Power Cable Engineering With HP-41 Programs

Robert W. Parkin

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PUBLISHER, **MCM SOFTWARE**
123 LEWIS COURT
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PREFACE

POWER CABLE ENGINEERING WITH HP-41 PROGRAMS (PCE) represents a culmination of essential design and application programs required in the power industry to help determine maximum operating performance of polymer insulated power cables and distribution systems. As well, **PCE** outlines program applications and parameters, creating a unique power cable handbook for those involved with the design, application, and installation of power cables and distribution systems.

The programs are written in standard HP-41 language (FOCAL) and can run on HP-41 models or other compatible computers. Many of these programs are new or updated; in this regard, **PCE** fills a gap in current literature and computer software by providing as large a base of useful information as possible in one publication.

The book is divided into three sections with each section subdivided into program-chapters. Section one covers **Electrical Programs**, section two deals with **Polymer Insulated Cable Design**, and section three covers **Installation Programs and Guidelines**. Each program-chapter includes a cover sheet, subject material, step by step program operating instructions, sample problems, and a program printout; so that each is complete within itself, although many tables and programs are interrelated.

The appendix helps locate various tables, drawings, example specifications and other reference aids used with the programs. Software, HP-41 hardware and user support can be obtained by contacting the author or distributors located in the back section.

I would like to acknowledge the technical help extended by Walter Zenger, Joseph L. Steiner, Ed Walcott and Albert McGrath and other members of Cablec Corporation who helped make this work possible, and to the standard associations and authors referenced herein for data tables, and of course to Hewlett Packard Ltd. and their employees.

RWP

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Section One

Electrical Programs

CABLE SYSTEM AMPACITIES

Robert W. Parkin

FUNCTION: This program provides a method for assessing ampacities of underground power cables or groups of cables, that are spaced or in trefoil configurations, based on the J.H Neher and M.H. McGrath method [1]. The program utilizes analytical techniques and boundary geometries for approximations of thermal circuit parameters and configurations, and is further enhanced by its ability to retain original values of previous calculations to compare alternative ambient operating temperatures, and losses associated when the metallic shields are bonded and grounded at multiple points . Different configurations can be explicated along with the ability to use non-unity load factors.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: Solutions assume that conductor currents of all phases are equal in magnitude, which is important to consider where two parallel circuits are used. Conduit is assumed to be non-magnetic.

REFERENCES:

[1] The Calculation of the Temperature Rise and Load Capability of Cable Systems, J.H. Neher and M.H. McGrath. AIEE Paper 57-660 published October, 1957.

[2] The Temperature Rise of Cables in a Duct Bank, - J.H. Neher, AIEE Trans. Vol. 68, Part I, 1949, pg. 540-9.

[3] Thermal Transients on Buried Cables, - F.H. Buller, AIEE Trans Vol. 70 Part I, 1951, pg. 45-55.

[4] Ampacities Including Effects of Shield Losses, IPCEA Pub. No. P-53-426 NEMA Pub. No. WC-50-1976

[5] El-Kady, M.A., Horrocks, D.J., "Extended Values for Geometric Factor for External Thermal Resistance of Cables in Duct Banks", IEEE Trans. on Power Apparatus and Systems, Vol. PAS-104, No. 8, August 1985, pp 1958-1962.

[6] Induced Shield Voltages and Losses, R.W. Parkin

Introduction

One of the most important needs of power cable engineering and operation is to have information about maximum current-carrying capacity which a cable can tolerate throughout its life without degradation to the cable and circuit. This becomes increasingly more important when cable systems are operated at maximum continuous current ratings.

The voltage rating and the environmental hazards of intended applications determine the type and the thickness of the insulations and other coverings applied over conductors.

The Neher/McGrath Standard Publication 57-660 is intended primarily for transmission cable computations. During development of this program, it became apparent that additional enhancements to the above methods would have to be made to account for the specific nature of modern distribution cables and adapted for efficient calculation on a computer. These enhancements are based on reference [4] and described with program algorithms.

Shield Current Effect on Cable Ampacity

When shields are bonded and grounded at multiple points, circulating currents, dependent on shield impedance, will flow in the metallic shield (or concentric neutrals). These currents are heat (I^2R) generators and must be included in the thermal circuit when computing the system ampacity. The highest losses occur mostly with concentric neutral cables, and the lowest cable ampacities occur when the mutual reactance between the concentric neutral and the conductor equals the resistance of one concentric neutral.

To reduce the circulating currents, it is necessary to change parameters to make the unit values of concentric neutral resistance and the mutual reactance as divergent as possible while still meeting the other criteria of the circuit. This generally is accomplished by reducing the axial spacing (and the mutual reactance), or by increasing the resistance of the concentric neutral by decreasing the number of wires and/or decreasing the size of the wires. It is also possible to accomplish the same by increasing the spacing and increasing the number and size of the concentric neutral wires; the latter, however is not economical. These circulating currents, and associated losses can be eliminated or minimized by bonding and grounding the shields at one point in a cable run or by special shield bonding techniques. This method will result in voltages between the shield and ground both under steady-state and transient operating conditions.

The mutual reactance is computed in the ampacity program and also can be determined in the shield loss program; which should be used first to obtain shield loss values associated with configuration and spacing if multi-point grounding is used, also the mutual heating of single conductors as they get closer together decreases the ampacity capabilities of the cable system.

The resistance of the concentric neutral can be increased by decreasing the number of wires and decreasing the size of the individual wires. ICEA recommends that concentric neutral wires should not be reduced below 6 x #14 AWG wires. It should also be noted that the concentric neutral should not be reduced below the capability to handle the fault current available to the cable system. The fault current capabilities for metallic shields can be determined in the fault program.

Observations

Ampacities up to size 4/0 AWG are affected slightly by varying the concentric neutral. In intermediate sizes, from approximately #4/0 AWG to 500 kcmil, the reduction in ampacity due to mutual heating is generally larger than the reduction in ampacity due to short circuit shield currents caused by spacing of the phase conductors. For the larger sizes, it is generally more efficient to keep the cables as close together as possible because the circulating neutral currents of the spaced cables provide greater losses and lower ampacities than the mutual heating effect of a close configuration.

The variation in ampacity with shield resistance for a given conductor size is a function of the slope of the loss ratio curve. In particular, the variation in ampacity increases as the shield resistance decreases except near the peak of the loss ratio curve. In general, the variation is greater for spaced than for trefoil configurations; separating the phases increases shield losses at a rate that exceeds the advantage gained by the reduction in mutual conductor heating.

Temperature Rise and Losses

All losses are developed on the basis of watts per conductor foot. The heat flows and temperature rises due to dielectric loss and to current produced losses are treated separately, and in the latter case all heat flows will be expressed in terms of the current produced loss originating in one foot of conductor by means of multiplying factors which take into account the added losses in the sheath and conduit.

In the case of underground cable systems, it is convenient to utilize an effective thermal resistance for the earth portion of the thermal circuit which includes the effect of the loading cycle and mutual heating effect of the other cables of the system. All cables in the system will be considered to carry the same load currents and to be operated under the same load cycle. The method employed by Neher-McGrath has been selected as it is the most consistent and most readily handled over the full scope of the problem.

PROGRAM STRUCTURE

The program is formatted to display four ampacities for four different configurations:

1) Triplexed- direct bury

2) Triplexed- in duct bank

3) Spaced- direct bury

4) Spaced- in duct bank

Program will repetitively loop after each sequence to re-enter different ambient and operating temperatures, and prompt for circuit operation (if multi-bonded). The shield losses in watts/foot should be determined in the shield loss program before loading "AMP". Refer to the user instructions for input structure.

Tables are provided in the proceeding sections that cover all input parameters. Data not found in this section can be located in other program-chapters.

Table V

Constants for use in Equations 41 and 41a

Condition	A	B	C	A'	B'
In metallic conduit	17	3.6	0.029	3.2	0.19
In Fiber Duct in Air	17	2.1	0.016	5.6	0.33
In Fiber Duct in Concrete	17	2.3	0.024	4.6	0.27
In Transite Duct in Air	17	3.0	0.014	4.4	0.26
In Transite Duct in Concrete	17	2.9	0.029	3.7	0.22
Gas-Filled Pipe Cable at 200 psi	3.1	1.16	0.0053	2.1	0.68
Oil-Filled Pipe Cable	0.84	0	0.0065	2.1	2.45

Table II

Recommended Values of ks and kp

Conductor Construction	Coating on Strands	Treatment	ks	kp
Concentric Round	None	None	1.0	1.0
"" ""	Tin or Alloy	""	1.0	1.0
"" ""	None	Yes	1.0	0.8
Compact Round	"	"	1.0	* 0.6
Compact Segmental	"	None	0.435	0.6
" "	Tin or Alloy	"	0.5	0.7
" "	None	Yes	0.435	0.37
Compact Sector	"	"	1.0	(see note)

Notes:

(1) Proximity effect on compact sector conductors may be taken as 1/2 of that for compact round having the same CSA and insulation thickness.

* Untreated compact round kp = 0.8

CALCULATION OF THERMAL RESISTANCE

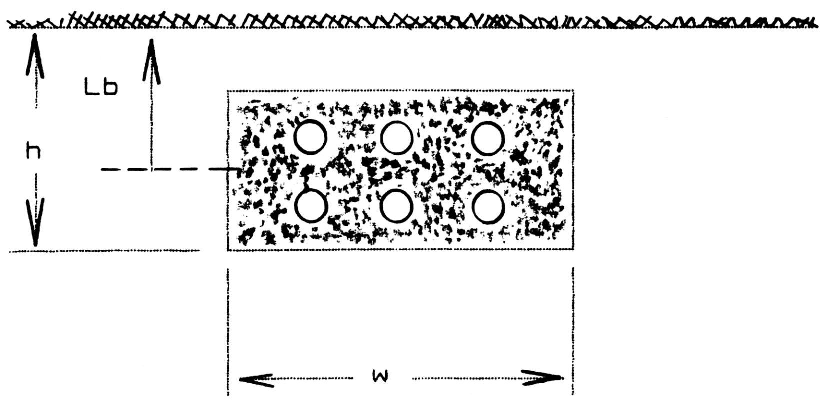
Table IV

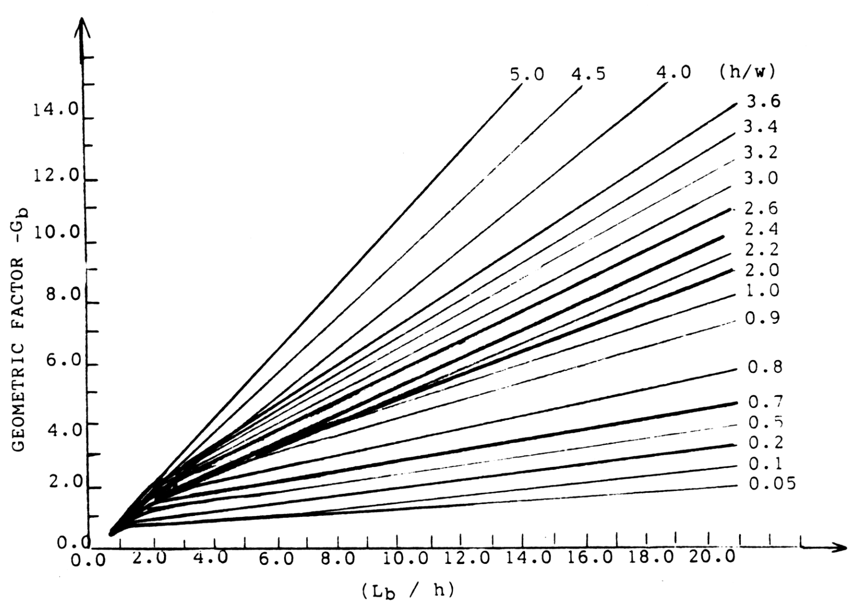
Thermal Resistivity of Various Materials

Materials	P in Ccm/watt
Paper Insulation (Solid Type)	700(IPCEA Value)
Varnished Cambric	600(IPCEA Value)
Paper Insulation (Other Type)	500-550
Rubber and Rubberlike	500 (IPCEA Value)
Jute and Textile Protective Covering	500
Fiber Duct	480
Polyethylene	450
Transite Duct	200
Somastic	100
Concrete	85
Polyvinyl Chloride	500
Polystyrene	250

GEOMETRIC FACTOR

Geometric factor Gb, associated with the external thermal resistance between cable duct banks and the ambient are based on approximating the rectangular duct bank by an isothermal circle of equivalent radius which is a function of the bank height and width dimensions. This approximation is valid only for height/width ratios in the range of 1/3 to 3. The values of Gb shown below are intended to provide accurate values over a wide range of Lb/h and h/w suitable for direct use. The technique that this table is derived from is based on the assumption that the duct bank surface represents an isothermal boundary.





Soil Thermal Resistivity

The most troublesome variable in making an accurate calculation is soil resistivity. Ampacities taken from IPCEA P-46-426 include columns for rhos of 60,90, and 120, but the NEC tables are limited to a rho of 90. The true resistivity may vary from around 40 for some wet clayey soils to over 300 for dry gravel. The true resistivity may be determined only by testing, but the measured value changes greatly with changes in soil moisture. Cable ampacities decrease considerably when soil thermal resistivity increases. Lowering the duct bank by 50 cm results in a reduction of cable ampacities between 2% for low soil resistivity and 4% for resistivity in the upper range.

Underground Duct Installations

For underground ducts consisting of one, three, six, or nine cables or circuits, the applicable tables in the NEC can be applied. These ampacities are only valid for the burial depths, spacing between ducts, and thermal resistivities shown in the tables and figure 1. For duct banks consisting of configurations different from those above, the computer program must be applied to determine ampacity. In general, the following rules apply to duct bank applications.

1) The maximum number of circuits in an underground duct bank is normally 12.

2) Equally sized cables in an underground duct bank have approximately two-thirds the ampacity of the same cable in a direct burial configuration. Therefore, direct burial applications are more economical.

3) In duct banks, as in all underground applications the NEC tables show ampacity ratings for applications where cables are all the same size. Where this is not true, special calculations must be made.

Where underground ducts are required as part of a direct bury buried cable system (under roadways,buildings etc.). It has been determined the cables in the duct bank portion will have the same ampacity rating as that for the cables in the direct buried system if the underground duct length does not exceed 25 feet, or if over 25 ft. long, the ducts are filled with a heat transfer medium; used to minimize the thermal resistance of the air void in the ducts.

