TU ELECTRIC

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February 26, 1993

William J. Cahill, Jr.
Group Vice President

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

SUBJECT: COMANCHE PEAK STEAM ELECTRIC STATION (CPSES) CLARIFICATIONS ON AMPACITY DERATING TEST AND THERMO-LAG FIRE ENDURANCE TEST

REF:
1) TU Electric letter logged TXX-93060 from Mr. William J. Cahill, Jr. to the USNRC dated January 25, 1993

2) TU Electric letter logged TXX-93061 from Mr. William J. Cahill, Jr. to the USNRC dated January 28, 1993

3) TU Electric letter logged TXX-93076 from Mr. William J. Cahill, Jr. to the USNRC dated February 1, 1993

4) Safety Evaluation Report, NUREG-0797, Supplement No. 26 dated February 1993

5) USNRC letter from Suzanne C. Black to William J. Cahill, Jr. dated October 29, 1992

Gentlemen:

During teleconferences on February 15 through 19, 1993, with your Staff, TU Electric committed to provide clarifications for the following:

Ampacity Derating Test

I. TU Electric will perform ampacity derating testing on cable tray as follows:

o The test configuration is a 24 inch cable tray filled with 126, 0.75 inch diameter, 3/c #6 AWG cables and enclosed with Thermo-Lag per CPSES installation requirements.

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- o The filled tray will be tested with the Thermo-Lag envelope installed to establish the allowable current for a conductor temperature of 90°C (I_F).

- o The Thermo-Lag envelope will then be removed and baseline test will be performed to establish current for a 90°C conductor temperature (I_O).

- o Ampacity derating factor will be calculated as follows:

$$\text{Ampacity Correction Factor} = \frac{I}{I_O}$$

$$\text{Ampacity Derating Factor} = 1 - \frac{I_F}{I_O}$$

- o The calculated derating factor will be applied to ICEA allowable values to determine the allowable ampacities for cables installed in cable tray which are in Thermo-Lag fire barriers.

- o Ampacity correction factors from "Fire Protection Wrapped Cable Tray" demonstrated that cable derating is not significantly affected by the cable depth. For the TSI one hour product the difference in the final ampacity will be approximately 3.8%. When this is applied to a cable with an ICEA ampacity of 45.8A, at a one inch depth of fill, the possible error will be 1.74A. The configuration utilized by CPSES should result in a baseline ampacity which exceeds the ICEA baseline by approximately 9.5%. This will result in an additional derating of 4.37A. Therefore; it is demonstrated that the utilization of actual baseline ampacities, in determining the derating factor, will more than offset for any changes in derating that would occur from the effects of cable tray depth of fill. (See Attachment 3 for calculation).

II. Conduit and air drop cable ampacity derating testing will be in accordance with revision 1 of the test plan (Attachment 2).

<u>Thermo-Lag Fire Endurance Testing</u>

36 Inch Cable Tray Test

In order to resolve NRC concerns regarding the qualification basis for Unit 2 Thermo-Lag configurations on 36 inch cable tray, TU Electric will perform a confirmatory fire endurance test. TU Electric offers the following information concerning this test:

(i) A 36 inch cable tray "straight run" configuration will be tested in accordance with the methodology and acceptance criteria established by the NRC's letter of October 29, 1992 (Ref. 5); however, circuit continuity will not be monitored during the test or utilized in the acceptance basis.

(ii) Consistent with the TU Electric fire endurance tests accepted by the NRC Staff (Ref. SSER-26), the cable tray steel supporting members will be protected for a 9 inch nominal distance from the cable tray protective envelope.

(iii) The test assembly will be upgraded using backfit measures for the Unit 1 plant configuration. Specifically, joints on the test assembly protective envelope will be reinforced using stress skin overlay techniques only. Should this test pass, it will envelope the Unit 2 configuration. Should this test fail to meet the acceptance criteria of the NRC's letter dated October 29, 1992 (Ref. 5), however, it would not indicate a deviated Unit 2 plant configuration. TU Electric would, however, still be required to perform a confirmatory test of the 36 inch cable tray configuration used on Unit 2 prior to completion of the first refueling outage for Unit 2 (Ref. 3).

(iv) Due to the expedited schedule for completion of this test, the thirty (30) day cure time invoked for previous tests will not be utilized. Application of the Thermo-Lag Topcoat will occur approximately 72 hours following completion of the Thermo-Lag raceway envelope. The test will then be performed approximately 72 hours following Topcoat application.

(v) As with previous TU Electric fire endurance tests, this test will be performed under the auspice of Omega Point Laboratories at their San Antonio, Texas facility. The test is scheduled for March 4, 1993, and the Staff is invited to witness the test. Should a change occur to this scheduled date, TU Electric will notify the NRC Staff.

Thermo-Lag Box Design Configurations

During a February 9, 1993 meeting, TU Electric committed to modify specific Unit 2 Thermo-Lag fire barrier "box design" configurations which enclosed portions of cable trays and associated cable air drops. The NRC Staff's concern was that the protective envelope associated with these specific configurations was not a direct extension of the cable tray coverage.

Consistent with the Unit 2 junction box tested configuration, a second layer of nominal 1/2 inch Thermo-Lag panels for these configurations, which are similar to the junction box tested configuration, will provide sufficient assurance that the enclosed cabling would remain free from fire damage. This method of modification was discussed with NRC's Staff, and was found to

be acceptable by them. TU Electric has determined that the scope of this concern consists of 13 plant configurations. Accordingly, design modifications have been issued to either increase the material thickness as described above or rework the configurations in accordance with designs bounded by test and previously accepted by the NRC Staff. These field modifications will be complete by March 15, 1993.

Should you need additional information please contact Obaid Bhatty at (817) 897-5839.

Sincerely,

William J. Cahill, Jr.

William J. Cahill, Jr.

OB/tg

Attachments: 1. Fire Protection Wrapped Cable Tray Ampacity
2. CPSES Test Procedure
3. Ampacity Calculation

c - Mr. J. L. Milhoan, Region IV
Mr. L. A. Yandell, Region IV
Mr. B. E. Holian, NRR
Mr. T. A. Bergman, NRR
Resident Inspectors, CPSES (2)

ATTACHMENT 1 TO TXX-93101

FIRE PROTECTION WRAPPED CABLE TRAY AMPACITY

FIRE PROTECTION WRAPPED CABLE TRAY AMPACITY

Phil Save
Member IEEE

Gary Engmann
Senior Member IEEE

Southern California Edison Company

Abstract

In this paper, a method is presented for calculation of ampacity of cable in fire protection wrapped cable trays. A brief description of the model is presented. The iterative technique used for solution of the model's simultaneous transcendental equations is presented with a description of the computer program. Cable derating for several typical installations is given and a graph is developed for use with ICEA P-54-440. Ampacity derating derived from the model is also compared with published test results for two different fire wrap systems.

Introduction

Raceway systems in electric generating stations are enclosed with a protective wrap to meet regulatory or underwriter requirements. The design objective of the protective raceway wrap is electrical circuit integrity when the raceway is subjected to the effects of a fire.

Fire protective wrap systems are designed to reduce the heat transfer from a fire source to the raceway interior. The fire wrap may also impede the transfer of heat from the cables inside of the raceway to the environment.

Although the effect of a fire wrap on power cable operating temperature was observed in a test configuration more than ten years ago, there is no industry accepted method for calculating the ampacity of cable in this configuration. The IEEE initiated an effort to develop a standard for cable ampacity in raceway with fire protection features, e.g. breaks, barrier penetrations. However, no standard has been published.

Papers have been presented by Esteves [1], Petty [2], and Hiranandani [10], that present methods for calculating the ampacity of cable in wrapped raceway.

The first two methods are similar in that the thermal system is approximated by a simple linear model. The method presented by Esteves is based on an approximation of the Stolpe [3] model. The Stolpe model is put in series linear combination with the thermal "conductance" of the fire wrap material.

88 WM 242-0 A paper recommended and approved by the IEEE Power Generation Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1988 Winter Meeting, New York, New York, January 31 - February 5, 1988. Manuscript submitted August 19, 1987; made available for printing December 11, 1987.

The method presented by Petty extends the Neher-McGrath equations and employs a thermal "resistance" to represent the wrap material in the thermal system.

The Esteves approach ignores the effects of an enclosed horizontal air space between the top of the packed cable mass and the fire wrap material. This air space has been shown to be significant [3]. The Neher-McGrath equations extended by Petty have been shown to be inappropriate for cable trays (ICEA P-54-440 [4]).

The method proposed by Hiranandani is a more complete heat transfer model, but the model is based on several assumptions that do not conform to actual practice. In addition, the model begins with a configuration of the cables in the tray, i.e., quantity and conductor size. This information may be available for an existing tray installation, but it is not generally available when designing new installations.

