IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors

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Abstract: A simplified method of calculating the current-temperature relationship of bare overhead lines, given the weather conditions, is presented. Along with a mathematical method, sources of the values to be used in the calculation are indicated. This standard does not undertake to list actual temperature-capacity relationships for a large number of conductors for a large number of conditions.

Keywords: bare overhead lines, current-temperature relationship.

The Institute of Electrical and Electronics Engineers, Inc. 345 East 47th Street, New York, NY 10017-2394, USA

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Introduction

(This introduction is not a part of IEEE Std 738-1993, IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors.)

In 1986, IEEE Std 738-1993, IEEE Standard for Calculation of Bare Overhead Conductor Temperature and Ampacity Under Steady-State Conditions, was first published. The standard was developed "so that a practical, sound, and uniform method (of calculation) might be utilized and referenced." As part of the revision cycle, the Working Group on the Calculation of Bare Overhead Conductor Temperatures, which was responsible for the revision of this standard, decided to address fault current and transient ratings and include their calculation in this standard. As a result of that decision, the name of this standard has been changed to reflect its broader application.

This standard includes a computer program on diskette. The working group has made every effort to ensure that the program yields accurate results. The user is cautioned that there may be values of rating parameters for which the method is not appropriate. A program listing, well documented with comment statements, is provided to allow the user to review the calculation method and assumptions to determine their validity for a particular case.

Many persons have contributed to the preparation, analysis, and review of this standard. We would like to recognize the contribution of the late B. S. Howington, who served as chair of the working group for many years and was responsible for developing the original standard and establishing the content of the revised standard.

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IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors

1. Overview

1.1 Introduction

The purpose of this standard is to present a method of calculating the current-temperature relationship of bare overhead conductors.

Conductor surface temperatures are a function of

a) Conductor material properties
b) Conductor diameter
c) Conductor surface conditions
d) Ambient weather conditions
e) Conductor electrical current

The first two of these properties are specific chemical and physical properties. The third may vary with time, and that variation is dependent upon ambient atmospheric conditions other than weather. The fourth, weather, varies greatly with the hour and season. The fifth, conductor electrical current, may be constant or may vary with power system loading, generation dispatch, and other factors.

The equations relating electrical current to conductor temperature may be used in either of the following two ways:

— To calculate the conductor temperature when the electrical current is known
— To calculate the current that yields a given maximum allowable conductor temperature

For the purposes of this standard, either the electrical current is assumed constant for all time or it is assumed to undergo a step change from an initial current to a final current. The ambient weather conditions are assumed to be constant with time in both the steady-state and transient calculation methods described in this standard.

This standard includes mathematical methods and indicates sources of the values to be used in the calculation of conductor temperatures and conductor thermal ratings. However, because there is a great diversity of weather conditions and operating circumstances for which conductor temperatures and/or thermal ratings must be calculated, the standard does not undertake to list actual temperature-current relationships for specific conductors or weather conditions. Each user must make their own assessment of which weather data and conductor characteristics best pertain to their area or particular transmission line.

The calculation methods in this standard are also valid for the calculation of conductor temperature under fault conditions.

1.1.1 Disclaimer

A computer program is included in this standard as a convenience to the user. Other numerical methods may well be more appropriate in certain situations.

The IEEE Working Group on Calculation of Bare Overhead Conductor Temperatures of the Towers, Poles and Conductors Subcommittee has made every effort to ensure that the program yields accurate calculations under anticipated conditions; however, there may well be certain calculations for which the method is not appropriate. It is the responsibility of the user to check calculations against either test data or other existing calculation methods.

1.2 Definition of terms

1.2.1 conductor temperature: The temperature of a conductor.

NOTE—The conductor is assumed to be isothermal (i.e., no axial or radial temperature variation) for all steady-state calculations and for all transient calculations where the time period of interest exceeds 1 min or the conductor consists of a single material. With transient calculations for times less than 1 min with nonhomogeneous ACSR conductors (i.e., aluminum conductor steel reinforced), the aluminum strands are isothermal; but the heat capacity of the steel core is assumed to be zero.

1.2.2 heat capacity: *(A) homogeneous conductors:* The specific heat of the conductor's material times the mass per unit length. *(B) nonhomogeneous conductors:* The sum of the heat capacities of the conductor's component materials.

1.2.3 maximum allowable conductor temperature: The maximum temperature limit that is selected in order to minimize loss of strength, sag, line losses, or a combination of the above.

1.2.4 Reynolds number: A nondimensional number equal to air velocity (V_w) times conductor diameter ($D/_{12}$) divided by kinematic viscosity (μ_f/ρ_f).

1.2.5 steady state thermal rating: The constant electrical current that would yield the maximum allowable conductor temperature for specified weather conditions and conductor characteristics under the assumption that the conductor is in thermal equilibrium (steady state).

1.2.6 transient thermal rating: The transient thermal rating is that final current (I_f) that yields the maximum allowable conductor temperature (T_{max}) in a specified time after a step change in electrical current from some initial current, I_i.

1.2.7 thermal time constant: The time required for the conductor temperature to accomplish 63.2% of a change in initial temperature to the final temperature when the electrical current going through a conductor undergoes a step change.

1.2.8 wind direction: The direction of the movement of air relative to the conductor axis. The wind direction and the conductor axis are assumed to be in a plane parallel to the earth. When the wind is blowing parallel to the conductor axis it is termed "parallel wind." When the wind is blowing perpendicularly to the conductor axis it is termed "perpendicular wind."

2. Temperature calculation methods

The Working Group on the Calculation of Bare Overhead Conductor Temperatures has conducted a study on the various methods used in calculating heat transfer and ampacities of transmission line conductors. Methods that were studied included the following:

a) House and Tuttle [B19][1]
b) House and Tuttle, as modified by East Central Area Reliability (ECAR) [B27]
c) ALCAN [B23]
d) Pennsylvania-New Jersey-Maryland Interconnection [B11], [B6]
e) Schurig and Frick [B24]
f) Hilpert [B17]
g) Davis [B9]
h) Morgan [B22]
i) Black and Byrd [B3], [B5], [B3]
j) Foss, Lin, and Fernandez [B14]

The mathematical models of this standard are based upon the House and Tuttle method as modified by ECAR [B27]. The House and Tuttle formulas consider all of the essential factors without the simplifications that made in some of the other formulas.

To differentiate between laminar and turbulent air flow, the House and Tuttle method [B19] uses two different formulas for forced convection; the transition from one to the other is made at a Reynolds number of 1000. Because turbulence begins at some wind velocity and reaches its peak at some higher velocity, the transition from one curve to another is a curved line, not a discontinuity. The single transition value was selected as a convenience in calculating conductor ampacities.

The single transition value results in a discontinuity in current magnitude when this value is reached. Therefore, to avoid this discontinuity that occurs using the House and Tuttle method [B19], ECAR [B27] elected to make the change from laminar to turbulent air flow at the point where the curves developed from the two formulas [equations (3a) and (3b)] cross. The formulas for forced convection heat loss have an upper limit of application validity of a Reynolds number of 50 000 [B21]. For additional information on convection heat loss, see 3.2 of this standard.

Since the primary purpose of this standard is the calculation of thermal ratings for constant weather conditions, the slower but simpler iterative approach is taken. Alternate noniterative methods may be used to calculate the conductor temperature given the current and weather conditions. In [B9], the heat balance equation is expressed as a biquadratic equation that can be solved to give the conductor temperature directly. In [B5] and [B29], the radiation term is linearized and the resulting approximate linearized heat balance equation is solved using standard methods of linear differential equations. In [B14], a somewhat more precise linearized radiation term is used to reduce the number of iterations required. These methods are computationally faster than the iterative method described in this standard; however, the algebraic expressions are more complex. While one expects to get the same answer from any valid calculation method, the noniterative methods are used normally in real-time thermal rating algorithms where calculation speed is essential.

2.1 Steady-state calculations

2.1.1 Steady-state thermal rating

For a bare stranded conductor, if the conductor temperature (T_c) and the steady state weather parameters (V_w, T_a, etc.) are known, the heat losses due to convection and radiation (q_c and q_r), the solar heat gain (q_s),

[1]The numbers in brackets correspond to the bibliographic references in clause 4.

and the conductor resistance $R(T_c)$ can be calculated by the formulas of 2.4. The corresponding conductor current (I) that produced this conductor temperature under these weather conditions can be found from the steady-state heat balance [equation (1b) of 2.4.1]. While this calculation can be done for any conductor temperature and any weather conditions, a maximum allowable conductor temperature (e.g., 95 °C) and "conservative" weather conditions (e.g., 2 ft/s wind speed, 40 °C summer ambient) are often used to calculate a steady-state thermal rating for the conductor.

2.1.2 Steady-state conductor temperature

Since the radiation and convection heat loss rates are not linearly dependent on the conductor temperature, the heat balance equation [equation (1b) of 2.4.1] is solved for conductor temperature in terms of the current and weather variables by a process of iteration. That is, given a conductor current,

a) A conductor temperature is assumed.
b) The corresponding heat losses are calculated.
c) The conductor current that yields this conductor temperature is calculated by means of equation (1b).
d) The calculated current is compared to the given conductor current.
e) The conductor temperature is then increased or decreased until the calculated current equals the given current.

2.2 Transient calculations

2.2.1 Transient conductor temperature

The temperature of an overhead power conductor is constantly changing in response to changes in electrical current and weather. In this standard, however, weather parameters (wind speed and direction, ambient temperature, etc.) are assumed to remain constant; and any change in electrical current is limited to a step change from an initial current, I_i, to a final current, I_f, as illustrated in figure 1.

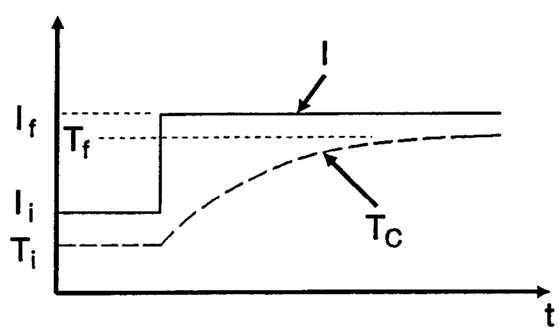

Figure 1 — Step change from initial current (I_i); to final current (I_f);

Immediately *prior* to the current step change ($t = 0^-$), the conductor is assumed to be in thermal equilibrium. That is, the sum of heat generation by Ohmic losses and solar heating equals the heat loss by convection and radiation.

Immediately *after* the current step change ($t = 0^+$), the conductor temperature is unchanged (as are the conductor resistance and the heat loss rate due to convection and radiation), but the rate of heat generation due to Ohmic losses has increased. Therefore, at time $t = 0^+$, the temperature of the conductor begins to increase at a rate given by the non-steady-state heat balance equation (2b) in 2.4.2.

After a period of time, Δt, the conductor temperature has increased by a temperature change of ΔT_c. The increased conductor temperature yields higher heat losses due to convection and radiation and somewhat higher Ohmic heat generation due to the increased conductor resistance. From Δt to $2\Delta t$, the conductor temperature continues to increase, but does so at a lower rate. After a large number of such time intervals, the conductor temperature approaches its final steady-state temperature (T_f).

During each interval of time, the corresponding increase in conductor temperature may be calculated using the formulas given in 2.4. The computer program included in annex A calculates the conductor temperature as a function of time after the step change in current.

Accuracy in the iterative transient calculation requires that the time step chosen be sufficiently small with respect to the thermal time constant. It is always prudent to rerun the calculation with a smaller time step to check whether the calculated values change.

2.2.2 Transient thermal rating

The transient thermal rating is normally calculated by repeating the preceding calculations of $T_c(t)$ over a range of I_f values, then selecting the I_f value that causes the conductor temperature to reach its maximum allowable value in the allotted time.

2.2.3 Fault current calculations

Conductor temperature changes in response to "fault" currents are calculated in the same manner as in 2.2.1, except that the step increase in current is usually quite large (>10 000 A), the corresponding time to reach maximum allowable temperature is typically short (<1 s), and the maximum temperatures attained may approach the melting point of aluminum or copper.

With nonhomogeneous conductors, such as ACSR (aluminum conductor steel reinforced), the heat generation in the lower conductivity steel core is much lower than in the surrounding aluminum strand layers. The resulting temperature difference between the core and the surrounding aluminum strands abates after no more than 60 s from any step change in current. This is discussed further in 2.4.8.

2.3 Identification of letter symbols

A'=	projected area of conductor (square feet per lineal foot)
D=	conductor diameter (in)
H_c=	altitude of sun (degrees)
H_e=	elevation of conductor above sea level (ft)
I=	conductor current (A at 60 Hz)
I_i=	initial current before step change (A at 60Hz)
I_f=	final current after step change (A at 60Hz)
K_{angle}=	wind direction factor
k_f=	thermal conductivity of air at temperature T_{film} W/ft (°C)
mC_p=	total heat capacity of conductor (W·s/ft °C)
m_i=	weight per unit length of i^{th} conductor material (lb/ft)
q_c=	convected heat loss (watts per lineal foot of conductor)
q_r=	radiated heat loss (watts per lineal foot of conductor)
q_s=	heat gain from the sun (watts per lineal foot of conductor)

Q_s=	total solar and sky radiated heat flux (W/ft^2)
$R(T_c)$=	60 Hz ac resistance per lineal foot of conductor at T_c (Ω/ft)
T_a=	ambient temperature (°C)
T_c=	conductor temperature (°C)
T_f=	conductor temperature attained many time constants after step increase (°C)
T_i=	conductor temperature prior to step increase, (°C)
T_{film}=	$(T_c + T_a)/2$ = air film temperature (°C)
T_{Low}, T_{High}=	minimum and maximum conductor temperatures for which the conductor's 60 Hz resistance is specified
V_w=	velocity of air stream (ft/h)
W=	watts
Z_c=	azimuth of sun (degrees)
Z_l =	azimuth of line (degrees)
C_{pi}=	specific heat of i^{th}conductor material (W·s/lb °C)
Δt=	time step used in transient calculation (s)
ΔT_c=	conductor temperature increment corresponding to time step Δt(°C)
α=	solar absorptivity (0.23 to 0.91)
$\in$=	emissivity (0.23 to 0.91)
τ=	thermal time constant of the conductor (min)
ϕ=	angle between wind and axis of conductor (degrees)
ρ_f=	density of air (lb/ft^3)
θ=	effective angle of incidence of the sun's rays (degrees)
μ_f=	absolute viscosity of air (lb/ft·hr)

2.4 Formulas

2.4.1 Steady-state heat balance

$$q_c + q_r = q_s + I2 \cdot R(T_c) \tag{1a}$$

$$I = \sqrt{\frac{q_c + q_r - q_s}{R(T_c)}} \tag{1b}$$

2.4.2 Non-steady-state heat balance

$$q_c + q_r + mC_p \frac{dT_c}{dt} = q_s + I^2 R(T_c) \tag{2a}$$

$$\frac{dT_c}{dt} = \frac{1}{mC_p}[R(T_c)I^2 + q_s - q_c - q_r] \tag{2b}$$

2.4.3 Forced convection heat loss

$$q_{c1} = \left[1.01 + 0.371\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.52}\right] \cdot k_f \cdot (T_c - T_a) \tag{3a}$$

$$q_{c2} = 0.1695\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.6} \cdot k_f \cdot (T_c - T_a) \tag{3b}$$

Equation (3a) applies at low winds but is too low at high speeds. Equation (3b) applies at high wind speeds, being too low at low wind speeds. At any wind speed, the larger of the two calculated convection heat losses is used.

