as given in Table (1), from which an average value for this factor can be taken as 0.9 . Therefore, for each standard transmission line the maximum current capacity should be multiplied by the average derating factor to obtain an actual current value, which will not cause the temperature of the core of the line to become higher than the maximum permissible temperature.

Table (1)

code word	stand. current (A)	core temp. (°c)	surface temp. (°c)	actual current (A)	core temp. (°c)	surf. temp. (°c)	derating factor
Waxwing	750	114.06	103.09	670	100.45	91.69	0.89333
Linnet	900	112.33	101.91	810	99.85	91.39	0.90000
Cardinal	970	110.55	100.49	875	98.68	90.49	0.90206
Bluebird	1060	111.16	101.09	955	99.07	90.89	0.90094

Average derating factor = 0.90

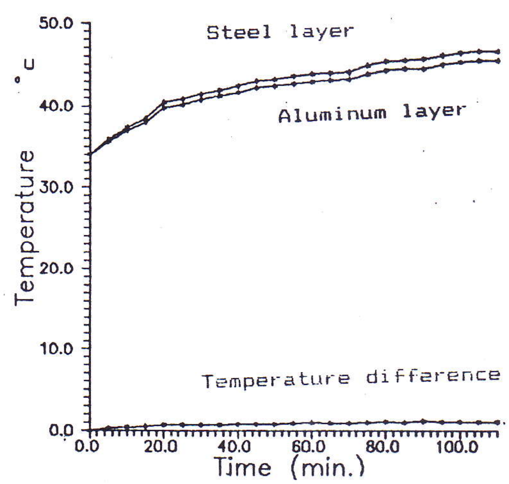

Fig.(3) Temperature of steel layer and aluminum layer of a transmission line versus time.

6. CONCLUSIONS

The proposed model at steady-state conditions can give the temperature distribution in each layer of composite overhead transmission lines. The line temperature at each time interval can be calculated from the model of the transient condition.

The comparison between the experimental results and the results

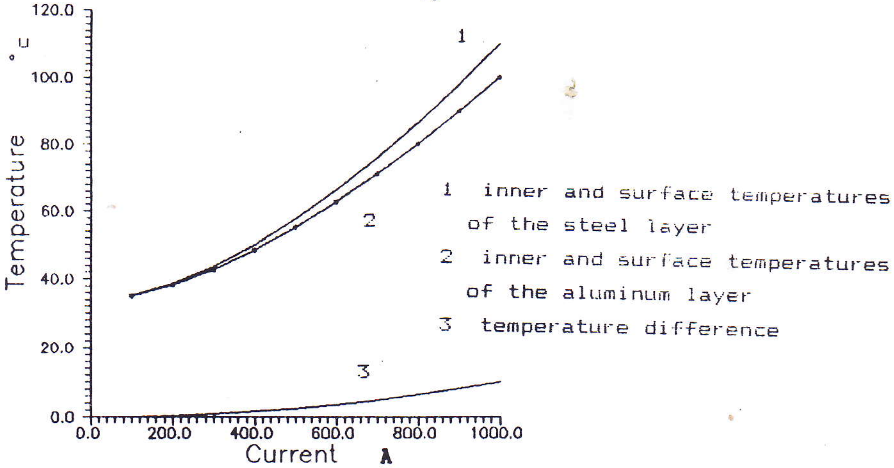

Fig. (4) Temperature distribution in a transmission line (Cardinal) at different values of current.

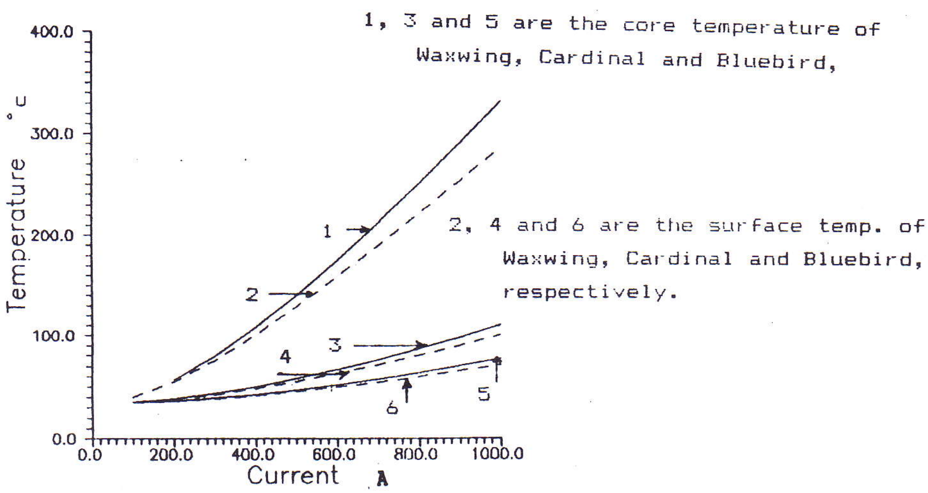

Fig.(5) Steady state temperature distribution for various types of standard lines versus current.

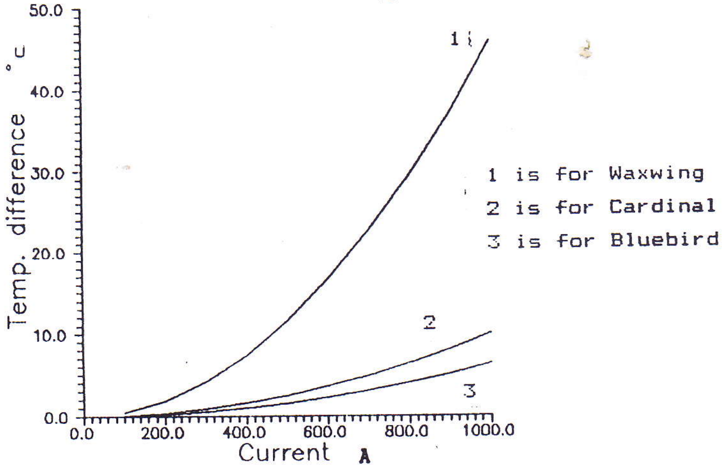

Fig. (6) Difference between the core and the surface temperatures for various types of standard lines versus current.