However, the most serious concern with the model presented in [10] is the assumption that the current carrying conductors are installed at the top and the bottom of the packed cable mass. This is not usually the case, and is acknowledged in the model given by Stolpe [6]. The model in [10] assumes a negligible temperature gradient in the packed cable mass. Test results reported by Stolpe [6] and given in [3] show that there can be a 5C to 10C gradient in the packed cable.

A method for calculation of ampacity in covered tray is given in [3]. The method is refined and extended to trays with raised covers in [5]. In this paper, the method is extended to fire protection wrapped cable trays. A brief description of the model is presented. The iterative technique used for solution of the model's simultaneous transcendental equations is presented with a description of the computer program. Cable derating for several typical installations is given and a graph is developed for use with ICEA P-54-440. Ampacity derating derived from the model is also compared with published test results for two different fire wrap systems.

Model Description

The model is essentially the same as that presented in [3] and [5] with the addition of a fire wrap material around the cable tray. The geometry of the thermal system is shown in Figure 1.

The model is applicable to cable in ladder, trough, or solid bottom trays, and to tray with or without tray covers. Any cable calculated depth of fill and tray loading depth can be used. The cable may be installed randomly, without maintained spacing and no maintained segregation of power and control cable.

The model is applicable to a fire wrap system that is

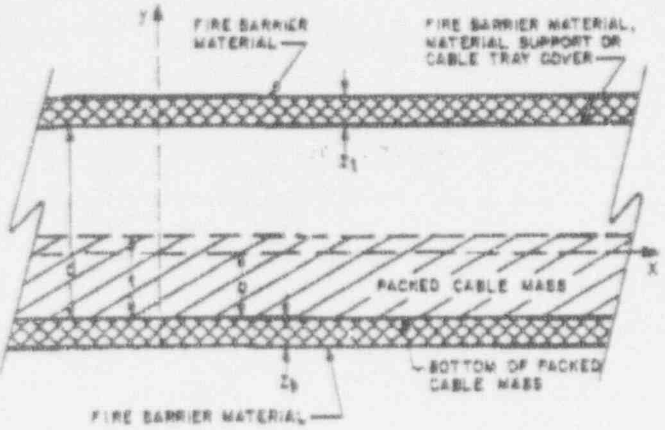


FIGURE 1: THERMAL SYSTEM GEOMETRY

made of a single, relatively homogeneous wrap material. If it is relatively uniform, any thickness of wrap material may be used and different thicknesses and thermal conductivities in top and bottom wrap can be accommodated. The wrap material support configuration (if any) need not be considered, if the support is relatively thin or has a relatively high thermal conductivity. Also, the configuration of the wrap system at the outside of the tray side rails need not be considered.

The heat transfer analysis, presented in Appendix I, results in two simultaneous equations with two unknowns. As shown by Appendix II, these equations are solved by using an iterative method which converges on the solution with a tolerance of less than 0.1% within two or three iterations.

Application

The method is applied in a computer program for several cases reflecting typical cable tray and fire wrap configurations, (in particular, materials of manufacturers 3M and TSI). The typical installations have equal thickness of the same fire wrap material on the top and the bottom of the cable tray, which results in the same thermal conductivities and emissivities. For each case, cable tray loading depths ranging from 3 to 5 inches, and cable mass thickness ranging from 1 to 3 inches are considered. Based on these cases, as shown by Table 1 below for 1 hour and 3 hour fire barriers, it is found that the cable derating due to fire wrap:

1. Is mostly a function of the fire wrap material and thickness (the emissivity e and the factor z/k, where $z = z_t = z_b$ is the total thickness and k is the thermal conductivity.

2. Is not significantly affected by the cable mass thickness; increasing the cable mass thickness from 1 inch to 3 inches results in a decrease of the derating ranging from 3% to 6% (depending on z/k).

3. Is independent of the loading depth of the cable tray.

As a result of these findings Figure 2 is proposed to provide a practical and simple determination of the cable derating due to fire wrap. Figure 2 consists of

TABLE 1: PERCENT CORRECTION FACTORS FOR 3M AND TSI MATERIALS FOR ONE-HOUR AND THREE-HOUR FIRE BARRIERS

Material Characteristics	3M	TSI
Conductivity $K_{zt} = K_{zb}$ (w/mx°C)	0.151	0.430
Emissivity Outside $e_{ot} = e_{ob}$	0.10	0.90
Emissivity Inside e_u	0.80	0.80
Barrier Thickness $z_b = z_t$ (in)		
One-Hour	1.0	0.5
Three-Hour	2.0	1.0

Cable Tray Fill (in)	Height (in)	3M Material 1 Hour z/K = .33	3M Material 3 Hour z/K = .67	TSI Material 1 Hour z/K = .06	TSI Material 3 Hour z/K = .11
1.0	3	50	42	75	70
1.0	4	50	42	75	70
1.0	5	50	42	75	70
1.5	3	51	43	76	71
1.5	4	51	43	76	71
1.5	5	51	43	76	71
2.0	3	52	44	76	71
2.0	4	52	44	76	71
2.0	5	52	44	76	71
2.5	3	53	45	76	72
2.5	4	53	45	76	72
2.5	5	53	45	77	72
3.0	4	55	47	78	73

three curves representing the percent correction factors to be applied to the ICEA P-54-440 ampacity tables, as a function of the factor z/k (ranging from 0.05 to 1.40 C x m²/w), respectively for outside emissivity $e_o = e_{ot} = e_{ob}$ of 0.9, 0.5, and 0.1.

The correction factor for a specific fire wrap is determined by finding the point corresponding to the factor z/k and the emissivity e (by interpolation if necessary). The curves of Figure 2 correspond to a cable mass thickness of 1.5 inch. For larger fills these curves are conservative since the ampacity could be increased by up to 5%. For smaller fills, the possible ampacity decrease of up to 1% can be neglected.

For non-typical cases (different top and bottom fire wraps configurations, etc.), one can use a computer program incorporating the iterative method, shown in the FORTRAN IV program listed in Appendix II.

Comparison with Published Test Results

The credibility of the model presented in this paper lies in its basis on accepted heat transfer analysis. However, it is useful to compare the model results with published test results.

Two vendors of raceway fire wrap systems have conducted cable ampacity tests. The results have been published in test reports [7], [8]. The model presented in this paper was used to calculate cable ampacity for the tested cable tray configurations.

For one fire wrap system, two tests were conducted with wrap that the vendor describes as a one hour cable tray system. The two tests were conducted at ifferent laboratories and the configurations were sentially identical. The two tests resulted in a erating of 42.5% and 47.5% derating from the open top tray ampacity. The ampacity calculated from the model for the two separate test configurations was a 44% derating from the ICEA P-54-440 ampacity. The fire wrap system was also tested with a wrap that the vendor describes as a three hour cable tray system. The test resulted in a 51.8% derating from the open top tray ampacity. The model yielded a 53% derating from the ICEA P-54-440 ampacity.

Another fire wrap system was tested at an independent laboratory with a fire wrap that the vendor describes as a one hour cable tray system. The test resulted in a 28.04% derating from the open top tray ampacity. The model yielded a 25% derating from ICEA P-54-440. When tested with a wrap that the vendor describes as a three hour cable tray wrap, the results were a 31.15% derating, and the model showed a 30% derating.

Discussion

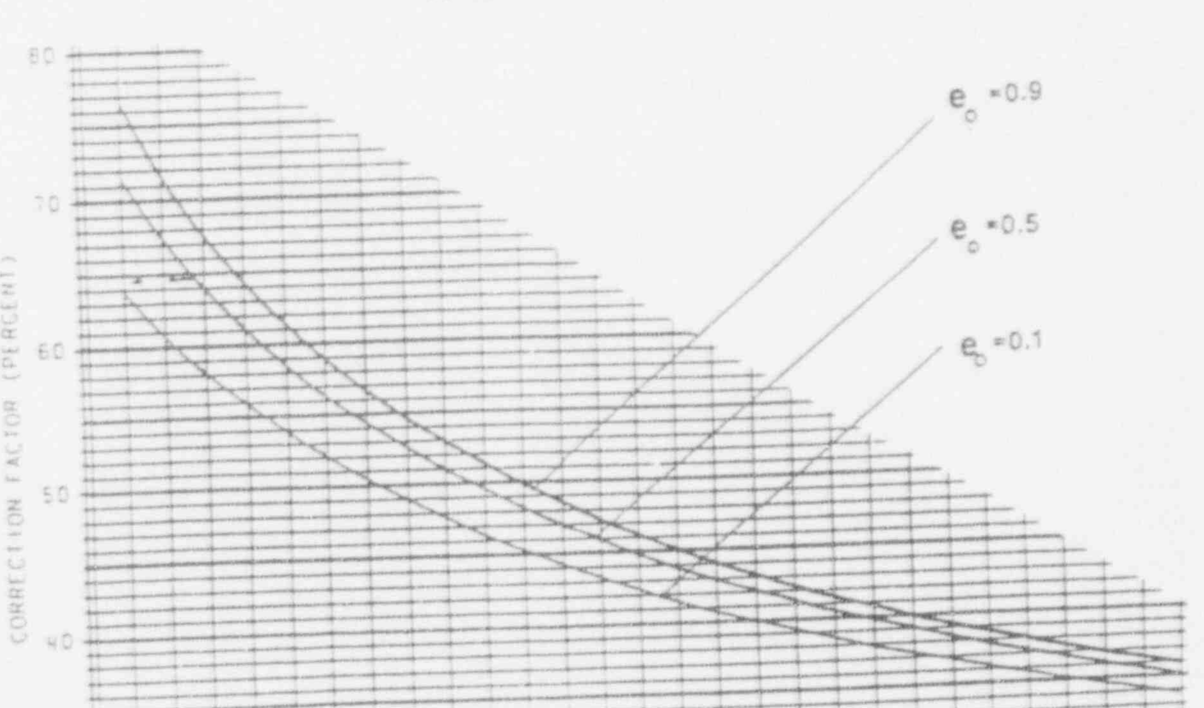
The model presented in this paper is a simple extension of the tray cover model presented in [3] and [4]. The model is based on accepted heat transfer analysis. In addition, the results obtained from the model have an acceptable consistency with the published results of tests conducted by separate independent testing laboratories on different cable tray fire wrap systems.