The convective cooling term is multiplied by the wind direction factor, K_{angle}, where ϕ is the angle between the wind direction and the conductor axis:

$$K_{angle} = 1.194 - \cos(\phi) + 0.194\ \cos(2\phi) + 0.368\ \sin(2\phi) \tag{4a}$$

Alternatively, the wind direction factor may be expressed as a function of the angle, ω, between the wind direction and a perpendicular to the conductor axis. This angle is the complement of ϕ, and the wind direction factor becomes:

$$K_{angle} = 1.194 - \sin(\omega) - 0.194\ \cos(2\omega) + 0.368\ \sin(2\omega) \tag{4b}$$

This is the form of the wind direction factor as originally suggested in [B9] and is used in the computer program listed in annex A.

2.4.4 Natural convection

With zero wind speed, natural convection heat loss occurs, where

$$q_c = 0.283\rho_f^{0.5} D^{0.75} (T_c - T_a)^{1.25} \tag{5}$$

It has been argued that at low wind speeds, the convection cooling should be calculated by using a vectorial sum of the wind speed and a “natural” wind speed, see [B22]. However, it is recommended that only the larger of the forced and natural convection heat losses be used at low wind speeds because this is conservative. The computer program listed in annex A takes this approach.

For both forced and natural convection, air density (ρ_f), air viscosity (μ_f), and coefficient of thermal conductivity of air (k_f) are taken from table 1 at T_{film}, where

$$T_{film} = \frac{T_c + T_a}{2} \tag{6}$$

2.4.5 Radiated heat loss

$$q_r = 0.138 D\,\varepsilon \cdot \left[\left(\frac{T_c + 273}{100}\right)^4 - \left(\frac{T_a + 273}{100}\right)^4\right]$$

2.4.6 Solar heat gain (see tables 2 and 3)

$$q_s = \alpha Q_s \sin(\theta) A' \tag{8}$$

where

$$\theta = \cos^{-1}[\cos(H_c)\cos(Z_c - Z_l)] \tag{9}$$

2.4.7 Conductor electrical resistance

The electrical resistance of bare stranded conductor varies with frequency, average current density, and temperature. For 60 Hz ac, at temperatures of 25 °C to 75 °C, [B1] gives calculated values of electrical resistance for most standard aluminum power conductors.

These calculated values include the frequency-dependent "skin effect" for all types of stranded conductor, but, for other than single-layer ACSR, do not include a correction for current density dependent magnetic core effects, which is significant for ACSR conductors having odd numbers of layers of aluminum strands. The resistance of single-layer ACSR conductors (6/1, 7/1, 8/1) is shown to be increased as much as 20% in [B1]. The resistance of three-layer ACSR (45/7, 54/7, etc.) may be as much as 3% higher than the tabulated values. Engineering judgment is required in thermal calculations involving these ACSR conductors.

Resistance at temperatures above 75 °C may be calculated according to the methods described in [B1], [B3], and [B12].

In this standard, electrical resistance is calculated solely as a function of conductor temperature; however, the resistance values entered may be a function of frequency and current density. For example, the values of conductor resistance at high temperature, T_{HIGH}, and low temperature, T_{LOW}, may be taken from the tabulated values in [B1]. The conductor resistance at any other temperature, T_C, is found by linear interpolation according to equation (10):

$$R(T_c) = \left[\frac{R(T_{High}) - R(T_{Low})}{T_{High} - T_{Low}}\right] \cdot (T_c - T_{Low}) + R(T_{Low}) \tag{10}$$

This method of resistance calculation allows the user to calculate the high and low temperature resistance values by whatever means is appropriate.

Since the resistivity of most common metals used in stranded conductors increases somewhat faster than linearly with temperature, the resistance calculated by equation (10) will be somewhat high (and thus conservative for rating calculations) so long as conductor temperature is between T_{LOW} and T_{HIGH}. If the conductor temperature exceeds T_{HIGH}, however, the calculated resistance will be too low (and thus nonconservative for rating calculations). For example, based upon measurements of individual 1350 H19 aluminum strand resistance for a temperature range of 20 °C to 500 °C, entry of resistance values at temperatures of 25 °C and 75 °C will yield estimates of conductor resistance that are approximately 1% and 5% lower than measured values at temperatures of 175 °C and 500 °C, respectively. Between 25 °C and 75 °C, the error is negligible. Similarly, entry of resistance values at temperatures of 25 °C and 175 °C, will yield estimates that are approximately 3% too low at 500 °C but 0.5% too high at 75 °C.

It is concluded that the use of resistance data for temperatures of 25 °C and 75 °C from [B1] is adequate for rough calculations of steady state and transient thermal ratings for conductor temperatures up to 175 °C, and may be used for approximate fault calculations up to the melting point of typical conductor materials.

2.4.8 Conductor heat capacity

Conductor heat capacity is defined as the product of specific heat and mass per unit length. If the conductor consists of more than one material (e.g., ACSR), then the heat capacities of the core and the outer strands are each defined in this way.

For transient thermal rating calculations with durations of 5 to 30 min, the temperature of the conductor components remains approximately equal after the step increase in current; and the heat capacity of the conductor can be taken as the sum of the component heat capacities as shown in equation (11):

$$mC_{\mathrm{p}} = \sum m_{\mathrm{i}} \cdot C_{\mathrm{pi}} \tag{11}$$

Values for the specific heat of common metals used in stranded overhead conductors are listed in [B5] and in 3.6 of this standard.

With a nonhomogeneous conductor, for faults with durations of less than 60 s, the internal temperature difference between the core and the outer strands cannot be neglected. In particular, for ACSR conductor, the heat capacity of the relatively nonconducting steel core should be neglected for step currents whose duration is less than 60 s. For step currents whose duration is greater than 60 s, the heat capacity of the core is included. For step current durations of 10 to 60 s, the calculated conductor temperatures are somewhat conservative because any temperature difference between the core and outer strands decreases to zero with an internal thermal time constant of the order of 10 to 20 s.

2.5 Equations for tables 1, 2, 3, and 4

Least square polynomial regressions were performed on tabular data in the included tables and coefficients determined to fit an equation of the form:

$$Y = A + BX + CX^2 + DX^3 + EX^4 + FX^5 + GX^6$$

As suggested by Lutwen [B12], the equation for density takes a different form so as to evaluate the effects of both temperature and elevation. The coefficients for the polynomial expressions and the equation for density are as follows:

2.5.1 Viscosity (table 1)

Y= absolute viscosity, μ_f(lb/ft·hr)
X= temperature, T_{film} (°C)

A= 0.0415
B= $1.2034 \cdot 10^{-4}$
C= $-1.1442 \cdot 10^{-7}$
D= $1.9416 \cdot 10^{-10}$
E to G= 0

2.5.2 Density (table 1)

$$\rho_f = \frac{0.080695 - 0.2901 \cdot 10^{-5}(H_c) + 0.37 \cdot 10^{-10}(H_c^2)}{1 + 0.00367(T_{film})}$$

2.5.3 Thermal conductivity of air (table 1)

Y= thermal conductivity of air, k_f, in W/ft (°C)

X= temperature, T_{film}(°C)

A= 0.007388

B= $2.27889 \cdot 10^{-5}$

C= $-1.34328 \cdot 10^{-9}$

D to G= 0

Table 1 — Viscosity, density, and thermal conductivity of air

Temperature T_{film}			Absolute viscosity [B15] (lb/ft·hr)	Air density [B17] ρ_r (lb/ft[2])				Thermal conductivity of air [B18] (W/ft, °C)
°F	°C	°K	μ_r	Sea level	5 000 ft	10 000 ft	15 000 ft	k_f
32	0	273	0.0415	0.0807	0.0671	0.0554	0.0455	0.00739
41	5	278	0.0421	0.0793	0.0660	0.0545	0.0447	0.00750
50	10	283	0.0427	0.0779	0.0648	0.0535	0.0439	0.00762
59	15	288	0.0433	0.0765	0.0636	0.0526	0.0431	0.00773
68	20	293	0.0439	0.0752	0.0626	0.0517	0.0424	0.00784
77	25	298	0.0444	0.0740	0.0616	0.0508	0.0417	0.00795
86	30	303	0.0450	0.0728	0.0606	0.0500	0.0411	0.00807
95	35	308	0.0456	0.0716	0.0596	0.0492	0.0404	0.00818
104	40	313	0.0461	0.0704	0.0586	0.0484	0.0397	0.00830
113	45	318	0.0467	0.0693	0.0577	0.0476	0.0391	0.00841
122	50	323	0.0473	0.0683	0.0568	0.0469	0.0385	0.00852
131	55	328	0.0478	0.0672	0.0559	0.0462	0.0379	0.00864
140	60	333	0.0484	0.0661	0.0550	0.0454	0.0373	0.00875
149	65	338	0.0489	0.0652	0.0542	0.0448	0.0367	0.00886
158	70	343	0.0494	0.0643	0.0535	0.0442	0.0363	0.00898
167	75	348	0.0500	0.0634	0.0527	0.0436	0.0358	0.00909
176	80	353	0.0505	0.0627	0.0522	0.0431	0.0354	0.00921
185	85	358	0.0510	0.0616	0.0513	0.0423	0.0347	0.00932
194	90	363	0.0515	0.0608	0.0506	0.0418	0.0343	0.00943
203	95	368	0.0521	0.0599	0.0498	0.0412	0.0338	0.00952
212	100	373	0.0526	0.0591	0.0492	0.0406	0.0333	0.00966

2.5.4 Altitude of the sun (table 2)

Y= sun altitude, H_c(degrees)
X= line locations (degrees north latitude)

10:00 am Local Sun Time (2:00 pm)

A= 35.9201
B= 5.106109
C= –0.4049362
D= 0.01644423
E= $-3.543 \cdot 10^{-4}$
F= $3.7704 \cdot 10^{-6}$
G= $-1.5636 \cdot 10^{-8}$

Noon Local Sun Time

A = –427.2643
B= 78.43841
C= –4.7439
D= 0.147356
E= –0.0025127
F= $2.2318 \cdot 10^{-5}$
G= $-8.0736 \cdot 10^{-8}$

Table 2 — Altitude, H_c, and Azimuth, Z_c, in degrees of the sun at various latitudes [B2], [B25] Declination 23.0° — Northern hemisphere — June 10 and July 3

Degrees North latitude	Local sun time					
	10:00 am		Noon		2:00 pm	
	H_c	Z_c	H_c	Z_c	H_c	Z_c
20	62	78	87	0	62	282
25	62	88	88	180	62	272
30	62	98	83	180	62	262
35	61	107	78	180	61	253
40	60	115	73	180	60	245
45	57	122	68	180	57	238
50	54	128	63	180	54	232
60	47	137	53	180	47	223
70	40	143	43	180	40	217

2.5.5 Azimuth of the sun (table 2)

Y= sun azimuth, Z_c(degrees)
X= line location (degrees north latitude)

10:00 am Local Sun Time

A= 40.1428
B= 1.4292
C= 0.039
D= $-8.9781 \cdot 10^{-4}$
E= $4.9848 \cdot 10^{-6}$
F *to* G= 0

2:00 pm Local Sun Time

A= 334.2192
B= –2.9656
C= 0.0185
D *to* G= 0

2.5.6 Total heat flux received by a surface at sea level (table 3)

Table 3 — Total heat flux received by a surface at sea level normal to the sun's rays

Degrees solar altitude	(Q_s W/ft^2) Clear atmosphere	(See table 4) Industrial atmosphere
5	21.7	12.6
10	40.2	22.3
15	54.2	30.5
20	64.4	39.2
25	71.5	46.6
30	77.0	53.0
35	81.5	57.5
40	84.8	61.5
45	87.4	64.5
50	90.0	67.5
60	92.9	71.6
70	95.0	75.2
80	95.8	77.4
90	96.4	78.9

Y= total heat flux, Q_s(W/ft^2)
X= solar altitude, H_c (degrees)

Clear atmosphere

$A = -3.92414$
$B = 5.92762$
$C = -0.17856$
$D = 0.003223$
$E = -3.3549 \cdot 10^{-5}$
$F = 1.80527 \cdot 10^{-7}$
$G = -3.7868 \cdot 10^{-10}$

Industrial atmosphere

$A = 4.940779$
$B = 1.320247$
$C = +0.061444$
$D = -0.0029411$
$E = 5.07752 \cdot 10^{-5}$
$F = -4.03627 \cdot 10^{-7}$
$G = 1.22967 \cdot 10^{-9}$

2.5.7 Elevation correction factor (table 4)

Table 4 — Solar heat multiplying factors for high altitudes [B30]

Elevation above sea level H_e	Multiplier for values in table 3
0	1.00
5 000	1.15
10 000	1.25
15 000	1.30

$Y =$ total heat multiplier
$X =$ elevation (feet above sea level)
$A = 1$
$B = 3.5 \cdot 10^{-5}$
$C = -1.0 \cdot 10^{-9}$

2.6 Sample calculations

2.6.1 Steady-state thermal rating

The calculation of steady-state thermal rating given a maximum allowable conductor temperature, weather conditions, and conductor characteristics may be performed by the computer program in annex A. The following sample calculation is done with that program and is included in annex B. However, since the process does not require iterative calculations, it can also be done by hand. Doing so demonstrates the use of the formulas and yields some insight into the calculation process.