Effect of Position of Cable in Duct Bank

When several equally loaded cables are located in the same duct bank, the maximum permissible loading will be the root mean square peak load of all the cables in the duct bank. If all the cables were actually carrying this load, the operating temperature of those in the interior ducts would exceed the safe operating temperature of the insulation, whereas the operating temperature of those in the outer ducts would not reach this value. The cables in the inner would accordingly be overloaded and those in the outer ducts underloaded. In order to equalize the operating temperatures of cables in different locations as near as possible at a value corresponding to the safe maximum temperature, the load must be multiplied by a position factor, which will decrease it for the inner ducts and increase it for the outer ducts, but will not change the root mean square of the loads when so modified. The same adjustment for the position of the cable in the duct bank should be made for unequally loaded cables.

The charts below display the relative watt losses for individual ducts and bank of ducts per foot of cable for the same temperature rise (percent of 2 by 2 bank)

$$\text{Position Factor} = \sqrt{\frac{\text{Relative Loss for any Duct}}{\text{Average loss}}}$$

95	95
83	83
83	83
95	95

Average = 89

100	100
100	100

Average =100

91	77	91
75	60	75
75	60	75
91	77	91

Average =78

93	79	93
79	64	79
93	79	93

Average=83.5

89	71	71	89
71	48	48	71
71	48	48	71
89	71	71	89

Average=70

93	93
80	80
78	78
76	76
76	76
78	78
80	80
93	93

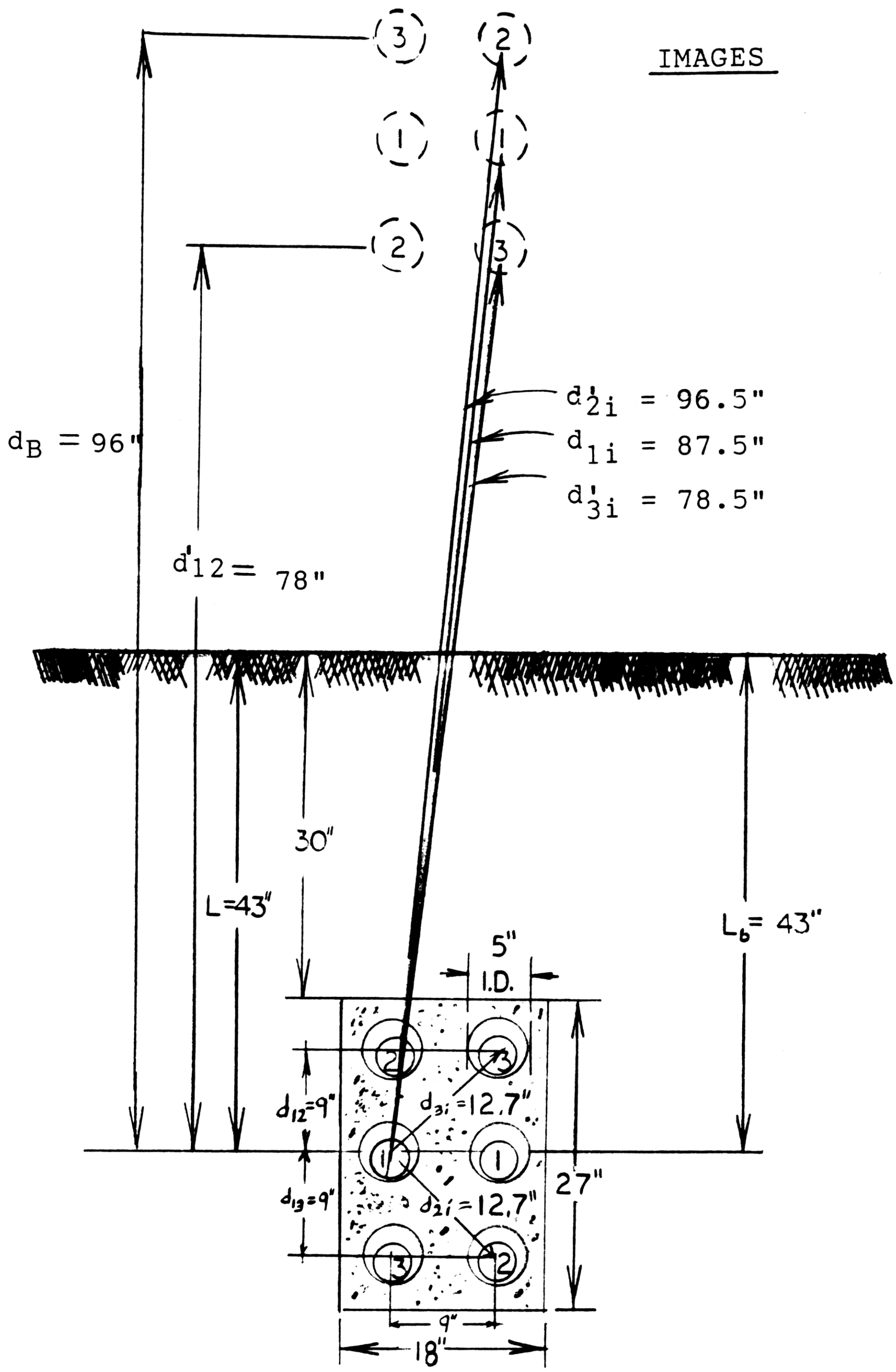
Average=82

90	77	90
73	55	73
71	52	71
70	47	70
71	52	71
73	55	73
90	77	90

Average=70

		85	65	62	62	65	85		
		65	38	31	31	38	65		
		62	31	20	20	31	62		
		62	31	20	20	31	62		
		65	38	31	31	38	65		
		85	65	62	62	65	85		

Average=51



Assumed duct bank configuration for typical calculations

AMPACITY CALCULATION PARAMETERS

The following outline lists the parameters needed to calculate the ampacities of various types of cable installations.

1. Circuit characteristics

A. Frequency
B. Single or three phase
C. Source voltage; phase-to ground
D. Neutral grounded or ungrounded
E. Time required to clear a ground fault
F. Load factor
G. Loss factor
H. Phase sequence

Note: The load factor is defined as the ratio of the average load current for any 24 hour period to the maximum average current for the peak one hour period during the same 24 hour period. The more customers that are included in the study area, the more nearly constant will be this ratio from one period to the next. This factor is not governed at all by the cable system, but is extremely important in cable size determination especially if the cable is buried or placed in underground ducts.

The loss factor is a number similar to the load factor, but is the ratio of the average of the square of the load currents over a 24 hour period to the maximum average square of the current for the peak one hour period during the same 24 hour period. The loss factor is actually the number that is used for cable sizing, while the load factor is the number usually given as a system parameter.

2. Cable construction

A. Temperature rating of cable
B. Conductor metal
C. Size and number of conductors
D. Conductor design (solid, compressed, compact etc.)
E. Type and O.D of insulation
F. Type and dimension of shielding system
G. Shields single or multi-point grounded
H. Type and dimension of cable overall jacket or sheath
I. Dielectric constant and power factor of insulation

3. Cables in underground ducts or conduits

B. Earth thermal resistivity
C. Duct dimensions
D. Duct material
E. Duct configuration and spacing
F. Material and dimensions of duct bank encasement
G. Depth of duct bank encasement below grade
H. Number of loaded cables in each duct

4. Cables buried in Earth

A. Earth ambient temperature
B. Earth thermal resistivity
C. Number of loaded cables in trench
D. Spacing of cable in trench
E. Depth of cable below grade

5.Cables in air

A. Ambient air temperature
B. If single conductor-cables, what is their spacing

6.Cables in conduit air

A. Ambient air temperature
B. Conduit material and dimensions
C. Number of loaded cables in each conduit
D. Number of spacing of loaded conduits
E. Other heat sources near conduits

7. Cables in tray or ladder supports

A. Ambient air temperature
B. Ladder or solid bottom trays
C. Open or solid bottom trays covers
D. Vertical separation between stacked trays
E. Width and depth of tray
F. Is cable spacing maintained
G. Size, number and diameters of cables in each tray

PROGRAM ALGORITHMS

Neher-McGrath Formulation of Temperature Rise

The permissible current rating an a-c cable can be derived from the expression for the temperature rise above ambient temperature due to its own losses, which may be divided into a rise due to current produced (I^2R) losses in the conductor, sheath and conduit T_c and the rise produced by its dielectric loss Thus:

$$T_c - T_a = \Delta T_c + \Delta T_d \quad \text{degrees Centigrade} \qquad (1)$$

Since the losses occur at several positions in the cable system, the heat flow in the thermal circuit will increase in steps. It is convenient to express all heat flows in terms of the loss per foot of conductor, and thus

$$\Delta T_c = W_c \left(\underline{R}_i + q_s \underline{R}_{se} + q_e \underline{R}_e\right) \text{ degrees C} \qquad (2)$$

Load Capability

From equation (1) it follows that:

$$I = \sqrt{\frac{T_c - (T_a + \Delta T_d)}{R_{dc}\ (1+Y_c)\ R_{ca}}} \quad \text{kiloamperes} \qquad (9)$$

Where the term R_{ca} (thermal resistance from conductor surface to ambient) is composed of a number of variables, including:

1. Thermal resistance of the conductor insulation
2. Thermal resistance of the air between the conductor surface and the duct wall
3. Thermal resistance of the duct wall
4. Thermal resistance of the concrete surrounding the duct bank
5. Thermal resistance of the earth surrounding the duct bank
6. Conductor load factor; and
7. Effect of mutual heating due to proximity of other conductors.

For buried cable systems T_a should be taken as the ambient temperature at the depth of the "hottest" cable.

PROGRAM ALGORITHMS

Equation 21 of reference 1 has been replaced with:

(F1) $Y_{cs} = F_{sp}(x)$

Where $x=R_{dc}/k_s$
and:

$$F_{sp}(x) = \frac{11.0}{\left(x + \frac{4}{x} - \frac{2.56}{x^2}\right)^2} \qquad \text{(F2)}$$

except where x has a value less than 7.2, where:

$$F_{sp}(x) = \frac{11.0\ (1 - 0.1102/x)}{\left(x + \frac{4}{x} - \frac{2.56}{x^2}\right)^2} \qquad \text{(F3)}$$

(3) For Aluminum : $R_2 = R_1 \frac{(228.1 + T_2)}{228.1 + T_1}$

For Copper: $R_2 = R_1 \frac{(234.5 + T_2)}{234.5 + T_1}$

(16) $W_s = I^2 R_{dc} Y_s$ watts per conductor foot

PROGRAM ALGORITHMS

(22) $$x_s = 0.875 \sqrt{\frac{f k_s}{Rdc}} \qquad \frac{6.80}{\sqrt{Rdc/k_s}} \qquad \text{at 60 cycles}$$

(21) $$Ycs = F(x_s)$$

(25) $$x_p = \frac{6.80}{\sqrt{Rdc/k_p}} \qquad \text{at 60 cycles}$$

(24) $$Ycp = F(x_p)\left(\frac{Dc}{S}\right)^2 \left[\frac{1.18}{F(x_p) + 0.27} + 0.312\left(\frac{Dc}{S}\right)\right]^2$$

(29a) $$Xm = 52.9 \log 2.3\ S/Dsm$$

(27) $$Ysc = \frac{Rs/Rdc}{1 + (Rs/Xm)^2}$$

(18) $$qs = \frac{Wc + Ws}{Wc} = 1 + \frac{Ys}{1 + Yc}$$

(36) $$Wd = \frac{0.00276\ E^2 \epsilon_r \cos\theta}{\log (2T + Dc)/Dc}$$ watts per conductor foot at 60 cycles

(38) $$R_i = 0.012 \rho_i \log D_i / D_c$$ Thermal ohm feet

PROGRAM ALGORITHMS

(41) $$R_{sd} = \frac{n' A}{1 + (B+CTm) D_s'}$$

(40) $$R = 0.0104 \quad n'\left(\frac{t}{D-t}\right)$$ thermal ohm feet

(44) $$R_e = 0.012 \rho_e \, n' \left[\log \frac{D_x}{De} + (LF) \log\left(\frac{4L}{D_x} \; x \; F\right)\right]$$

in thermal ohm feet

(44a) $$R_e' = 0.012 \rho_c \, n' \left[\log \frac{D_x}{De} + (LF) \log \frac{4L}{Dx} \; x \; F\right]$$

$$+ \; 0.012 \; (\rho_e - \rho_c) \; n' \; N \; (LF) \; G_b$$ thermal ohm feet

(8) $R_{ca}' = R_i + q_s R_{se} + q_e R_e'$ thermal ohm feet

(28a) $Xm = 52.9 \log 2S/D_{sm}$ microhms per foot at 60 cycles

(14) $R_{ac}/R_{dc} = 1 + Yc + Ys + Y_p$

(26) $W_s = I^2 \, Rdc \; (Ysc + Yse)$ watts per conductor foot

* (30) $$Y_{se} = \frac{3 \; Rs/Rdc}{\left(\frac{5.2 \; Rs}{f}\right)^2 + \frac{1}{5}\left(\frac{2S}{Dsm}\right)}\left(\frac{Dsm}{2S}\right)^2 \left[1 + \frac{5}{12}\left(\frac{Dsm}{2s}\right)^2\right]$$

* When the sheaths are short-circuited, the sheath eddy loss will be reduced and may be multiplied by $R_s^2 / R_s^2 + X_m^2$

PROGRAM ALGORITHMS

(3) $(LF) = 0.3\ (lf) + 0.7\ (lf)^{2}$ per unit

(2) $T_c = Wc\ (R_i + q_s R_{se} + q_e R_e)$ degrees Centigrade

(46) The factor F accounts for the mutual heating effect of the other cables of the cable system, and consists of the product of the ratios of the distance from the reference cable to the image of each of the other cables to the distance to that cable. Thus,

$$F = \frac{d^1_{12}}{d_{12}} \times \frac{d^1_{13}}{d_{13}} \times --- \frac{d^1_{1N}}{d_{1N}} \quad (\text{ N-1 terms})$$

It will be noted that the value of F will vary depending upon which cable is selected as the reference, and the maximum conductor temperature will occur in the cable for which F is a maximum. N refers to the number of cables or pipes, and F is equal to unity when N = 1 .