Another model [1] for cable ampacity in fire wrapped cable tray is a useful approximation. However, that model lacks the detail necessary to determine the effect of critical changes in cable, tray, and fire wrap configuration, and the effect of changes in material thermal properties. In addition, that model assumes that the horizontal air space between cable and fire wrap has a neglible effect in the thermal system. The effect of an air layer has been demonstrated in a large body of heat transfer literature. (See, for example, the references given in [5]).

A second model [10] for wrapped cable tray ampacity is based on assumptions that do not conform with actual installations. It assumes current carrying conductors are placed at the top and bottom of the packed cable mass and the cables in the center of the packed cable mass have negligible load. The model also ignores the significant thermal gradient that has been observed within packed cable. Practically, this model cannot be implemented for new cable tray installations.

FIGURE 2: DERATING OF CABLES IN CABLE TRAYS DUE TO FIRE BARRIERS

PERCENT CORRECTION FACTOR TO BE APPLIED TO ICEA P-54 440 AMPACITY TABLES



Conclusion

The ampacity of cable in wrapped cable tray can be determined from the curves given in Figure 2 and ICEA P-54-440. The graph is an extension of the model used to develop the ICEA P-54-440 ampacity tables. The model is consistent with the cablu tray fire wrap systems of at least two vendors. To use the graph, the only data needed are the wrap thickness-to-conductivity ratio and emissivity.

REFERENCES

[1] D.M. Esteves, "Derating Cables in Trays Traversing Firestops or Wrapped in Fireproofing", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, pp. 1478-1481, 1983.

[2] Keith Petty, "Ampacity of Wrapped Cables," IEEE Transactions on Power Apparatus and Systems, 86 SM 398-2, Recommended and Approved for IEEE/PES 1986 Summer Meeting.

[3] Gary Engmann, "Ampacity of Cable in Covered Tray," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-103, pp. 345-350, 1984.

[4] ICEA Pub. No. P-54-440 (Second Edition) - 1979, NEMA Pub. No. WC 51-1975, ICEA - NEMA Standards Publication, Ampacities - Cables in Open-Top Cable Trays.

[5] Gary Engmann, "Cable Ampacity in Tray with Raised Covers," IEEE Transactions on Energy Conversion, Vol. EC-1, pp. 113-119, 1986.

[6] J. Stolpe, "Ampacities for Cable in Randomly Filled Trays," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-90, pp. 962-973, 1971.

[7] Interam Fire Protection Products "Ampacity Considerations When Usings 3M Interam Fire Protection Mat," Prepared by Randal G. Koza, January 1987.

[8] Thermal Science, Inc., "Summary of Derating Tests Conducted on Thermo-Lab 330 Fire Barrier System-Protected Cable Tray Test Assemblies," January 30, 1987.

[9] Joseph Hilsenrath - National Bureau of Standards, et al, Tables of Thermodynamic and Transport Properties (of Air, etc.), Pergamon Press, 1960.

[10] Ajit K. Hiranandani, "Rating Power Cables in Wrapped Cable Trays", Paper 87 SM 593-7 presented at the IEEE Power Engineering Society 1987 Summer Meeting.

APPENDIX I

NOTATION AND MODEL DEVELOPMENT

Notation

a = distance from the bottom of the packed cable mass to a plane surface that is at the maximum temperature in the packed cable mass (meters).

C_p = heat capacity of air at constant pressure per unit mass [(watt-sec)/(gram-degree C)]

d = loading depth of cable tray (meters)

e_m = emissivity of packed cable mass surfaces (dimensionless)

e_{ob} = emissivity of outside of wrap material on bottom of tray (dimensionless)

e_{ot} = emissivity of outside of wrap material on top of tray side rails (dimensionless)

e_u = emissivity of inside of material on top of tray side rails - tray cover, wrap material, etc. (dimensionless)

g = gravitational acceleration = 9.807 meter/second^2

h = convection cooling coefficient at outside surface of fire wrap [(watt/mater-degree C)]

I = current (amperes)

k_e = thermal conductivity of air [watt/(meter-degree C)]

k_m = thermal conductivity of the packed cable mass [watt/(meter-degree C)]

k_{zb} = thermal conductivity of wrap material on bottom of the tray [watt/(meter-degree C)]

k_{zt} = thermal conductivity of wrap material on top of tray side rails [watt/(meter-degree C)]

k_3 = empirically derived equivalent thermal conductivity in the region between the top of the packed cable mass and the material on top of the tray side rails - wrap, tray cover, etc. [watt/(meter-degree C)]

m_e = viscosity of air [gram/(meter-second)]

n = number of conductors in a cable in the packed cable mass (dimensionless).

N_u = Nusselt number (dimensionless)

$$= \frac{k_3}{k_e}$$

pi = constant = 3.1416

Q_m = heat flux in the packed cable mass (watt/meter^2)

Q_{zb}= heat flux in the fire barrier material at the bottom of the tray (watt/meter^2)

Q_{zt} = heat flux in the fire barrier material on the top of the tray side rails (watt/meter^2)

r_w = radius of a cable in the packed cable mass (meter)

ro = density of air (gram/meter^3)

R = electrical resistance of a cable conductor in the packed cable mass (ohm/meter)

Ra = Rayleigh number (dimensionless).

$$= \frac{ro^2 \cdot g \cdot (d-t)^3 \cdot (T_2-T_3) \cdot C_p}{\overline{TK} \cdot m_e \cdot k_e}$$

(Note. Values for ro, C_p, m_e, k_e from [9].

s = heat generation per unit volume of packed cable mass (watt/meter^3)

sb = Stefan - Boltzman constant = 5.705 (10 exp -8) [watt/(meter^2 - degree k^4)] (see [4])

t = thickness of the packed cable mass (meter), see calculated depth in [4].

T_e = temperature of the environment (degree C)

T_w = maximum temperature in the packed cable mass, (degree C)

T_1 = temperature at the bottom of the packed cable mass (degree C)

T_2 = temperature at the top of the packed cable mass (degree C)

T_3 = temperature of the underside of the material on top of the tray side rails - wrap, tray cover, etc. (degree C)

T_4 = temperature of the outside of the fire barrier material at the bottom of the tray (degree C)

T_5 = temperature of the outside of the fire barrier material on the top of the tray side rails (degree C)

TK_e = temperature of the environment (degree K)

TK_w = maximum temperature in the packed cable mass, (degree K)

TK_2 = temperature at the top of the packed cable mass (degree K)

Tk_3 = temperature of the underside of the material on top of the tray side rails - wrap, tray covers, etc. (degree K)

TK_4 = temperature at the outside of the fire barrier material at the bottom of the tray (degree K)

TK_5 = temperature at the outside of the fire barrier material on the top of the tray side rails (degree K)

$\overline{TK}$ = average temperature of the horizontal air layer (degree K)

$$= \frac{TK_2 + TK_3}{2}$$

w = loading width of the cable tray (meter)

z_b = thickness of the fire barrier material at the bottom of the tray (meter)

z_t = thickness of the fire barrier material on the top of the tray side rails (meter)

Model Development

The model development is based on the assumption that all of the cables are installed so that there is a uniform depth of fill, and the cable in the tray is a homogeneous mass of constant thermal conductivity and uniform heat generation per unit volume of cable mass (See [6]). The heat transfer is from the top and bottom of each unit length of packed cable mass. However, the thermal system is not symmetrical (there can be an air layer above, but not below, the packed cable mass). Since the system is asymmetrical the analysis must determine which portion of the heat flux is downward, and which is upward. It is assumed that there is no heat transfer from the sides of the packed cable mass nor down the axis of cable and tray. The region between the top of the packed cable mass and the tray cover or fire wrap material includes conductive, free convection, and radiation heat transfer with reradiation from the tray side rails. The thermal conductivity of tray material (bottom, rungs, cover, etc.) is assumed to be relatively high and conduction temperature gradients in the tray material are ignored. The fire wrap material is assumed to be in direct thermal contact with the bottom of the packed cable and tray. The downward heat transfer through the packed cable mass and fire wrap is by conduction only. The fire wrap material is assumed to be installed directly on top of the tray side rails or tray cover. If a fire wrap support material (other than the tray cover) is used, it is assumed to have neglible effect on the system.