Note that in the following, the number of significant digits does not indicate the accuracy of the formula.

2.6.1.1 Problem statement

Find the steady-state thermal rating (ampacity) for a Drake conductor, 795 kcmil 26/7 ACSR, under the following conditions:

a) Wind velocity, V , is 2 ft/s at sea level perpendicular to the conductor.
b) Emissivity, $\in$, is 0.5.
c) Solar absorptivity, α, is 0.5.
d) Ambient air temperature, T_a, is 40 °C.
e) Maximum allowable conductor temperature is 100 °C.
f) Conductor outside diameter, D, is 1.108 in.
g) Conductor ac resistance, $R(T_c)$, is:
   $R(25\ °C) = 2.220 \cdot 10^{-5}\Omega/ft$
   $R(75\ °C) = 2.648 \cdot 10^{-5}\Omega/ft$
h) The line runs in a East-West direction.
i) Latitude is 30°N.
j) Atmosphere is clear.
k) Average sun altitude, H_c, between 10:00 am and 12:00 noon.

2.6.1.2 Convection heat loss (q_c).

The natural convection heat loss is calculated by means of equation (5):

$$q_c = 0.283\ \rho_f^{\ 0.5}\ D^{\ 0.75}\ (T_c - T_a)^{1.25}\ \text{W/ft} \tag{5}$$

where

D =1.108 in
T_c =100 °C

T_a =40 °C $T_{film} = \frac{100 + 40}{2} = 70\ °C$

ρ_f =0.0643 lb/ft^3(from table 1 at 70 °C)

q_c =0.283 (0.0643)$^{0.5}$(1.108)$^{0.75}$(100 – 40)$^{1.25}$
=0.283 (0.2536) (1.0799) (166.989)
=12.9 W/ft

Since the wind velocity is greater than 0 ft/s, the forced convection heat loss for perpendicular wind is calculated according to both equations (3a) and (3b) corrected for wind direction, and compared to the natural convection heat loss. The larger of the heat losses due to both natural and forced convection is then used in calculating the thermal rating:

$$q_{c1} = \left[101 + 0.371\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.52}\right]k_f(T_c - T_a) \tag{3a}$$

$$q_{c2} = 0.1695\left(\frac{D\rho_f V_w}{\mu_f}\right)^{0.6}k_f(T_c - T_a) \tag{3b}$$

where

D = 1.108 in

V_w = (2 ft/s) · 3600 (s/h)
T_c = 100 °C

T_a = 40 °C $T_{film} = \frac{T_c + T_a}{2} = \frac{100 + 40}{2} = 70$ °C

μ_f = 0.0494 lb/h (ft) (from table 1 at 70 °C)
ρ_f = 0.0643 lb/ft^3(from table 1 at 70 °C)
k_f = 0.00898 W/ft (°C) (from table 1 at 70 °C)

$$qc1 = \left[1.01 + 0.371\left(\frac{1.108 \cdot 0.0643 \cdot 7200}{0.0494}\right)^{0.52}\right] \cdot 0.00898 \cdot 100 - 40 = 25.052 \text{ W/ft}$$

$$qc2 = \left[\frac{1.108 \cdot 0.0643 \cdot 7200}{0.0494}\right]^{0.6} \cdot 0.00898 \cdot 60 = 23.464 \text{ W/ft}$$

therefore,

q_c = 25.052 W/ft of conductor

Since the wind is perpendicular to the axis of the conductor, the wind direction multiplier, K_{angle}, is 1.0, and the forced convection heat loss is greater than the natural convection heat loss. Therefore, the forced convection heat loss will be used in the calculation of thermal rating.

2.6.1.3 Radiated heat loss (q_r)

$$q_r = 0.138 D\varepsilon \cdot \left[\left(\frac{T_c + 273}{100}\right)^4 - \left(\frac{T_a + 273}{100}\right)^4\right] \quad (7)$$

where

D = 1.108 in
$\in$ = 0.5
T_c = 100 °C
T_a = 40 °C

$$q_r = 0.138 \cdot 1.108 \cdot 0.5\left[\left(\frac{373}{100}\right)^4 - \left(\frac{313}{100}\right)^4\right] = 7.461 \text{ W/ft of conductor}$$

2.6.1.4 Solar heat gain

$$q_s = \alpha Q_s (\sin \theta) A' \quad (8)$$

$$\theta = \cos^{-1} [(\cos H_c) \cos (Z_c - Z_l)] \quad (9)$$

where

α = 0.5

$A¢ = \frac{D}{12} = \frac{1.108}{12} = 0.092$ ft^2/ft

From table 2 at 30° North latitude:

H_c at 10:00 am = 62°
H_c at 12:00 noon = 83°

H_c at 11:00 am $= \frac{83 + 62}{2} = 72.5°$

Z_c at 10:00 am $= 98°$
Z_c at 12:00 noon $= 180°$

Z_c at 11:00 am $= \frac{98 + 180}{2} = 139°$

From table 3 for $H_c = 72.5°$ with a clear atmosphere:

By interpolation, $Q_s = 95.2$ W/ft^2
$Z_l = 90°$ or $270°$
$\theta = \cos^{-1}[\cos(72.5)\cos(139 - 90)] = 78.62°$
$q_s = 0.5 \cdot 95.2 \cdot \sin(78.62) \cdot 0.092$
$= 4.293$ W/ft of conductor

2.6.1.5 Resistance at 100 °C

$$R(100) = R(25) + \left[\frac{R(75) - R(25)}{75 - 25}\right](100 - 25)$$

$$= 2.220 \cdot 10^{-5} + \left(\frac{2.648 \cdot 10^{-5} - 2.220 \cdot 10^{-5}}{50}\right) \cdot 75$$

$$= 2.862 \cdot 10^{-5}\ \Omega/\text{ft}$$

2.6.1.6 Steady-state thermal rating

$$I = \sqrt{\frac{q_c + q_r - q_s}{R(100)}}$$

where

$q_c = 25.052$ W/ft of conductor
$q_r = 7.461$ W/ft of conductor
$q_s = 4.293$ W/ft of conductor
$R(100) = 2.862 \cdot 10^{-5}\ \Omega$/ft

$$I = \sqrt{\frac{25.052 + 7.461 - 4.293}{2.862 \cdot 10^{-5}}} = 992\ \text{A}$$

The program listed in annex A can also be used to calculate the steady-state thermal rating. The results of such a run are presented in annex B.

2.6.2 Steady-state conductor temperature

The steady-state conductor temperature for a given electrical current, weather conditions, and conductor characteristics can be calculated by means of the computer program in annex A. A sample calculation is included in annex C. This calculation cannot easily be done by hand since it requires repeated calculations of current, given trial values of conductor temperature, to converge to a solution.

2.6.3 Transient conductor temperature

The calculation of conductor temperature vs. time in response to a step change in electrical current can be accomplished by means of the program in annex A. The program is capable of calculating conductor temperature changes in response to a step change in electrical current where either the initial current or the initial conductor temperature is known.

For example, one may calculate the transient conductor temperature for the same “Drake” conductor and weather parameters as used in the previous steady-state sample calculation of 2.6.1, but where there is a step change in current from an initial current of 800 A to final currents of 1200 and 1300 A. The weather conditions and conductor parameters are assumed constant for all time before and after the step change in current.

With reference to annex D, it can be seen that the steady-state conductor temperature corresponding to an initial current of 800 A is 81 °C. The steady-state conductor temperatures corresponding to the final current of 1200 A and 1300 A are 128 °C and 144 °C, respectively. In the computer runs of annex D, conductor temperature is calculated for every 2 min after the step change in current. Plots of conductor temperature vs. time are shown in figure 2 for the first 60 min after the increase in current.

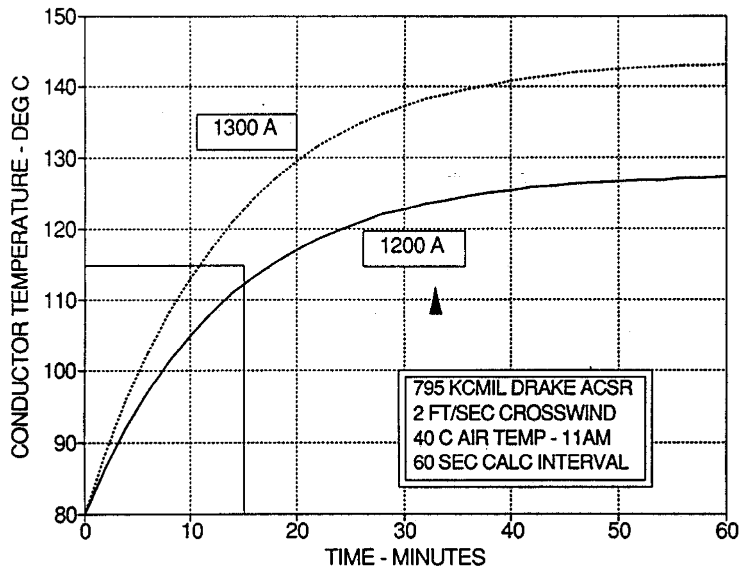

Figure 2 — Conductor temperature vs. time curves

From figure 2, it may be seen that the rate of increase in conductor temperature after the current step and the final steady-state conductor temperature both increase as the final current increases. The variation in conductor temperature with time is approximately exponential.

Transient conductor temperature calculations for relatively high fault currents for short times can also be performed with the same program. As shown in the last pages of annex D, a step current of 80 000 A causes a rapid increase in conductor temperature to over 300 °C in 0.5 s.

2.6.4 Transient thermal ratings

Transient thermal ratings may also be calculated with the computer program included in annex A. The program determines transient thermal ratings by calculating a number of conductor temperature vs. time curves (such as those shown in figure 2). This is illustrated in the following sample problem.

The initial electrical current in a “Drake” conductor is 800 A. The final current level that will yield a maximum allowable conductor temperature of 115 °C in 15 min, i.e., the 15 min Transient Thermal Rating, is to be found. The weather conditions and conductor parameters remain the same as in the preceding examples.

Referring to figure 2, it can be seen that a final current of 1200 A causes the conductor temperature to increase from 81 °C to 115 °C in about 17 min. From the same figure, one can also see that a final current of

1300 A causes the conductor temperature to reach 115 °C in about 10 min. The 15 min transient thermal rating is therefore between 1200 and 1300 A.

The computer program performs a series of such calculations, adjusting the assumed final current until the conductor temperature just reaches 115 °C, 15 min after the step increase in current. As shown in annex E, an emergency current of 1231 A causes the conductor temperature to reach 115 °C in 15 min. The 15 min transient thermal rating of the Drake conductor is therefore 1231 A.

Fault current ratings can also be calculated with this program. As shown in annex E, for a maximum allowable conductor temperature of 640 °C (the melting point of aluminum) and a duration of 0.25 s, the transient thermal (fault) rating is 123 000 A.

2.6.5 Thermal time constant

The thermal time constant is a useful concept in thermal ratings in that it allows convenient comparison of thermal response time for overhead conductors and other potentially thermally limited equipment such as transformers or circuit breakers. As an example, consider the Drake conductor exposed to a step increase in current from 800 to 1200 A as shown in figure 2. Reading from the figure directly, the conductor temperature increases from 81 °C to 111 °C, [81 °C + 0.63 · (128 °C – 81 °C)], in 12.5 min. See annex F for a more detailed discussion of time constant.

3. Input data

3.1 Introduction

Careful selection of input data for current-temperature relationships is as important as the method of calculation itself, and requires considerable engineering judgment in the selection of values for each of the variables. These variables are discussed separately under separate headings, with suggestions given on how to select values to suit particular circumstances. Some suggestions are given as to what factors should be considered when it is necessary to make decisions.

3.2 Wind and ambient temperature

Weather conditions have a considerable effect on the thermal loading of bare overhead conductors. The weather provides cooling, principally by means of convective heat loss, q_c, to the surrounding air. The degree of cooling depends on air temperature and the wind velocity component perpendicular to the conductor.

Weather information can be obtained from local weather bureaus and, possibly, from other local weather stations. Recorded wind speeds of less than 3 m/s (3.5 m/h, 5 ft/s) from weather bureau records are often inaccurate [B26]. Most wind speeds have been obtained by the weather bureau standard cup-type anemometer which has significant starting inertia; therefore, readings at low wind speeds are in doubt.

The effect of wind direction relative to the conductor is included in this standard as equation (4) in the form suggested by Davis [B9]. The difference between the wind correction factors suggested by Morgan [B22] and Davis are considered to be minor. For a given wind speed, winds blowing parallel result in a 60% lower convective heat loss than winds blowing perpendicular to the conductor.

Effects of wind turbulence and conductor stranding appear to be of minor importance in thermal rating or conductor temperature calculations. Evaporative cooling is a major factor, but it occurs sporadically along transmission lines. Both are neglected in this standard.

Height of conductors above ground is significant in terms of wind shielding. Higher voltage lines (where the conductor ground clearance is greater) may be expected to be less shielded by trees and terrain than low-voltage lines.

3.3 Air density, viscosity, and conductivity

The density, viscosity, and thermal conductivity of air are used in the calculation of convection losses and can be obtained from table 1. The regression equations provided in clause 2 may be more useful for computer applications, as they can reduce the amount of data stored and save on computer time.

Regardless of whether the tables or equations are used, it is recommended that the highest altitude that is applicable at the location of the line be selected, because this will tend to give the most conservative results.

3.4 Emissivity and absorptivity

References [B27] and [B19] indicate that $\in$ and α increase from about 0.2 to about 0.9 with age. The exact rate of increase depends on the level of atmospheric pollution and the line's operating voltage. α is generally higher than $\in$ over the life of the conductor. Both values increase with age and atmospheric pollution. Values of 0.5 for both absorptivity and emissivity, or 0.7 for absorptivity and 0.5 for emissivity, have been used when the actual conductor surface condition is unknown.

3.5 Solar heat gain

A simple method for the calculation of solar heat gain is provided by equations (8) and (9). The most conservative results are obtained by assuming an angle of incidence of 90°, which will give the lowest value of ampacity and will be appropriate for many purposes.

It may be desired to establish summer and winter values, in which case it is suggested that [B19] and [B25] be consulted for values appropriate to the location, time of year, and time of day.

Weather simulation models (see [B10]) may also be used. For real-time rating systems, the direct-beamed and sky or diffuse radiation may be input directly from data obtained from weather stations, see [B7] and [B8].

