CABLE DERATING PRACTICE

Verified

No.	DATE	REVISIONS	BY	CH'K	APPR
2	10-29-84	Revised Derating of Covered Tray	GAR	EL	
1	5-11-83	General Revision	GAR	EL	
0	7-7-75	ISSUED AS A TPO DESIGN GUIDE	MR	KDB	

ORIGIN ELECTRICAL SFPD BPC	BECHTEL	Cable Derating Practice	JOB No. STANDARD DESIGN GUIDE E.2.6.4 REV. 2 SHEET 1 OF 27

G1000442-01

REVISION 2

SUMMARY OF REVISIONS

1. General editing of entire document.

2. Changed "ventilated" cable trays to "open top" cable trays throughout to conform to ICEA.

3. Paragraph [illegible].4; Deleted section on derating 4% for solid tray covers, added reference to paragraphs 3.7, 3.8, 3.9 where 3.9 is a new section titled "Addtional Derating for Cables Routed in Open Top Tray with Solid Covers".

4. Paragraph 3.6.6, b); Deleted derating for solid tray covers from sample calculation.

5. Added notations that tray covers should be removed prior to applying firestop materials or enclosing raceway with fire protecting material.

6. Paragraph 3.8; Revised to include derating for a 3-hour fire rating for Thermo-Lag. General revision to separate discussion of Thermo-Lag and ceramic fiber blankets.

7. Renumbered "3.9 General Precautions" to "3.10 General Precautions".

1. SUBJECT

Cable Derating Practice

2. PURPOSE

To establish a design guide to determine cable ampacity ratings for cable directly buried, in underground ducts, embedded and exposed conduits, and in open top cable trays. (For industrial projects and utility buildings not included in the power block, the National Electrical Code should be used for ampacity values and calculational methods).

3. DESIGN GUIDE

3.1 General

The following is to set forth a definite and uniform procedure to determine cable ampacity ratings. It encompasses various types of cable installation, namely:

a) Underground
   1) Directly buried
   2) In ducts

b) In Conduit
   1) Embedded in slabs or walls
   2) Exposed Conduit

c) In Cable Trays
   1) With Maintained Cable Spacing
   2) Random Fill of Cables in Tray

Publication No. P-46-426 of the ICEA contains tabulated ampacities for a variety of cable voltage classes, thermal ratings, and installations, and provides the basic ampacities for cases a), b), and c)1) above. Two volumes comprise this publication. Volume 1 deals with copper conductors and contains an Introduction and Appendices applicable to both volumes. Volume 2 contains ampacity tables for aluminum conductors.

Sections II.D.2 and 3. of the Introduction Section in Volume 1 of the above publication set forth a method for calculating ampacities for case c)2)-Cable tray installations with random fill. This section has been superseded by a newer ICEA publication, Publication No. P-54-440 "Ampacities for Cables in Open Top Trays." The latter should be used exclusively since the older method, as set forth in Sections D.2 and 3., is in error.

If shielded medium voltage power cables are installed so that individual conductors are not symmetrically disposed, circulating currents in the insulation shields of the cables may reach a magnitude where the thermal effect of the I^2R factor requires derating of the cable conductor. Wherever such cases occur, a third ICEA publication, Publication No. P-53-426, "Ampacities Including Effect of Shield Losses for Single Conductor Solid Dielectric Power Cable 15kV through 35kV," should be consulted. The title could be misleading in that this effect applies at other voltages as well. Whenever shielded power cables are installed with individual conductors in a non-symmetrical arrangement, these effects should be investigated and either taken into account if the losses are significant, or steps should be taken to eliminate the circulating shield current. (See Design Guide E-2.6.5 "Power Cable Shielding and Shield Grounding")

This design guide contains sample ampacity calculations. Although these are primarily based on copper conductors, the same procedures and considerations are applicable to aluminum.

3.1.1 It is important to remember that current-carrying capacity, voltage regulation, and short-circuit capacity of cables must be considered independently in order to assure proper selection of cable sizes with various types of insulations, voltage classes, and modes of installation.

3.1.2 Although it is not specifically called for in the Introduction Section of Volume 1 of P-46-426 (nor elsewhere in this standard), combining circuit "sets" of power cables in the same conduit or underground duct requires that the tabulated ampacity be reduced (derated) accordingly. The derating effects of mutual heating is addressed in other sections of the Introduction -- derating for adjacent conduits in air or in concrete-encased duct banks, etc.

Since the methods set forth in Section II.D.2 and II.D.3 of the P-46-426 Introduction (including Table VIII) have been superseded (and should be crossed out in all copies of the standard presently in use), the table is reproduced in this Design Guide in Section 3.5.1.

3.1.3 Ampacity calculations for underground cables, whether run in duct banks or directly buried, can be rapidly and conveniently made by means of a privately developed computer program now available at some Bechtel offices.

The program, designated E-700 (originally designated "WE-80"), is run on a Texas Instruments TI-59, a hand held, card-programmable calculator, and a printer auxiliary unit.

It calculates ampacities for cables in a large number of ducts or cable groups, with complete flexibility regarding duct size, spacing, and bank configuration. Where some cables are loaded to less than their permissible ampacity, this reduction in mutual heating is taken into account to permit higher loading of other cables in the particular run. Consult with your local office Chief Electrical Engineer's staff regarding possible use of this program.

When this program is available, it is recommended for use instead of the methods set forth in Sections 3.2 and 3.3.

3.2 Direct Burial Cable

3.2.1 Types of directly buried cable configurations with typical dimensions as per ICEA Pub. No. P-46-426 are shown in Figures 1, 2 and 3. Final detail with respect to trenching and backfill are to be supplied by the project.

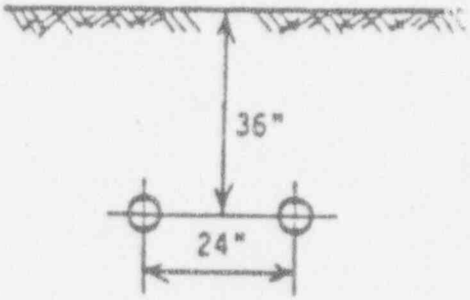

Figure 1 - Buried 3/C Cables

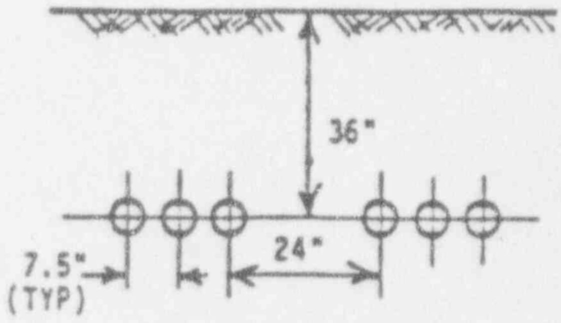

Figure 2 - Buried 1/C Cables

* Note that the arrangement in Figure 2 may cause significant shield losses if shielded cables are used and shields are grounded at more than one point.