With this set of assumptions, the thermal analysis is divided into seven regions (See Figure 1). Region 1 is the bottom part of the packed cable mass ($-a < y < 0$), and the heat transfer equations solved at $y = -a$ are:

$$q_m = s.a \qquad (1)$$

$$T_1 = T_w - \frac{s.a^2}{2.k_m} \qquad (2)$$

The second region is the fire wrap material at the bottom of the cable mass and tray. ($-a-z_b < y < -a$). In this region the heat transfer equations solved for $y = -a-z_b$ are:

$$q_{zb} = s.a \qquad (3)$$

$$T_4 = T_w - \frac{s.a^2}{2.k_m} - \frac{s.a.z_b}{k_{zb}} \qquad (4)$$

The third region is at the outside surface of the fire wrap at the bottom of the cable mass and tray, and heat transfer is free convection and radiation. The convection cooling coefficient is given in [4], and converting to metric,

$$h = 1.917 \left[\frac{T_4 - T_e}{w}\right]^{0.25}$$

The convection heat flux is given by

$$h\,(T_4 - T_e) = \frac{1.917}{w^{0.25}}\,(T_4 - T_e)^{1.25}$$

Radiation heat flux is given by

$$sb.e_{ob}.\,(TK_4^4 - TK_e^4)$$

The total heat flux is the heat generated in the bottom part of the cable mass (s.a) and equals the convection and radiation heat flux at the outside

surface of the bottom fire wrap. Substituting equation (4) into the heat flux equation,

$$s.a = \frac{1.917}{w^{0.25}} \left[T_w - \frac{s\ a^2}{2k_m} - \frac{s\ a\ z_b}{k_{zb}} - Te \right]^{1.25}$$

$$+ sb\ e_{ob} \left[\left[TK_w - \frac{s\ a^2}{2\ k_m} - \frac{s\ a\ z_b}{k_{zb}} \right]^4 - TK_e^4 \right] \quad (5)$$

Region 4 is the top part of the packed cable mass ($o < y < t-a$), and the heat transfer equations solved at $y = t-a$ are:

$$q_m = s(t-a) \quad (6)$$

$$T_2 = T_w - \frac{s(t-a)^2}{2.k_m} \quad (7)$$

The fifth region in the thermal analysis is the air space between the top of the packed cable mass and the cable tray cover or fire wrap material. From [3] and [5] the conductive and convective heat transfer can be characterized by an equivalent thermal conductivity (k_3), which is a function of Nu and Ra.

$$k_3 = Nu\ .\ k_e$$

$$Nu = 1 + 1.44\left[1 - \frac{1708}{Ra}\right] + \left[\left[\frac{Ra}{5830}\right]^{0.33} - 1\right]$$

The quantity in brackets should be set equal to zero when it becomes negative.

The conduction and convection heat flux is

$$\frac{k_3}{d-t} \ (T_2 - T_3)$$

The radiation heat transfer in Region 5 is a function of the view factor and the emissivities of the cable mass (e_m) and the underside of the tray cover or fire wrap (e_u). From [3] and [5], the radiation heat flux in this region is given by

$$4.sb. \left[\frac{e_m . e_u}{e_m + e_u - 0.462 . e_m . e_u}\right] \left[\frac{2.TK_e + TK_w}{3}\right]^3 \ (T_2 - T_3)$$

The term

$$\left[\frac{2.TK_e + TK_w}{3}\right]^3 \ (T_2 - T_3)$$

is an approximation, and must be verified after a solution is obtained (see Discussion and Closure [3]). The conductive, convective, and radiation heat flux in Region 5 must equal the heat generation in the top part of the packed cable mass.

$$s\ (t-a)$$

From these three equations, it is possible to obtain an expression for T_3, the temperature of the bottom surface of the material on top of the tray side rails.

$$T_3 = TK_w - \frac{s(t-a)^2}{2.k_m} - \frac{s(t-a)}{\frac{k_3}{d-t} + 4.sb\left[\frac{e_m . e_u}{e_m + e_u - 0.462 . e_m . e_u}\right]\left[\frac{2.TK_e + TK_w}{3}\right]^3} \quad (8)$$

Region 6 is the fire wrap material on top of the tray side rails ($d < y < t-a+z_t$). In this region the heat transfer equations solved at $y = t-a + z_t$ are:

$$q_{zt} = s\ (t-a) \quad (9)$$

$$T_5 = T_3 - \frac{s(t-a)\ z_t}{k_{zt}} \quad (10)$$

Substitution of (8) into (10) yields equation (11).

Finally, Region 7 is at the outside surface of the fire wrap material on the top of the tray, and heat transfer is free convection and radiation. The convection and radiation heat flux equations are similar to those given for Region 3. Solution of the equations yields (12)

The solution of the heat transfer analysis is the pair of equations (5) and (12).

From [6], the allowable ampacity of a cable is given by

$$I = \left[\frac{s\ \ pi\ \ r_w^2}{n\ \ R}\right]^{0.5} \quad (13)$$

If the maximum conductor temperature (T_w) and the ambient temperature (T_e) are known, equations (5) and (12) can be solved for the allowable heat generation (s) and for the asymmetry of the system (a). The allowable heat generation (s) can then be used with the cable properties (r_w, n, R) in equation (13).

$$T_5 = T_w - T_e - \frac{s(t-a)^2}{2.k_m} - \frac{s(t-a)}{\frac{k_3}{d-t} + 4.sb\left[\frac{e_m . e_u}{e_m + e_u - 0.462 . e_m . e_u}\right]\left[\frac{2.TK_e + TK_w}{3}\right]^3} - \frac{s(t-a) z_t}{k_{zt}} \quad (11)$$

$$s.(t-a) = \frac{1.917}{w^{0.25}}\left[T_w - T_e - \frac{s(t-a)^2}{2k_m} - \frac{s\ .\ (t-a)}{\frac{k_3}{d-t} + 4\ \ sb\left[\frac{e_m . e_u}{e_m + e_u - 0.462\ .\ e_m . e_u}\right]\left[\frac{2TK_w + TK_e}{3}\right]^3} - \frac{s(t-a)\ \ z_t}{k_{zt}}\right]^{1.25}$$

$$+ sb.e_{ot} \cdot \left[\left[TK_w - \frac{s(t-a)^2}{2.k_m} - \frac{s\ .\ (t-a)}{\frac{k_3}{d-t} + 4\ .\ sb\ .\left[\frac{e_m . e_u}{e_m + e_u - 0.462 . e_m . e_u}\right] \cdot \left[\frac{2TK_w + TK_e}{3}\right]^3} - \frac{s(t-a)\ \ z_t}{k_{zt}}\right]^4 - TK_e^4\right] \quad (12)$$

APPENDIX II

SOLUTION OF TWO SIMULATANEOUS HEAT TRANSFER EQUATIONS WITH TWO UNKNOWNS

The two resulting heat transfer equations (5) and (12) of Appendix I can be expressed as follows:

Unknowns: $x = s$
$y = a$

With Constants:

$$A = \frac{1.917}{w^{0.25}} \qquad D = T_w - T_e \qquad G = (TKe)^4$$

$$B = \frac{1}{2k_m} \qquad E = s_b\, e_{ot}$$

$$C = \frac{z_b}{k_{zb}} \qquad F = TK_w$$

$$H = \frac{1}{\dfrac{k_3}{d - t} + \left[\dfrac{4\, sb\, e_m\, e_u}{e_m + e_u - 0.462\, e_m\, e_u}\right]\left[\dfrac{2TK_w + TK_e}{3}\right]^3} + \frac{z_t}{k_{zt}}$$

Equation (5) becomes Equation (14) below:

$$xy - A\,[-Bxy^2 - Cxy + D]^{1.25}$$

$$- E[(-Bxy^2 - Cxy + F)^4 - G] = 0$$

$$AD = -Bxy^2 - Cxy + D$$

$$AF = -Bxy^2 - Cxy + F$$

$$P(x,y) = xy - A(AD)^{1.25} - E[(AF)^4 - G] \qquad (14)$$

Equation (12) becomes Equation (15) below:

$$x(t - y) - A[-B\,[x(t - y)^2] - H\,[x(t - y) + D]^{1.25}$$

$$- E\,[-B\,[x\,(t - y)^2] - H\,[x\,(t - y) + F]^4 - G] = 0$$

$$BD = -B\,[x\,(t - y)^2] - H\,[x\,(t - y)] + D$$

$$BF = -B\,[x\,(t - y)^2] - H\,[x\,(t - y)] + F$$

$$Q(x,y) = x\,(t - y) - A\,(BD)^{1.25} - E\,[(BF)^4 - G] \qquad (15)$$

The above simultaneous equations (14) and (15) with unknowns x and y: $P(x,y) = 0$ and $Q(x,y) = 0$ cannot be solved algebreically. They can be solved numerically, however, as shown by Exhibit II-1 by using an extension of the Newton iterative method to three dimensions.