3.6 Conductor heat capacity

The conductor heat capacity is the sum of the products of specific heat and mass per unit length of its components. The mass per unit length of conductor and conductor components for all common aluminum and aluminum composite conductors is given in [B1]. The specific heats of usual conductor materials are listed below as taken from this reference.

The computer program in annex A of this standard calls for heat capacity in mixed units. For 795 kcmil 26/7 Drake ACSR, the weights of the steel core and the outer layers of aluminum are 0.344 lb/ft and 0.750 lb/ft, respectively, so that the total conductor heat capacity at 25 °C is:

$$mC_p(\text{aluminum at } 25°\text{C}) = 0.750\ (\text{lb/ft}) \cdot 433\ (\text{W·s/lb °C}) = 325\ \text{W·s/ft °C}$$

$$mC_p(\text{steel at } 25°\text{C}) = 0.344\ (\text{lb/ft}) \cdot 216\ (\text{W·s/lb °C}) = 74.3\ \text{W·s/ft °C}$$

As listed in [B5], the specific heats of common conductor materials are:

Material	C_p (W-s/lb-°C)
Aluminum	433
Copper	192
Steel	216
Alumoweld	242

The specific heat of alumoweld depends on the aluminum-to-steel ratio. This is a typical value.

3.7 Maximum allowable conductor temperature

Since the thermal rating of any conductor is dependent upon its maximum allowable temperature, and since this temperature varies widely according to engineering practice and judgment (temperatures of 50 °C to 180 °C are in use for ACSR), the thermal rating of any conductor also varies widely. Therefore, one of the most important aspects of thermal rating calculations is the proper selection of a maximum allowable conductor temperature.

The maximum allowable conductor temperature is normally selected so as to limit either conductor loss of strength due to the annealing of aluminum or to maintain adequate ground clearance. Loss of conductor strength and/or permanent sag increase due to creep elongation of the conductor accumulates over time. When these effects are considered, it is common to use a higher maximum allowable conductor temperature for transient thermal rating calculations than for steady-state thermal rating calculations. For fault calculations, the maximum allowable temperature is normally close to the melting point of the conductor material.

3.8 Time step

For calculation of transient ampacity and temperature, the time step must be made sufficiently small so as to result in an accurate calculation. A time step equal to 1% of the conductor thermal time constant is usually sufficient.

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Annex A

(informative)

Listing of the "RATEIEEE" program for steady-state and transient calculations of temperature and thermal rating for bare overhead conductors