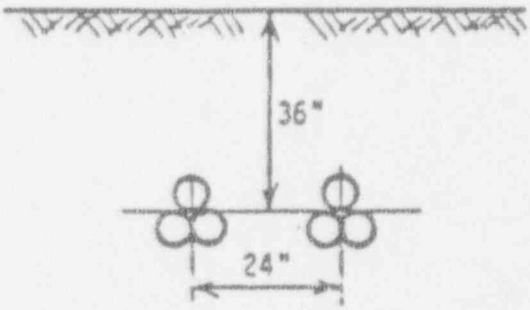

Figure 3 - Buried Triplex Cable

3.2.2 Information required to enter ICEA Pub. No. P-46-426 for Direct Burial Cable:

a) Cable Description (e.g. 1/C, 3/C, or Triplex)

b) Cable Operating Voltage (e.g. 1kV, 8kV, 15kV, or 25kV)

c) Cable Insulation (e.g. Rubber or Thermoplastic, Varnished Cloth, Paper, LP Gas or Oil-Filled)

d) Conductor Temperature (e.g. 60, 65, 70, 75, 80, 85 or 90C)

e) The ampacity values tabulated in ICEA for direct burial cable are for an ambient earth temperature of 20°C. Adjustments must be made for ambient earth temperatures which are substantially different from this. A frequently used guideline is to assume the 20°C ambient for "Northern US" locations and 30°C for "Southern US" locations. While this approach may suffice for feeders in which ampacity margin factors offset the importance of this item, important or critically loaded underground cable systems should utilize testing or other methods (per EEI "Underground Systems Reference Book" - Chapter 10). An important precaution in this regard is to ensure that cable trenches or duct banks are not affected by close proximity to other underground systems creating a higher-than-normal earth ambient. An example of this might be the installation of a cable run from the power block to the intake station or cooling tower in the same excavation with the circulating water discharge line.

If ambient earth temperatures above 20°C are encountered, one method of derating the cables is to lower the conductor operating temperature by the same amount as the increase in ambient temerature (e.g. to find the ampacity of cable with conductor temperature of 90°C and an ambient temperature of 30°C, find the ampacity of a cable with 80°C conductor temperature and a 20°C ambient temperature which can be read directly from the tables).

f) Load Factor:

Ampacities are tabulated for 30, 50, 75 and 100% load factors. These are indicated as 30LF, 50LF, 75LF, and 100LF. It is recommended that 100LF be used for all calculations involved with generating station applications.

g) Earth Thermal Resistivity:

ICEA Pub. No. P-46-426 ampacities are tabulated for in-earth thermal resistivity, RHO, in degree centigrade-centimeters per watt, for RHO-60, RHO-90, and RHO-120. Procedures are given for interpolation and extrapolation, if other than indicated values of RHO are encountered. ICEA recommends that RHO-90 be used when earth thermal resistivity is not known. However, in the instances of major cable installations, where engineering judgement and economics dictate, we should determine RHO as closely as possible. Some of the factors which must be considered are: type of soil, type of backfill, moisture content of soil, depth below surface, and presence of nearby concrete slabs or structures. In addition, the "baking" of the soil by the current-carrying conductors can cause RHO to change (for the worse) with time. **Two reference articles on this subject are: "Rapid Measurement of Thermal Resistivity of Soil" by V. V. Mason and M. Kurtz, AIEE Transactions, Vol. 71, 1952, page 570; "Soil Thermal Resistivity Measured Simply and Accurately" by John Stolpe, IEEE Transactions Vol. PAS-89, Number 2, February 1970, page 297.**

3.2.3 Sample Calculation:

Given: Directly Buried Cable; 3-1/C; 4.16kV, Rubber Insulated, Conductor Temperature 90°C, Ambient Earth Temperature 30°C.

Find: Ampacities for 2/0, 4/0, and 500 kcmil at 100LF.

Solution: ICEA Pub. No. P-46-426 ampacities of directly buried cable are tabulated for 20°C Ambient Earth Temperature. To maintain same temperature difference between conductor and earth, use a conductor temperature of 80°C.

ICEA Pub. No. P-46-426 index page iii refers to table on page 202.

Wire Size	Ampacity	
2/0	303	
4/0	393	RHO-90, 100LF, 1 Circuit, 8kV
500 kcmil	629	

3.3 Cables in Underground Ducts

3.3.1 Type of duct configurations and typical dimensions as per ICEA Pub. No. P-46-426 for 5" duct are shown in Figures 4, 5, 6 and 7. Duct bank overall dimensions are approximate, to give minimum 3" encasement coverage:

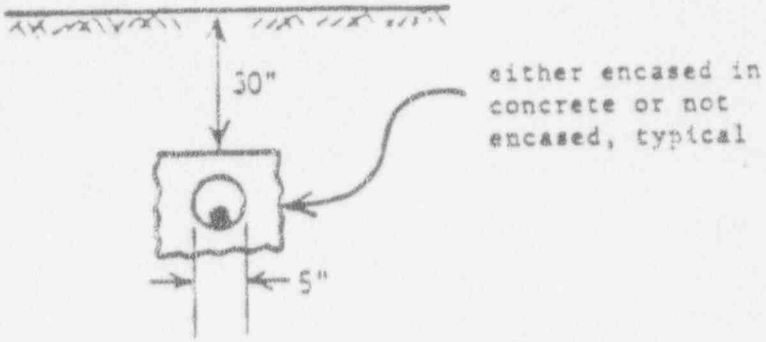

Figure 4
11.5" by 11.5" overall
Duct Bank

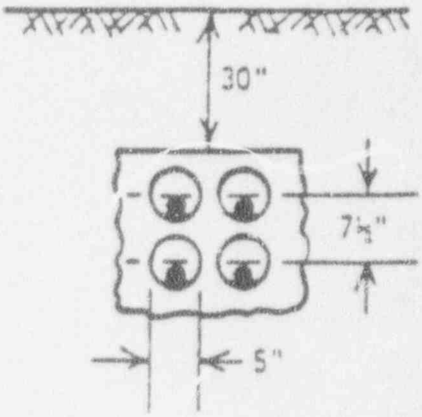

Figure 5
19" by 19" overall
Duck Bank

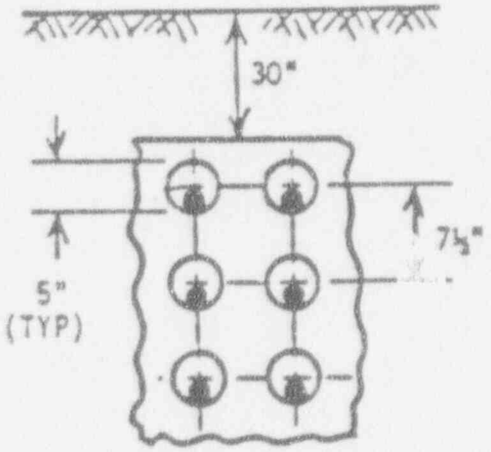

Figure 6
19" by 26.5" overall
Duct Bank

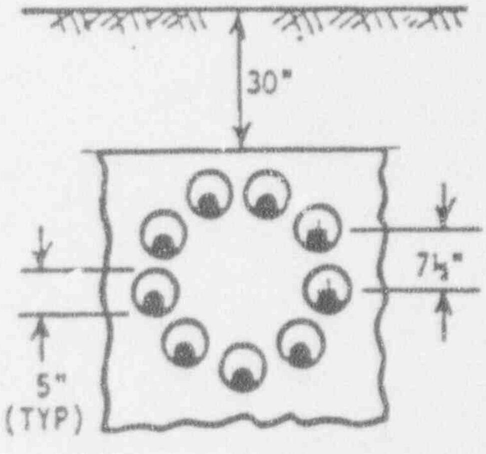

Figure 7
33.4" by 33.4" overall
(Not a feasible design)

Notes:

a) Cable in individual duct can be 1/C, 3/C or Triplex. To find ampacity, use the appropriate ICEA Pub. No. P-46-426 table. If 3-1/C cables are used per duct, the table for Triplex Cable is recommended for use.

b) For any normal duct bank configuration, phase and conductor imbalances will result if multiple paralleled cables for each phase are installed each in a separate duct. To preclude this, paralleled runs of cable should be designed with all three phases installed in each of multiple ducts (3/C, triplex, or 3-1/C), with sizes and lengths of all cable matched. For large loads, such as the secondary connections for station service transformers, this may require several more (smaller) conductors per phase but compares favorably from a cost viewpoint and avoids a possibly serious problem. If for some reason paralleled single 1/C cables per duct must be used, the individual ducts should be transposed at intervals along the duct run to balance the impedances of the three phases - a slow and expensive duct installation method. Another way is to symmetrically arrange the ducts as shown in the Underground Systems Reference Book, Figure 10-39, arrangements 4,5,6,7, 8 and 16.

c) If cable sizes larger than tabulated in ICEA are required or more than nine occupied ducts per bank are required, extrapolation of ICEA Pub. No. P-46-426 tables may be considered. It is recommended that the extrapolation, either ampacity versus cable size or ampacity versus number of ducts in bank, be done on log-log paper since an approximate straight line will be obtained. As with any extrapoltion, this method is limited - the further the extrapolation, the lower the accuracy. For duct bank arrangements other than those shown in P-46-426, extrapolation should be limited to smaller duct banks with not more than two, or at most three, layers of power conduits. Beyond this, the Neher-McGrath analysis should be applied, manually, if necessary, or preferably by means of the EE-700 (WE-80) computer program. If duct banks are run in parallel, the normal ampacity tables must be further derated. The derating will never be more severe than:

Distance Between Nearest Ducts	Depth of Burial of Lowest Ducts	Also Applies to Any Ratio of Distance/Depth	Additional Derating for All Cables In Both Duct Bank
1 ft	3 ft	1/3	0.79
2 ft	3 ft	2/3	0.87
3 ft	3 ft	1	0.91
4 ft	3 ft	1-1/3	0.94
5 ft	3 ft	1-2/3	0.95

When a horizontal separation of 6 ft or greater is maintained, the mutual heating effect of adjacent duct banks can be safely ignored.

d) In particular situations where the available tables and extrapolations are inadequate, the general equations for ampacity, as stated in ICEA Pub. No. P-53-426, Section F.4, are recommended as the best available approach.

e) Information required to enter ICEA Pub. No. P-46-426 Tables for Cable in Underground Duct is the same as that required for Direct Burial Cables, see Section 3.2.2.

f) When 1/C cable installations are designed, care must be exercised to avoid placement of steel or other magnetic material between or around conductors.

g) Tabulated ampacities apply only to a single cable or single set of cables in each duct bank conduit. Where additional circuits are installed in the same conduit, the ampacity factors tabulated at the end of Section 3.5.1 must be applied.

3.3.2 Sample Calculation:

Given: Underground Duct Installation; 13.8kV Rubber Insulated Cables; Conductor Temperature 90°C; Ambient Earth Temperature 20°C; 1600A (full load current requirements).

Find: Size, number and configuration of cables required.

Solution: a) First consider 3-1/C or 1 Triplex per duct in order to obtain balanced currents in each individual phase.

b) ICEA Pub. No. P-46-426, index page iv refers to the Table on page 242 for Triplex for the given conditions stated above.

c) We see the <u>3</u> Triplex will not carry the current for the maximum size tabulated. However, <u>6</u> Triplex will give the required ampacity (i.e. 500 kcmil, RHO-90, 100LF ampacity is 288; 6 x 288 = 1728 which is greater than the 1600A required).

d) If duct size will permit triplexed cable of larger sizes, interpolation of the tabulated data indicates that 4-750 kcmil will be marginally satisfactory and 4-1000 kcmil will provide a conservative application.

e) Note that the tabulated data for triplexed cables applies to corresponding sizes of 3-1/C cables installed in a duct.

3.4 Cables in Conduit Embedded

3.4.1 Types of Embedded Conduit Installation:

Embedded conduit refers to conduit in concrete slabs and walls. Normal configurations of conduit in underground duct installations are illustrated in Section 3.3.1. All provisions of Section 3.3.1 are equally applicable to embedded conduit.