The partial derivatives required in the iterative method shown in Exhibit II-1 are:

For P(x,y):

$$DAX = \frac{\partial AD}{\partial x} = \frac{\partial AF}{\partial x} = -By^2 - Cy$$

$$DAY = \frac{\partial AD}{\partial y} = \frac{\partial AF}{\partial y} = -2Bxy - Cx$$

$$DPX = \frac{\partial P}{\partial x} = y - (1.25)\,(A)\,(AD)^{0.25}(DAX) - 4E\,(AF)^3[DAX]$$

$$DPY = \frac{\partial P}{\partial y} = x - (1.25)\,(A)\,(AD)^{0.25}(DAY) - 4E\,(AF)^3[DAY]$$

For Q(x,y):

$$DBX = \frac{\partial BD}{\partial x} = \frac{\partial BF}{\partial x} = -B\,(t - y)^2 - H\,(t - y)$$

$$DBY = \frac{\partial BD}{\partial y} = \frac{\partial BF}{\partial y} = +2B\,[x\,(t - y)] + Hx$$

$$DQX = \frac{\partial Q}{\partial x} = (t - y)$$

$$- 1.25\,(A)\,(BD)^{0.25}\,(DBX) - 4(E)\,x\,(BF)^3\,(DBX)$$

$$DQY = \frac{\partial Q}{\partial y} = -x$$

$$- 1.25\,(A)\,(BD)^{0.25}(DBY) - 4(E)(BF)^3\,(DBY)$$

Using the above formulas and the method described in Exhibit II-1, a computer program was developed, as shown by Exhibit II-2 which shows the main portion of the iterative method. Subscripts other than i and $i + 1$ are not kept but the principle is the same.

The initial values for x_0 and y_0, before the first iterating, are chosen automatically by the computer program, as follows:

> $x_0 = s_0$ is 80% of minimum x which would make 0 AB or BD terms (which are raised to the 1.25 power in P(x,y) and Q(x,y)
>
> $y_0 = a = (0.5) \times t$

This iterative method was used successfully in all cases, it converged on the solution with a tolerance of less than 0.1% within two or three iterations.

Biographies

Gary Engmann (SM '83) holds a MSEE and a MBA. He joined Southern California Edison Company in 1985 and has held the position of Supervisor of Electric System Planning.

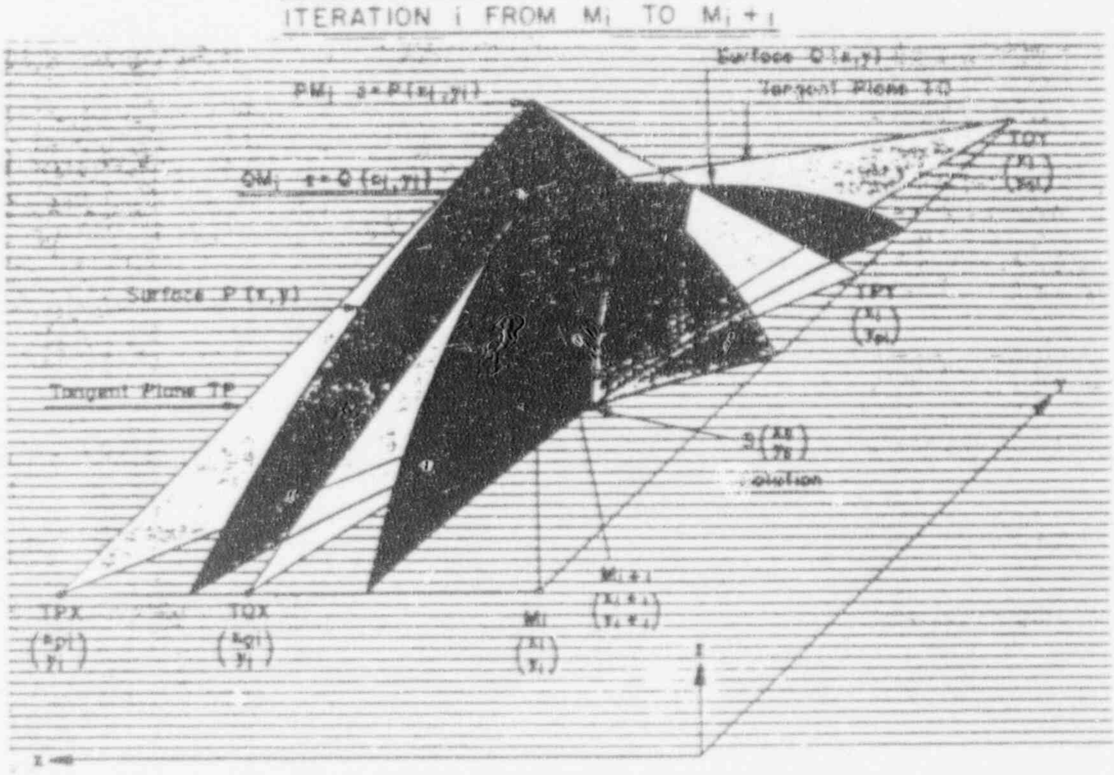
Phil Save (M '70) holds degrees in Physics and Engineering from France, and a MSEE from USC. He joined Southern California Edison Company in 1966 and has been an Engineer in the System Development and Engineering Departments.

EXHIBIT II -1

ITERATIVE SOLUTION OF SIMULTANEOUS EQUATIONS

Solution of simultaneous equations $P(x,y) = 0$ and $Q(x,y) = 0$ is represented by point $S(x_S, y_S)$ intersection of surface P $[z=P(x,y)]$ and Q $[z=Q(x,y)]$ with horizontal plane $z=0$, as shown by Figure below:

SOLUTION OF TWO EQUATIONS WITH TWO UNKNOWNS
EXTENSION OF NEWTON METHOD
ITERATION i FROM M_i TO M_{i+1}



ITERATION i: Starting Point: $M_i\ (x_i,\ y_i,\ 0)$

1. P_{Mi} on Surface P $z = P(x,y)$

   $P_{Mi}\ [x_i,\ y_i,\ z_i = P(x_i,\ y_i)]$

2. Plane Tangent to Surface P at P_{Mi}
   Defined by P_{Mi}, TPx, TPx

   $$xP_i = x_i - \frac{P(x_i,\ y_i)}{\partial P(x_i,\ y_i)/\partial x}$$

   $$xP_i = y_i - \frac{P(x_i,\ y_i)}{\partial P(x_i,\ y_i)/\partial y}$$

3. Intersection of Tangent Plane with $z = 0$
   Straight line: TPx TPX

   $$y - yp_i = \frac{Yp_i - Y_i}{x_i - xp_i}\ (x - x_i)$$

   $$y = MP_i\ x + CONP_i$$

1. Q_{Mi} on Surface Q $z = Q(x,\ y)$

   $Q_{Mi}\ [\ x_i,\ y_i,\ z_i = Q(x_i,\ y_i)]$

2. Plane Tangent to Surface Q at Q_{Mi}
   Defined by Q_{Mi}, TQx, TQy

   $$xQ_i = x_i - \frac{Q(x_i,\ y_i)}{\partial Q(x_i,\ y_i)/\partial x}$$

   $$yQ_i = y_i - \frac{Q(x_i,\ y_i)}{\partial Q(x_i,\ y_i)/\partial y}$$

3. Intersection of Tangent Plane with $z = 0$
   Straight line: TQx TQX

   $$y - yQ_i = \frac{YQ_i - Y_i}{x_i - xQ_i}\ (x - x_i)$$

   $$y - MQ_i\ x + CONQ_i$$

4. New Point $M_{i+1}\ (x_i + 1,\ y_i + 1,\ 0)$ Intersection of Lines TPX, TPX and TQX, TQY

$$x_{i+1} = \frac{CONP_i - CONQ_i}{MQ_i - MP_i} \qquad y_{i+1} = \frac{(MQ_i)\ (CONP_i) - (MP_i)\ (CONQ_i)}{MQ_i - MP_i}$$