NOMENCLATURE

(AF) = Attainment Factor - per unit

A_s = Cross-section area of a shielding tape or skid wire-square inches

α = Thermal diffusivity - square inches per hour

CI = Conductor Area - circular inches

d = distance inches

- d_{12} etc. = from center cable #1 to center of cable #2 etc.
- d'_{12} etc. = from center of cable #1 to image of cable #2 etc.
- d_{11} etc. = from center of cable #1 to point of interference
- d'_{11} etc. = from image of cable #1 to point of interference

D = Diameter - inches

- D_o = inside of annular conductor
- Dc = outside of conductor
- D_i = outside of insulation
- D_s = outside of sheath
- D_{sm} = mean diameter of sheath
- D_j = outside of jacket
- $D^1{}_s$ = effective(circumscribing circle) of several cables in contact
- D_p = inside of duct wall, pipe or conduit
- D_e = diameter at start of the earth portion of the thermal circuit
- D_x = fictitious diameter at which the effect of loss factor commences

E = Line to neutral voltage - kilovolts

ϵ = Coefficient of surface emissivity

ε_r = Specific inductive capacitance of insulation

f = Frequency - cycles per second

F, F_{int} = Products of ratios of distance

F(x) = Derived Bessel function of x (Table VIII and Figure 1)

I = Conductor current - kiloamperes

k_s = Skin effect correction factor for annular and segmental conductors

k_p = Relative transverse conductivity factor for calculating conductor proximity effect

ℓ = Lay of shielding tape or skid wire - inches

G = Geometric factor

- G1 = applying to insulation resistance (Figure 2 of Reference 1)
- G2 = applying to dielectric loss (Figure 2 of Reference 1)
- Gb = applying to a duct bank (Figure 2)

L = Depth of reference cable below Earth's surface - inches

Lb = Depth to center of duct bank (or backfill) - inches

(lf) = Load factor-per unit

(LF) = Load factor-per unit

n = Number of conductors per cable

n^1 = Number of conductors within a stated diameter

N = Number of cables or cable groups in a system

P = Perimeter of a duct bank or backfill - inches

$\cos\theta$ = Power factor of the insulation

q_s = Ratio of the sum of the losses in the conductors and sheaths to the losses in the conductors

q_e = Ratio of the sum of the losses in the conductors, sheath and conduit to the losses in the conductors

R = Electrical resistance - Ohms

- R_{dc} = d-c resistance of conductor
- R_{ac} = total a-c resistance per conductor
- R_s = d-c resistance of sheath or of the parallel paths in a shield-skid wire assembly

$\underline{R}$ = Thermal Resistance (per conductor losses) - thermal ohm feet

- $\underline{R}_i$ = of insulation
- $\underline{R}_j$ = jacket
- $\underline{R}_{sd}$ = between cable surface and surrounding enclosure
- $\underline{R}_d$ = of duct wall or asphalt mastic covering
- $\underline{R}_{se}$ = total between sheath and diameter D_e including $\underline{R}_j$, $\underline{R}_{sd}$ and $\underline{R}_d$
- $\underline{R}_e^1$ = between cable surface and ambient air
- $\underline{R}_{ca}^1$ = effective between conductor and ambient for conductor loss
- $\underline{R}_{ct}^1$ = effective transient thermal resistance of cable system

$\underline{R}_{da}$= effective between conductor and ambient for dielectric loss

$\underline{R}_{int}$= of the interference effect

$\underline{R}_{ya}$= between a steam pipe abd ambient earth

ρ = Electric resistivity - circular mil - ohms per foot

ρ = Thermal resistivity - degrees Centigrade centimeters per watt

s = distance in three-conductor cable between the effective current center of the conductor and the axis of the cable - inches

S = Axial spacing between adjacent cables - inches

S^1 = Axial spacing between outside cables in a cradled configuration - inches

t,T = Thickness (as indicated) - inches

T = Temperature - degrees Centigrade

T_a = of ambient air or earth

T_c = of conductor

T_m = mean temperature of medium

ΔT = Temperature rise - degrees Centigrade

ΔT_c = of conductor due to current produced losses

ΔT_d = of conductor due to dielectric loss

ΔT_{int}= of a cable due to extraneous heat source

W = Losses developed in a cable - watts per conductor foot

W_c = portion developed in the conductor

W_s = portion developed in the sheath or shield

W_p = portion developed in the pipe or conduit

W_d = portion developed in the dielectric

X_m = Mutual reactance, conductor to sheath or shield in microhms per foot

Y = The increment of a-c/d-c ratio - per unit

Y_c = due to losses originating in the conductor, having components Y_{cs} due to skin effect and Y_{cp} due to proximity effect

Y_s = due to losses originating in the sheath or shield having components Y_{sc} due to circulating current effect and Y_{sa} due to eddy current effect

Y_p = due to losses originating in the pipe or conduit

Y_a = due to losses originating in the armor

AMPACITY PROBLEM

Cable: B.

750 kcmil Aluminum Compressed Class B Strand, rated 15kV, .025" ESS, 0.175" XLPE, .050" EIS, 15 x #10 AWG (1/3 neutral), .080" encapsulating LDHMWPE jacket.

To Be Installed:

1. Triplexed in a duct (4 way bank in concrete)
2. One conductor per duct (6 way bank in concrete)
3. Triplexed direct buried
4. On 8" centers (flat) directly buried

Conditions:

Maximum Conductor Temperature	90 ^{o}C
System Voltage	13.2/7.6kV
Earth Ambient Temperature	20 ^{o}C
Duct	Fibre
Burial Depth	36"
Load Factor	75%

Cable and Duct Dimensions

O.D. Conductor (Dc)	0.968"
O.D. ESS	1.020
O.D. Insulation (Di)	1.400"
O.D. EIS	1.520"
Mean Neutral Diameter	1.620"
O.D. Overall	1.91"
O.D. Triplexed	4.12"
5" I.D. Fibre Duct	0.25" wall

SAMPLE PROBLEM

```
        XEQ "AMP"
Rdc? 25C
           .0236    RUN
AL:1 /CU:0
          1.0000    RUN
T2?
         90.0000    RUN
Rdc:T2= 29.6608
KS?
          1.0000    RUN
YCS= 0.0124
KP?
          1.0000    RUN
Dc?
           .9680    RUN
S?
          8.0000    RUN
Yc:SP= 0.0132
SP? :TX:
          1.9100    RUN
Yc:TX= 0.0259
RS?
         71.0000    RUN
DSM?
          1.6200    RUN
XM= 55.8255
O.C:1 / S.C:0
          0.0000    RUN
YS= 0.9156
TRPX:
XM= 19.7078
O.C:1 / S.C:0
          0.0000    RUN
YS= 0.2049
QS:SP:= 1.9038
QS:TX= 1.1997
VG?
          7.6000    RUN
e?
          2.3000    RUN
DF?
           .0150    RUN
T:INSL?
           .1750    RUN
WD= 0.0410
TR:INSL?
        400.0000    RUN
O.D: INSL?
          1.4000    RUN
```

```
C?
           .0240    RUN
TM?
         65.0000    RUN
B?
          2.3000    RUN
A?
         17.0000    RUN
TR:DUCT?
        480.0000    RUN
T?:DUCT
           .2500    RUN
O.D: DUCT?
          5.5000    RUN
JKT? : Y/N?
Y                   RUN
TR?: JKT
        450.0000    RUN
T?: JKT
           .0800    RUN
N?
          1.0000    RUN
RHO?
         90.0000    RUN
L?: DB
         36.0000    RUN
LOSS F?
           .6190    RUN
TR?
         85.0000    RUN
De?
          5.0470    RUN
L?: DUCT
         36.0000    RUN
N?
          1.0000    RUN
Gb:TX:DT?
           .9000    RUN
F? SP:DB
         82.0000    RUN
F? SP:DT
         82.0000    RUN
N?
          3.0000    RUN
Gb? SP:DT
           .8400    RUN
```

SAMPLE PROBLEM

```
Ta?
        20.0000    RUN
I:TX:DB=  666
I:TX:DT=  498
I:SP:DB=  599
I:SP:DT=  485
M:BOND? Y/N?
Y                  RUN
I?
            666    RUN
TX:3 /SP:0?
              3    RUN
Wc=  13.4976
WS?: W/FT
         4.5800    RUN
QS=  1.3393
Ta?
        20.0000    RUN
I:TX:DB=  635
I:TX:DT=  474
I:SP:DB=  599
I:SP:DT=  538
M:BOND? Y/N?
Y                  RUN
I?
            498    RUN
TX:3 /SP:0?
              3    RUN
Wc=  7.5469
WS?: W/FT
         4.5800    RUN
QS=  1.6069
Ta?
        20.0000    RUN
I:TX:DB=  586
I:TX:DT=  435
I:SP:DB=  599
I:SP:DT=  522
M:BOND? Y/N?

Y                  RUN
I?
            599    RUN
TX:3 /SP:0?
              0    RUN
Wc=  10.7823
WS?: W/FT
        10.9100    RUN
QS=  2.0118
Ta?
        20.0000    RUN
I:TX:DB=  586
I:TX:DT=  435
I:SP:DB=  584
I:SP:DT=  487
M:BOND? Y/N?
```

USER INSTRUCTIONS

Size:034

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load program "SV" if shield losses by configuration is desired. Record values for input to ampacity program.		
4.	Load programs "AMP" "VW"		
5.	Check status		
6.	Initialize: XEQ "AMP"		
7.	Enter D-C resistance of conductor in ohms per 1000 feet at 25 C	Rdc	Rdc? 25C
8.	Enter type metal of conductor **Aluminum = 1** **Copper = 0**	1or0	AL:1/CU:0
9.	Enter operating temperature of conductor in degrees C.	T2	T2?
10.	Display Rdc in microhms per foot at temperature T2.	-	Rdc:T2=
11.	Enter ks value from Table II	Ks	KS?
12.	Display losses due to skin effect component	-	YCS=
13.	Enter kp value from Table II	Kp	KP?
14.	Enter O.D. of conductor, inches	Dc	Dc?

STEP	INSTRUCTIONS	INPUT	DISPLAY
15.	Enter axial spacing between adjacent cables - inches	S	S?
16.	Display increment of a-c/d-c ratio per unit due to losses orginating in the conductor having components Ycs and Ycp for spaced cables	-	Yc:SP=
17.	Enter spacing for triplexed cables, inches	SP	SP? :TX:
18.	Display increment of a-c/d-c ratio per unit due to losses orginating in the conductor having components Ycs and Ycp for triplexed cables	-	Yc:TX=
19.	Enter d-c resistance for metallic shield component in microhms per foot at 20 C	RS	RS?
20.	Enter mean diameter of sheath or shield, inches	DSM	DSM?
21.	Display mutual reactance between conductor and shield or sheath in microhms per foot at 60 cycles for spaced cable configuration.	-	XM=
22.	Select circuit operation for spaced cables **Open circuit = 1** **Short circuit = 0**	1or0	O.C:1/S.C:0
23.	Display losses originating in sheath or shield, having components YSC and YSE, for spaced cables.	-	YS=

STEP	INSTRUCTIONS	INPUT	DISPLAY
			TRPX:
24.	Display mutual reactance between conductor and shield or sheath in microhms per foot at 60 cycles for triplexed cables.	-	XM=
25.	Select circuit operation for triplexed cables **Open circuit = 1** **Short circuit = 0**	1orO	O.C:1/S.C:O
26.	Display losses originating in sheath or shield, having components YSC and YSE, for triplexed cables.	-	YS=
27.	Display ratio of the sum of the losses in the conductors and sheaths to the losses in the conductors for spaced cables.	-	QS:SP=
28.	Display QS for triplexed cables	-	QS:TX=
29.	Enter phase to neutral voltage in kilovolts.	Vg	VG?
30.	Enter dielectric constant (SIC)	e	e?
31.	Enter dissipation factor in decimal form	DF	DF?
32.	Enter insulation thickness in inches	T	T:INSL?
33.	Display Dielectric loss in watts per conductor foot at 60 cycles	-	WD=

STEP	INSTRUCTIONS	INPUT	DISPLAY
34.	Enter thermal resistivity of insulation	TR	TR:INSL?
35.	Enter diameter over insulation, inches	Di	O.D.INSL?
36.	Enter constant C from table V	C	C?
37.	Enter mean temperature of medium degrees C	TM	TM?
38.	Enter constant B from table V	B	B?
39.	Enter constant A from table V	A	A?
40.	Enter thermal resistivity for duct in Ccm/watt. Table IV	TR	TR:DUCT?
41.	Enter thickness of duct wall in inches	T	T:DUCT?
42.	Enter O.D. of duct, inches	O.D	O.D:DUCT?
43.	Does cable have an overall outer jacket? Y = Yes N = No	Y or N	JKT? Y/N?
44.	If yes, enter thermal resistivity of jacket material, if no proceed to step 47	TR	TR?: JKT
45.	Enter thickness of jacket in inches.	T	T?: JKT
46.	Enter number of cables or cable groups in a system	N	N?

STEP	INSTRUCTIONS	INPUT	DISPLAY
47.	Enter thermal resistivity of earth	RHO	RHO?
48.	Enter depth of reference cable below earth's surface for direct buried cable in inches	L	L? DB
49.	Enter Loss factor per unit	LF	LOSS F?