3.4.2 Information required to enter IPCEA Tables for Cable in Embedded Conduit:

a) The ampacity of cable in embedded conduit should be taken from the ICEA P-46-426 tables for similar cables in underground duct. The same data set forth in Section 3.2.2 for entering the tables for direct burial cable is required for cable in embedded conduit.

b) It is recommended that RHO-60 be used for cables in embedded conduit (RHO-60 is typical for "hardrock" structural grade concrete).

c) An ambient temperature of greater than 20°C is frequently the case for embedded conduit in a power or industrial plant (i.e. conduit in a concrete slab with a heated room above and below may have ambient temperature 40°C or greater). Thus, it will be necessary in most cases to derate the ampacities given in ICEA Pub. No. P-46-426 for cable in underground duct, since these ampacities are for an ambient temperature of 20°C. The procedure outlined in 3.2.2e may be used to derate for ambient temperature greater than 20°C, or the ampacities may be found for an ambient temperature of 20°C and then derated by the equation shown below.

$$I' = I\sqrt{\frac{T_c - T_a'}{T_c - T_a}} \quad \text{where}$$

I' = derated ampacity (amperes)

I = ampacity tabulated for T_c and T_a (amperes)

T_c = rated continuous conductor temperature (°C)

T_a = tabulated ambient temperature (20°C)

T_a' = actual ambient temperature (°C)

3.5 Cable in Conduit Exposed

3.5.1 Information required to enter ICEA Pub. No. P-46-426 Tables for Cable in Conduit is the same as set forth in Section 3.2.2 a, b, c, and d for directly buried cables.

Consult the Index of ICEA Pub. No. P-46-426 for tabulated ampacities for triplexed or three conductor cables in isolated conduit. Note that the tabulations are based on an ambient air temperature of 40°C. If ambient air temperatures higher than 40°C are encountered, then one of the same derating procedures outlined in 3.4.2c should be followed.

Note that tabulated ampacities are for a single three conductor or triplexed cable in an isolated conduit. If more conductors are in the same conduit and concurrently loaded, the following ampacity factors (100% ampacity MINUS the percentage derating) must be applied:

Total Number of Conductors	Ampacity Factor
3	1.00
4-6	0.80
7-9	0.70
10-24*	0.70
25-42*	0.60
43 & up*	0.50

*Includes the effects of load diversity.

Where a fourth conductor is included as the neutral in 3 Phase 4 Wire systems, the neutral is not counted as a current carrying conductor and no derating is required.

Where nominal load diversity cannot reasonably be assumed, an appropriate Ampacity Factor can be calculated using the methods set forth in Appendix 1 of the Neher-McGrath paper, "The Calculation of the Temperature Rise and Load Capability of Cable Systems." The matter should be reviewed with the office Chief Electrical Engineer.

Note: When derating approaches 30%, an alternative cable routing or raceway arrangement should be considered.

3.5.2 Derating Factors for Cables in Exposed Groups of Conduits in Air:

a) If the vertical and horizontal spacing between surfaces of conduits grouped on racks or other supports equals or exceeds the outside diameter of the conduits, the ampacities for cables in isolated conduits in air should be used without derating.

b) Table I shows ampacity factors by which ampacities tabulated for cables in isolated conduit in air should be multiplied where conduits are grouped more closely than outlined in a) above. The table is based on separation between adjacent conduit exterior surfaces not less than one fourth of the outside diameter of the larger of the two adjacent conduits, (d/4). THIS SHOULD BE CAREFULLY NOTED IN PROJECT RACEWAY INSTALLATION "NOTES AND DETAILS." If separations are less than these minima, a complex heat transfer calculation is required to accurately determine ampacity.

TABLE 1

CABLES IN CONDUIT, AMPACITY FACTORS

Number Vertically	Number Horizontally					
	1	2	3	4	5	6
1	1.00	0.94	0.91	0.88	0.87	0.86
2	0.92	0.87	0.84	0.81	0.80	0.79
3	0.85	0.81	0.78	0.76	0.75	0.74
4	0.82	0.78	0.74	0.73	0.72	0.72
5	0.80	0.76	0.72	0.71	0.70	0.70
6	0.79	0.75	0.71	0.70	0.69	0.68

3.5.3 Sample Calculation:

Given: Conduit installation in air of 3 vertical and 4 horizontal conduits, each conduit separated by 1/2 conduit diameter; 3/C, 600V, rubber insulated; conductor temperature 85°C; ambient air temperature 40°C.

Find: Ampacities for #4 AWG and #6 AWG cables.

Solution: ICEA Pub. No. P-46-426, index page V refers to table on page 312 for isolated conduit.

Size of Each Cable	Ampacity in Isolated Conduit		Ampacity Factor		Ampacity in Grouped Conduit
#4	87	x	0.76	=	66
#6	66	x	0.76	=	50.2

3.6 Cables in Open Top Cable Tray

3.6.1 Cable may be installed in tray with "maintained spacing" or randomly pulled or laid in the tray. In the maintained spacing method, cable spacers of plastic, impregnated wood, or porcelain are inserted to maintain a selected vertical and horizontal spacing dimension between adjacent cables in the tray. Rows of such spacers are installed in the tray at intervals, depending on the stiffness of the cables involved, sufficient to ensure that the design spacing is effectively "maintained". The labor required to do this type of installation is many times that required to install the same cables randomly in the same tray. It can only be economically justified for large, important feeders involving comparitively heavy electrical loads. The offsetting benefit is substantially higher ampacity. It is suggested that cable duct be considered whenever conditions are such that maintained spacing appears to be a desirable option.

3.6.2 If cable duct is selected, the ampacity used should comply with the recommendations of the cable duct manufacturer. If field-fabricated maintained spacing is to be used and the spacing is maintained to exceed the full cable diameter, the ampacity will be the same as for the same cable isolated in air. For maintained spacing from 1 diameter (cable o.d.) to 1/4 diameter, apply the ampacity factors tabulated in Table VII on page V of Volume 1- (Copper), of the ICEA ampacity tables (P-46-426) to the ampacities tabulated in the book(s) for isolated cable in air.

3.6.3 For power circuits in tray other than the major, heavily loaded runs which justify the expense of maintained spacing, the method used is "random spacing" or "random tray fill". Sections II.D.2 and 3 on page V of ICEA P-46-426 describe a method for determining ampacities for this condition, using Table VIII from these same sections, but the results are unsuitable for our applications and SHOULD NOT BE USED. The correct reference is ICEA Pub. No. P-54-440 (NEMA WC-51) entitled "Ampacities - Cables in Open-Top Cable Trays".