EXHIBIT II-2

ITERATIVE SOLUTION OF HEAT TRANSFER EQUATIONS

P(x,y) = 0 AND Q(x,y) = 0

FORTRAN IV SOURCE PROGRAM EXCERPT

```
C  INITIAL VALUES  X0 = B0  AND  Y0 = T/2
C  X0 IS SUCH THAT IT IS 80 % OF MINIMUM X0 WHICH WOULD MAKE 0 THE
C  AE OR BE TERMS WHICH ARE RAISED TO THE 1.25 POWER.
      Y0 = (0.50)*T
      XAE = D/(B*(Y0**2) + C*Y0)
      XBE = D/(B*(Y0**2) + H*Y0)
      X0 = (0.80)*(AMIN1(XAE,XBE))
      IT = 0
  512 FORMAT(10X,'ITERATION NO. = ',I5,///)
      WRITE(6,513) X0,Y0
  513 FORMAT(10X,'X0 = B0 = ',F10.6,10X,'  Y0 = A0 = ' ,F10.6,/,
     1       10X,52(1H_),/)
   10 IT = IT + 1
      WRITE(6,512) IT
C  CALCULATION OF FUNCTION P0 = P(X0,Y0)
      AE = - (B*X0*(Y0**2))  - (C*X0*Y0)  + D
      AF = - (B*X0*(Y0**2))  - (C*X0*Y0)  + F
      P0 =   X0*Y0 - A*(AE**1.25) - E*(AF**6 - G)
      WRITE(6,514) AE,AF,P0
  514 FORMAT(10X,'AE = ',E10.4,' AF = ',E10.4,' P0 = ', E10.4,/)
C   CALCULATION OF PARTIAL DERIVATIVES DPX(X0,Y0)  AND DPY(X0,Y0)
      DAX = - B*(Y0**2)  - C*Y0
      DAY = - 2*B*X0*Y0  - C*X0
      DPX = Y0 - (1.25)*A*(AE**(0.25))*DAX - 6*E*(AF**5)*DAX
      DPY = X0 - (1.25)*A*(AE**(0.25))*DAY - 6*E*(AF**5)*DAY
      WRITE(6,515) DAX,DAY,DPX,DPY
  515 FORMAT(10X,'DAX = ',E10.4,' DAY = ',E10.4,
     1       10X,'DPX = ',E10.4,' DPY = ',E10.4,/)
C   CALCULATION OF FUNCTION Q0 = Q(X0,Y0)
      BE = -(B*(X0*((T-Y0)**2))) - (H*(X0*(T-Y0))) + D
      BF = -(B*(X0*((T-Y0)**2))) - (H*(X0*(T-Y0))) + F
      Q0 =  X0*(T-Y0) - A*(BE**(1.25)) - E1*(BF**6 - G)
      WRITE(6,516) BE,BF,Q0
  516 FORMAT(10X,'BE = ',E10.4,' BF = ',E10.4,' Q0 = ', E10.4,/)
C   CALCULATION OF PARTIAL DERIVATIVES DQX(X0,Y0) AND DQY(X0,Y0)
      DBX = -(B*(T-Y0)**2 + H*(T-Y0))
      DBY = 2*B*X0*(T-Y0) + H*X0
      DQX = T-Y0 - (1.25)*A*(BE**(0.25))*DBX - 6*E1*(BF**5)*DBX
      DQY = -X0  - (1.25)*A*(BE**(0.25))*DBY - 6*E1*(BF**5)*DBY
      WRITE(6,517) DBX,DBY,DQX,DQY
  517 FORMAT(10X,'DBX = ',E10.4,' DAY = ',E10.4,
     1       10X,'DQX = ',E10.4,' DQY = ',E10.4,/)
C   INTERSECTION OF TANGENT PLANES WITH HORIZONTAL PLANE Z = 0
      XP1 = X0 - P0/DPX
      YP1 = Y0 - P0/DPY
      XQ1 = X0 - Q0/DQX
      YQ1 = Y0 - Q0/DQY
      WRITE(6,518) XP1,YP1,XQ1,YQ1
  518 FORMAT(10X,'XP1= ',F10.6,'  YP1 = ',F10.6,
     1       10X,'XQ1= ',F10.6,'  YQ1 = ',F10.6,/)
      MP = (YP1 - Y0)/(X0 - XP1)
      MQ = (YQ1 - Y0)/(X0 - XQ1)
      CONP = YP1 - MP*X0
      CONQ = YQ1 - MQ*X0
      WRITE(6,519) MP,MQ,CONP,CONQ
  519 FORMAT(10X,'MP = ',E10.4,' MQ = ', E10.4,
     1       10X,'CONP = ',E10.4,' CONQ = ',E10.4,/)
C   NEW POINT X1,Y1 INTERSECTION OF STRAIGHT LINES ON Z = 0 PLANE
      X1 = (CONP - CONQ)/(MQ - MP)
      Y1 = (MQ*CONP - MP*CONQ)/(MQ - MP)
      WRITE(6,520) X1,Y1
  520 FORMAT(10X,'X1 =  B1 = ',F10.6,10X,' Y1 = A1 = ',F10.6,/,10X,
     155(1H_),/)
C   PERCENT CHANGE FOR X AND Y FROM PREVIOUS ITERATION
      TOLX = (100)*(ABS(X1-X0))/X0
      TOLY = (100)*(ABS(Y1-Y0))/Y0
      WRITE(6,521) TOLX,TOLY
  521 FORMAT(10X,'PERCENT CHANGE FROM PREVIOUS ITERATION VALUES : ',
     1'       FOR X : ',F8.5,'  , FOR Y : ',F8.5,/)
      IF ((TOLX.LT.(0.5)).AND.(TOLY.LT.(1.0))) GO TO 20
      X0 = X1
      Y0 = Y1
      GO TO 10
   20 CONTINUE
```

Discussion

Keith A. Petty (Stone & Webster Engineering, Boston, MA): The authors are to be commended for such a well organized paper. Test results should be used to verify modeling techniques, as the authors have done. IEEE/Insulated Conductors Committee's Subcommittee 12 should re-consider development of a test standard in light of the results of this paper. A calculation approach for derating factors would better serve the industry, than suggesting that for any small product change a new ampacity is required.

I would like to point out that my paper [2], does not apply to raceway, as the authors correctly point out. It addresses wrap material applied directly to cable surface where the cable is located is outside of tray or conduit.

The tests that 3M performed also included an unwrapped tray. These results showed that the unwrapped ampacity were 7.4% higher than ICEA P-54-440. Since the authors compared their modeling results against test results of the wrapped trays, would they comment on the effect this has on the correlation analysis?

Ladder type trays are used frequently in the power plant, in fact, 3M used ladder trays in their test. With ladder trays, you get an air gap between the bottom of the cable mass and the fire barrier material. The modeling technique presented in this paper assumed direct contact between the cable mass and the fire barrier material. In light of this, is it appropriate to compare the modeling results with the 3M and the TSI test results?

3M has several products with varying dimensions and characteristics. My review of their literature and discussions with 3M indicate that the 1 hour product is 0.8 inch thick, instead of 1 in; the thermal conductivity is 0.13 vs 0.151 watt/m-C. The resulting Z/k would be 0.156 instead of 0.33 as you indicated. The correction factor from your Figure 2 would be 58% (which is a 42% derating). The 3M test data indicates a correction factor of 53.3% against test data of unwrapped tray, and 57% against the ICEA P-54-440 values. Modeling results correlate well with test data, except for the issue of the air gap at the bottom of the cables, as mentioned above.

Manuscript received February 23, 1988.

A. K. Hiranandani (The Detroit Edison Co. Detroit, MI): The authors have developed a convenient chart for derating cables in wrapped trays. However since I have the honor of being referenced [10] I would appreciate if the authors would note their oversight in interpreting para 1.0.6 of my paper. The para refers to the heat generated by the cablemass—the arrangement of cables in the tray merely refers to a configuration for producing the best heat distribution in the cablemass by locating the cables producing more heat in the outer layers for better heat dissipation. The purpose of using an arrangement refers to a means of obtaining a cablemass of rectangular crossection as used in the Stolpe model. My model does not require any special constraints and can be used for all types of installations—the cables within the rectangular cablemass can be arranged at random. Para 1.0.6 refers to the easy way of obtaining a rectangular section of cablemass.

As shown in the paper cable derating is based on heat dissipated to ambient air between the cable mass and wrap. Each cable has a definate temperature based on the factors stated in para 1.0.2 of my model.

Manuscript received July 26, 1989.

PHIL SAVE GARY ENGMANN

We thank Mr. Petty for his comments on the paper. Mr Petty notes that tests performed by 3M indicated that the allowable ampacity of cable in open top tray is 7.4% higher than the values given in ICEA P54-440. Since publication of Stolpe's paper in 1971, there have been reports in the literature of tests results that indicated allowable ampacity that differed from that calculated with Stolpe's method, which is the basis for the ICEA standard. However, none of the reported test results are sufficient justification for changing the calculation method or the standard. These test results do point out that care must be exercised in comparing test results and calculated values. In the paper, the firewrap derating factors are ratios of calculated values. The ratio of calculated values was compared with the ratio of test results for wrapped and unwrapped tray, i.e. the 44% derating, that is the ratio of calculated values, is compared with the 42.5% and 47.5% derating that are the ratios of the test results.