Load Factor	Loss Factor
50%	0.325
75%	0.619
100%	1.000

STEP	INSTRUCTIONS	INPUT	DISPLAY
50.	Enter thermal resistivity of concrete or other duct surrounding medium	TR	TR?
51.	Enter De, Diameter at start of the earth portion of the thermal circuit in inches, for cable in duct	De	De?
52.	Enter Depth of reference cable below earth's surface in inches for cable in duct.	L	L? DUCT
53.	Enter number of cables of cable groups in duct system	N	N?
54.	Enter geometric factor applying to duct bank for triplexed cable	Gb	Gb:TX:DT?
55.	Enter F, Fint, product of ratios of distance for spaced cables directly buried.	F	F? SP:DB?
56.	Enter F, Fint, product of ratios of distance for spaced cable in duct	F	F? SP:DT

STEP	INSTRUCTIONS	INPUT	DISPLAY
57.	Enter number of cables or cable groups in a system	N	N?
58.	Enter Geometric factor applying to duct bank for spaced cables in duct	Gb	Gb? SP:DT
59.	Enter temperature of ambient air or earth in degrees C	Ta	Ta?
	[TRIPLEXED]		
60.	Display conductor current in amperes for triplexed direct buried cable	-	I:TX:DB=
61.	Display conductor current in amperes for triplexed cable in duct	-	I:TX:DB=
	[SPACED]		
62.	Display conductor current in amperes for spaced cables direct bury	-	I:SP:DB=
63.	Display conductor current in amperes for triplexed cables in duct	-	I:SP:DT=

STEP	INSTRUCTIONS	INPUT	DISPLAY
64.	Is system grounded or bonded at multiple points? Y = Yes N = No	Y or N	M:BOND? Y/N?
65.	If Yes. enter conductor current in amperes, if no proceed to step 70.	I	I?
66.	Which group; triplexed or spaced? 3 = Triplexed 0 = Spaced	3 or 0	TX:3 / SP:0?
67.	Display losses developed in conductor - watts per conductor foot	-	Wc=
68.	Enter losses developed in sheath or shield (from program "SV") in watts per foot	Ws	Ws? W/ft
69.	Display Qs	-	QS=
70.	Re-enter or enter new ambient temperature in degrees C	Ta	Ta?
71.	Ampacities are displayed, see step 60.		

<u>Cable System Ampacities</u>

STEP/KEY CODE	COMMENTS
01♦LBL "AMP"	Intialize
02 FIX 4	
03 CF 03	
04 CF 01	
05 0	
06 STO 31	
07 STO 32	
08 "Rdc? 25 C"	Enter Rdc
09 PROMPT	
10 STO 00	
11 "AL:1 /CU:0"	
12 PROMPT	
13 X=0?	
14 GTO 14	Aluminum
15 "T2?"	
16 PROMPT	
17 STO 33	(3)
18 228.1	
19 +	
20 253.1	
21 GTO 15	
22♦LBL 14	
23 "T2?"	
24 PROMPT	<u>Copper</u>
25 STO 33	(3)
26 234.5	
27 +	
28 259.5	
29♦LBL 15	
30 /	
31 RCL 00	
32 *	
33 1 E3	
34 *	
35 "Rdc:T2="	Rdc at operating temperature
36 XEQ "VW"	
37 STO 00	
38 "KS?"	
39 PROMPT	Enter ks
40 /	
41 XEQ "F1"	
42 STO 01	
43 "YCS="	(21)
44 XEQ "VW"	
45 RCL 00	
46 "KP?"	
47 PROMPT	Enter kp
48 /	
49 XEQ "F1"	
50 STO 01	

STEP/KEY CODE	COMMENTS
51 "Dc?"	(25)
52 PROMPT	
53 STO 02	
54 "S?"	
55 PROMPT	
56 STO 03	
57 STO 04	
58 XEQ "YCP"	(24)
59 STO 14	
60 "Yc:SP="	
61 XEQ "VW"	
62 "SP? :TX:"	
63 PROMPT	
64 STO 03	
65 XEQ "YCP"	(24)
66 STO 15	
67 "Yc:TX="	
68 XEQ "VW"	
69 "RS?"	
70 PROMPT	
71 STO 07	(29a)
72 RCL 04	
73 "DSM?"	
74 PROMPT	
75 STO 06	
76 /	
77 2.3	
78 *	
79 LOG	
80 52.9	
81 *	
82 STO 09	
83 XEQ "YSC"	(27)
84 RCL 03	
85 RCL 06	
86 /	
87 2	
88 *	
89 LOG	
90 52.9	
91 *	
92 STO 09	
93 SF 03	
94 RCL 04	(28a)
95 STO 08	
96 RCL 03	
97 STO 04	
98 XEQ "TPX"	
99 XEQ "YSC"	
100 RCL 16	

```
STEP/KEY CODE            COMMENTS

101  1
102  RCL 14
103  +                   (18)
104  /
105  1
106  +
107  "QS:SP:=
"
108  XEQ "VW"
109  STO 17
110  RCL 01
111  1
112  RCL 15
113  +
114  /
115  1
116  +                   (18)
117  "QS:TX="
118  XEQ "VW"
119  STO 18
120  "VG?"
121  PROMPT              (36)
122  X↑2
123  "e?"
124  PROMPT
125  *
126  "DF?"
127  PROMPT
128  *
129  .00276
130  *
131  "T:INSL?
"
132  PROMPT
133  2
134  *
135  RCL 02
136  +
137  RCL 02
138  /
139  LOG                 (38)
140  /
141  "WD="
142  XEQ "VW"
143  STO 19
144  "TR:INSL
?"
145  PROMPT
146  .012
147  *
148  "O.D: IN
SL?"
149  PROMPT
150  RCL 02
```

```
STEP/KEY CODE            COMMENTS

151  /
152  LOG
153  *
154  STO 20
155  "C?"
156  PROMPT
157  "TM?"
158  PROMPT
159  *
160  "B?"
161  PROMPT
162  +
163  STO 10
164  RCL 03
165  *
166  1                   (41)
167  +
168  "A?"
169  PROMPT
170  STO 11
171  X<>Y
172  /
173  STO 21
174  RCL 03
175  2.155
176  *
177  RCL 10
178  *
179  1
180  +                   (41)
181  RCL 11
182  3
183  *
184  X<>Y
185  /
186  STO 22
187  "TR:DUCT
?"
188  PROMPT
189  .0104
190  *
191  "T?:DUCT
"
192  PROMPT              (40)
193  STO 12
194  "O.D: DU
CT?"
195  PROMPT
196  RCL 12
197  -
198  /
199  *
200  STO 23
```

STEP/KEY CODE COMMENTS

```
201 3
202 *
203 STO 24
204 "Y"            (40)
205 ASTO Y
206 "JKT? :
Y/N?"
207 AVIEW
208 AON
209 STOP
210 AOFF
211 ASTO X
212 X=Y?
213 GTO 03
214 GTO 04
215◆LBL 03
216 "TR?: JK
T"
217 PROMPT
218 .0104
219 *
220 "T?: JKT        (40)
"
221 PROMPT
222 STO 12
223 RCL 03
224 RCL 12
225 -
226 /
227 *
228 STO 31
229 "N?"
230 PROMPT
231 *
232 STO 32
233◆LBL 04
234 "RHO?"
235 PROMPT
236 STO 05
237 3
238 *
239 .012
240 *
241 8.3
242 RCL 03
243 2.155
244 *
245 /
246 LOG
247 "L?: DB"
248 PROMPT
249 STO 27
250 4
```

STEP/KEY CODE COMMENTS

```
251 *
252 8.3
253 /
254 LOG            (44)
255 "LOSS F?
"
256 PROMPT
257 STO 10
258 *
259 +
260 *
261 RCL 32
262 +
263 STO 25
264 "TR?"
265 PROMPT
266 STO 13
267 3
268 *
269 .012
270 *
271 STO 12
272 8.3
273 "De?"
274 PROMPT
275 STO 28
276 /
277 LOG
278 "L?: DUC
T"
279 PROMPT
280 STO 09
281 4
282 *
283 8.3
284 /
285 LOG
286 RCL 10
287 *
288 +
289 RCL 12
290 *
291 STO 12
292 RCL 05
293 RCL 13
294 -
295 3
296 *
297 .012
298 *
299 RCL 10
300 *
```

STEP/KEY CODE COMMENTS

```
301 "N?"
302 PROMPT
303 *
304 "Gb:TX:D
T?"
305 PROMPT          (44a)
306 *
307 RCL 12
308 +
309 RCL 32
310 +
311 STO 26
312 RCL 05
313 .012
314 *
315 STO 06
316 8.3
317 RCL 03
318 /
319 LOG
320 RCL 27
321 4
322 *               Enter F
323 8.3
324 /
325 "F? SP:D        (46)
B"
326 PROMPT
327 *
328 LOG
329 RCL 10
330 *
331 +
332 RCL 06
333 *
334 RCL 31
335 +
336 STO 29
337 RCL 13
338 .012            (44)
339 *
340 STO 08
341 8.3
342 RCL 28
343 /
344 LOG
345 RCL 09
346 4
347 *
348 8.3
349 /
350 "F? SP:D
T"
```

STEP/KEY CODE COMMENTS

```
351 PROMPT
352 *
353 LOG
354 RCL 10
355 STO 06
356 *
357 +
358 RCL 08
359 *
360 STO 08          (44a)
361 RCL 05
362 RCL 13
363 -
364 .012
365 *
366 RCL 06
367 *
368 "N?"
369 PROMPT
370 *
371 "Gb? SP:
DT"
372 PROMPT
373 *
374 RCL 08
375 +
376♦LBL 05
377 CF 03
378 RCL 31          (8)
379 +
380 STO 30
381 RCL 18
382 RCL 25
383 *
384 RCL 20
385 +
386 STO 01
387 RCL 26
388 RCL 24
389 +
390 RCL 22
391 +
392 RCL 18
393 *
394 RCL 20
395 +
396 STO 02
397 RCL 20
398 2
399 /
400 RCL 25
```

STEP/KEY CODE	COMMENTS
401 +	
402 RCL 19	
403 *	
404 STO 03	
405 RCL 26	
406 RCL 24	
407 +	
408 RCL 22	(8)
409 +	
410 RCL 20	
411 2	
412 /	
413 +	
414 RCL 19	
415 *	
416 STO 04	
417 RCL 29	
418 RCL 17	
419 *	
420 RCL 20	
421 +	
422 STO 05	
423 RCL 30	
424 RCL 23	
425 +	
426 RCL 21	
427 +	
428 RCL 17	
429 *	
430 RCL 20	
431 +	(8)
432 STO 06	
433 RCL 29	
434 RCL 20	
435 2	
436 /	
437 +	
438 RCL 19	
439 *	
440 STO 07	
441 RCL 30	
442 RCL 23	
443 +	
444 RCL 21	
445 +	
446 RCL 20	
447 2	
448 /	
449 +	
450 RCL 19	
451 *	
452 STO 08	
453♦LBL 02	
454 RCL 33	
455 STO 09	

STEP/KEY CODE	COMMENTS
456 "Ta?"	
457 PROMPT	(9)
458 STO 10	
459 FIX 0	
460 RCL 09	
461 RCL 10	
462 RCL 03	
463 +	
464 -	
465 RCL 00	
466 RCL 15	
467 1	
468 +	
469 *	
470 RCL 01	
471 *	
472 /	
473 SQRT	
474 1 E3	
475 *	
476 "I:TX:DB ="	(9)
477 XEQ "VW"	
478 RCL 09	
479 RCL 10	
480 RCL 04	
481 +	
482 -	
483 RCL 00	
484 RCL 15	
485 1	
486 +	
487 *	(9)
488 RCL 02	
489 *	
490 /	
491 SQRT	
492 1 E3	
493 *	
494 "I:TX:DT ="	
495 XEQ "VW"	
496 RCL 09	
497 RCL 10	
498 RCL 07	
499 +	(9)
500 -	
501 RCL 00	
502 RCL 14	
503 1	
504 +	
505 *	

STEP/KEY CODE — COMMENTS

```
506 RCL 05
507 *
508 /
509 SQRT
510 1 E3
511 *
512 "I:SP:DB
="                          (9)
513 XEQ "VW"
514 RCL 09
515 RCL 10
516 RCL 08
517 +
518 -
519 RCL 00
520 RCL 14
521 1
522 +
523 *
524 RCL 06
525 *
526 /
527 SQRT
528 1 E3
529 *
530 "I:SP:DT
="
531 XEQ "VW"
532 "Y"
533 ASTO Y
534 "M:BOND?
 Y/N?"
535 AVIEW
536 AON
537 STOP
538 AOFF
539 ASTO X
540 X=Y?
541 GTO 06
542 GTO 02
543◆LBL 06
544 "I?"
545 PROMPT
546 1 E3
547 /
548 X↑2
549 STO 12
550 "TX:3 /S
P:0?"
551 PROMPT
552 X=0?
553 GTO 07
554 SF 03
555 RCL 15
556◆LBL 08
557 1
558 +
559 RCL 00
560 *
561 RCL 12
562 *
563 FIX 4
564 "Wc="
565 XEQ "VW"
566 STO 11
567 "WS?: W/                    (WS)
FT"
568 PROMPT
569 +
570 RCL 11
571 /
572 "QS="
573 XEQ "VW"
574 FS? 03
575 GTO 11
576 STO 17
577 GTO 05
578◆LBL 07
579 RCL 14
580 GTO 08
581◆LBL 11
582 STO 18
583 GTO 05
584◆LBL "TPX
"
585 "TRPX:"
586 AVIEW
587 CF 03
588 RTN
589◆LBL "YCP                    (24)
"
590 RCL 02
591 RCL 03
592 /
593 X↑2
594 STO 05
595 RCL 01
596 *
597 STO 12                      (27)
598 RCL 05
599 .312
600 *
601 1.18
602 RCL 01
603 .27
604 +
605 /
```

STEP/KEY CODE	COMMENTS	STEP/KEY CODE	COMMENTS

```
606 +
607 RCL 12
608 *
609 RCL 01
610 +
611 RTN
612◆LBL "YSC          (27)
"
613 RCL 09
614 "XM="
615 XEQ "VW"
616 RCL 07
617 X<>Y
618 /
619 X↑2
620 1
621 +
622 RCL 07
623 RCL 00
624 /
625 X<>Y
626 /
627 STO 11
628 RCL 07
629 RCL 00
630 /
631 3
632 *
633 5.2
634 RCL 07
635 *
636 60
637 /
638 X↑2
639 RCL 04             (30)
640 2
641 *
642 RCL 06
643 /
644 .2
645 *
646 +
647 /
648 STO 12
649 RCL 06
650 RCL 04
```

```
651 2
652 *
653 /
654 X↑2
655 STO 05             (30)
656 .4166667
657 *
658 1
659 +
660 RCL 12
661 *
662 RCL 05
663 *
664 STO 13
665 "O.C:1 /
 S.C:0"
666 PROMPT
667 X=0?
668 GTO 12
669◆LBL 13
670 RCL 11
671 RCL 13
672 +
673 "YS="
674 XEQ "VW"
675 FS? 01
676 GTO 00
677 STO 16
678◆LBL 01
679 SF 01
680 RTN
681◆LBL 00
682 STO 01
683 GTO 01
684◆LBL "F1"
685 STO 02
686 7.2                (3)
687 X>Y?
688 GTO "F3"
689 11
690 ENTER↑
691 4
692 RCL 02
693 /
694 RCL 02
695 +
696 2.56
697 RCL 02
698 X↑2
699 /
700 -
701 X↑2
702 /
703 RTN
```