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10 REM ******************************************************************
20 REM * IEEE METHOD - CALCULATION OF THERMAL BEHAVIOR OF BUS OR
30 REM * OVERHEAD CONDUCTOR IN AIR UNDER THE FOLLOWING CONDITIONS:
40 REM * - STEADY STATE CONDUCTOR TEMPERATURE
50 REM * - STEADY STATE THERMAL RATING
60 REM * - TRANSIENT CONDUCTOR TEMPERATURE
70 REM * - TRANSIENT THERMAL RATING
80 REM * - MAXIMUM FAULT CURRENT RATING
90 REM * - MAXIMUM FAULT DURATION
100 REM * SOURCE OF FORMULAS IN IEEE STANDARD 738
110 REM * PROGRAM LISTED IN ANNEX A
120 REM * PROGRAM LAST MODIFIED 6/10/91 BY DAD
130 REM * FILE NAME "RATEIEEE.BAS"
140 REM * PROGRAM MODIFIED FOR PC BASIC
150 REM * AVAILABILITY - SOURCE LISTINGS ONLY
160 REM ******************************************************************
170 REM * DATA STATEMENTS FOR DRAKE ACSR AND STANDARD WEATHER CONDITIONS
180 REM * ARE INCLUDED FOR TEST PURPOSES - YOU MAY CHOOSE THESE OR ENTER
190 REM * YOUR OWN VALUES.
200 REM * THE IEEE 738 STANDARD PRESENTS THE MATHEMATICAL EQUATIONS
210 REM * REQUIRED TO CALCULATE THERMAL RATINGS AND TEMPERATURE FOR
220 REM * BARE OVERHEAD CONDUCTOR. THIS PROGRAM HAS BEEN WRITTEN TO
230 REM * PERFORM THE CALCULATIONS DESCRIBED IN THE STANDARD AS A CONVE-
NIENCE
240 REM * TO OTHERS. REASONABLE EFFORT HAS BEEN EXPENDED TO
250 REM * ENSURE THAT THE PROGRAM YIELDS ACCURATE CALCULATIONS UNDER
252 REM * ANTICIPATED CONDITIONS. IT IS THE USER'S RESPOSIBILITY, HOWEVER,
254 REM * TO CHECK SUCH CALCULATIONS AGAINST TEST DATA OR OTHER METHODS.
260 REM ***********************************
270 REM * INITIALIZE VARIABLES AND ARRAYS *
280 REM ***********************************
290 DIM ATCDR (3000)
300 DIM TIME (3000)
305 FLAG1 = 0
310 XIDUMMY = 0
320 XIPRELOAD = 0
330 XISTEP = 0
340 TCDR = 0
350 TCDRPRELOAD = 0
360 TCDRMAX = 0
370 IORTPRELOAD = 0
372 DELTIME = 0
373 FS1 = 0
374 FS2 = 0
375 REM CHG 6/12/90 FS3 = 0
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376 X$ = STRING$ (56, 45)
377 REM ******************************
378 REM * START REPEAT CALCULATION HERE
379 REM ******************************
380 FOR KI = 1 TO 3000
390 ATCDR(KI) = 0
400 TIME(KI) = 0
410 NEXT KI
420 FLAG = 0
450 NFLAG = 0
470 PI = 3.141593
475 IF FLAG1 = 99 GOTO 610
480 REM ************************************
490 REM * CHOOSE THE DESIRED CALCULATION
500 REM ************************************
510 CLS
520 PRINT "**********MENU OF POSSIBLE CALCULATIONS*************"
530 PRINT "1 = STEADY-STATE CONDUCTOR TEMPERATURE GIVEN CURRENT"
540 PRINT "2 = AMPACITY (STEADY-STATE THERMAL RATING)"
550 PRINT "3 = CONDUCTOR TEMPERATURE GIVEN STEP CHANGE IN CURRENT"
560 PRINT "4 = TRANSIENT THERMAL OR FAULT RATING "
565 INPUT " ENTER THE NUMBER OF THE DESIRED CALCULATION ", NSELECT
570 IF (NSELECT <> 1) AND (NSELECT <> 2) AND (NSELECT <> 3) AND (NSELECT <> 4) THEN
GOTO 520
580 REM ***********************************************
590 REM ENTER INPUT DATA DESCRIBING CONDUCTOR AND WEATHER
600 REM ***********************************************
610 CLS
620 PRINT "ENTER WEATHER DATA "
630 GOSUB 2000
640 PRINT "ENTER CONDUCTOR DATA "
650 GOSUB 3000
660 PRINT "ENTER CURRENT OR CONDUCTOR TEMPERATURE DATA"
670 GOSUB 4000
680 REM ***************************************
690 REM * CALCULATE SOLAR HEAT INPUT TO CONDUCTOR
700 REM ***************************************
710 GOSUB 5000
720 REM ***********************************************************
730 REM * CALCULATE THERMAL COEF OF RESISTANCE & WIND ANGLE CORRECTION
740 REM ***********************************************************
750 GOSUB 9000
760 REM ******************************
770 REM * SELECT THE CALCULATION DESIRED
780 REM ******************************
790 ON NSELECT GOTO 1060, 800, 1020, 1020
800 REM ***********************************************************
810 REM *FOR NSELECT = 2
820 REM * GO TO AMPACITY SUBROUTINE TO CALCULATE THE STEADY STATE
830 REM * CURRENT (TR) GIVEN THE STEADY STATE CONDUCTOR TEMPERATURE (TCDR)
840 REM * THE CONDUCTOR TEMPERATURE IS GIVEN SO ONLY ONE PASS THROUGH
850 REM * THE SUBROUTINE IS REQUIRED.
860 REM ****************************************************************
870 TCDR = TCDRPRELOAD
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```
880 GOSUB 15000
890 GOTO 1290
900 REM *****************************************************************
910 REM
920 REM ****************************************************************
930 REM *FOR NSELECT = 1, 3, OR 4
940 REM * GO TO AMPACITY SUBROUTINE REPEATEDLY IN ORDER TO CALCULATE
950 REM * THE STEADY STATE CURRENT (TR) CORRESPONDING TO TRIAL VALUES OF
960 REM * CONDUCTOR TEMPERATURE (TCDR). IF T=1 THEN THE OUTPUT OF THE
970 REM * SUBROUTINE, TR, IS THE STEADY STATE CURRENT FOR
980 REM * WHICH A STEADY STATE TEMPERATURE WAS TO BE FOUND.
990 REM * IF T=3 OR 4 AND IORTPRELOAD=1, THEN TR IS THE INITIAL PRE-STEP
1000 REM * CHANGE CURRENT FOR WHICH AN INITIAL TEMPERATURE WAS TO BE CALCU-
LATED.
1010 REM *******************************************************************
1020 ON IORTPRELOAD GOTO 1060, 1210
1030 REM ********************************************
1040 REM * CALCULATE TCDR GIVEN XIDUMMY = XIPRELOAD *
1050 REM ********************************************
1060 XIDUMMY = XIPRELOAD
1070 NFLAG = 0
1080 GOSUB 13000
1090 TCDRPRELOAD = TCDR
1100 REM **************************************************************
1110 REM * FOR NSELECT = 1 THE PROGRAM HAS FOUND THE STEADY STATE CONDUCTOR
1120 REM * TEMPERATURE (TCDRPRELOAD) CORRESPONDING TO THE GIVEN STEADY
STATE
1130 REM * CURRENT (XIPRELOAD) AND CONTROL IS PASSED TO THE PRINTOUT SECTION
1140 REM **************************************************************
1150 IF NSELECT = 1 THEN 1290
1160 REM ****************************************************************
1170 REM * FOR NSELECT = 3 OR 4, THE PROGRAM HAS DETERMINED (IORTPRELOAD=1) OR
BEEN
1180 REM * GIVEN (IORTPRELOAD=2) THE INITIAL STEADY STATE CONDUCTOR TEMPERA-
TURE
1190 REM * AND CONTROL PASSES TO FURTHUR TRANSIENT CALCULATIONS
1200 REM ****************************************************************
1210 IF NSELECT = 4 THEN GOSUB 10000
1220 REM ************************************************************
1230 REM * BEGIN CALCULATION OF CONDUCTOR TEMP AS A FUNCTION OF TIME
1240 REM * FOR A STEP INCREASE IN ELECTRICAL CURRENT, NSELECT = 3
1250 REM ************************************************************
1270 XISTEP = XISTEP
1280 GOSUB 11000
1290 REM *************************
1300 REM * PRINT RESULTS TO SCREEN
1310 REM *************************
1320 GOSUB 6000
1330 REM ********************************************
1340 REM * REPEAT PROGRAM CALCULATIONS WITH NEW DATA
1350 REM ********************************************
1360 INPUT "DO YOU WANT TO RUN THE PROGRAM AGAIN (YES = 1, NO = 2)", YN
1370 IF YN <> 1 AND YN <> 2 THEN GOTO 1360
1380 IF YN = 2 GOTO 1400
```

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1385 REM REMOVED GENERAL RESTORE FROM FOLLOWING LINE 6/12/90
1390 IF YN = 1 THEN FLAG1 = 99: GOTO 380
1400 END
2000 REM ////////////////////////////////////
2010 REM / SUBROUTINE TO ENTER WEATHER DATA
2020 REM ////////////////////////////////////
2030 CLS
2035 IF FLAG1 = 99 THEN GOTO 2300
2040 PRINT "DO YOU WANT TO ENTER WEATHER DATA FROM THE KEYBOARD (ENTER 1)"
2050 INPUT "OR USE BUILT-IN EXAMPLE WEATHER DATA (ENTER 2)? ", FS1
2060 IF FS1 <> 1 AND FS1 <> 2 THEN GOTO 2040
2070 IF FS1 = 2 THEN GOTO 2250
2080 INPUT "ENTER THE AIR TEMPERATURE IN DEG. C ", TAMB
2090 INPUT "ENTER THE WINDSPEED IN ft/sec ", VWIND
2110 PRINT "ENTER ANGLE (DEG) BETWEEN WIND AND CONDUCTOR "
2120 INPUT " (0=PARALLEL, 90=PERPENDICULAR, etc) ", WINDANG.DEG
2130 INPUT "ENTER CONDUCTOR ELEV IN FEET ABOVE SEA LEVEL ", CDR.ELEV
2140 PRINT "ENTER THE CONDUCTOR DIRECTION, 1 FOR EAST-WEST "
2150 INPUT " OR 0 FOR NORTH-SOUTH ", CDR.DIR
2160 IF CDR.DIR = 0 THEN Z1 = 0: AS = "NORTH-SOUTH"
2170 IF CDR.DIR = 1 THEN Z1 = 90: AS = "EAST-WEST"
2180 INPUT "ENTER THE CONDUCTOR LATITUDE IN DEGREES ", CDR.LAT
2190 PRINT "ENTER THE LOCAL SUN TIME BETWEEN 10AM AND 2PM"
2200 PRINT "10AM(10), 11AM(11), 12PM(12), 1PM(13), 2PM(14)"
2210 INPUT "OR ENTER 99 IF THERE IS NO SOLAR HEATING ", SUN.TIME
2220 INPUT "ENTER 1 FOR AN INDUSTRIAL AND 0 FOR A CLEAR ATMOSPHERE ", A3
2230 IF A3 = 1 THEN B$ = "INDUSTRIAL" ELSE B$ = "CLEAR"
2240 GOTO 2300
2250 REM ************************************
2260 REM * ENTER BUILT-IN TEST WEATHER DATA
2270 REM ************************************
2275 REM ADD FOLLOWING LINE 6/12/90
2276 RESTORE 2290
2280 READ TAMB, VWIND, WINDANG.DEG, CDR.ELEV, CDR.DIR, AS, CDR.LAT, SUN.TIME, A3, B$
2290 DATA 40, 2, 90, 0, 1, EAST-WEST, 30, 11, 0, CLEAR
2292 REM ***********************************
2294 REM * PLAYBACK WEATHER DATA TO SCREEN
2296 REM ***********************************
2300 CLS
2310 IF FS1 = 1 AND FLAG1 = 0 THEN PRINT "YOU HAVE ENTERED THE FOLLOWING WEATHER DATA: "
2320 IF FS1 = 2 AND FLAG1 = 0 THEN PRINT "THE BUILT-IN TEST WEATHER DATA IS:"
2325 IF FLAG1 = 99 THEN PRINT "THE WEATHER DATA IS:"
2330 PRINT "AIR TEMPERATURE = "; TAMB; "DEG C"
2340 PRINT "WIND SPEED = "; VWIND; "FT/SEC"
2350 PRINT USING "ANGLE BETWEEN WIND AND CONDUCTOR = ### DEG"; WINDANG.DEG
2360 PRINT USING "CONDUCTOR ELEVATION = ##### FT ABOVE SEA LEVEL"; CDR.ELEV
2370 PRINT USING "CONDUCTOR DIRECTION IS & "; AS
2380 PRINT USING "THE CONDUCTOR LATITUDE IS ### "; CDR.LAT
2390 PRINT "THE LOCAL SUN TIME VARIABLE IS "; SUN.TIME
2400 PRINT USING "THE ATMOSPHERE IS &"; B$
2410 INPUT " DO YOU WANT TO RE-ENTER THE WEATHER DATA (1=YES;0=NO)", YN
2420 IF YN <> 1 AND YN <> 0 THEN GOTO 2410
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2435 IF YN = 1 GOTO 2040
2440 RETURN
3000 REM ************************************
3010 REM * SUBROUTINE TO ENTER CONDUCTOR DATA
3020 REM ************************************
3030 CLS
3035 IF FLAG1 = 99 THEN GOTO 3495
3040 PRINT "DO YOU WANT TO ENTER CONDUCTOR DATA FROM THE KEYBOARD (ENTER 1)"
3050 INPUT "OR USE BUILT-IN DATA FOR DRAKE ACSR (ENTER 2)? ", FS2
3060 IF FS2 <> 1 AND FS2 <> 2 THEN GOTO 3040
3070 IF FS2 = 2 THEN GOTO 3420
3080 INPUT "ENTER A DESCRIPTION OF THE CONDUCTOR ", CS
3090 INPUT "ENTER THE CONDUCTOR DIAMETER IN INCHES ", D
3100 PRINT
3110 PRINT "CONDUCTOR RESISTANCE IS ASSUMED TO BE A LINEAR FUNCTION OF "
3120 PRINT "CONDUCTOR TEMPERATURE IN THIS PROGRAM. THEREFORE YOU MUST ENTER
"
3130 PRINT "THE CONDUCTOR RESISTANCE AT A LOW AND A HIGH TEMPERATURE. THE "
3140 PRINT "PROGRAM WILL AUTOMATICALLY CALCULATE THE RESISTANCE AT ALL
OTHER "
3150 PRINT "TEMPERATURES."
3160 INPUT "ENTER THE LOW CONDUCTOR TEMPERATURE (IN DEG C)", TLO
3170 INPUT "ENTER THE HIGH CONDUCTOR TEMPERATURE (IN DEG C)", THI
3180 INPUT "THE CONDUCTOR RESISTANCE (IN OHM/MI) AT THE LOW TEMP = ", RLO
3200 INPUT "THE CONDUCTOR RESISTANCE (IN OHM/MI) AT THE HIGH TEMP = ", RHI
3220 INPUT "ENTER THE CONDUCTOR'S EMISSIVITY, 0.23 TO 0.91 ", EMISS
3230 INPUT "ENTER THE CONDUCTOR'S SOLAR ABSORPTIVITY, 0.23 TO 0.91 ", ABSORP
3240 IF NSELECT = 1 OR NSELECT = 2 THEN GOTO 3470
3250 PRINT "IS THE CONDUCTOR HOMOGENEOUS (ALL ALUMINUM, ALL COPPER, ACAR,
ETC)"
3260 PRINT "OR DOES IT HAVE A STEEL CORE (ACSR, ACSR/AW, ETC.)? "
3270 PRINT "HOMOGENEOUS CONDUCTOR - ENTER 1"
3280 INPUT "CONDUCTOR HAS A STEEL CORE - ENTER 2"; HNH
3290 IF HNH <> 1 AND BNH <> 2 THEN GOTO 3250
3300 IF HNH = 2 THEN GOTO 3350
3310 PRINT "THE CONDUCTOR IS HOMOGENEOUS"
3320 INPUT "ENTER ITS HEAT CAPACITY IN (WATTS-SEC/FT-C) ", HEATOUT
3330 HEATCORE = 0
3340 GOTO 3470
3350 PRINT "THE CONDUCTOR HAS A STEEL CORE. THEREFORE, THE PROGRAM WILL"
3360 PRINT "NEGLECT THE CORE HEAT CAPACITY FOR 'FAULT' CURRENTS OF"
3370 PRINT "LESS THAN 60 SECONDS DURATION."
3380 PRINT
3390 INPUT "ENTER THE HEAT CAPACITY OF THE STEEL CORE (IN WATTS-SEC/FT-C) ", HEAT-
CORE
3400 INPUT "ENTER THE HEAT CAPACITY OF THE OUTER STRAND LAYERS (IN WATT-SEC/FT-
C)", HEATOUT
3410 GOTO 3470
3420 REM *****************************************
3430 REM * ENTER BUILT-IN TEST DATA FOR DRAKE ACSR
3440 REM **********************************************
3445 REM ADD FOLLOWING LINE 6/12/90
3446 RESTORE 3460
3450 READ CS, D, TLO, THI, RLO, RHI, EMISS, ABSORP, HNH, HEATOUT, HEATCORE
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3460 DATA DRAKE, 1.108, 25, 75, .1172, .1398, .5, .5, 2, 318.9, 70.7
3470 HEATCAP = HEATCORE + HEATOUT: CLS
3472 REM ************************************
3474 REM * PLAYBACK CONDUCTOR DATA TO SCREEN
3476 REM ************************************
3480 IF FS2 = 1 THEN PRINT "YOU HAVE ENTERED THE FOLLOWING CONDUCTOR DATA: "
3490 IF FS2 = 2 THEN PRINT "THE DEFAULT CONDUCTOR DATA IS:"
3495 IF FLAG1 = 99 THEN PRINT "THE CONDUCTOR DATA IS:"
3500 PRINT "DESCRIPTION": PRINT CS