A variety of tray constructions, including ladder type, might be used in a fire wrapped installation. The model presented in the paper assumes that the packed cable mass is in direct contact with the fire wrap material. For ladder type tray, this assumption is an approximation. However, all of the model assumptions are approximations to any actual installation. The issue is the acceptability of the assumptions. Although ladder tray might result in an additional air space at the bottom of the packed cable mass, we believe that the effect would be small and acceptable.

As noted in the paper, comparison of model results with a few test results does not validate the model or the assumptions on which it is based. The validity of the model is established by its basis in accepted heat transfer analysis and engineering judgement of the credibility of the model assumptions. The merit of the comparison presented in the paper lies in the comfort level required when presented with abstruse and unfamiliar heat transfer equations. In addition to the difference in tray construction, there might be other differences between the model and the 3M and TSI tests. We are not aware of any that we believe to be significant, and feel that the comparison was an appropriate and useful one.

For actually using the factors given in Figure 2, we thank Mr. Petty and have the opportunity to highlight a significant typographical error in Figure 2 of the preprint of the paper. The scale values on the abscissa in Figure 2 in the preprint are in error by a factor of 2. The error has been corrected in this publication. However, the configuration of the wrap and thermal data given by Mr. Petty are not those published by 3M for the test from which data was used for comparison. The comparison given in the paper is based on the information we received from 3M and is given in Table 1. We also note that Mr. Petty apparently used an emmissivity value of 0.9 in arriving at a factor of 58%. According to 3M, the emmissivity of the outside of the wrap is 0.1.

We also thank Mr. Hiranandani for his comment, and we apologize if we have incorrectly interpreted the model presented in his paper. However, we quote from item 6 of his paper, "Cables generating more heat will be assumed to be placed in the upper and lower outer layers of the cable-mass". With that statement, it is difficult to arrive at the interpretation that the model does not require any special constraints on placement of the cable. We agree that the methodology used by Mr. Hiranandani could be extended to randomly installed cables, but the model presented in the paper does not address that configuration. A random cable installation would require that Mr. Hiranandani include the maximum temperature in the packed cable mass and additional equations for heat transfer through the cable mass. The maximum temperature would lie somewhere between T1 and T6 shown in Figure 2 of Mr. Hiranandani's paper [10].

Manuscript received August 23, 1988.

ATTACHMENT 2 TO TXX-93101

CPSES TEST PROCEDURE

February 8, 1993

TEST PLAN Rev. 1

AMPACITY DERATING TESTS OF ARTICLES PROTECTED WITH THE THERMO-LAG FIRE BARRIER SYSTEM

1 SCOPE

This test plan describes the methods and guidelines to be utilized for the preparation of test specimens, installation of the THERMO-LAG (hereafter referred to as "Thermo-Lag") Fire Barrier Systems, performance of ampacity derating tests and all applicable documentation of these tasks and the test results.

2 OBJECTIVE

The objective of these tests is to determine the ampacity derating factors for a protective generic fire barrier system for cables at TU Electric's Comanche Peak Steam Electric Station. Results of this test program will provide documented evidence of the necessary current derating factors for a different cable installation configurations. These tests shall satisfy the requirements for ampacity derating by testing the cable raceway fire barriers as detailed in the IEEE P848 "Procedure for the Determination of the Ampacity Derating of Fire Protected Cables," Draft 11, dated April 6, 1992, except as otherwise outlined herein. (Note: IEEE-P848/D11 is presently undergoing review by members of Subcommittee 12 of the Insulated Conductors Committee of the IEEE. TU Electric has incorporated into this procedure those revisions expected to be included in Draft 12. The deviations from Draft 11 are highlighted in bold italics throughout the procedure).

3 REFERENCES

3.1 Documents

3.1.1 IEEE P848/D11 Procedure for the Determination of the Ampacity Derating of Fire Protective Cables," Draft 11, April 6, 1992

3.1.2 Thermal Science, Inc.'s Technical Note 20684, Revision V "THERMO-LAG 330 Fire Barrier System, Installation Procedures Manual, Power Generating Plant Application," including TSI letters of clarification thereto

3.1.3 Specification CPES-M-2032, Rev. 0, "Procurement and Installation of Fire Barrier Fireproofing Material."

3.1.4 ICEA Standard P-54-440, "Ampacities for Cables in Open-top Trays", May 1975

3.1.5 ICEA Standard P-46-426, "Power Cable Ampacities"

3.1.6 Construction/Quality Procedure CQP-CV-107, Rev 0, "Application of Fire Barrier and Fireproofing Material."

3.1.7 Construction/Quality Procedure CQP-EL-222, Rev.1, "Installation and Fabrication of Conduit Raceway Systems."

4 RESPONSIBILITIES

4.1 Texas Utilities Electric (TU Electric) and Associated Contractor Organizations

4.1.1 Establish the criteria, guidelines, drawings (draft quality), recommendations, etc., to govern the installation of the test items. Supply the test item pieces, including all hardware, electrical cables, conduit, tray systems, etc.

4.1.2 Establish the criteria, guidelines, drawings (final, report quality if needed), recommendations, etc., to govern the installation of the Thermo-Lag Fire Barrier System Materials to the test articles.

4.1.3 Provide the specific Thermo-Lag installation procedures and work package documentation.

4.1.4 Provide materials representative of existing or future site installations.

4.1.5 Provide the Thermo-Lag Fire Barrier System materials and installation tools and equipment.

4.1.6 Provide scheduling of personnel, equipment and material necessary to perform the installation and QC documentation of the fire barrier system materials utilizing the appropriate installation procedures.

4.1.7 Coordinate all phases of the ampacity test preparation with the testing organization including approval of variations .

4.1.8 Apply the fire barrier system to the test articles.

4.1.9 Supply QC and construction personnel to witness and document assembly and test article raceway configurations.

4.1.10 Perform as a liaison with the testing organization and provide the testing organization with all applicable TU Electric Documents as identified in Section 3. 1.

4.1.11 Provide all applicable quality control documentation for the fire barrier system materials, cables, and installation of the fire barrier system to each test article.

4.2 Omega Point Laboratories, Inc. (Laboratory)

4.2.1 Prepare the test assemblies and provide all required test instrumentation in accordance with Appendix B Quality Assurance and Quality Control Programs and other applicable procedures.

4.2.2 Provide thermocouple calibration and instrumentation, storage temperature recorder, surface temperature probe and relative humidity instrumentation.

4.2.3 Assemble, install and document the installation of all trays, conduits, cables, etc. to be supplied by TU Electric. Provide computer-generated drawings of tray, conduit and cabling systems which clearly indicate dimensions, thermocouple locations, etc.

4.2.4 Observe and document the installation of the Thermo-Lag Fire Barrier System Materials to the test articles, and attendant instrumentation on each test article.

4.2.5 Conduct the ampacity baseline and derating tests.

4.2.6 Document the test parameters and provide a formal detailed written report of the test program and test results.

4.2.7 Provide 35mm photographic coverage of the test project.

4.3 Laboratory Quality Assurance/Quality Control

4.3.1 Verify and document the quality control documentation of the fire barrier system materials used in the test program.

4.3.2 Perform and document inspections of the fire barrier system materials at various points during the installation process.

4.3.3 Verify and document that TU Electric's installation procedures are utilized in the installation of the fire barrier system materials.

4.3.4 Inspect and document the construction and instrumentation of the test articles.

4.3.5 Provide written calibration documentation of all thermocouples, ammeters, measurement devices and data acquisition systems used in this test program.

5 SPECIAL PRECAUTIONS

5.1 Precautions For Installation Of The Fire Barrier System Materials

5.1.1 Thermo-Lag Fire Barrier System materials shall be installed by TU Electric in accordance with applicable specifications, design drawings and procedures (Ref. 3.1.6, 3.1.7 and 3.1.8) such that the test articles are representative of CPSES upgraded Thermo-Lag installations .

5.1.2 Observe specific precautions recommended by Thermal Science, and other's material safety data sheets.

6 PREREQUISITES

6.1 Traceability Requirements

To insure that the materials used in this test are representative of those in actual use at Comanche Peak Steam Electric Station (CPSES), all aspects of traceability as required by the Laboratory QA Program shall be applied.

The cables used in this test program shall be traceable to the respective cable manufacturer and shall be supplied by TU Electric or the Laboratory with documentation of traceability.

All thermocouples used in this test program shall be calibrated.

6.2 Test Configuration

6.2.1 Cable Tray Test Article

One(1) tray article will be tested as prescribed in the IEEE P848/DII draft test method: a 24" wide x 4" deep straight section of ladder back cable tray, 12 feet long, filled to 40% with 3/C 6AWG Cu 600v cable. The entire assembly shall be clad in 1/2" Thermo-Lag.