3.6.4 Ampacities for power cables installed in trays without maintained spacing should be based on the methods and data contained in ICEA Pub. No. P-54-440. The ampacity tables in this publication are generally based on the calculated depth of cables in trays carefully packed to approximate maximum cable density-of-installation, considering this as the "worst case basis" for conservative design. The tables are further based on 100% load factor and no diversity. As the title indicates, the tables are based on "Open-Top Trays". The effects of tray covers, fire protecting material wraps, or routing of tray through firestops require derating to the ampacities as determined from ICEA P54-440. The additional derating required for each is covered in the following sections:

- 3.7 Additonal Derating for Tray Cables Transiting Firestops
- 3.8 Additonal Derating for Cable Trays or Conduits Enclosed in Fire Protecting Material
- 3.9 Additional Derating for Cables Routed in Open Top Tray with Solid Covers.

3.6.5 Scope of ICEA Ampacity Tables for Cable Tray

a) Data is tabulated for single conductor, triplexed, and three conductor cables. For multiconductor power cable other than three conductor, a conversion formula is provided in the Introduction section of the Tables.

b) Data is tabulated based on the overall cable sizes (outside diameters) corresponding to the more common cable constructions. Since cable ampacity in random-fill trays generally varies directly as the cable outside diameter (other factors being equal), a simple proportion multiplier enables determination of ampacities for outside diameters other than those tabulated for given conductor sizes. A special case occurs where cable o.d. equals or exceeds the design basis depth of fill. In these cases, cables can be laid parallel in the tray, one layer deep. Ampacity will be as tabulated for depth corresponding to cable o.d. regardless of percent fill or exact cable "size".

c) Ampacities are tabulated for four different voltage classes, 0-600V., 601-2,000V., 2,001-5,000V., and 15,000V. Ampacities for nominal 8kV class may be determined by applying the sizing (cable overall o.d.) correction described in b) (above) to the ampacity tabulated for corresponding conductor sizes for 5,000V. class cable. (While this is not precise or theoretically true, the resulting error will be negligible.)

d) Tabulations are based on cables rated for 90°C maximum continuous conductor temperature operation and 40°C maximum ambient air temperature. Correction coefficients for each of these factors are tabulated in the Introduction section of the Tables.

e) The ampacities are tabulated on the basis of "depth" of cables in the tray with "depth" defined in the Introduction section of the Tables as follows:

$$\text{Depth} = \frac{n_1 d_1^2 + n_2 d_2^2 + \ldots.\ n_n d_n^2}{\text{Width of Tray}} \text{ where}$$

$d_1, d_2, \quad d_n$ = Overall o.d. of different cable sizes, and

$n_1, n_2, \quad n_n$ = Number of cables of each corresponding diameter
All units are in inches.

Our usual method of calculating tray fill is to select a percentage of the usable cross section area of the tray under consideration, then to determine how many cables of various cross section areas can be accommodated in that percentage of the tray. For this, we use the actual cross section area of the cables, and since these are (usually) circular, we multiply $d^2 \times \pi/4$ for each cable o.d. Using the notations of the Introduction section of the Tables, our "depth" would be:

$$\text{Depth} = \frac{n_1 d_1^2 (\frac{\pi}{4}) + n_2 d_2^2 (\frac{\pi}{4}) + \ldots n_n d_n^2 (\frac{\pi}{4})}{\text{Width of Tray}}$$

$$= \frac{(n_1 d_1^2 + n_2 d_2^2 + \ldots\ldots n_n d_n^2)(\frac{\pi}{4})}{\text{Width of Tray}}$$

Note that our method differs from that on which the tables are based by our inclusion of the factor $\pi/4$.

Because of this difference, our calculated depth must be divided by $\pi/4$ (or 0.7854) to be consistent with the definition of "depth" on which the Tables are based. (Some find it easier to multiply our calculated depth by the reciprocal of $\pi/4$, or 1.273).

3.6.6 Use of the Tables

A frequent practice is to select trays for random fill with power cable which have a usable tray depth of 3 inches and to design for a 30 percent fill. (While the same tray usable depth is very widely used in the power industry, both of these parameters are selected arbitrarily. The 30% fill figure supposedly represents filling the tray, using random cable pulling or laying of cables into the tray, to the point where covers may be installed wherever desired without particular difficulty. Many others take 40% as approximating "complete" tray fill. So far, neither figure has been claimed to represent a "cost-effective" optimum.)

SAMPLE CALCULATIONS

a) Given: Horizontal tray, 3" usable depth, 1/C #2 AWG jacketed, 600V. copper conductor cable, 0.53" o.d., air ambient temperature-50°C, insulation rated for 125°C conductor temperature, random fill.

Find: Ampacity at 30% tray fill.

Solution: "Depth" of cable @ 30% fill:

$$= (3'' \times 30\%) \div \pi/4$$
$$= (3'' \times 0.3) \div 0.7854$$
$$= 1.15$$

Enter Tables ICEA Pub. No. P-54-440 Table 4. Use straight line interpolation to interpolate between ampacities tabulated for #2 AWG @ 1.0" depth (75A.) and 1.5" depth (58A.)

$$I_{1.15} = I_{1.0} - \frac{1.15 - 1.0}{1.5 - 1.0} \times (I_{1.0} - I_{1.5})$$
$$= 75A - 0.3 \times (75A. - 58A.)$$
$$= 75A. - 5.1A.$$
$$= 70 \text{ Amperes}$$

Note that this ampacity is for 40°C ambient air, where ours is 50°C. Refer to page i right hand column "Correction for Ambient Temperature" - for 50°C ambient, multiply the above result by 0.90:

$$= 0.90 \times 70A. = 63A.$$

Note that this ampacity is for 90°C rated conductor temperature where ours is 125°C. Refer to same page, same column "Correction for Conductor Temperature" - for 125°C conductor temperature multiply our above result by 1.24:

$$= 1.24 \times 63A. = 78A.$$

Note that this is for a cable outside diameter of 0.45" where ours is 0.53". Recall from 3.6.5 b) of this Design Guide that, ignoring other parameters, ampacity is directly proportional to cable overall o.d.:

$$I_{cable} = \frac{d_{cable}}{d_{table}} \times I_{table}$$

$$= \frac{0.53}{0.45} \times 78A \text{ (as calculated thus far)}$$

$$= 1.18 \times 78A$$

$$= 92 \text{ Amperes}$$

b) Given: Horizontal tray, 3" usable depth, 2/C #4 AWG copper conductor 600V. cable of unjacketed "singles," 90°C conductor temperature rating, 40°C ambient air temperature, cable fillers added to make cable round in section with overall o.d. of 0.75". Cables are installed with random lay.