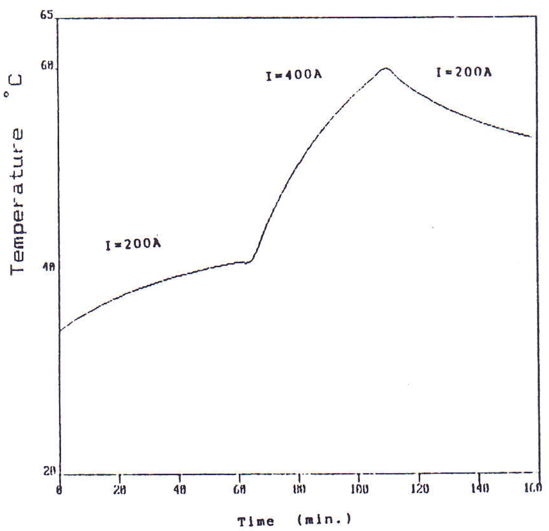

Fig.(7) Temperature of Cardinal transmission line at different currents versus time.

obtained from the mathematical models shows satisfactory agreements. The difference between the obtained temperatures may be attributed to the instruments errors and to the taken assumptions in the mathematical models (the difference is about 7.2 %).

The core temperature is higher than the surface temperature of the transmission line. The difference between these two temperature values increases with time until it reaches a constant value at steady state. Therefore, the core temperature should be considered as a base for calculating the maximum current carrying capacity corresponding to the maximum permissible temperature of the transmission line. The maximum current capacity for each standard line should be multiplied by a derating factor, about 0.9 , to obtain the actual current capacity. This actual value will not cause the temperature of the core of the transmission line to rise over the maximum permissible temperature, to limit damage in the transmission line and to give minimum disruption of electric service.

7. REFERENCES

1. Koval, D.O., Billinton, R. :" Determination of transmission line ampacities by probability and numerical methods ", IEEE Trans. on P A S, vol. PAS-89, no. 7, September / October 1970, pp 1485-1492.
2. Davis, M.W. :"A new thermal rating approach : The real time thermal rating systems for strategic overhead conductor transmission lines" Part 1 and Part 2, IEEE Trans. on P A S, vol. PAS-96, no. 3, May / June 1977, pp 803 - 825.
3. Tanaka, A., Hoshino, H. :" Transient current capacity of aluminum-clad steel ground wires ", IEEE Trans. on P A S, vol. PAS-89, no. 7, September / October 1970, pp 1493 - 1498.
4. Matusz, J.S. :" High temperature tests of ACSR conductor hardware ", IEEE Trans. on Power Delivery, vol. 4, no. 1, January 1989, pp 524 - 531.
5. Wong, T.Y., Findly, J.A., and McMurtrie, A.N. :" An on-line method for transmission ampacity evaluation", IEEE Trans. on P A S, vol. PAS-101, no. 2, February 1982, pp 309 - 315.
6. " The thermal behaviour of over head conductors ", ELECTRA No. 144, October 1992, pp 107 - 125.
7. Incropera, F.P. :" Fundamentals of heat and mass transfer ", Second Edition, John Wiley & Sons, New York 1981.
8. Morgan, V.T. :" The thermal Rating of overhead line conductors Part 1, the steady state thermal model ", Elect. Power System Research, 1982, pp 119 - 139.
9. Morgan, V.T. :" The current- carrying capacities of overhead line conductors ", IEEE P. E. S. Summer meeting, July 1978, Paper A 78575-3.
10. Foda, M.A. :" Modified analysis of current carrying capacity of overhead transmission lines ", M.Sc. thesis, Faculty of Eng. (Shoubra), Zagazig University, Egypt, 1992.

نموذج رياضي لإيجاد درجات حرارة خطوط النقل الهوائية

يقوم البحث بدراسة درجات الحرارة فى الاتجاه العمودى على خطوط النقل الهوائية المركبة فى الحالة المستقرة و التى عندها تكون كمية الحرارة المكتسبة فى الموصل متوازنة مع كمية الحرارة المفقودة منه . و تم تكوين نموذج رياضى لإيجاد درجة حرارة كل طبقة من طبقات مقطع الموصل .

و لإيجاد التغير فى درجة حرارة الخطوط مع الزمن (الحالة العابرة أو اللحظية) أمكن معاملة الموصل كجسم مدمج و تم تكوين نموذج رياضى آخر مع الأخذ فى الاعتبار الظروف المحيطة لإنتقال الحرارة بالحمل و الإشعاع .

و تم تكوين دائرة لتغذية قطاع طولى لخط هوائى و قياس درجة حرارة كل طبقة من طبقات مقطع الموصل و وجد أن هناك توافقا مرضيا بين النتائج التى تم الحصول عليها معمليا مع مثيلاتها التى تم حسابها بإستخدام النموذج الرياضى .

و للحصول على قيمة فعلية للتيار تم إختزال أقصى تيار لتحميل الخطوط الهوائية القياسية بمعامل سمى " معامل تخفيض المعدل " و ذلك لكي لا ترتفع درجة حرارة قلب الموصل عن أقصى درجة حرارة يتحملها الموصل بغرض حماية الموصلات و تقليل التلف و الأعطال .