STEP/KEY CODE	COMMENTS	STEP/KEY CODE	COMMENTS

```
704♦LBL "F3"
705 1
706 ENTER↑
707 .1102
708 RCL 02
709 /
710 -                    (3)
711 11
712 *
713 4
714 RCL 02
715 /
716 RCL 02
717 +
718 2.56
719 RCL 02
720 X↑2
721 /
722 -
723 X↑2
724 /
725 RTN
726♦LBL 12
727 RCL 07
728 X↑2
729 RCL 09
730 X↑2
731 RCL 07
732 X↑2
733 +
734 /
735 RCL 13
736 *
737 STO 13
738 GTO 13
739 END
```

DATA REGISTERS

00	Rdc:CDTR
01	FX, Ycs, YsTX
02	Dc
03	Cable O.D.
04	Spacing
05	Program
06	Dsm
07	Rs
08	Program
09	XM
10	Program (LF)
11	Ysc
12	Program
13	Program
14	Yc- SP
15	Yc-TRPX
16	Ys- SP
17	QS-SP
18	QS-TX
19	Wd
20	Ri
21	Rsd:sp
22	Rsd:TX
23	RDE:SP
24	RDE:TX
25	Re:TX:DB
26	Re:TX:DT
27	L
28	De
29	Re:SP:DB
30	Re:SP:DT
31	RJE:SP
32	RJE:TX
33	Tc

01	RCA:DB:TX
02	RCA:DT:TX
03	ΔTD:TX:DB
04	ΔTD:TX:DT
05	RCA:SP:DB
06	RCA:SP:DT
07	ΔTD:SP:DB
08	ΔTD:SP:DT
09	TC
10	TA
11	Wc

STATUS

Size: 033

All modes automatically set

Flag 01 set for single or spaced cables

Flag 03 set for triplexed cables

No function assignments keys used

Note: Data registers 01-10 have double use

INDUCED SHIELD VOLTAGES AND LOSSES

Robert W. Parkin

FUNCTION: Program calculates the induced shield voltages and shield losses for single conductor cables in six arrangements: single phase, equilateral, flat, rectangular, and two circuit. This program can be used in conjunction with the ampacity program to determine the input value for shield losses.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: program assumes that the cables are carrying balanced currents. Formulas neglect proximity loss, but are accurate enough for practical purposes.

For cables installed three per conduit use arrangement II (equilateral). The spacing S in this case will be equal to the outside diameter of the cable increased by 20 percent to allow for random spacing in the conduit.

REFERENCES:

[1] Underground Systems Reference Book, Edison Electric Institute
[2] ICEA S-66-524 NEMA Pub. No. WC-7
[3] ICEA Ampacities Including Effect of Shield Losses for Single Conductor Solid Dielectric Power Cables P-53-426 NEMA Pub. No 50-1976
[4] Essex Underground Cable Engineering Handbook, Cablec Corp

GROUNDING OF POWER CABLE SHIELDS

The purpose of the shielding system on a power cable is to provide a fixed, known path to ground for the cable charging or displacement current. To perform that function the shield must be solidly grounded. Where conductors are individually shielded each conductor must have its shield grounded. Where grounding conductors are part of a cable assembly, they must be connected with the shielding at both ends of the cable.

For safe and effective operation, the shielding should be grounded at each end of the cable and at each splice. For short lengths or where special bonding arrangements are used, grounding at one point only may be satisfactory.

All grounding connections should be made to the cable shield in such a way as to provide a permanent low resistance bond. Soldering the connection to the cable shield is usually preferable to a mechanical clamp, as there is less danger of a poor connection, loosening, or injury to the cable. The area of contact should be ample to prevent the current from heating the connection and melting the solder.

For additional security, a mechanical device, such as a nut or bolt, may be used to fasten the ends of the connection together. This combination of a soldered and mechanical connection provides permanent low resistance which will maintain contact even though the solder melts.

The wire or strap used to connect the cable shield ground connection to the permanent ground must be of ample size to carry fault currents.

If there is an insulating jacket over the shield and if, because of an accident or corrosion, the shield ground connection is broken, the voltage between that shield and ground can approach the conductor to ground voltage that is on the insulated conductor. This one good reason for multi-point shield ground. Installations of shielded single conductor cables must be studied to determine the best method of grounding. This is necessary as voltage is induced in the shield of a single conductor cable carrying alternating current due to mutual inductance between its shield and any other conductors in its vicinity. This induced voltage can result in two conditions.

1. **Single Point Grounding**

The current in the conductor induces a voltage along the shield. The amount of induced voltage depends on many factors, including cable geometry, cable spacing, conductor current, and frequency. Some systems are designed with a particular maximum value of shield voltage in mind. Values are selected for safety and sometimes to reduce the possibility of corrosion due to a-c electrolysis. As distance increases from the grounded point, so does the voltage of the shield. These values are displayed in the program. The usual safe potential is about 25 volts for cables having non-metallic coverings over the sheath.

2. **Multiple Point Grounding**

When the cable shields are bonded and grounded at multiple points, the shield to ground voltages are essentially eliminated. However, the longitudinal voltage induced along the shield by the conductor current causes a current to flow in the shield which results in additional heating known as shield losses. The additional heating caused by shield losses may require a derating of the cable ampacity. The amount of derating depends on many factors, including cable size, cable separation, and frequency. The shield resistance is a major factor affecting the shield losses. If the shield loss exceeds 5 percent of the copper loss, the current carrying capacity should be reduced.

If operating conditions permit, it is desirable to bond and ground cable shields at more than one point, to improve the reliability and safety of the circuit. This decreases the reactance to fault currents and increases the human safety factor.

General recommendations may be made to operate single conductor cables (a-c) with multisheath grounds, however variations in insulation wall thickness, conductivity of sheath, spacing of conductors and the current being carried all affect these recommendations.

1. Shielded cables installed with all three phases in the same duct.

2. Cables of any size may be installed with multi-shield grounds, provided allowance is made for heating due to currents induced in the shield. Cables carrying direct current may always be solidly grounded at more than one point, except where insulating joints are required to isolate earth currents or to permit cathodic protection.

3. Shielded cables up to and including 250 MCM with phases in separate ducts. Cables in a-c circuits should not be installed with each phase in separate magnetic conduits due to the high inductance under such conditions. Cables in a-c circuits should not be installed with each phase in separate metallic non-magnetic conduit when their size exceeds #4/0 AWG unless the conduit is insulated to prevent circulating currents.

The table below gives the formulas for calculating the induced voltage and shield loss that the program is based.

Note: Where double sign, +/- is shown, use the upper sign for lagging and lower one for leading power factor.

FORMULAS FOR CALCULATING SHIELD VOLTAGES—CURRENTS AND LOSSES FOR SINGLE-CONDUCTOR CABLES

Cable Arrangement Number and Diagram	I One phase S Ⓑ Ⓐ	II Equilateral Ⓐ Ⓑ Ⓒ S	III Rectangular Ⓐ S Ⓑ Ⓒ S	IV Flat S S Ⓐ Ⓑ Ⓒ	V Two circuit Ⓐ Ⓑ Ⓒ S S S Ⓐ Ⓑ Ⓒ	VI Two circuit Ⓐ Ⓑ Ⓒ S S S Ⓒ Ⓑ Ⓐ
INDUCED SHIELD VOLTAGE—SHIELDS OPEN CIRCUITED				**MICRO VOLTS TO NEUTRAL PER FT. (MULTIPLY BY 10^{-6} TO OBTAIN VOLTS PER FT.)**		
Cable—A, Cable—C	IX_M	IX_M	$\frac{I}{2}\sqrt{3Y^2+\left(X_M-\frac{A}{2}\right)^2}$	$\frac{I}{2}\sqrt{3Y^2+(X_M-A)^2}$	$\frac{I}{2}\sqrt{3Y^2+\left(X_M-\frac{B}{2}\right)^2}$	$\frac{I}{2}\sqrt{3Y^2+\left(X_M-\frac{B}{2}\right)^2}$
Cable—B	IX_M	IX_M	IX_M	IX_M	$I\left(X_M+\frac{A}{2}\right)$	$I\left(X_M+\frac{A}{2}\right)$
SHIELD LOSS—SHIELDS SOLIDLY BONDED				**MICRO WATTS PER FT. (MULTIPLY BY 10^{-6} TO OBTAIN WATTS PER FT.)**		
Cable—A, Cable—C	$I^2R_s\frac{X_M^2}{R_s^2+X_M^2}$	$I^2R_s\frac{X_M^2}{R_s^2+X_M^2}$	$I^2R_s\frac{(P^2+3Q^2)\pm2\sqrt{3}(P-Q)+4}{4(P^2+1)(Q^2+1)}$			
Cable—B	$I^2R_s\frac{X_M^2}{R_s^2+X_M^2}$	$I^2R_s\frac{X_M^2}{R_s^2+X_M^2}$	$I^2R_s\frac{1}{Q^2+1}$			
Total loss	$2I^2R_s\frac{X_M^2}{R_s^2+X_M^2}$	$3I^2R_s\frac{X_M^2}{R_s^2+X_M^2}$	$3I^2R_s\frac{P^2+Q^2+2}{2(P^2+1)(Q^2+1)}$			
	$P=\frac{R_s}{Y}$	$Y=$	$X_M+\frac{A}{2}$	X_M+A	$X_M+A+\frac{B}{2}$	$X_M+A+\frac{B}{2}$
	$Q=\frac{R_s}{Z}$	$Z=$	$X_M-\frac{A}{6}$	$X_M-\frac{A}{3}$	$X_M+\frac{A}{3}-\frac{B}{6}$	$X_M+\frac{A}{3}-\frac{B}{6}$

To facilitate calculating the shield resistance, the following formulas may be used:

$X_M = 2\pi f\left(0.1404 \log_{10}\frac{S}{r_m}\right)$ micro-ohms per ft.

$A = 2\pi f\,(0.1404 \log_{10} 2)$ micro-ohms per ft.

$B = 2\pi f\,(0.1404 \log_{10} 5)$ micro-ohms per ft.

$R_S = \frac{\rho}{8 r_m t}$ micro-ohms per ft.

R_S = resistance of shield (micro-ohms per ft.)
t = thickness of metal tapes used for shielding (inches)
f = frequency (60 cycles)
S = spacing between center of cables (inches)
r_m = mean radius of shield (inches)
I = conductor current (amperes)

for 60 cycles

$X_M = 52.92 \log_{10}\frac{S}{r_m}$ micro-ohms per ft.

A = 15.93 micro-ohms per ft.
B = 36.99 micro-ohms per ft.
ρ = apparent resistivity of shield in ohms/cir mil ft. at operating temperature (assumed 50 degrees C.). This includes allowance for the spiraling of the tapes or wires.

Typical Values of ρ

Overlapped tinned copper tape .... 30 ohms/cir mil ft.
Lead sheath .... 150 ohms/cir mil ft.
Aluminum sheath .... 20 ohms/cir mil ft.

USER INSTRUCTIONS

Size: 013

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "SV","VW"		
4.	Check status		
5.	Initialize: XEQ "SV"		
6.	Enter frequency in hertz	HZ	HZ ?
7.	Enter spacing between center of cable, inches	S	S ?
8.	Enter mean radius of shield, inches	rm	RM ?
9.	Display mutual reactance in micro-ohms per foot		XM =
10.	Enter ampacity of cable, amperes	amps	AMPS ?
11.	Select cable arrangement:		

Label	Arrangement
A	One Phase
B	Equilateral
C	Rectangular
D	Flat Spacing
E	Two Circuit

[XEQ "A" One Phase]

STEP	INSTRUCTIONS	INPUT	DISPLAY
12.	Display Induced Shield Voltage for cable A and B in micro-volts to neutral/foot		SV: A + B=

STEP	INSTRUCTIONS	INPUT	DISPLAY
13.	Enter shield resistance in micro-ohms/foot	RS	RS ?
14.	Display shield loss in watts/foot		SL =
15.	Total shield loss in watts/foot	-	TL =

[XEQ "B" Equilateral]

12.	Shield voltage for cable A and C	-	SV: A + C =
13.	Shield voltage for cable B		SV: B =
14.	Enter shield resistance	RS	RS ?
15.	Shield loss watts/foot		SL =
16.	Total shield loss		TL =

[XEQ "C", "D", or "E" Rectangular, Flat Spacing and Two Circuit]

12.	Enter shield resistance	RS	RS ?
13.	Shield voltage for cables A + C		SV: A+C=
14.	Shield Voltage for Cable B		SV: B =
15.	Shield loss for cables A and C (with upper sign for lagging power factor)		SL: A + C =
16.	Shield loss for cables A and C (with lower sign for leading power factor)		SL: A + C =
17.	Shield loss for cable B		SL: B =
18.	Total shield loss		TL =

SAMPLE PROBLEM

```
    XEQ "SV"
HZ?
 60.0000
           RUN
S?
 7.5000     R
           UN
RM? DSM?
 1.6200     R
           UN
XM= 51.1606
AMPS?
     500.0000    RUN
SELECT A-E
               XEQ A
SV:A+B= 25580.2
841
RS?
      71.0000    RUN
SL= 6.0664
TL= 12.1328
```

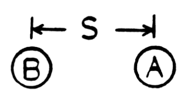
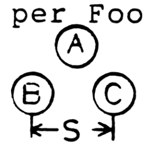
```
                 XEQ "SV"
HZ?
          60.0000    RUN
S?
           8.4220    RUN
RM? DSM?
           1.6200    RUN
XM= 53.8258
AMPS?
         500.0000    RUN
SELECT A-E
                    XEQ C
RS?
          71.0000    RUN
SV:A+C= 29109.1
869
SV:B= 26912.89
39
SL:A+C= 6.7143
SL:A+C= 2.5641
SL:B= 6.0680
TL= 20.5768
```