Find: Ampacity for 40% fill

Solution: Depth of cable for 40% fill

$$= (3" \times 0.40) \div \pi/4$$

$$= 1.2" \div 0.7854$$

$$= 1.53"$$

(For practical purposes, the last 0.03" depth can be ignored and tabulated data for 1.5" depth can be used without interpolation). Enter Table 3 and note the ampacity for 1.5" depth #4 AWG 3/C:

$$= 49 \text{ Amperes}$$

Note that no corrections need be made for either ambient air temperatures or conductor temperature rating. However, we must correct for a different number of conductors and for a different cable o.d. These corrections can be made in one step utilizing the equation shown in the upper left corner of page ii of the tables:

$$I'_x = \frac{d'}{d'_o} \times I_o \sqrt{\frac{3}{n_x}}$$

$$= \frac{0.75"}{0.83"^*} \times 49A \sqrt{\frac{3}{2}}$$

*From Table 3

$$= 0.905 \times 49A \times 1.225$$

$$= 54.3A.$$

c) Given: Horizontal tray, 4" usable depth, 1/C #1/0 AWG aluminum conductor 8kV nominal rating shielded cable, 0.97" o.d., 90°C conductor rating, 40°C ambient, open top randomly filled tray.

Find: Ampacity at 30% fill

Solution: Depth of cable for 30% fill

$= (4'' \times 30\%) \div \pi/4$

$= 1.53''$ Again for practical purposes we can omit interpolation for the 0.03" incremental depth.

$= 1.5''$

Enter Table 29 for 1/0 AWG conductor and 1.5" cable depth:

$I_{1.5} = 94A.$ for 5kV cable w/0.72" o.d.

(Assume that the voltage class difference between 5kV and 8kV has negligible ampacity effect and make correction only for difference in o.d's.):

$$I_{cable} = \frac{d_{cable}}{d_{table}} \times I_{table}$$

$$= \frac{0.97}{0.72} \times 94A$$

$$= 126.6A.$$

$$= 127 \text{ Amperes}$$

d) Given: Horizontal tray, 3" usable depth, 1/C 1,000 kcm copper conductor 15kV shielded cables 2.15" o.d., 90°C conductor rating 40°C ambient open top randomly filled tray.

Find: Ampacity at 30% fill

Solution: Depth of cable for 30% fill

$= (3'' \times 0.30) \div \pi/4$

$= 1.15''$

Note that the cable diameter exceeds the prescribed depth of fill. The cables can, however, be laid in the tray in a single layer. The ampacity may be calculated as described in the second paragraph under Section B "Use of Tables" on page "i" of P-54-440. It may more readily be looked up directly in this standard by entering Table 33 for 1,000 kcmil conductor size:

I = 833A

Where the cable o.d. exceeds the prescribed depth, the ampacity is 80% of the ampacity of the same cable in free air, as tabulated in P-46-426. It is therefore independent of the cable o.d., so no correction need be made for the difference between the actual o.d. (2.15") vs. the tabulated o.d. (1.90").

3.7 Additional Derating for Tray Cables Transitting Firestops

Many of the firestops commonly used for sealing wall and floor openings for tray cable passage make use of a flame-retardant thermal insulating material such as silicone foam. Any solid or ventilated tray covers should be removed prior to forming the firestop.

Several manufacturers or installers of this type of material claim that the use of their product or method does not require derating of enclosed power cables. They base these claims on data from tests, including one or two in which the cables were loaded to the full P-54-440 ampacity, without the firestop hot-spot temperature exceeding 90°C.

According to Stolpe, whose analyses and testing are the basis for P-54-440, 90°C hot spots will only occur where a number of cables are packed together - a typical "worst case" to use as a design basis. Commenting on his own test results, Stolpe stated, "Note that even though the majority of cables -- ran cooler than calculated, there was a group of cables -- that did reach the calculated temperature. This points out the fact that all cables in a randomly filled tray cannot be expected to have the most thermally adverse environment, but some of them will." Stolpe also demonstrated that ampacity should not be increased because of diversity (i.e., some or many of the cables in the tray are only lightly loaded or are completely unloaded).

Because of these facts, good engineering practice requires that when thermal insulating material is used as a firestop, additional derating must be considered and applied when necessary.

The Los Angeles Power Division performed a series of tests in 1980 to determine the thermal effect of two different types of firestops on tray cables. One type represented the BISCO firestop comprised of a 9" thickness of 17 lb/ft^3 density silicone foam. The other was the minimum thickness BPC firestop comprised of two layers of 1/2" Marinite with a 3-1/4" thick layer of 17 lb/ft^3 density silicone foam between, plus Flamemastic coating on the cables on each exposed face of the firestop.

Although the hot-spot temperature of the BPC firestop was slightly lower, the conclusions were that either type required a nominal incremental (additional) derating of 15%. It should also be noted that in the opening test group in this series, as in Stolpe's tests, hot-spot temperatures for trays without firestops or ceramic fiber blanket wrapping were found with virtually no thermal margin when all cables were continuously loaded to their P-54-440 ampacities. Summarizing, these tests show that cables transitting either of these typical minimum firestops should be given an additional derating of 15%. (i.e., a tray cable with P-54-440 ampacity of 100 amperes for open top tray should be derated to 85 amperes if it passes through a firestop).

Another approach that can be used is to analyse the I^2R heat gain (in watts) for a one foot length of tray. This is done by the following method:

A. Take dc resistance for ONE foot of each individual stranded conductor from a cable engineering handbook such as Okonite Cable Engineering Data Booklet, Table 1-3 (tinned conductors where appropriate).

B. Convert "A" to ac (where appropriate), by multiplying by the factors tabulated in Okonite Data booklet, Table 1-5.

C. Multiply each value by 1.25 to convert R tabulated for 25°C to 90°C maximum conductor temperature (1.258 for aluminum conductor).

D. Multiply each "C" value by the SQUARE of the current corresponding to the actual full load of the device being served. Short time intermittent loads (such as MOV operator motor loads), or loads that only occur during abnormally lightly loaded conditions, can be ignored.

E. Add all of these "watts per foot" (of tray).

F. The total wattage for each 6" increment of tray width should be 24.5 Watts @ 40°C or less to ensure hot-spot conductor temperatures less than 90°C within the firestop.

Example:

70 - 3/C #12 awg cables are routed in a 12" wide tray with each circuit loaded to 9.5 amps/phase. Can a 9" thick silicone foam firestop be installed in the tray without creating hot-spot internal temperatures >90°C?