3510 PRINT USING "CONDUCTOR DIAMETER = ##.### INCHES"; D
3520 PRINT USING "CONDUCTOR RESISTANCE IS ##.#### OHMS/MI AT #### DEG C"; RLO; TLO
3530 PRINT USING" AND ##.#### OHMS/MI AT #### DEG C"; RHI; THI
3540 PRINT" EMISSIVITY IS "; EMISS
3550 PRINT" ABSORPTIVITY IS "; ABSORP
3560 IF NSELECT = 1 OR NSELECT = 2 THEN GOTO 3630
3570 IF HNH = 1 THEN PRINT "THE CONDUCTOR IS HOMOGENEOUS"
3580 IF HNH = 2 THEN PRINT "THE CONDUCTOR HAS A STEEL CORE": GOTO 3610
3590 PRINT USING "THE HEAT CAPACITY OF THE CONDUCTOR IS ####.# WATTS-SEC/FT-C";
HEATOUT
3600 GOTO 3630
3610 PRINT USING "THE HEAT CAPACITY OF THE STEEL CORE IS ####.# WATT-SEC/FT-C";
HEATCORE
3620 PRINT USING "THE HEAT CAPACITY OF THE OUTER STRAND LAYERS IS ####.# WATT-
SEC/FT-C";
HEATOUT
3630 PRINT
3640 INPUT "DO YOU WANT TO RE-ENTER THE CONDUCTOR DATA (1=YES;0=NO)", YN
3650 IF YN = 1 GOTO 3040
3660 RETURN
4000 REM ****************************************************************
4010 REM * SUBROUTINE TO ENTER CONDUCTOR TEMPERATURE, TIME & CURRENT DATA
4020 REM ****************************************************************
4030 REM * ENTER STEADY STATE CALCULATION DATA
4040 REM **************************************
4045 IF FLAG1 = 99 GOTO 4650
4050 ON NSELECT GOTO 4090, 4060, 4150, 4150
4060 CLS : PRINT "ENTER THE MAXIMUM ALLOWABLE STEADY STATE "
4070 INPUT " CONDUCTOR TEMPERATURE IN DEG. C ", TCDRPRELOAD
4080 GOTO 4640
4090 CLS : INPUT "ENTER THE STEADY STATE CONDUCTOR ELECTRICAL CURRENT IN
AMPERES ", XIPRELOAD
4100 IF XIPRELOAD = 0 THEN XIPRELOAD = 1.111
4110 GOTO 4640
4120 REM **********************************
4130 REM * ENTER TRANSIENT CALCULATION DATA
4140 REM **********************************
4150 CLS : PRINT "ALL TRANSIENT CALCULATIONS ASSUME:"
4160 PRINT " (1) THE CONDUCTOR IS INITIALLY IN THERMAL EQUILIBRIUM (STEADY-
STATE)"
4170 PRINT " (2) A STEP INCREASE IN ELECTRICAL CURRENT OCCURS AT TIME 'ZERO'"
4180 PRINT " (3) WEATHER CONDITIONS ARE THE SAME BEFORE & AFTER THE STEP "
4190 PRINT
4200 PRINT "TO DEFINE THE INITIAL STATE OF THERMAL EQUILIBRIUM, YOU MAY SPECIFY"
4210 PRINT " - AN INITIAL STEADY-STATE CONDUCTOR CURRENT (ENTER 1) "
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4220 INPUT " - AN INITIAL STEADY-STATE CONDUCTOR TEMPERATURE (ENTER 2) ", IORT-
PRELOAD
4230 IF IORTPRELOAD <> 1 AND IORTPRELOAD <> 2 THEN 4200
4240 PRINT
4250 IF IORTPRELOAD = 2 THEN GOTO 4280
4260 INPUT "ENTER THE INITIAL STEADY-STATE CURRENT (AMPS) ", XIPRELOAD
4270 GOTO 4290
4280 INPUT "ENTER THE INITIAL STEADY-STATE TEMPERATURE (DEG C) ", TCDRPRELOAD
4290 CLS
4300 IF NSELECT = 3 THEN 4450
4310 PRINT "IN A TRANSIENT THERMAL RATING CALCULATION, THE PROGRAM WILL"
4320 PRINT "TRY DIFFERENT STEP INCREASES IN CURRENT UNTIL ONE IS FOUND "
4330 PRINT "FOR WHICH THE CONDUCTOR TEMPERATURE JUST REACHES THE MAXIMUM "
4340 PRINT "ALLOWABLE CONDUCTOR TEMPERATURE IN A SPECIFIED PERIOD OF TIME."
4350 PRINT "YOU MUST ENTER BOTH THE MAXIMUM ALLOWABLE CONDUCTOR TEMPERA-
TURE"
4360 PRINT "AND THE TIME DURATION OF THE STEP INCREASE IN CURRENT."
4370 PRINT
4380 INPUT "ENTER THE MAXIMUM ALLOWABLE CONDUCTOR TEMPERATURE IN DEG C. ",
TCDRMAX
4390 IF TAMB > TCDRMAX > 1000 THEN PRINT "TEMP MUST BE LESS THAN 1001 C &
GREATER THAN AIR
TEMP - ",
TCDRMAX: GOTO 4380
4400 PRINT
4410 PRINT "ARE YOU GOING TO ENTER THE TIME DURATION OF THE STEP INCREASE IN
CURRENT"
4420 INPUT "IN SECONDS (ENTER 0) OR IN MINUTES (ENTER 1)? ", SORM
4425 IF SORM <> 1 AND SORM <> 0 GOTO 4410
4430 INPUT "ENTER THE TIME DURATION ", TT
4440 GOTO 4550
4450 PRINT "THE CHANGE IN CONDUCTOR TEMPERATURE IS DUE TO A STEP INCREASE"
4460 PRINT "IN CONDUCTOR CURRENT. "
4470 INPUT "ENTER THE CONDUCTOR CURRENT AFTER THE STEP INCREASE IN AMPERES ",
XISTEP
4480 PRINT
4490 TCDRMAX = 1000
4500 PRINT "THE PROGRAM WILL CALCULATE THE CONDUCTOR TEMPERATURE FOR A
PERIOD"
4510 PRINT "OF TIME AFTER THE STEP CHANGE IN CURRENT WHICH YOU MUST SPECIFY."
4520 INPUT "WILL YOU ENTER THE TIME PERIOD IN SECONDS (0) OR MINUTES (1)?", SORM
4530 IF SORM <> 0 AND SORM <> 1 THEN GOTO 4500
4540 INPUT "ENTER THE CALCULATION TIME PERIOD ", TT
4550 IF SORM = 1 THEN TT = TT * 60
4560 CLS
4570 DELTIME = TT / 100
4580 PRINT
4590 PRINT "THE PROGRAM WILL CALCULATE THE CONDUCTOR TEMPERATURE"
4600 PRINT USING "EVERY ###.#### SECONDS. IF A DIFFERENT CALCULATION"; DELTIME
4610 PRINT "TIME INTERVAL IS DESIRED, ENTER IT NOW, IN SECONDS, OTHERWISE"
4620 INPUT "SIMPLY HIT THE CARRIAGE RETURN ", DELTIME
4625 IF DELTIME = 0 THEN DELTIME = TT / 100
4630 IF DELTIME > TT / 10 THEN PRINT ">>TIME STEP TOO LARGE<<": GOTO 4560
4632 REM *******************************************
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4634 REM * PLAYBACK TEMP/CURRENT, TIME DATA TO SCREEN
4636 REM **********************************************
4640 CLS
4650 PRINT "THE CURRENT/CONDUCTOR TEMPERATURE/TIME DATA IS:"
4660 ON NSELECT GOTO 4690, 4670, 4710, 4710
4670 PRINT USING "THE STEADY STATE CONDUCTOR TEMPERATURE IS #### DEG. C ";
TCDRPRELOAD
4680 GOTO 4850
4690 PRINT USING "THE STEADY STATE ELECTRICAL CURRENT IS #######.# AMPERES ";
XIPRELOAD
4700 GOTO 4850
4710 PRINT
4720 IF IORTPRELOAD = 1 THEN PRINT USING "THE INITIAL STEADY STATE CURRENT IS
#######.# AMPS";
XIPRELOAD
4730 IF IORTPRELOAD = 2 THEN PRINT USING "THE INITIAL STEADY STATE TEMPERATURE IS
#####.# DEG C";
TCDRPRELOAD
4740 PRINT
4750 IF NSELECT = 3 THEN GOTO 4800
4760 PRINT USING "THE MAXIMUM ALLOWABLE CONDUCTOR TEMPERATURE IS ###.# DEG
C"; TCDRMAX
4770 PRINT USING "THE TRANSIENT THERMAL RATING IS FOR A TIME DURATION OF
####.#### SEC"; TT
4780 GOTO 4840
4790 PRINT
4800 PRINT USING "THE CURRENT AFTER THE STEP CHANGE IS #######.#AMPERES "; XISTEP
4810 PRINT " THE TOTAL TIME PERIOD OF INTEREST IS"
4820 IF SORM = 0 THEN PRINT USING "#####.#### SECONDS "; TT
4830 IF SORM = 1 THEN PRINT USING "#####.#### MINUTES "; TT / 60
4840 PRINT USING "THE CALCULATION TIME INTERVAL IS ####.#### SECONDS "; DELTIME
4850 PRINT
4860 INPUT " DO YOU WANT TO RE-ENTER THE TEMP, TIME & CURRENT DATA (1=YES;0=NO)",
YN
4870 IF YN <> 1 AND YN <> 0 THEN GOTO 4860
4880 IF YN = 1 THEN GOTO 4050
4890 RETURN
5000 REM ////////////////////////////////////////////////////////////
5010 REM / SUBROUTINE TO CALCULATE SOLAR HEAT GAIN (QS) FOR SUMMER SUN
5020 REM ////////////////////////////////////////////////////////////
5030 IF SUN.TIME >= 24 THEN 5560
5040 REM ************************************
5050 REM * ALTITUDE (H1) OF SUN AT NOON (P6)
5060 REM ************************************
5070 H1 = -427.2643 + 78.43801 * CDR.LAT - 4.7439 * CDR.LAT ^ 2
5080 H1 = H1 + .147356 * CDR.LAT ^ 3 - .0025127 * CDR.LAT ^ 4 + 2318E-05 * CDR.LAT ^ 5
5090 H1 = H1 - 8.0736E-08 * CDR.LAT ^ 6
5100 REM********************************************
5110 REM* ALTITUDE (H2) OF SUN AT 10AM AND 2PM (P6)
5120 REM********************************************
5130 H2 = 35.9201 + 5.106109 * CDR.LAT - .4049362 * CDR.LAT ^ 2
5140 H2 = H2 + 1.644423E-02 * CDR.LAT ^ 3 - .0003543 * CDR.LAT ^ 4
5150 H2 = H2 + 3.7704E-06 * CDR.LAT ^ 5 - 1.5636E-08 * CDR.LAT ^ 6
5160 H3 = H1 - (H1 - H2) * (ABS(12 - SUN.TIME) / 2)
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```
5170 IF A3 = 1 THEN 5290
5180 REM*****************************************************************
5190 REM* SOLAR HEATING (Q3) AT EARTH SURFACE (W/FT2) IN CLEAR AIR (P6)
5200 REM*****************************************************************
5210 Q3 = -3.92414 + 5.92762 * H3 - .17856 * H3 ^ 2
5220 Q3 = Q3 + .003223 * H3 ^ 3 - 3.3549E-05 * H3 ^ 4
5230 Q3 = Q3 + 1.80527E-07 * H3 ^ 5 - 3.7868E-10 * H3 ^ 6
5240 B$ = "CLEAR"
5250 GOTO 5330
5260 REM*******************************************************************
5270 REM* SOLAR HEAT (Q3) AT EARTH SURFACE (W/FT2) IN INDUSTRIAL AIR (P6)
5280 REM*******************************************************************
5290 Q3 = 4.940779 + 1.320247 * H3 + .061444 * H3 ^ 2
5300 Q3 = Q3 + .0029411 * H3 ^ 3 + 5.07752E-05 * H3 ^ 4
5310 Q3 = Q3 - 4.03627E-07 * H3 ^ 5 + 1.22968E-09 * H3 ^ 6
5320 B$ = "INDUSTRIAL"
5330 IF CDR.LAT > 20 THEN 5360
5340 Z2 = 0
5350 GOTO 5370
5360 Z2 = 180
5370 IF SUN.TIME > 12 THEN 5460
5380 REM**********************************
5390 REM* AZIMUTH OF SUN (Z3) AT 2PM (P6)
5400 REM**********************************
5410 Z3 = 334.2192 - 2.9656 * CDR.LAT + .0185 * CDR.LAT ^ 2
5420 GOTO 5510
5430 REM **********************************
5440 REM * AZIMUTH OF SUN (Z3) AT 10AM (P6)
5450 REM **********************************
5460 Z3 = 40.1428 + 1.4292 * CDR.LAT + .039 * CDR.LAT ^ 2
5470 Z3 = Z3 + 8.9781E-04 * CDR.LAT ^ 3 + 4.9848E-06 * CDR.LAT ^ 4
5480 REM **************************************************
5490 REM * AZIMUTH OF SUN AT 10AM, 11AM, 12AM, 1PM, OR 2PM
5500 REM **************************************************
5510 Z4 = Z2 + (Z3 - Z2) * (ABS(12 - SUN.TIME) / 2)
5520 E1 = COS(H3 * PI / 180) * COS((Z4 - Z1) * PI / 180)
5530 E2 = ATN(SQR(1 / E1 ^ 2 - 1))
5540 QS = ABSORP * Q3 * SIN(E2) * D / 12 * (1 + .000035 * CDR.ELEV - 1E-09 * CDR.ELEV ^ 2)
5550 GOTO 5570
5560 QS = 0!
5570 RETURN
6000 REM///////////////////////////////////////////////
6010 REM/ SUBROUTINE TO PRINT OUTPUT TO MONITOR SCREEN
6020 REM///////////////////////////////////////////////
6030 REM*****************
6040 REM* PRINT TO SCREEN
6050 REM*****************
6060 CLS
6070 PRINT
6080 PRINT X$
6090 PRINT "IEEE STD 738-1993 METHOD OF CALCULATION"
6100 PRINT "CONDUCTOR IS "; CS
6110 PRINT "AIR TEMPERATURE = "; TAMB; "DEG C &"; "WIND SPEED = "; VWIND; "FT/SEC"
```

```
6120 PRINT USING "THE ANGLE BETWEEN WIND AND CONDUCTOR IS ### DEG"; WIN-
DANG.DEG
6130 PRINT USING "THE CONDUCTOR IS #####. FT ABOVE SEA LEVEL;"; CDR.ELEV
6140 PRINT USING "IN THE & DIRECTION; AT A LATITUDE OF ###.# DEG"; AS; CDR.LAT
6150 PRINT "THE SUN TIME IS "; SUN.TIME; "HOURS &"; "THE ATMOSPHERE IS "; B$
6160 PRINT
6170 PRINT "CONDUCTOR DIAMETER IS "; D; "INCHES"
6180 PRINT USING "CONDUCTOR RESISTANCE IS ##.#### OHMS/MI AT #### DEG C"; RLO; TLO
6190 PRINT USING" AND ##.## OHMS/MI AT #### DEG C"; RHI; THI
6200 PRINT "EMISSIVITY = "; EMISS; "& SOLAR ABSORPTIVITY = "; ABSORP
6210 IF NSELECT = 3 OR NSELECT = 4 GOTO 6370
6220 PRINT
6230 PRINT USING "SOLAR HEAT INPUT IS ####.## WATTS PER CONDUCTOR FOOT"; QS
6240 PRINT USING "RADIATION COOLING IS ####.# WATTS PER CONDUCTOR FOOT"; QR
6250 PRINT USING "CONVECTIVE COOLING IS ####.### WATTS PER CONDUCTOR FOOT"; QC
6260 PRINT
6270 IF NSELECT = 1 THEN GOTO 6320
6280 PRINT USING "GIVEN A MAXIMUM CONDUCTOR TEMPERATURE OF ####.# DEG C,";
TCDRPRELOAD
6290 PRINT USING "THE STEADY STATE THERMAL RATING IS ######.# AMPERES"; TR
6300 GOSUB 7000
6310 RETURN
6320 IF XIPRELOAD = 1.111 THEN XIPRELOAD = 0
6330 PRINT USING "GIVEN A CONSTANT CURRENT OF #####.# AMPERES,"; XIPRELOAD
6340 PRINT USING "THE CONDUCTOR TEMPERATURE IS ####.# DEG C"; TCDRPRELOAD
6350 GOSUB 7000
6360 RETURN
6370 REM PRINT
6380 PRINT " ******* TRANSIENT THERMAL CALCULATIONS *******"
6390 PRINT USING "INITIAL STEADY STATE CONDUCTOR TEMP = ###.# DEG C"; TCDRPRE-
LOAD
6400 IF IORTPRELOAD = 1 THEN PRINT USING "FORA PRE-STEP STEADY STATE CURRENT =
#####.#
AMPERES";
XIPRELOAD
6410 IF HNH = 2 THEN GOTO 6440
6420 PRINT USING " HEAT CAPACITY = ####.# WATTS-SEC/FT-C"; HEATCAP
6430 GOTO 6460
6440 PRINT USING "CORE HEAT CAPACITY = ####.# WATTS-SEC/FT-C"; HEATCORE
6445 REM CHG HEATCAP TO HEATOUT IN FOLLOWINGLINE 6/12/90
6450 PRINT USING " OUTER STRAND LAYERS HEAT CAPACITY = ####.# WATTS-SEC/FT-C";
HEATOUT
6460 IF NSELECT = 4 THEN 6500
6470 PRINT "THE TOTAL TIME OF INTEREST AFTERTHE CURRENT"
6480 IF SORM = 0 THEN PRINT USING "INCREASES TO #######.# AMPS = ####.#### SECONDS";
XISTEP;
TT
6490 IF SORM = 1 THEN PRINT USING "INCREASES TO #######.# AMPS = ####.#### MINUTES";
XISTEP;
TT / 60
6500 PRINT USING "CALCULATION TIME INTERVAL = ###.#### SECONDS"; DELTIME
6510 IF ABS((ATCDR(2) - ATCDR(1)) / (ATCDR(KTIMEMAX) - ATCDR(1))) < .05 THEN GOTO 6540
6520 PRINT" CALCULATION ACCURACY WOULD IMPROVE IF THIS TIME INTERVAL WERE
REDUCED" 6530 REM PRINT
```

```
6540 IF FLAG = 0 OR HEATCORE = 0 THEN 6580
6550 PRINT "CORE HEAT CAPACITY IS IGNORED SINCE STEP DURATION LESS THAN 60 SEC"
6580 IF NSELECT = 4 GOTO 6720
6590 IF ATCDR(KTIMEMAX) < TCDRMAX THEN GOTO 6630
6600 PRINT USING "IT TAKES ####.#### SEC (####.#### MIN) "; TIME(KTIMEMAX);
TIME(KTIMEMAX) / 60!
6610 PRINT "TO REACH THE MAXIMUM ALLOWABLE CONDUCTOR TEMPERATURE "
6620 PRINT USING "OF ####.# DEGREES C"; TCDRMAX
6630 GOSUB 7000
6640 FOR K = 1 TO KTIMEMAX
6650 IF SORM = 0 THEN PRINT USING "TIME=#####.#### SEC CDRTEMP= ####.# DEG C";
TIME(K);
ATCDR (K)
6660 IF SORM = 1 THEN PRINT USING "TIME=#####.#### MIN CDRTEMP= ####.# DEG C";
TIME(K) / 60;
ATCDR(K)
6670 IF K <> 20 AND K <> 40 AND K <> 60 AND K <> 80 THEN GOTO 6690
6680 GOSUB 7000