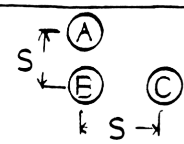
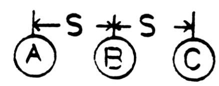
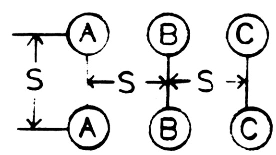
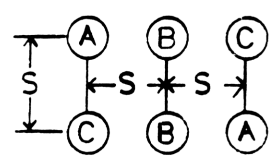
```
                 XEQ "SV"
HZ?
          60.0000    RUN
S?
           9.4500    RUN
RM? DSM?
           1.6200    RUN
XM= 56.4731
AMPS?
         500.0000    RUN
SELECT A-E
                    XEQ E
RS?
          71.0000    RUN
SV:A+C= 40489.0
110
SV:B= 32219.07
44
SL:A+C= 8.1567
SL:A+C= 3.3699
SL:B= 6.7501
TL= 26.6612
```

```
                 XEQ "SV"
HZ?
          60.0000    RUN
S?
           1.9000    RUN
RM? DSM?
           1.6200    RUN
XM= 19.5982
AMPS?
         500.0000    RUN
SELECT A-E
                    XEQ B
SV:A+C= 9799.09
82
SV:B= 9799.098
2
RS?
          71.0000    RUN
SL= 1.2567
TL= 3.7700
```

```
                 XEQ "SV"
HZ?
          60.0000    RUN
S?
           9.4500    RUN
RM? DSM?
           1.6200    RUN
XM= 56.4731
AMPS?
         500.0000    RUN
SELECT A-E
                    XEQ D
RS?
          71.0000    RUN
SV:A+C= 32949.1
984
SV:B= 28236.57
44
SL:A+C= 7.2128
SL:A+C= 3.2081
SL:B= 6.0668
TL= 22.6732
```

Induced Shield Voltages and Shield Losses

STEP / KEYCODE	COMMENTS
01◆LBL "SV"	
02 "HZ?"	Enter Frequency in Hertz
03 PROMPT	
04 60	
05 /	f/60
06 STO 00	
07 15.93	A = $2\pi f(0.1404 \log_{10} 2)$ Micro-Ohms per Foot
08 *	
09 STO 04	
10 "S?"	Enter Spacing Between Center of Cables, Inches
11 PROMPT	
12 2	Enter Mean Radius of Shield, Inches
13 *	
14 "RM? DSM	
?"	
15 PROMPT	Xm = $2\pi f(0.1404 \log_{10} \frac{2S}{rm})$,Micro-Ohms per Foot
16 /	
17 LOG	
18 .1404	
19 *	Display Xm
20 376.992	
21 *	
22 RCL 00	Enter Ampacity of Cable
23 *	
24 STO 01	
25 "XM="	
26 XEQ "VW"	Select Cable Arrangement
27 "AMPS?"	
28 PROMPT	
29 STO 02	<u>One Phase</u> 
30 SF 27	
31 "SELECT	
A-E"	IXm
32 PROMPT	
33◆LBL A	Display Induced Shield Voltage-Shields Open Circuited
34 RCL 01	for Cables A and B in Micro Volts to Neutral Per Foot
35 RCL 02	
36 *	
37 "SV:A+B=	
"	Total Shield Loss-Shields Solidly Bonded
38 XEQ "VW"	in Watts per Foot
39 XEQ "TL"	
40 2	<u>Equilateral</u>  $2I^2Rs \frac{Xm^2}{Rs^2 + Xm^2}$
41 *	
42 "TL="	
43 XEQ "VW"	Shield Voltage Cables A + C
44 STOP	
45◆LBL B	
46 RCL 01	
47 RCL 02	
48 *	
49 "SV:A+C=	
"	Total Shield Loss
50 XEQ "VW"	$3I^2Rs \quad \frac{Xm^2}{Rs^2 + Xm^2}$
51 XEQ "IX"	
52 XEQ "TL"	
53 3	
54 *	
55 "TL="	

STEP / KEYCODE	COMMENTS	
56 XEQ "VW"		
57 STOP	<u>Rectangular</u>	
58◆LBL C		
59 RCL 04	Xm -	
60 2		
61 /		
62 STO 09	$Y = Xm + \frac{A}{2}$	
63 RCL 01		
64 +		
65 STO 11		
66 RCL 01		
67 RCL 04	$Z = Xm - \frac{A}{6}$	
68 6		
69 /		
70 -		
71 STO 10		
72 XEQ "PQ"		
73 XEQ "CB"		
74 XEQ "IX"		
75 XEQ "BC"	<u>Flat Spacing</u>	
76 STOP		
77◆LBL D	Xm -	
78 RCL 04		
79 STO 09		
80 RCL 01	$Y = Xm + A$	
81 RCL 04		
82 +		
83 STO 11		
84 RCL 01	$Z = Xm - \frac{A}{3}$	
85 RCL 04		
86 3		
87 /		
88 -		
89 STO 10		
90 XEQ "PQ"		
91 XEQ "CB"	<u>Two Circuit</u>	
92 XEQ "IX"		
93 XEQ "BC"	B	
94 STOP		
95◆LBL E	B/2	
96 36.99		
97 RCL 00	Xm -	
98 *		
99 2	$Y = Xm + A + \frac{B}{2}$	
100 /		
101 STO 09		
102 RCL 04		
103 RCL 09		
104 +		
105 RCL 01		
106 +		
107 STO 11	$Z = Xm + \frac{A}{3} - \frac{B}{6}$	
108 RCL 04		
109 3		
110 /		
111 RCL 09		
112 3		
113 /		
114 -		

STEP / KEYCODE	COMMENTS	
115 RCL 01		
116 +		
117 STO 10		
118 XEQ "PQ"		
119 XEQ "CB"		
120 RCL 01	$I(Xm + \frac{A}{2})$	
121 RCL 04		
122 2		
123 /		
124 +	Shield Voltage Cable B	
125 RCL 02		
126 *		
127 "SV:B="		
128 XEQ "VW"		
129 XEQ "BC"		
130 STOP		
131◆LBL "TL"	$I^2 Rs \frac{Xm^2}{Rs^2 + Xm^2}$	Enter Resistance of Shield in Micro-Ohms per FOOt
132 RCL 01		
133 X↑2		
134 "RS?"		
135 PROMPT		
136 STO 03		
137 X↑2		
138 RCL 01		
139 X↑2		
140 +		
141 /	Display Shield Loss of Cable, Micro Watts per Foot	
142 RCL 03		
143 *		
144 RCL 02		
145 X↑2		
146 *		
147 1 E6		
148 /		
149 "SL="	$P = \frac{Rs}{Y}$	
150 XEQ "VW"		
151 RTN	$Q = \frac{Rs}{Z}$	
152◆LBL "PQ"		
153 "RS?"		
154 PROMPT		
155 STO 03		
156 RCL 11		
157 /		
158 STO 05		
159 RCL 03	$\frac{I}{Z} \sqrt{3Y^2 + (Xm - n)^2}$	
160 RCL 10		
161 /		
162 STO 06		
163 RTN		
164◆LBL "CB"		
165 RCL 01	$n = \frac{A}{2}$ Rectangular	
166 RCL 09		
167 -		
168 X↑2	$n = A$ Flat	
169 RCL 11		
170 X↑2		
171 3	$n = \frac{B}{2}$ Two Circuit	
172 *		
173 +		

STEP / KEYCODE	COMMENTS
174 SQRT	
175 RCL 02	
176 2	
177 /	
178 *	Find Shield Loss-Shields Solidly Bonded
179 "SV:A+C= "	
180 XEQ "VW"	
181 RTN	
182♦LBL "BC"	$I^2 R_s \frac{(P^2 + 3Q^2) \pm 2\sqrt{3}(P - Q) + 4}{4(P^2 + 1)(Q^2 + 1)}$
183 RCL 05	
184 RCL 06	
185 -	
186 3.4641	
187 *	
188 4	
189 +	
190 STO 12	
191 RCL 05	
192 X↑2	
193 RCL 06	
194 X↑2	
195 3	
196 *	
197 +	
198 STO 07	
199 RCL 06	
200 X↑2	
201 1	
202 +	
203 RCL 05	
204 X↑2	
205 1	
206 +	
207 *	
208 STO 08	
209 4	
210 *	
211 STO 13	Display Negative Solution
212 RCL 07	
213 RCL 12	
214 +	
215 XEQ "LL"	$I^2 Rs \frac{1}{Q^2 + 1}$
216 RCL 07	
217 RCL 12	
218 -	
219 XEQ "LL"	
220 RCL 06	
221 X↑2	
222 1	
223 +	
224 1/X	Display Shield Loss Cable B
225 RCL 03	
226 *	
227 RCL 02	
228 X↑2	
229 *	
230 1 E6	

STEP / KEYCODE	COMMENTS
231 /	
232 "SL:B="	
233 XEQ "VW"	
234 RCL 05	
235 X↑2	
236 RCL 06	$3I^2R_s \dfrac{P^2 + Q^2 + 2}{2(P^2 + 1)\,(Q^2 + 1)}$
237 X↑2	
238 +	
239 2	
240 +	
241 RCL 08	
242 2	
243 *	
244 /	
245 RCL 03	Display Total Loss in Watts per Foot
246 *	
247 RCL 02	
248 X↑2	
249 *	
250 3	
251 *	
252 1 E6	
253 /	
254 "TL="	
255 XEQ "VW"	IXm
256 RTN	
257♦LBL "IX"	
258 RCL 01	
259 RCL 02	
260 *	
261 "SV:B="	Display Routine for SL : A + C
262 XEQ "VW"	
263 RTN	
264♦LBL "LL"	
265 RCL 13	
266 /	
267 RCL 03	
268 *	
269 RCL 02	
270 X↑2	
271 *	END
272 1 E6	
273 /	
274 "SL:A+C="	
275 XEQ "VW"	
276 RTN	
277 END	

STEP/KEY CODE | COMMENTS

DATA REGISTERS

00	f/60		
01	XM		
02	AMPS		
03	RS		
04	A		
05	P		
06	Q		
07	Program		
08	Program		
09	Xm -		
10	Z		
11	Y		
12	Program		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
27	C	User Mode On	User Off

STATUS

SIZE 013 TOT. REG. ____ USER MODE
ENG ____ FIX 0 SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
One Phase	A		
Equilaterial	B		
Rectangular	C		
Flat	D		
2 Circuit	E		

CABLE EMERGENCY OVERLOAD CAPABILITIES

Robert W. Parkin

FUNCTION: This program determines the current-temperature-time relationship of a cable when operated under overload-emergency conditions. Four separate program modules can be called:

PROGRAM	FUNCTION
TR	Temperature rise during time t (deg C)
TF	Total temperature rise
TM	Maximum permissible time overload
IO	Cable overload current rating

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: None

REFERENCES:

[1] Essex Underground Cable Handbook, 1971

[2] Electric Power Distribution System Engineering, Turan Gonen

[3] Aluminum Electrical Conductor Handbook, The Aluminum Association

EMERGENCY RATINGS

Maximum conductor operating temperature limits are based on maintaining insulation stability indefinitely, it is recognized that certain short periods of overloading are not only reasonably safe but inevitable in service.

Emergency overload ratings always specify both a temperature and duration limit, and a limit on the total number of emergency events. They are subject to revision as better thermal performance is developed for insulating materials and more reliable field data are obtained.

Emergency current ratings of cable may be used as a design basis in special cases, (such a case could be where a load occurring only on start-up would overload a main cable and transformer, but not breaker, of a secondary-selective substation operating single ended).

The table below gives cable emergency ratings of single circuits in percent of normal rating at 100% load factor for the same ambient temperatures for periods of overload not exceeding a total of 100 hours per year.

Cable Type	Voltage Rating	Tc	Te	Emergency Rating % Ambient Temperature °C 10	20	30	40	50
XLPE	600V	90	125	114	116	120	124	130
XLPE	15 kV	90	125	114	116	120	124	130
EPR (EPM or EPDM)	0-35kV	90	125	116	118	122	127	133
PVC	600V	75	87	107	108	110	114	119

Where:

Tc = Normal conductor temperature

Te = Emergency conductor temperature

The increase of a load current in a cable does not produce an immediate rise in the cable temperature to the overload temperature equilibrium level. It is possible to take advantage of this fact when a cable must be overloaded, for a limited, during an emergency.

The equations describing the current-temperature-time relationship are as follows:

$$T = Tf\,[\,1-e^{-(t/k)}\,]$$

Where:

T= temperature rise during time t (deg C)

Tf= Total temperature rise if emergency current is maintained indefinitely (deg C)

t= Overload duration (hours)

k= Thermal time constant (hours)

The total temperature rise, Tf, can be approximated by the following equation:

$$Tf = (Tc-Ta)\,(Io/Ic)^2$$

Where:

Tc= Rated normal conductor temperature (deg C)

Ta= Ambient temperature (deg C)

Io= Overload current in amperes

Ic= Rated normal conductor current to produce a temperature of Tc at 100% load factor with an ambient temperature of Ta.

The thermal time constant, k, is defined as the time required for the conductor to complete 63% of the total temperature rise, Tf. The constant depends on the two following parameters:

1) The thermal resistance between the conductor and the surrounding environment.

2) The thermal capacity of the cable and its surroundings.

Approximate values of k, for estimation, are given below.