R (each cable) $1.71 \times 10^{-3} \times 1.25 = 0.00215$ (No dc/ac correction required)

I^2 (each cable) $= 9.5^2 = 90.25$

I^2R (each conductor) $= 90.25 \times 0.00215 = 0.1940375$

I^2R total $= 0.1940375 \times 70 \times 3 = 40.75$

Maximum permissible watts for 12" w. tray $= 2 \times 24.5 =$ 49.0 watts

$40.75 < 49.0$ watts

Therefore the firestop hot-spot is less than 90°C

CAUTION: Since "watts per foot" or "watts per foot per unit width" correlates with AVERAGE temperatures, each such case should be analyzed to ensure against hot-spots. If many of the cables are lightly loaded, one or a few small cables can be overloaded to the point of damage without the "watts per (square) foot" limitation being exceeded. The analysis should verify that the cables are evenly distributed in the fire stop. The review should be based on reasonable values of watts per linear foot per unit of cross-sectional area of each of the cables of interest.

Some firestops use silicone not as a foam but as a solid elastomer, either unfilled or filled with granular metallic lead for resistance to radioactivity. Because in its normal state it has thermal conductivity much greater than that of foam, it dissipates the internally-generated heat of the cable such that no ampacity derating is required in the 4" to 12" thicknesses of normal firestops. Even with these materials, derating may be required in substantially thicker sections such as those sometimes used for radiation barrier seals. These materials pyrolize when exposed to fire, and the resulting "char" is a good thermal insulator, thereby enabling the material to fulfill its function as a firestop.

3.8 Additional Derating for Cable Trays or Conduits Enclosed in Fire Protecting Material

In order to protect cable from damage by fire, cable trays and conduits are sometimes enclosed in fire protecting material. Among the first such materials to be used was ceramic fiber blanket material such as Kaowool or Cera-blanket. Its incombustibility and very low thermal conductivity makes it effective for protecting control, instrumentation, and communications type cables. However, the second characteristic makes it generally unsuitable for power cables, at least as a design basis.

Another fire protection covering for trays or conduits is a plaster-like material named Thermo-Lag 330-1. In addition to being easier to install and much more durable than ceramic fiber blanket, the derating required for power cables is more reasonable due to a much higher thermal conductivity.

CAUTION: Fire protecting materials should not be used inconjunction with solid or ventilated type cable tray covers on power tray. If used together, the cable would have to be derated for both the tray covers and the fire protecting materials.

3.8.1 Derating Required When Using Thermo-Lag 330-1

When fire protection material is required on trays containing power cable, Thermo-Lag 330-1 is preferred over ceramic fiber blanket materials as the cable derating is substantially less for Thermo-Lag. Based on ASTM E-119 fire tests of Thermo-Lag 330-1, 1/2" thickness will provide a 1 hour fire rating and 1" thickness will provide a 3 hour fire rating. Ampacity tests have shown that 1/2" thickness of Thermo-Lag requires that power cable be derated 12.5% for cable tray and 7.6% for conduit. Tests using 1" thickness have shown that a derating of 17% is required for cable tray.

Since tests of conduit with 1" thickness of Thermo-Lag were not conducted, the derating for power cable in conduit is estimated to be 10.5% based on the 36% increase in the derating shown between the 1/2" and 1" thicknesses which were tested on cable tray.

3.8.2 Derating Required When Using Ceramic Fiber Blankets

In 1980, the Los Angeles Power Division conducted tests of ceramic fiber blankets (Cera-Blanket). These tests indicated a requried derating of 73% (2.28 watts per foot allowable dissipation per 6" width of tray) if two 1" thick layers are used, or 64% (4.4 watts per foot per 6" width of tray) if a single 1" thick layer is used for wrapping cable trays. For wrapping conduits, these tests indicated a maximum permissible watts per (linear) foot of conduit internal heat generation of 5.98 for 4" conduit with a single 1" layer wrap.

For the three 250 kcmil cables involved in the testing, this represents a derating of 33.5% from the actual measured ampacity for the similar "unwrapped" conduit condition.

Since only a single case was tested, it was necessary to calculate the maximum permissible watts per foot of internal heat generation for other sizes of conduit and other thickness of thermal insulation wrapping. A fairly detailed mathematical model was developed and the calculations performed for various trade sizes of conduit, each wrapped with one 1" thick layer of ceramic fiber blanket. Conclusions were as follows:

Conduit Size (RS, IMT, or EMT)	Maximum Allowable Internal Heat (I^2R) Watts/Ft.*
1"	3.28
1-1/2"	3.88
2"	4.30
2-1/2"	4.70
3"	5.18
3-1/2"	5.54
4"	5.88
5"	6.53
6"	7.11

Where one or two power circuits are installed in a wrapped conduit, these limits can be directly applied without exceeding the cable rating(s). Where three or more power circuits are installed in the same common conduit, two separate criteria must be applied, as follows:

(1) The sum of the I^2R losses* of all of the insulated conductors shall not exceed the tabulated Watts per foot tabulated above, and

(2) No insulated conductor may be loaded to more than its ampacity tabulated in ICEA P-46-426 for isolated conduit in air derated for the total number of current-carrying conductors in accordance with Table VIII of the Introduction to Volume I (Copper) of P-46-426, and reproduced in this Design Guide in Section 3.5.1

*Use the method set forth in the latter part of Section 3.7 of this Design Guide, steps "A" through "E".

3.9 Additional Derating for Cables Routed in Open Top Tray with Solid Covers

Solid metal tray covers are often used on cable tray to provide mechanical protection and prevent the accumulation of debris. Nuclear power plant projects may consider the use of solid tray covers to address the separation criteria in Regulation Guide 1.75.

Ampacity tests conducted in 1980, by the Los Angeles Power Division indicated that a derating of 27% is required for solid metal covers mounted directly on the tray sills. The test consisted of a tray with a 12 foot long solid metal cover mounted directly on the tray sills with a 1/8" opening at each end. For the configuration tested, a maximum allowable dissipation of 17.25 watts per linear foot for each 6" increment of tray width was determined. Subsequent to the LAPD tests, IEEE paper No. 83 SM 305-0 presented test results indicating that a 25%-30% derating should be used for solid metal covers. The test configuration for the IEEE paper was a 24" wide tray with a 24 foot long solid cover mounted on the tray sills.