6690 NEXT K
6700 IF KTIMEMAX < 20 THEN GOSUB 7000
6710 RETURN
6720 PRINT USING "THE TRANSIENT THERMAL RATING = ########.# AMPERES"; XISTEP
6730 PRINT "THAT IS, WITH THIS CURRENT, THE CDR TEMPERATURE JUST REACHES "
6740 IF TT > 60 THEN PRINT USING "THE MAXIMUM OF ####.# DEG C IN ##.#### MINUTES";
TCDRMAX;
TT / 60!
6750 IF TT <= 60 THEN PRINT USING "THE MAXIMUM OF ####.# DEG C IN ###.#### SECONDS";
TCDRMAX;
TT
6760 GOSUB 7000
6770 RETURN
7000 REM /////////////////////////////////////
7010 REM / SUBROUTINE TO FREEZE MONITOR SCREEN
7020 REM /////////////////////////////////////
7030 PRINT X$
7040 PRINT "PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE"
7050 FOR P = 1 TO 1000000!
7060 DS = INKEY$: IF LEN(D$) <> 0 THEN 7090
7070 NEXT P
7080 CLS
7090 RETURN
9000 REM//////////////////////////////////////////////////////////////////////
9010 REM/ SUBROUTINE TO CALCULATE THERM COEF OF RAC & HEATCAP & WIND CORREC-
TION
9020 REM//////////////////////////////////////////////////////////////////////
9030 REM**********************************************************
9040 REM* SETUP LINEAR CONDUCTOR RESISTANCE EQ AS FUNCTION OF TEMP
9050 REM**********************************************************
9060 B = (RHI - RLO) / (THI - TLO)
9070 B1 = RLO - B * TLO
9110 REM**************************************************
9120 REM* CORRECTION FACTOR (YC) FOR NON-PERPENDICULAR WIND
9130 REM**************************************************
9140 WINDANG.RAD = 1.570796 - WINDANG.DEG * (6.283185 / 360!)
```

```
9150 YC = 1.194 - SIN(WINDANG.RAD) - .194 * COS(2! * WINDANG.RAD) + .368 * SIN(2! * WIN-
DANG.RAD)
9160 RETURN
10000 REM /////////////////////////////////////////////////////////////////
10010 REM / SUBROUTINE TO CALCULATE STARTING VALUE FOR CURRENT ITERATION
10020 REM / BY ASSUMING ADIABATIC HEATING DURING TIME TT
10030 REM /////////////////////////////////////////////////////////////////
10040 TCDR = (TCDRMAX + TAMB) / 2
10050 IF TT < 60 THEN HEATCAP = HEATOUT ELSE HEATCAP = HEATOUT + HEATCORE
10060 GOSUB 15000
10070 AT = SQR(HEATCAP * (TCDRMAX - TAMB) / TT) / W4
10080 TCDR = TCDRPRELOAD
10090 NFLAG = 1
10100 GOSUB 13000
10110 RETURN
11000 REM ///////////////////////////////////////////////////////////////
11010 REM / SUBROUTINE CALCS CDR TEMP VS TIME FOR STEP CHANGE CURRENT
11020 REM ///////////////////////////////////////////////////////////////
11030 IF NSELECT = 4 THEN PRINT USING "TRYING A CURRENT OF #######.### AMPS";
XISTEP
11040 FLAG = 0
11050 ATCDR(1) = TCDRPRELOAD
11060 TCDR = ATCDR(1)
11070 GOSUB 15000
11080 K = 1
11090 ATCDR(K + 1) = TCDR + (W4 ^ 2 * XISTEP ^ 2 + QS - QR - QC) * DELTIME / HEATCAP
11100 TIME(K + 1) = TIME(K) + DELTIME
11110 TCDR = ATCDR(K + 1)
11115 IF NSELECT = 4 GOTO 11130
11120 PRINT "TIME = "; TIME(K + 1); " SECONDS / "; "CDR TEMP = "; TCDR; "DEG C"
11130 IF NSELECT = 3 AND TCDR > TCDRMAX THEN 11280
11140 REM*****************************************************************
11150 REM*
11160 REM*****************************************************************
11170 GOSUB 15000
11180 K = K + 1
11190 IF K = 3000 THEN PRINT "TIME INTERVAL TOO SMALL. ARRAY OUT OF BOUNDS ":
GOTO 1360
11200 IF TIME(K) < TT THEN 11090
11210 IF XISTEP = 0 AND TCDR > TCDRMAX THEN 11220 ELSE 11250
11220 PRINT "EVEN IF THE CURRENT IS REDUCED TO ZERO AMPS, THE CONDUCTOR"
11230 PRINT USING "TEMPERATURE WILL NOT DECREASE TO ####.# DEG C IN ####.# MIN-
UTES"; TCDRMAX
TT /
60
11240 GOTO 1360
11250 REM **********************************
11260 REM * CHECK FOR SHORT DURATION FAULTS
11270 REM **********************************
11275 REM REVERSE INEQUALITY ON TT 6/14/90
11280 IF TIME(K) >= 60 OR FLAG = 1 OR HEATCORE = 0 OR TT > 60 THEN GOTO 11320
11290 HEATCAP = HEATOUT
11300 FLAG = 1
11310 GOTO 11050
```

```
11320 KTIMEMAX = K
11330 RETURN
12000 REM ////////////////////////////////////////////////////
12010 REM / SUBROUTINE ITERATES TO FIND CONDUCTOR TEMPERATURE
12020 REM / GIVEN THE CONDUCTOR CURRENT
12030 REM ////////////////////////////////////////////////////
12040 IF NFLAG = 0 THEN TCDR = X: GOSUB 15000: TEMP = XIDUMMY - TR: RETURN
12050 IF NFLAG = 1 THEN XISTEP = X: GOSUB 11000
12060 IF TCDRPRELOAD <= TCDRMAX THEN TEMP = TCDRMAX - TCDR: RETURN
12070 IF TCDRPRELOAD > TCDRMAX THEN TEMP = TCDR - TCDRMAX: RETURN
13000 REM ///////////////////////////////////////////////////////////////////
13010 REM / SUBROUTINE RTMI MUELLER-S ITERATION METHOD SELECTS A CURRENT
13020 REM / WHICH JUST RAISES TCDR TO TCDMAX IN THE TIME TT. THIS CURRENT
13030 REM/IS THE TRANSIENT RATING OF THE CONDUCTOR. IT DOES THIS BY
13040 REM/ REPEATEDLY GUESSING A CURRENT - XISTEP - CALCULATING TCDR AT TT
13050 REM/ AND COMPARING THE CALCULATED TCDR TO TCDRMAX. ROUTINE SUPPLIED
13060 REM/ COURTESY OF BILL HOWINGTON.
13070 REM///////////////////////////////////////////////////////////////////
13080 REM * START BY PREPARING TO ITERATE
13090 REM ********************************
13100 XLI = 0: XRI = 0: EPS = .049: IEND = 20: X = 0
13110 GOSUB 14000
13120 IER = 0: XL = XLI: XR = XRI: X = XL: TOL = X
13130 GOSUB 12000
13140 F = TEMP: IF XLI = XRI OR F = 0 THEN 13530
13150 FL = F: X = XR: TOL = X
13160 GOSUB 12000
13170 F = TEMP: IF F = 0 THEN 13530
13180 FR = F: IF (SGN(FL) + SGN(FR)) = 0 THEN 13200 ELSE 13760
13190 REM************************************************
13200 REM BASIC ASSUMPTION FL*FR LESS THAN 0 IS SATISFIED.
13210 REM************************************************
13220 I = 0
13230 REM ********************
13240 REM START ITERATION LOOP
13250 REM ********************
13260 I = I + 1
13270 REM ********************
13280 REM START BISECTION LOOP
13290 REM ********************
13300 FOR JK = 1 TO IEND
13310 X = .5 * (XL + XR) : TOL = X: GOSUB 12000
13320 F = TEMP: IF F = 0 THEN 13530
13330 IF (SGN(F) + SGN(FR)) = 0 THEN 13370 ELSE 13380
13340 REM *****************************************************************
13350 REM INTERCHANGE XL AND XR IN ORDER TO GET THE SAME SIGN IN F AND FR
13360 REM *****************************************************************
13370 TOL = XL: XL = XR: XR = TOL: TOL = FL: FL = FR: FR = TOL
13380 TOL = F - FL: DA = F * TOL: DA = DA + DA
13390 IF (DA - FR * (FR - FL)) >= 0 THEN 13410
13400 IF (I - IEND) <= 0 THEN 13570
13410 XR = X: FR = F
13420 REM ************************************************
13430 REM TEST ON SATISFACTORY ACCURACY IN BISECTION LOOP
```

```
13440 REM *********************************************
13450 TOL = EPS
13460 IF (ABS(FR - FL) - TOL) <= 0 THEN 13530
13470 NEXT JK
13480 REM **************************************************************
13490 REM END OF BISECTION LOOP - NO CONVERGENCE AFTER IEND ITERATION STEPS
13500 REM FOLLOWED BY IEND SUCCESSIVE STEPS OF BISECTION
13510 REM **************************************************************
13520 IER = 1: GOTO 13780
13530 RETURN
13540 REM **************************************************************
13550 REM COMPUTATION OF ITERATED X-VALUE BY INVERSE PARABOLIC INTERPOLATION
13560 REM **************************************************************
13570 DA = FR - F: DX = (X - XL) * FL * (1 + F * (DA - TOL) / (DA * (FR - FL))) / TOL
13580 XM = X: FM = F: X = XL - DX: TOL = X
13590 GOSUB 12000
13600 F = TEMP: IF F = 0 THEN 13530
13610 REM *********************************************
13620 REM TEST ON SATISFACTORY ACCURACY IN ITERATION LOOP
13630 REM *********************************************
13640 TOL = EPS
13650 IF (ABS(F) TOL) <= 0 THEN 13530
13660 REM ***********************************
13670 REM PREPARATION OF NEXT BISECTION LOOP
13680 REM ***********************************
13690 IF (SGN(F) + SGN(FL)) <> 0 THEN 13710
13700 XR = X: FR = F: GOTO 13260
13710 XL = X: FL = F: XR = XM: FR = FM: GOTO 13260
13720 REM *****************************************
13730 REM END OF ITERATION LOOP
13740 REM ERROR RETURN IN CASE OF WRONG INPUT DATA
13750 REM *****************************************
13760 IF XHI <> XLO THEN 13770 ELSE RETURN
13770 IER = 2: JK = 0
13780 BEEP: PRINT "NUMBER OF ITERATIONS= "; JK
13790 PRINT "ITERATION ROUTINE CONDITION CODE, IER= "; IER
13800 IF IER = 2 THEN PRINT "TCDR OUT OF TEMPERATURE RANGE"
13810 IF IER = 1 THEN PRINT "NO CONVERGENCE IN SUBROUTINE TRANS"
13820 STOP
14000 REM /////////////////////////////////////////////////////////////////
14010 REM / SUBROUTINE GUESS TO DETERMINE INITIAL BOUNDS FOR ITERATION
14020 REM /////////////////////////////////////////////////////////////////
14030 IF NFLAG = 0 THEN XLO = TAMB: XHI = 1000: DIV = 10
14040 IF NFLAG = 1 THEN XLO = 0: XHI = 10 * AT: DIV = 10
14050 CHA = (XHI - XLO) / DIV: NUM = INT(DIV) : X = XLO
14060 GOSUB 12000
14070 FO = TEMP
14080 FOR JK = 1 TO NUM
14090 X = XLO + JK * CHA: GOSUB 12000
14100 FF = TEMP: IF (SGN(FF) + SGN(FO)) = 0 THEN 14140
14110 FO = FF
14120 NEXT JK
14130 XLI = XLO: XRI = XHI: RETURN
14140 XRI = X: XLI = X - CHA: RETURN
```

```
15000 REM ////////////////////////////////////////////////////////////////////
15010 REM / SUBROUTINE TO CALCULATE THERMAL RATING GIVEN A CDR TEMP (TCDR),
15020 REM / AND CONDUCTOR PARAMETERS AND WEATHER CONDITIONS
15030 REM ////////////////////////////////////////////////////////////////////
15040 REM PRINT USING "TRYING A TCDR OF ####.### DEG C"; TCDR
15050 REM *******************************************************************
15060 REM * CALC CONDUCTOR HEAT LOSS (QR) BY RADIATION (WATTS/FT)
15070 RES *******************************************************************
15080 T3 = TCDR + 273
15090 T4 = TAMB + 273
15100 QR = .138 * EMISS * D * ((T3 / 100) ^ 4 - (T4 / 100) ^ 4)
15110 REM *******************************************************************
15120 REM * CALC CONDUCTOR HEAT LOSS BY CONVECTION (WATTS/FT)
15130 REM *******************************************************************
15140 T5 = (TCDR + TAMB) / 2
15150 U1 = .0415 + 1.2034E-04 * T5 - 1.1442E-07 * T5 ^ 2
15160 U1 = U1 + 1.9416E-10 * T5 ^ 3
15170 P1 = (8.069501E-02 - 2.901E-06 * CDR.ELEV + 3.7E-11 * CDR.ELEV ^ 2) / (1 + .00367 * T5)
15180 K1 = .007388 + 2.27889E-05 * T5 - 1.34328E-09 * T5 ^ 2
15182 REM *******************************************************************
15184 REM * CALC CONDUCTOR HEAT LOSS (QC) BY NATURAL CONVECTION (WATTS/FT)
15186 REM *******************************************************************
15188 IF (TCDR - TAMB) < 0! THEN TCDR = TAMB + .1
15190 QC = .283 * P1 ^ .5 * D ^ .75 * (TCDR - TAMB) ^ 1.25
15192 IF VWIND = 0 THEN 15450
15194 REM *******************************************************************
15196 REM * CALC CONDUCTOR HEAT LOSS (QCF) BY FORCED CONVECTION (WATTS/FT)
15198 REM *******************************************************************
15200 Z = D * P1 * VWIND * 3600 / U1
15210 Q1 = .1695 * Z ^ .6 * K1 * (TCDR - TAMB)
15220 Q2 = (1.01 + .371 * Z ^ .52) * K1 * (TCDR - TAMB)
15230 IF Q1 - Q2 <= 0 THEN 15260
15240 QCF = Q1
15250 GOTO 15270
15260 QCF = Q2
15270 QCF = QCF * YC
15370 REM *******************************************************************
15380 REM * SELECT LARGER OF NATURAL OR FORCED HEAT LOSSES (QC VERSUS QCF)
15390 REM *******************************************************************
15400 IF QCF < QC THEN 15450
15410 QC = QCF
15420 REM ****************************************
15430 REM * CALC SUM OF STEADY STATE HEAT FLOWS
15440 REM ****************************************
15450 R5 = -QS + QC + QR
15460 REM *******************************************************************
15470 REM * CALC SQRT OF CONDUCTOR RESISTANCE IN OHMS/FT
15480 REM *******************************************************************
15490 W4 = SQR((B1 + B * TCDR) / 5280)
15500 IF R5 <= 0 THEN TR = 0: GOTO 15560
15510 R4 = R5 ^ .5
15520 REM ****************************************************
15530 REM * CALCULATE THERMAL RATING (AMPACITY) IN AMPERES
15540 REM ****************************************************
```

```
15550 TR = R4 / W4
15560 RETURN
20000 REM ////////////////////
20010 REM / COMMENTS ON PROGRAM
20020 REM ////////////////////
20030 REM *
20040 REM * THE PROGRAM DOES NOT CALCULATE ANY INTERNAL RADIAL OR AXIAL
20050 REM * TEMPERATURE GRADIENTS. THIS IS NORMALLY NOT A SOURCE OF
20060 REM * SIGNIFICANT ERROR EXCEPT FOR INTERNALLY COMPLEX CONDUCTORS
20070 REM * SUCH AS FIBER-OPTIC SHIELD WIRE AND FOR NON-HOMOGENEOUS CONDUC-
TORS
20080 REM * FOR FAULT CURRENTS OF LESS THAN 1 MINUTE. THE PROGRAM DOES NOT
20090 REM * APPLY TO INTERNALLY COMPLEX CONDUCTORS, IT DOES CALCULATE A
WORST
20100 REM * CASE ESTIMATE OF TEMPERATURE/RATING FOR ACSR OR ACSR/AW BY
NEGLECTING
20110 REM * THE HEAT STORAGE CAPACITY OF THE RELATIVELY POORLY CONDUCTING
CORE
20120 REM * FOR STEP CURRENTS WHICH PERSIST FOR LESS THAN ONE MINUTE.
```