Conductor Size **Single and Multi**	**In Air**	**Aerial Duct**	**Under-ground Duct**	**Direct Bury or Submarine**
Up to #2 AWG	.33	.67	1.00	1.25
#2 to #4/0 AWG	1.00	1.50	2.50	3.00
250 MCM and up	1.50	2.50	4.00	6.00

It is common to require the maximum permissible time overload [t], with all other parameters known:

$$t = k \log e \frac{Tf}{Tf - T}$$

In order to determine the overload current rating directly, the following approximation has been developed:

$$Io = Ic \quad \frac{(To-Ta) + B\,(To- Tc1)}{(Tc-Ta)}$$

Where:

Ic = Cable overload current rating in amperes

To = Maximum overload conductor temperature (deg C)

Tc1 = Conductor temperature at time overload is applied (deg C)

$$B = \frac{e^{-[t/k]}}{1-e^{-[t/k]}}$$

USER INSTRUCTIONS

Size:003

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "TR","VW"		
4.	Check status		
5.	Initialize: XEQ either "TR","TF", "TM", or "IO"		
	[XEQ "TR"]		
6.	Enter overload duration (hours)	T	T ?
7.	Enter thermal time constant (hours)	K	K ?
8.	Enter total temperture rise if emergency current is maintained indefinitely (deg C)	Tf	Tf ?
9.	Display temperature rise during time T (deg C)	-	TR =
5.	**[XEQ "TF"]**		
6.	Enter overload current (amperes)	IO	IO ?
7.	Enter rated normal conductor current to produce a temperature of Tc at 100% load factor with an ambient temperature, Ta	Ic	Ic ?
8.	Enter rated normal conductor temperature (deg. C)	Tc	Tc ?
9.	Enter ambient temperature (deg. C)	Ta	Ta ?
10.	Display total temperature rise	-	TF =

STEP	INSTRUCTIONS	INPUT	DISPLAY
5.	[XEQ "TM"]		
6.	Enter total temperature rise (deg.C)	TF	TF ?
7.	Enter temperature rise during time T (deg. C)	TR	TR ?
8.	Enter thermal time constant (hours)	K	K ?
9.	Display overload duration (hours)	-	T =
5.	[XEQ "IO"]		
6.	Enter overload duration in hours	T	T ?
7.	Enter thermal constant (hours)	K	K ?
8.	Display B	-	B =
9.	Enter maximum overload conductor temperature (deg. C)	To	TO ?
10.	Enter conductor temperature at time overload is applied (deg. C)	Tc 1	Tc 1?
11.	Enter ambient temperature (deg. C)	Ta	TA?
12.	Enter rated normal conductor temperature (deg. C)	Tc	TC ?
13.	Enter rated normal conductor current to produce a temperature of Tc at 100% load factor with ambient temperature of Ta	Ic	IC ?
14.	Display cable overload current rating in amperes		IO =

SAMPLE PROBLEM

```
            FIX 4
        XEQ "TR"
T?
     2.0000   RUN
K?
     1.3000   RUN
TF?
    15.0000   RUN
TR= 11.7793


        XEQ "TF"
IO?
    50.0000   RUN
Ic?
    40.0000   RUN
Tc?
   100.0000   RUN
TA?
    90.0000   RUN
TF= 15.6250


        XEQ "TM"
TF?
    15.0000   RUN
T?
     7.8000   RUN
K?
     1.3000   RUN
T= 0.9542


        XEQ "IO"
T?
     7.8000   RUN
K?
     1.3000   RUN
B= 0.0025
TO?
    90.0000   RUN
Tc1?
    80.0000   RUN
TA?
    60.0000   RUN
Tc?
    70.0000   RUN
Ic?
   100.0000   RUN
IO= 173.2768
```

STEP/KEY CODE — COMMENTS

Cable Emergency Overload

```
01♦LBL "TR"
02 "T?"              Enter T
03 PROMPT
04 "K?"
05 PROMPT
06 /
07 CHS
08 E↑X
09 1
10 X<>Y              T = Tf
11 -
12 "TF?"
13 PROMPT
14 *
15 "TR="
16 XEQ "VW"
17 STOP
18♦LBL "TF"
19 "IO?"
20 PROMPT
21 "Ic?"
22 PROMPT
23 /
24 X↑2
25 "Tc?"
26 PROMPT
27 "TA?"
28 PROMPT
29 -
30 *
31 "TF="
32 XEQ "VW"
33 STOP
34♦LBL "TM"
35 "TF?"
36 PROMPT
37 ENTER↑
38 "T?"
39 PROMPT
40 -
41 /
42 LN
43 "K?"
44 PROMPT
45 *
46 "T="
47 XEQ "VW"
48 STOP
49♦LBL "IO"
50 "T?"
51 PROMPT
52 "K?"
53 PROMPT
54 /
55 CHS
56 E↑X
57 STO 00
58 1
59 RCL 00
60 -
61 /
62 "B="
63 XEQ "VW"
64 "TO?"
65 PROMPT
66 STO 01
67 "Tc1?"
68 PROMPT
69 -
70 *
71 RCL 01
72 "TA?"
73 PROMPT
74 STO 02
75 -
76 +
77 "Tc?"
78 PROMPT
79 RCL 02
80 -
81 /
82 SQRT
83 "Ic?"
84 PROMPT
85 *
86 "IO="
87 XEQ "VW"
88 .END.
```

SHORT CIRCUIT RATINGS OF PHASE CONDUCTORS

Robert W. Parkin

FUNCTION: Program calculates either the maximum allowable short circuit current for, or the minimum cross-sectional area of, a cable passing fault current, given the cross-sectional area of a conductor in kcmil, or fault current in amperes to be withstood. Fault duration is entered in cycles per second and will double in value for each program loop, i.e., enter 8 cycles per second originally and the second calculation will be based on 16 cycles per second, etc. This determines the maximum time a cable may be subjected to a particular short circuit load without damage to the insulation.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: Program can be used for copper and aluminum phase conductors that have cross-linked polyethylene (XLPE) or ethylene propylene rubber (EPR) insulations rated 90 C at maximum operating temperature, and 250 C maximum short circuit temperature. Fault currents are assumed to be symmetrical amperes and deals only with the thermal effects of short circuit current; not the electromagnetic, or bursting effects. It is assumed that all heat created is stored in the conductor, and that short currents will not persist for longer than ten seconds.

The maximum fault current is based on the following assumptions:

1) All generators are connected, i.e., in service

2) The fault is a bolted one; i.e., the fault impedance is zero.

3) The load is maximum, i.e., on-peak load.

REFERENCES:

[1] ICEA Pub. No. P-32-382 Short Circuit Characteristics of Insulated Cables.
[2] Electric Power Distribution System Engineering, Turan Gonen
[3] Short Circuit Ratings of Cables, Ross D. Guppy

USER INSTRUCTIONS

Size: 007

Mode: [Conductor cross-section known]

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "SCP","VW","AE","CY"		
4.	Check status		
5.	Initialize: XEQ "SCP"		
6.	Enter cross-sectional area of conductor in kcmil or Enter zero if fault current is known.	kcmil	KCMIL?
7.	Select type of metal conductor 0 = Aluminum 1 = Copper	1 or 0	AL:0/CU:1
8.	Enter fault duration in cycles per second	cycle	CYCLES ?
9.	Display Fault duration in seconds		T:SEC =
10.	Total fault current displayed		AMPS =
11.	Display two times original fault duration (cycles) and re-calculate based on this value. Press R/S to continue loop if no printer attached.		CYCLES=

Mode: [Conductor cross-section not known]

STEP	INSTRUCTIONS	INPUT	DISPLAY
6.	Enter zero	0	KCMIL ?
7.	Enter fault current in amperes	Amp	AMPS?
8.	Select metal type: **0 = Aluminum** **1 = Copper**	0 or 1	AL:0/CU:1
9.	Enter duration in cycles per second	cycles	CYCLES?
10.	Display Fault duration in seconds		T SEC =
11.	Total Area in circular mils required for conductor		CMA =

SAMPLE PROBLEM

```
    XEQ "SCP"
KCMIL?
            350.    RUN
CMA=350,000.
AL:0 / CU:1
              0.    RUN
ALUMINUM
CYCLES?
              2.    RUN
CYCLES= 2.
T:SEC= 0.0333
AMPS= 90,182.

CYCLES= 4.
T:SEC= 0.0667
AMPS= 63,768.

CYCLES= 8.
T:SEC= 0.1333
AMPS= 45,091.

CYCLES= 16.
T:SEC= 0.2667
AMPS= 31,884.

CYCLES= 32.
T:SEC= 0.5333
AMPS= 22,545.

CYCLES= 64.
T:SEC= 1.0667
AMPS= 15,942.

CYCLES= 128.
T:SEC= 2.1333
AMPS= 11,273.

CYCLES= 256.
T:SEC= 4.2667
AMPS= 7,971.
```

```
    XEQ "SCP"
KCMIL?
              0.    RUN
AMPS?
         15,000.    RUN
AMPS? 15,000.
AL:0 / CU:1
              1.    RUN
CYCLES?
              2     RUN
CYCLES? 2
T:SEC= 0.0333
CMA= 38,052.
```

STEP/KEY CODE	COMMENTS	STEP/KEY CODE	COMMENTS

Short Circuit - Phase Conductor

```
01♦LBL "SCP
"
02 FIX 0
03 SF 29
04 CF 12
05 "KCMIL?"
06 PROMPT
```

Enter Conductor Cross - Section kcmil

```
07 X=0?
08 XEQ "AE"
09 1 E3
10 *
```

Enter Zero if Fault Current is Known

```
11 CF 12
12 "CMA="
13 ARCL X
14 AVIEW
15 STO 01
16 "AL:0 /
CU:1"
17 PROMPT
18 X=0?
19 GTO 00
20 "COPPER"
21 AVIEW
22 RCL 01
23 X↑2
24 .00518
25 *
26 STO 00
27 XEQ "YC"
```

$$I = \sqrt{\frac{0.00518 \times A^2}{t}}$$

Aluminum

$$I = \sqrt{\frac{0.002213 \times A^2}{t}}$$

```
28♦LBL 00
29 "ALUMINU
M"
30 AVIEW
31 RCL 01
32 X↑2
33 .002213
34 *
35 STO 00
36♦LBL "YC"
37 "CYCLES?
"
38 PROMPT
39 STO 02
```

Enter Fault Duration in Cycles per Second (60HZ)

```
40♦LBL 01
41 RCL 02
42 "CYCLES=
"
43 XEQ "VW"
44 60
45 /
46 FIX 4
47 "T:SEC="
48 XEQ "VW"
49 FIX 0
50 RCL 00
```

Fault Duration in Seconds

```
51 X<>Y
52 /
53 SQRT
54 "AMPS="
55 XEQ "VW"
56 RCL 02
57 2
58 *
59 STO 02
60 FS? 55
61 ADV
62 GTO 01
63 STOP
64 END
```

Fault Current

```
01♦LBL "AE"
02 "AMPS?"
03 PROMPT
04 XEQ "AV"
05 STO 00
06 "AL: 0 /
CU: 1"
07 PROMPT
08 X=0?
09 GTO 02
10 XEQ "CY"
11 .07197
12 GTO 03
13♦LBL 02
14 XEQ "CY"
15 .047043
16♦LBL 03
17 X<>Y
18 /
19 RCL 00
20 /
21 1/X
22 SF 29
23 "CMA="
24 XEQ "VW"
25 STOP
26 .END.
```

Finds Area Required

$$\frac{1}{A} = \frac{n/t}{I}$$

SHORT CIRCUIT RATINGS OF METALLIC SHIELDS

Robert W. Parkin

FUNCTION: This program calculates either the maximum allowable short circuit current for, or the minimum effective cross-sectional area required of a metallic shield carrying a short circuit current. The types of shields covered are:

A – Wires applied either helically, as a braid or serving, or longitudinally with corrugations

B – Helically applied tape, not overlapped

C – Helically applied flat tape, overlapped

D – Corrugated tape, longitudinally applied

The effective area of composite shields is the sum of the effective areas of the components,i.e., the effective area of a helically applied tape and concentric wires would be the sum of the areas. Program incorporates a loop function to re-enter different wire sizes so that the best arrangement and least amount of copper is used to carry the fault.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: Calculation method applies for cables that are:

1) Shielded or sheathed
2) Voltage ratings up to 69kV
3) Insulated with thermoplastic,XLPE,EPR,impregnated paper or varnished cloth.

It is assumed that all heat generated by the fault current will be effective in raising the temperature of the shield,i.e.; no heat will be dissipated into adjacent cable components. This assumption is accurate only for short fault durations. For faults re-established with automatic reclosing of circuit protective devices, a significant amount of heat may be dissipated because of the relatively long cooling periods involved, and therefore will yield conservative results for faults of longer time durations.

REFERENCES:

[1] ICEA Pub. No. P-45-482, Short Circuit Performance of Metallic Shields and Sheaths of Insulated Cable, second edition.

[2] EPRI EL-3014, Optimization of the Design of Metallic Shield-Concentric Conductors of Extruded Dielectric Cables Under Fault Conditions.

PROGRAM PARAMETERS AND NOMENCLATURE

With the increasing use of solid dielectric power cable on electric utility distribution systems with higher fault currents and multiple circuit breaker reclosures emphasizes the importance in determining the optimum metallic shield structure, its performance under fault conditions and its influence on the design and operating characteristics of the cable.

The temperature of the shield is limited to the material in contact with it. Upon conclusion of any program module, XEQ "TP" to enter a different maximum allowable shield transient temperature in degrees Celsius, T2,. or operating temperature T1. The original calculation uses 200 C as T2.

The maximum withstand temperature under short-circuit conditions for cables with extruded thermoplastic jackets, is highly dependent on jacket thickness over the metallic shield. This dependence is less pronounced in the case of cross-linked polyethylene jackets. Values of T2 are given below in degrees Celsius.

Cable Material in Contact with Shield	**T2**
Crosslinked (thermoset)	350
Thermoplastic	200
Impregnated Paper	200
Varnished Cloth	200

Program Nomenclature:

I = Short circuit current, amperes

A = Effective cross-sectional area of shield

t = Time of short circuit,seconds (program in cycles)

= Inferred temperature of zero resistance for shield at temperature T , microhm-cm

T2 = Maximum allowable shield transient temperature, C

T1 = Operating temperature of shield, C

There has been serious concern as to the capability of helically applied copper tape and conventional ICEA wire shields to handle the increasingly high fault currents that are normally experienced on a typical utility underground distribution system and on large industrial systems. This concern is based on considerations of circular mil area (5000 circular mils per inch of core diameter based on ICEA standards) in the case of wire shields and the fact that contact resistance at the tape overlap significantly increases the resistance and inductance of the helically applied copper tape shield. Where such shielded cables are installed with a separate neutral conductor, the influence of the neutral conductor and its spacing from the power cable in carrying high fault current has not been well established.

The effective area of helically applied overlapped tapes depends upon the degree of electrical contact resistance of the overlaps. Program "C" may be used to calculate the effective cross-sectional area of the shield for new cable. However, an increase in contact resistance may occur after cable installation; during service exposed to moisture and heat. Under these conditions the contact resistance may approach infinity, where program "B" could apply.