The use of solid covers on tray containing power cable should be avoided when it is practical and feasible to provide an economical layout routing the trays in areas not requiring covers. Realizing this is not always possible, projects which utilize solid metal tray covers for debris protection should consider means other than mounting the covers directly on the tray sills. Instead of covers mounted directly on the tray sills, covers or shields supported above the trays can be used with no additional derating for power cables if a minimum of 4" clear space is maintained between the tray sill and the cover. When adequate protection can be provided by a shield or cover suspended above the tray, (supported a long or beneath walkways, etc.) this also has the advantage that cable may be added at some future time without incurring the cost of removing covers.

When solid tray covers greater than six (6) feet in length are utilized on power trays and are mounted directly on the tray sills, the ICEA ampacities should be derated 27%. Current Bechtel practice for cable sizing and selection is such that the 27% derating for solid tray covers may not require larger conductors. Based on an analysis of current SFPD projects, cable sizing and selection has been sufficiently conservative as to not require larger conductors to compensate for the additional derating for solid tray covers.

Prior to applying the 27% derating for solid tray covers, the following items should be considered:

a) Cables feeding motors are sized based on 125% of motor full load current which provides a 25% margin over rated full load. Most motors are selected as the next larger "trade size" over the horsepower requirements of the driven equipment which provides additional margin. Mechanical equipment selection is also based on "worst case" conditions rather than normal operating conditions. Briefly, motor feeders usually have a margin greater than 27% above the actual motor load current.

b) Some motors are not continuous duty motors such as motor operated valves, cycling sump pumps, etc. and do not contribute to heating of cables in a covered tray (ie., ICEA tables are based on all cables at 100% load with no diversity).

c) Cables feeding load centers, motor control centers and power panels in power generating stations are usually sized large enough to be capable of handling the full ampacity rating of the bus. It is recommended that this criteria be used to size such feeders as this permits the addition of loads throughout the life of the plant as long as sufficient transformer capacity is available. This technique typically results in cable ampacity margins greater than 27% above the actual load currents.

In summary, the use of solid tray covers mounted directly on the sills of power tray should be avoided. When specifically required, solid tray covers may be installed directly on the sills of power trays (without concern) as long as proper design techniques were employed in sizing the power cables.

CAUTION: When selecting the size of cable feeders to panels that are dedicated to loads which are all simultaneously energized, special care must be taken to assure that the conductors are of adequate size, and that all derating factors have been considered. Panels which are dedicated to loads such as unit heaters, HVAC equipment and freeze protection are typical of those which require special attention in selecting the proper cable size.

3.10 General Precautions

The consequence of overloading power cables insulated with the high quality thermosetting elastomers generally used in our industry is a reduction in full service life expectancy rather than sudden catastrophic failure during startup. Even a seriously overloaded cable may function for many years before failing.

However, good engineering demands thoughtfulness and care in performing these calculations. The relationship between conductor temperature and cable life expectancy is exponential rather than linear, so that small overtemperatures over an extended period of time can seriously shorten cable life. Premature approach to the end-of-service-life condition due to thermal aging of cables is considered by the USNRC as providing the potential for common-mode failure of class 1E circuits under accident conditions.

Probably the highest possibility of future problems in this regard is improper evaluation (or estimation) of the actual cable environment from the point of view of ambient temperature. The "standard" procedure is to find the nominal high ambient areas from the Plant Facilities group on the project, design for that, and consider the problem solved. There are many tight or isolated areas in an operating plant through which cables are routed where the temperatures substantially exceed the HVAC design figures. These hot-spot areas should not necessarily establish the limits for design of the whole plant, but cables traversing these areas should be derated accordingly on a special case basis or their premature failure should be anticipated. Raceway layouts should be reviewed and checked against piping and equipment layout to minimize hot-spot exposures or verify that power cables in the area have been derated to be conservative.

Our ampacities for cable in tray are based on "percentage fill" of the usable cross sectional area of a tray, but it has been proven that the controlling factor for fully loaded cables in tray is the <u>depth</u>. Our usual practice of 30% fill in 3" deep tray converts to 1.15" depth per ICEA Pub. No. P-54-440 (See preceding Sample Calculation 3.6.6 a). Our design basis is conservative only if the cables are spread across the width of the tray in a reasonably uniform manner. Project "cable installation notes and details" should point out to the installers the possible hazard of cable piling up in the trays (especially on inside corners of tray bend fittings) and making the actual depth be 3", for example, for a fraction of the usable width of the tray.

We should also be aware that our own electrical equipment may create a serious heat problem. If power cable trays are routed one above another, the upward convection from the lower tray(s) will create a higher temperature ambient for the upper one(s). The upward convection "exhaust" air from a class H insulated load center (AA or FA rated) transformer creates an ambient exceeding the total temperature capability of our "standard" cables - the cables would overheat at <u>zero</u> ampacity. Such areas should be carefully avoided in raceway layout (conduit or tray) or special ventilation provided.

Solar radiant heating can also seriously affect the ampacity of cables if their rating is not to be exceeded. In most cases, natural breeze or forced air circulation substantially reduces the effect, but consideration should be given to both indoor and outdoor cable runs in tray or conduit where solar exposure is substantial and possibly accentuated by restricted ventilation. One method of dealing with the problem is to provide sunshields of sheet metal or other suitable paneling. Another approach is to determine the maximum estimated temperature for an enclosed area in direct sunlight (or uninsulated attic temperature) from project plant facilities engineers and derate the cable for operation in this higher ambient. A method of directly calculating the required additional derating is set forth in the Neher-McGrath Paper "The Calculation of the Temperature Rise and Load Capability of Cable Systems" on page 759 under "Aerial Cables". To complete the calculation outlined therein, it is helpful to refer to the "Method of Calculation" section on page IV of the Introduction to ICEA Pub. No. P-46-426 and utilize the values in Table IV of that section.

4.0 REFERENCES

4.1 "The Calculation of the Temperature Rise and the Load Capability of Cable Systems", J. H. Neher and M. H. McGrath; AIEE Transactions, Part III, Volume 76, October 1957.

4.2 "Ampacities for Cables in Randomly Filled Trays", J. Stolpe; IEEE Transactions Paper No. 70 TP 557-PWR, April 1970.

4.3 "Engineering Data - Copper and Aluminum Conductor Electrical Cables" - Okonite Company's Bulletin EHB-81.

4.4 "Ampacity of Cable in Covered Tray", G. Engmann; IEEE Paper No. 83 SM 305-0, Presented at the IEEE/PES 1983 Summer Meeting in Los Angeles, May 1983.

ENCLOSURE 4

CALCULATION 13-EC-PA-210 REVISION 5