Annex B

(informative)

Sample calculation of steady-state thermal rating

IEEE STD 738-1993 METHOD OF CALCULATION

CONDUCTOR IS DRAKE

AIR TEMPERATURE = 40 DEG C & WIND SPEED = 2 FT/SEC

THE ANGLE BETWEEN WIND AND CONDUCTOR IS 90 DEG

THE CONDUCTOR IS 0. FT ABOVE SEA LEVEL;

IN THE EAST-WEST DIRECTION; AT A LATITUDE OF 30.0 DEG

THE SUN TIME IS 11 HOURS & THE ATMOSPHERE IS CLEAR

CONDUCTOR DIAMETER IS 1.108 INCHES

CONDUCTOR RESISTANCE IS 0.1172 OHMS/MI AT 25 DEG C

AND 0.1398 OHMS/MI AT 75 DEG C

EMISSIVITY = .5 & SOLAR ABSORPTIVITY = .5

SOLAR HEAT INPUT IS 4.281 WATTS PER CONDUCTOR FOOT

RADIATION COOLING IS 7.461 WATTS PER CONDUCTOR FOOT

CONVECTIVE COOLING IS 25.016 WATTS PER CONDUCTOR FOOT

GIVEN A MAXIMUM CONDUCTOR TEMPERATURE OF 100.0 DEG C,

THE STEADY STATE THERMAL RATING IS 992.6 AMPERES

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

Annex C

(informative)

Sample calculation of steady-state conductor temperature

IEEE STD 738-1993 METHOD OF CALCULATION

CONDUCTOR IS DRAKE

AIR TEMPERATURE = 40 DEG C & WIND SPEED = 2 FT/SEC

THE ANGLE BETWEEN WIND AND CONDUCTOR IS 90 DEG

THE CONDUCTOR IS 0. FT ABOVE SEA LEVEL;

IN THE EAST-WEST DIRECTION; AT A LATITUDE OF 30.0 DEG

THE SUN TIME IS 11 HOURS & THE ATMOSPHERE IS CLEAR

CONDUCTOR DIAMETER IS 1.108 INCHES

CONDUCTOR RESISTANCE IS 0.1172 OHMS/MI AT 25 DEG C

AND 0.1398 OHMS/MI AT 75 DEG C

EMISSIVITY = .5 & SOLAR ABSORPTIVITY = .5

SOLAR HEAT INPUT IS 4.281 WATTS PER CONDUCTOR FOOT

RADIATION COOLING IS 7.598 WATTS PER CONDUCTOR FOOT

CONVECTIVE COOLING IS 25.374 WATTS PER CONDUCTOR FOOT

GIVEN A CONSTANT CURRENT OF 1000.0 AMPERES,

THE CONDUCTOR TEMPERATURE IS 100.9 DEG C

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

Annex D

(informative)

Sample calculation of transient conductor temperature for a step increase in current

(informative)

IEEE STD 738-1993 METHOD OF CALCULATION

CONDUCTOR IS DRAKE

AIR TEMPERATURE = 40 DEG C & WIND SPEED = 2 FT/SEC

THE ANGLE BETWEEN WIND AND CONDUCTOR IS 90 DEG

THE CONDUCTOR IS 0. FT ABOVE SEA LEVEL;

IN THE EAST-WEST DIRECTION; AT A LATITUDE OF 30.0 DEG

THE SUN TIME IS 11 HOURS & THE ATMOSPHERE IS CLEAR

CONDUCTOR DIAMETER IS 1.108 INCHES

CONDUCTOR RESISTANCE IS 0.1172 OHMS/MI AT 25 DEG C

AND 0.1398 OHMS/MI AT 75 DEG C

EMISSIVITY = .5 & SOLAR ABSORPTIVITY = .5

******* TRANSIENT THERMAL CALCULATIONS *******

INITIAL STEADY STATE CONDUCTOR TEMP = 80.6 DEG C

FOR A PRE-STEP STEADY STATE CURRENT = 800.0 AMPERES

CORE HEAT CAPACITY = 70.7 WATTS-SEC/FT-C

OUTER STRAND LAYERS HEAT CAPACITY=318.9 WATTS-SEC/FT-C

THE TOTAL TIME OF INTEREST AFTER THE CURRENT

INCREASES TO 1200.0 AMPS = 30.0000 MINUTES

CALCULATION TIME INTERVAL = 120.0000 SECONDS

CALCULATION ACCURACY WOULD IMPROVE IF THIS TIME INTERVAL WERE REDUCED

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

CALCULATION TIME INTERVAL = 120.0000 SECONDS

CALCULATION ACCURACY WOULD IMPROVE IF THIS TIME INTERVAL WERE REDUCED

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

TIME= 0.0000 MIN CDRTEMP= 80.6 DEG C

TIME= 2.0000 MIN CDRTEMP= 87.2 DEG C

TIME= 4.0000 MIN CDRTEMP= 93.0 DEG C

TIME= 6.0000 MIN CDRTEMP= 97.9 DEG C

TIME= 8.0000 MIN CDRTEMP= 102.2 DEG C

TIME= 10.0000 MIN CDRTEMP= 105.9 DEG C

TIME= 12.0000 MIN CDRTEMP= 109.1 DEG C

TIME= 14.0000 MIN CDRTEMP= 111.8 DEG C

TIME= 16.0000 MIN CDRTEMP= 114.2 DEG C

TIME= 18.0000 MIN CDRTEMP= 116.2 DEG C

TIME= 20.0000 MIN CDRTEMP= 117.9 DEG C

TIME= 22.0000 MIN CDRTEMP= 119.3 DEG C

TIME= 24.0000 MIN CDRTEMP= 120.6 DEG C

TIME= 26.0000 MIN CDRTEMP= 121.6 DEG C

TIME= 28.0000 MIN CDRTEMP= 122.5 DEG C

TIME= 30.0000 MIN CDRTEMP= 123.3 DEG C

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

IEEE STD 738-1993 METHOD OF CALCULATION

CONDUCTOR IS DRAKE

AIR TEMPERATURE = 40 DEG C & WIND SPEED = 2 FT/SEC

THE ANGLE BETWEEN WIND AND CONDUCTOR IS 90 DEG

THE CONDUCTOR IS 0. FT ABOVE SEA LEVEL;

IN THE EAST-WEST DIRECTION; AT A LATITUDE OF 30.0 DEG

THE SUN TIME IS 11 HOURS & THE ATMOSPHERE IS CLEAR

CONDUCTOR DIAMETER IS 1.108 INCHES

CONDUCTOR RESISTANCE IS 0.1172 OHMS/MI AT 25 DEG C

AND 0.1398 OHMS/MI AT 75 DEG C

EMISSIVITY = .5 & SOLAR ABSORPTIVITY = .5

******* TRANSIENT THERMAL CALCULATIONS *******

INITIAL STEADY STATE CONDUCTOR TEMP = 40.0 DEG C

CORE HEAT CAPACITY = 70.7 WATTS-SEC/FT-C

OUTER STRAND LAYERS HEAT CAPACITY = 318.9 WATTS-SEC/FT-C

THE TOTAL TIME OF INTEREST AFTER THE CURRENT

INCREASES TO 80000.0 AMPS = 1.0000 MINUTES

CALCULATION TIME INTERVAL = 0.0500 SECONDS

CORE HEAT CAPACITY IS IGNORED SINCE STEP DURATION LESS THAN 60 SEC

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

TIME= 0.0000 MIN CDRTEMP= 40.0 DEG C

TIME= 0.0500 MIN CDRTEMP= 63.6 DEG C

TIME= 0.1000 MIN CDRTEMP= 89.1 DEG C

TIME= 0.1500 MIN CDRTEMP= 116.9 DEG C

TIME= 0.2000 MIN CDRTEMP= 147.1 DEG C

TIME= 0.2500 MIN CDRTEMP= 179.8 DEG C

TIME= 0.3000 MIN CDRTEMP= 215.4 DEG C

TIME= 0.3500 MIN CDRTEMP= 254.0 DEG C

TIME= 0.4000 MIN CDRTEMP= 295.9 DEG C

TIME= 0.4500 MIN CDRTEMP= 341.5 DEG C

TIME= 0.5000 MIN CDRTEMP= 390.0 DEG C

TIME= 0.5500 MIN CDRTEMP= 444.5 DEG C

TIME= 0.6000 MIN CDRTEMP= 502.8 DEG C

TIME= 0.6500 MIN CDRTEMP= 566.1 DEG C

TIME= 0.7000 MIN CDRTEMP= 634.7 DEG C

TIME= 0.7500 MIN CDRTEMP= 709.2 DEG C

TIME= 0.8000 MIN CDRTEMP= 790.1 DEG C

TIME= 0.8500 MIN CDRTEMP= 877.9 DEG C

TIME= 0.9000 MIN CDRTEMP= 973.2 DEG C

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

Annex E

(informative)

Sample calculation of transient thermal rating

IEEE STD 738-1993 METHOD OF CALCULATION

CONDUCTOR IS DRAKE

AIR TEMPERATURE = 40 DEG C & WIND SPEED = 2 FT/SEC

THE ANGLE BETWEEN WIND AND CONDUCTOR IS 90 DEG

THE CONDUCTOR IS 0.FT ABOVE SEA LEVEL;

IN THE EAST-WEST DIRECTION; AT A LATITUDE OF 30.0 DEG

THE SUN TIME IS 11 HOURS & THE ATMOSPHERE IS CLEAR

CONDUCTOR DIAMETER IS 1.108 INCHES

CONDUCTOR RESISTANCE IS 0.1172 OHMS/MI AT 25 DEG C

AND 0.1398 OHMS/MI AT 75 DEG C

EMISSIVITY = .5 & SOLAR ABSORPTIVITY = .5

******* TRANSIENT THERMAL CALCULATIONS *******

INITIAL STEADY STATE CONDUCTOR TEMP = 80.6 DEG C

FOR A PRE-STEP STEADY STATE CURRENT = 800.0 AMPERES

CORE HEAT CAPACITY = 70.7 WATTS-SEC/FT-C

OUTER STRAND LAYERS HEAT CAPACITY = 318.9 WATTS-SEC/FT-C

CALCULATION TIME INTERVAL = 9.0000 SECONDS

THE TRANSIENT THERMAL RATING = 1231.0 AMPERES

THAT IS, WITH THIS CURRENT, THE CDR TEMPERATURE JUST REACHES

THE MAXIMUM OF 115.0 DEG C IN 15.0000 MINUTES

PRESS PRTSC TO PRINT OR ANY KEY TO CONTINUE

Annex F

(informative)

Thermal time constant

The non-steady-state heat balance equation (2) cannot be solved analytically for conductor temperature as a function of time because certain of its terms are nonlinear. Considering the equation term by term, it may be seen that the Ohmic heating term, and the forced convection equation term are linear in conductor-temperature. The solar heating term is also linear since it is independent of conductor temperature. The radiation heat loss term and the natural convection (zero wind speed) term are both nonlinear in conductor temperature.

Several references (see [B4], [B21], and [B11]) describe methods of approximating the radiation cooling equation (7) as a linear function of temperature. Doing so yields a linear non-steady-state heat balance equation of the form:

$$\frac{d}{dt}(T_c - T_a) = K_1(T_c - T_a) + K_2 I^2 \qquad \text{(F1)}$$

For a step change in electrical current, the solution of the linearized non-steady-state heat balance equation is:

$$T_c(t) = T_i + (T_f - T_i) \cdot (1 - e^{-t/\tau}) \qquad \text{(F2)}$$

The steady-state conductor temperature prior to the step increase in current is T_i. The steady-state conductor temperature that occurs long after the step increase in current is T_f. The thermal time constant, τ, may be calculated by use of the formula:

$$\tau = \frac{(T_f - T_i) \cdot mC_p}{R(T_c) \cdot (l^2{}_f - l^2{}_i)} \qquad \text{(F3)}$$

where the conductor resistance is that corresponding to the average conductor temperature, $(T_i + T_f)/2$.

Consider the exponential change in conductor temperature shown in figure F1. This is the “1200 A” curve shown previously in figure 2. The current undergoes a step change from 800 to 1200A. The initial-conductor temperature is 80 °C. The final conductor temperature is 128 °C. If the average conductor temperature is taken as 100 °C, the resistance of the Drake conductor is $2.86 \cdot 10^{-5}$ Ω/ft. From 3.6 of this standard, the heat capacity of the conductor is 300 W·s/ft °C. The time constant is:

$$\tau = \frac{(128 - 80) \cdot 399}{2.86 \cdot 10^{-5}(1200^2 - 800^2)} = 837 \text{ s}$$

$$= 14 \text{ min}$$

Alternatively, the temperature change reaches 63% of its final value at a conductor temperature of 80 °C + (128 - 80) · 63 = 110 °C. From figure F1, this corresponds to a time of about 13 min.

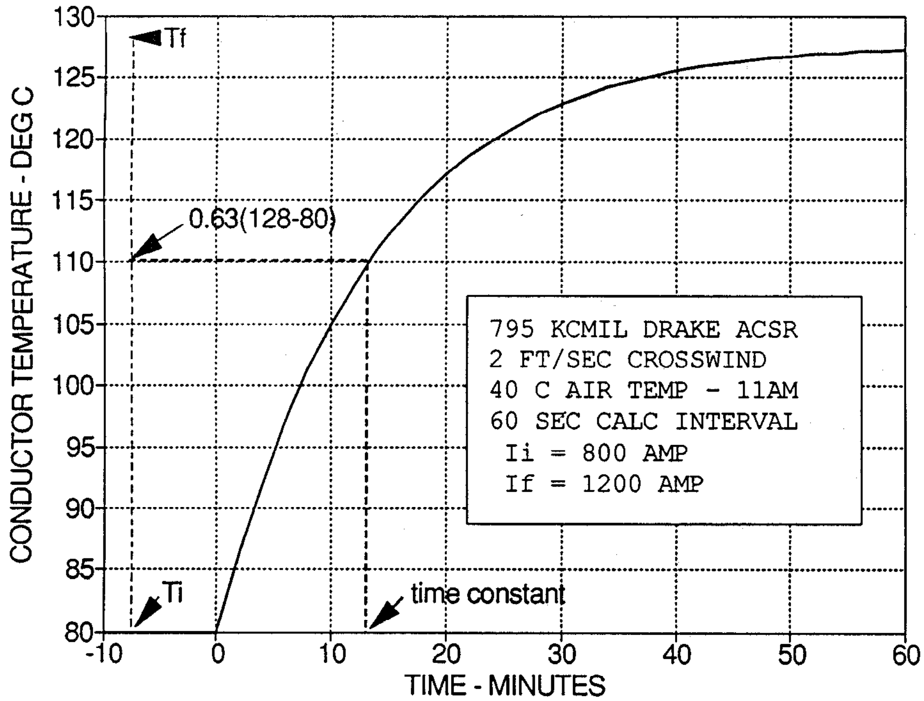

Figure F.1 — Conductor temperature vs. time curve