6.2.2 Conduit Test Articles

Three(3) configurations of galvanized rigid steel conduit supplied by TU Electric will be tested. All will be 12 feet long and will contain electrical cables as described below.

a. *A 3/4" diameter conduit, with a single 3/C 10 AWG 600v Cu cable, clad in a 1/2 inch thick layer of Thermo-Lag with a 1/4" overlay*

b. *A 2" diameter conduit, with a single 3/C 6 AWG Cu 600v cables, clad in a 1/2 inch thick layer of Thermo-Lag with a 1/4" overlay*

c. *A 5 " diameter conduit, with three-1/C 750 kcmil Cu, 600 V EPR-insulation/Hypalon jacket cables , clad in a 1/2 inch thick layer of Thermo-Lag.*

Note: These configurations were chosen to be consistent with CPSES installation (i.e., 3/4" to 5" instead of 1" to 4" specified in the standard).

6.2.3 Free Air Drop Test Articles

Two (2) configurations of cable bundle free air drops supplied by TU Electric will be tested. Each will consist of a 12 foot long cable bundle as described below.

a. A single 3/C 6 AWG Cu 600 V cable, clad in three layers of 660-Flex Blanket Thermo-Lag

b. Three 1/C 750 kcmil Cu 600 V EPR-insulation/Hypalon jacket cables, clad in three layers of 660-Flex Blanket Thermo-Lag

6.2.4 Baseline Test Articles

Baseline test articles shall be constructed in the same manner as the test configurations described above except they will not be clad in Thermo-Lag. *In order to ensure repeatability and consistency with the ampacity testing used to model and confirm the ampacity in random filled tray of ICEA P-54-440, a 3 mil thick plastic sheet shall be placed on the bottom of the tray when conducting the baseline test for the cable tray article.*

6.2.5 *Test articles shall be supported on wood blocks during the performance of the ampacity tests.*

6.3 Cable Installation

An itemized listing of cable types and quantities including the percentage cable fill to be installed in the test articles will be prepared by the Laboratory and included in the final report. Cable location within the test articles shall be documented and included with data to be evaluated by the testing laboratory. All conductors inside each test article will be connected into a single, series electrical circuit.

6.4 Thermocouple Installation

All thermocouples used in this test program shall be provided and installed by the Laboratory, with QC surveillance by Laboratory personnel. The thermocouple wires shall be calibrated (by Lot No.) prior to installation and for use, and applicable quality control documentation for record purposes generated. ***Type T special accuracy thermocouples shall be used on the conduit and free air drop configurations and for all ambient temperature measurements. Type K thermocouples will be used for tray configurations and adjustment made to account for any difference in accuracy.*** All thermocouples will be electrically welded at the thermojunctions.

Calibration will consist of manufacturer-supplied (and audited) certifications of calibrations at five temperatures of thermocouples taken from both ends of each purchased lot number.

Three thermocouples shall be installed at each location for the conduit and the free air drop test articles.. Thermocouples in the cable tray test articles shall be installed in locations that are consistent with the requirements of IEEE-P848/D11.

6.5 Ammeter Installation

(Later)

6.6 Pretest Inspection

6.6.1 Prior to the commencement of the test, a thorough check of each test assembly and associated equipment (including data recording equipment) shall be performed and documented by the testing laboratory.

6.6.2 Approval of the construction, assembly, installation and instrumentation will be documented by TU Electric and the Laboratory prior to performance of each test (a sign-off sheet for this purpose will be supplied by the Laboratory).

6.6.3 Ampacity derating testing of assemblies will not commence until Thermo-Lag Fire Barrier Materials attain a moisture meter reading that does not exceed 20% content. A meter with a scale of 0-100 (with 100 being 20% actual moisture content) such as a Delmhorst Model DP or equivalent shall be used.

7 PROCEDURE

7.1 Ampacity Baseline Tests

7.1.1 The unprotected test articles shall be energized with 60 Hz AC voltage as specified in IEEE P848/Dll and the baseline current ampacity determined as that which results in a thermal equilibrium at 90 C at the hottest location at the center of the test article.

7.1.2 The conditions specified in IEEE P848/Dll for ambient temperature and current/temperature equilibrium will be adhered to.

7.1.3 *If the final conductor and ambient temperatures are not 90 C and 40 C respectively for any test, the measured current shall be normalized as outlined in ICEA P-46-426.*

7.1.4 *Baseline tests may be run before or after the TSI protected raceway/free air drop test assemblies; However, the cable and thermocouple placements must remain unchanged.*

7.2 Ampacity Derating Tests

7.2.1 The protected test articles shall be energized with 60 Hz AC voltage as specified in IEEE P848/D11 and the baseline current ampacity determined as that which results in a thermal equilibration at 90 C at the hottest location at the center of the test article.

7.2.2 The conditions specified in IEEE P848/Dll for ambient temperature and current/temperature equilibrium will be adhered to.

7.2.3 *If the final conductor and ambient temperatures are not 90 C and 40 C respectively for any test, the measured current shall be normalized as outlined in ICEA P-46-426.*

7.3 Calculation of Ampacity Derating

7.3.1 Ampacity derate factors shall be calculated in accordance with IEEE P848/D11.

7.3.2 *The normalized measured current for the baseline configuration shall be used in computing the cable ampacity derating factor. When the normalized measured current is less than the published ampacity from ICEA Standard P-54-440, the ampacity from the standard shall be used as the baseline current.*

8 DATA SYSTEMS

8.1 During the ampacity test period, all thermocouples will be scanned at one minute intervals or less.

8.2 The data acquisition computer will determine the hottest single point at the center of each assembly and, using Proportional, Integral and Derivative (PID) process control computer routines, will output a voltage signal which will update the position of a motor-driven variable transformer to drive the system to equilibrium at 90 C.

8.3 The data acquisition computer will concurrently measure the current flow through the assembly, by interfacing with a calibrated current loop circuit. When equilibrium has been reached (in accordance with the P848/Dll Draft standard), the system will be de-energized and the test will be complete.

9 TEST REPORT

9.1 The Laboratory will submit a report on the results of the test and thermocouple data.

9.2 The Laboratory will assemble the final test report, containing the collected data and required quality control documentation.

9.3 The test report shall be prepared in sufficient detail to summarize the total testing activity. The report shall include as a minimum:

a) Date of the test
b) Location of the test
c) Description of the test equipment and test articles
d) Calibration documentation of all thermocouples
e) Qualification and certification for test personnel
f) Test procedures used
g) Ampacity values determined and accompanying equilibrium temperatures.
h) Provide quality control records for:

 * Test article construction
 * Qualification and certification for installation and inspection personnel
 * Identification and installation of fire barrier material
 * Thermocouple locations
 * Cables, size, type, and location
 * Actual tray and conduit cable fill
 * Actual calculated cable depths in tray

i) Computer printout and graphic results of the ampacity test
j) All raw data
k) 35mm photographic coverage of the test project
l) Provide a chronological log (Event Log) of all activities from receipt of materials through final test report

ATTACHMENT 3 TO TXX-93101

AMPACITY CALCULATION

The Ampacity Correction Factor (ACF) for a 1 inch depth of fill with TSI one hour material is .75. The ACF for the same material with a 3 inch depth of fill is .78.* The difference between the derating in the 3 inch and 1 inch depth of fill is 3.8%.

$$\frac{78 - 75}{78} \times 100 = 3.8\% \qquad [1]$$

ICEA P-54-440 (second edition), dated August 1979, Table 3 has an ampacity of 44A for a 3/c #6 AWG (.72 diameter) at a 1 inch depth of fill. Appendix B of P-54-440 provides the following equation for calculating the ampacities for cables at different diameters than those in the ampacity tables.

$$I_x = \frac{d_x}{d_o} Io \qquad [2]$$

Where:

I_o = ampacity for cable diameter d_o from ampacity tables in P-54-440.

* ACF, from Attachment 1

I_x = ampacity for cable diameter d_x

The cables used, by CPSES at Omega Point, for our ampacity testing are 3/c #6 AWG with a .75 inch diameter. The ampacity for this cable at a 1 inch depth of fill is 45.8A.

$$I_x = \frac{.75}{.72} \times 44A = 45.8A \qquad [3]$$

When the maximum derating difference, from equation 1 is applied to 45.8A the possible difference in actual cable ampacity would be 1.74A.

$$45.8A \times .038 = 1.74A \qquad [4]$$

The test sample, utilized by CPSES, in our ampacity test should produce a baseline ampacity of approximately 23.96A (this is reflective of baseline tests preformed in the past by Omega Point on this sample). The ampacity from ICEA tables for our cables, and corrected using equation 2 is 21.875A, for a 3 inch depth of fill.

$$I_x = \frac{.75}{.72} 21A = 21.875A \qquad [5]$$

The utilization of the baseline ampacity from the test will result in a 9.5% increase in the derating factor.

$$\frac{23.96 - 21.875}{21.875} \times 100 = 9.5\% \qquad [6]$$

This will result in a conservative additional derating of 4.35A at a 1 inch depth of fill (from equation 1).

$$45.8A \times .095 = 4.35A$$

While any increase in derating above 3.8% will compensate for the difference in derating, the anticipated derating of 9.5% will more than offset any changes in the derating that would occur from the effect of a 3 inch tray depth of fill.