<u>Longitudinal Corrugated Tape Shield</u>

A Longitudinal Corrugated (LC) shield consists of corrugated copper tape longitudinally folded and overlapped over the extruded insulation shield. Material specifications should comply with ASTM standard B248. It was developed for use on solid dielectric power cable in the interest of eliminating the deficiencies and questionable performance characteristics of concentric neutral wires (shield losses) and the uneven restraint of helically applied copper tape shields (increase in contact resistance and possible tearing due to the high coefficient of expansion of XLPE under emergency operating conditions).

Type LC shield provides a permanently low resistance, low reactance, tubular metallic shield covering 100% of the cable core to insure distribution of fault current. It does not adhere to other cable components or itself at the overlap, and hence is capable of adjusting itself to the changing cable core diameter due to the expansion and contraction of the insulation structure under load cycling and particularly under emergency operating conditions. Under this action, unlike that of the helically applied copper tape shield, little if any resistance is exposed on expansion and contraction of the cable during load cycling. In caparison with wire and tape shields, type LC shield impedes the ingress of moisture into the insulation structure of the cable.

TAPE SHIELDS

The two formulas applicable for tape shields are used when:

1) Perfect interturn contact exits (a tubular current path)

or when

2) No interturn contact exists (a helical current path)

ICEA P-45-482 allows that new cable may have perfect contact resistance, but that contact resistance may increase after installation. This increase is caused by corrosion of the tape in wet and dirty environments. Wrinkling and separation of the shield tape during installation also causes an increase in contact resistance. At points of heavy resistance or total separation, the path of charging current changes from a tube to a helix. Resistance decreases the fault current capacity of the shield. The reality of these situations in tape shields is that contact resistance is unknown and may approach infinity.

The effective area of a shield increases as the overall diameter of the cable increases. It is impossible to determine the effective area of a tape shield where perfect contact no longer exists. Therefore during the lifetime of a cable's life, the actual effective shield area of a copper tape shield falls somewhere between perfect contact and that of no contact.

The selection of the type shield to carry fault currents must first be based on the magnitude of the fault current and the time interval between fault occurrence and breaker operation. Generally, the latter is a function of the former and can be provided by the breaker manufacture. Secondly, the type of shield selected should be adequate to carry nominal charging currents with a shielding system designed to carry fault currents if the circuit operation dictates. Most conventional shields are inadequate to carry faults without serious degradation to the cable, therefore a supplementary neutral is sometimes added, or the shielding system is within system capabilities. This program offers the user multi-shield design options to help select the most suitable shielding system incorporated within the cable.

USER INSTRUCTIONS

Size: 007

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "ST","VW",'AR"		
4.	Check status		
5.	Initialize: XEQ "ST"		
6.	Enter Fault Current in amperes or enter zero if fault is not known.	AMPS	AMPS ?
7.	Enter fault duration in cycles per second	cycles	CYCLES ?
8.	Display fault current in seconds		T: SEC =
9.	Enter system voltage in kilovolts	KV	KV ?
10.	Effective cross-sectional area required in circular mils (CMA)		CMA =
11.	Apparent power, MVA rating (for three phase circuit)		MVA =

STEP	INSTRUCTIONS	INPUT	DISPLAY
12.	Enter percent lap of copper tape shield, if applicable, or Enter zero if wires only are used without a tape shield.	% lap	% LAP ?
13.	Enter mean diameter of shield, mils	DM	DM ?
14.	Enter thickness of tape shield, mils	T	T:TAPE ?
15.	Display total effective cross-sectional area required in circular mils	-	A:TOT =
16.	Effective cross sectional area in circular mils of copper tape shield	-	A:TAPE =
17.	Display difference in CSA	-	A: DIFF =

NOTE: If positive, cable needs additional metallic cross - sectional area, and if negative, copper tape alone will carry fault.

STEP	INSTRUCTIONS	INPUT	DISPLAY
18.	Enter cross-sectional area of wire in circular mils	CSA	CMA: WIRE ?
19.	Display number of wires required to carry fault; without copper tape	-	NO. WIRES=
20.	Display number of wires required to carry fault; with copper tape	-	WITH TAPE =
21.	Program loop to step 18 to re-enter different wire size.		CMA: WIRE ?
22.	**Option:** can XEQ "TP" to determine fault current at higher shield or sheath operating or maximum temperatures; see last page.		

MODE: [FAULT NOT KNOWN]

STEP	INSTRUCTIONS	INPUT	DISPLAY
6.	Enter zero; if fault current is not known, to find maximum fault current.	0	AMPS ?
7.	Select type shield:	ABCD	Select:ABCD

Label	**Shield**
A	**Wires**
B	**Copper Tape (worst case)**
C	**Copper Tape (best tape)**
D	**LC Shield**

["A" - WIRES]		A	
8.	Enter number of wires	N	No. Wires ?
9.	Enter diameter of wires in mils	Dia.	DIA.MILS ?
10.	Display cross-sectional area required in circular mils	-	CMA =
11.	Enter system voltage in kV	kV	Kv?
12.	Enter fault duration in cycles per second	cycles	CYCLES?
13.	Display duration of fault in seconds	-	T:SEC=
14.	Display maximum fault current in amperes	-	AMPS=

STEP	INSTRUCTIONS	INPUT	DISPLAY
	["B" - COPPER TAPE , WORST CASE		
8.	Enter number of tapes	N	NO. TAPES?
9.	Enter width of tape, mils	W	W? MIL
10.	Enter thickness of tape, mils	T	T? MIL
11.	Display cross-sectional area required in circular mils	-	CMA =
12.	Enter kV; continue to step 11 in wire shield		
	["C" - COPPER TAPE SHIELD - BEST CASE]		
8.	Enter percent overlap of tape	%lap	% LAP?
9.	Enter mean diameter of shield, mils	Dm	DM?
10.	Enter tape thickness, mils	T	T: TAPE?
11.	Display effective CSA	-	CMA =
12.	Enter kV; continue to step 11 in wire shield		

STEP	INSTRUCTIONS	INPUT	DISPLAY
	["D" - LC SHIELD]		
8.	Enter minimum O.D. over insulation shield	O.D	MIN:O.D:EIS?
9.	Enter tape overlap, mils	lap	OVERLAP:MIL?
10.	Enter thickness of tape, mils	T	T?
11.	Display CSA required	-	CMA?
12.	Enter kV; continue to stepp 11 in wire shield		

MODE: [FAULT CURRENT AT MAXIMUM SHIELD OPERATING TEMPERATURE]

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	XEQ "TP" after concluding any one program		
2.	Enter maximum allowable shield or sheath temperature, T2, deg. C	T2	T2? MAX
3.	Enter operating shield temperature, T1, deg C	T1	T1? OP
4.	Display maximum fault current in amperes.	-	AMPS =

SAMPLE PROBLEM

XEQ "ST"

```
AMPS? 15,000.
CYCLES? 8
T:SEC= 0.1333
KV? 25
CMA:TOT= 86,940.
MVA= 650.
% LAP? 10
DM? 1560
T:TAPE? 5
A:TOT = 86940
A:TAPE= 23255
A:DIFF= 63685

CMA:WIRE? 812
NO.WIRES= 107.1
WITH TAPE= 78.4

CMA:WIRE? 1020
NO.WIRES= 85.2
WITH TAPE= 62.4

CMA:WIRE? 2580
NO.WIRES= 33.7
WITH TAPE= 24.7

CMA:WIRE? 4110
NO.WIRES= 21.2
WITH TAPE= 15.5

            XEQ "TP"
T2?: MAX
          350    RUN
T2?: MAX 350
T1?: OP
           90    RUN
T1?: OP 90
AMPS= 20860
```

```
                XEQ "ST"
AMPS?
                0.    RUN
AMPS? 0.
SELECT:A,B,C,D
                   XEQ A
NO. WIRES?
               16.    RUN
DIA? MILS
             64.1    RUN
CMA= 65,741.
KV?
               15.    RUN
KV? 15.
CYCLES?
                8    RUN
CYCLES? 8
T:SEC= 0.1333
AMPS= 11342

                XEQ "ST"
AMPS?
                0.    RUN
AMPS? 0.
SELECT:A,B,C,D
                   XEQ B
NO. TAPES?
                1.    RUN
W? MIL
           1,500.    RUN
T? MIL
                5.    RUN
CMA= 9,525.
KV?
               15.    RUN
KV? 15.
CYCLES?
                8    RUN
CYCLES? 8
T:SEC= 0.1333
AMPS= 1643
```

```
                XEQ "ST"
AMPS?
                0.    RUN
AMPS? 0.
SELECT:A,B,C,D
                   XEQ C
% LAP?
               10.    RUN
% LAP? 10.
DM?
           1,560.    RUN
DM? 1,560.
T:TAPE?
                5.    RUN
T:TAPE? 5.
CMA= 23,255.
KV?
               15.    RUN
KV? 15.
CYCLES?
                8    RUN
CYCLES? 8
T:SEC= 0.1333
AMPS= 4012

                XEQ "ST"
AMPS?
                0.    RUN
AMPS? 0.
SELECT:A,B,C,D
                   XEQ D
MIN:O.D:EIS?
           2,220.    RUN
MIN:O.D:EIS? 2,220
.
OVERLAP?:MIL?
             375.    RUN
OVERLAP?:MIL? 375.
T?
                8.    RUN
T? 8.
CMA= 76,265.
KV?
               15.    RUN
KV? 15.
CYCLES?
                8    RUN
CYCLES? 8
T:SEC= 0.1333
AMPS= 13158
```

Short Circuit Shields

STEP/KEY CODE	COMMENTS
01♦LBL "ST"	Initialize
02 CF 01	
03 SF 29	
04 FIX 0	
05 "AMPS?"	Enter Fault Current
06 PROMPT	
07 XEQ "VW"	Enter Zero if Not Known
08 X=0?	
09 XEQ "AR"	XEQ Area Program to Find Fault Current
10 STO 05	
11 STO 00	
12 XEQ "CY"	Cycle Module
13 FIX 0	
14 RCL 00	
15 *	
16 STO 00	
17 XEQ "VK"	VK Module Determine M Value
18 RCL 00	
19 X<>Y	
20 /	$A = \frac{\sqrt{t}}{M}$
21 FIX 0	
22 STO 06	
23 SF 29	
24 "CMA:TOT ="	Display CMA Required View Module
25 XEQ "VW"	
26 RCL 05	
27 RCL 01	
28 1 E3	Calculates MVA Rating
29 *	
30 1.7321	
31 *	
32 *	$MVA = \frac{E\sqrt{3} * I}{10^6}$
33 1 E6	
34 /	(3 Phase)
35 "MVA= "	
36 XEQ "VW"	
37♦LBL 02	
38 CF 29	
39 FIX 0	Calculate CMA For Tape Shield (if Present)
40 100	
41 "% LAP?"	
42 PROMPT	
43 XEQ "VW"	
44 X=0?	Enter Zero if No Tape
45 GTO 00	
46 -	
47 2	
48 *	$4\ bdm \sqrt{\frac{100}{2(100-L)}}$
49 100	
50 X<>Y	Full Contact Resistance

STEP/KEY CODE	COMMENTS
51 /	Enter d_m $\left(\frac{\text{Dia.Over} + \text{Dia. Under}}{2}\right)$
52 SQRT	
53 DM?	
54 PROMPT	
55 XEQ "VW"	View
56 *	
57 "T:TAPE? "	Enter Copper Tape Thickness in Mils
58 PROMPT	
59 XEQ "VW"	
60 *	
61 4	
62 *	
63 RCL 06	$A = \frac{I\sqrt{t}}{M}$
64 "A:TOT = "	
65 XEQ "VW"	Effective Cross-sectional Area
66 SF 01	
67 RCL Y	
68 "A:TAPE= "	CMA of Tape
69 XEQ "VW"	
70 RCL 06	
71 X<>Y	
72 -	
73 STO 02	Display Difference of CMA Required to CMA of Tape
74 "A:DIFF= "	
75 XEQ "VW"	
76 FS? 55	
77 ADV	
78♦LBL 00	
79 FIX 0	Enter CMA of Round Wire
80 "CMA:WIRE?"	
81 TONE 9	
82 PROMPT	If Zero Entered Returns to Shield Tape (Tape Shield Only)
83 X=0?	
84 GTO 02	
85 XEQ "VW"	
86 STO 03	
87 FIX 1	
88 RCL 06	
89 X<>Y	
90 /	
91 "NO.WIRES="	Number of Wires Required Displayed Without Tape and Then With Tape
92 XEQ "VW"	
93 FS? 01	
94 GTO 01	
95 GTO 00	
96♦LBL 01	
97 RCL 03	
98 RCL 02	
99 X<>Y	
100 /	

STEP/KEY CODE	COMMENTS
101 "WITH TAPE="	
102 XEQ "VW"	
103 FS? 55	
104 ADV	
105 GTO 00	Return to Enter
106 STOP	Different Wire
107 END	Size
	End

DATA REGISTERS

00	Calculated Result St. CMA		
01	Voltage -		
02	Difference CSA		
03	CMA Wire		
04	$\sqrt{t}$ - Seconds		
05	Fault Current		
06	Effective CSA		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
01	C	No Wire With Tape	Med-High kv
02	C	Above 35kv	Below 35kv
03	C	Solid Cdtr.	Strand Cdtr.
04	C	Copper	Aluminum
05	C	With Weights	Without Weights
12	C	Print Double Wide	Normal Print
21	C	Printer On/Off	Disables Printer
27	C	Turns On User Mode	Turns Off User Mode
29	C	Digit Group On	Digit Group Off
55	C	Printer Exists	No Printer

STATUS AUTO

SIZE 007 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
Wires	A		
CU Tape-Worst	B		
CU Tape-Best	C		
LC Shield	D		

STEP/KEY CODE	COMMENTS
01♦LBL "VW"	VIEW Module
02 CF 21	
03 FC? 55	
04 GTO 01	
05 SF 21	
06 ACA	
07 SF 12	Accumulate and
08 ACX	Printout if Printer
09 PRBUF	Attached, Alpha-
10 TONE 5	Display if No Printer
11 CF 12	
12 RTN	
13♦LBL 01	
14 ARCL X	
15 AVIEW	
16 TONE 5	
17 STOP	
18 RTN	
19♦LBL "VK"	Find M Module By KV
20 "KV?"	Rating
21 PROMPT	
22 XEQ "VW"	Voltage / M Value
23 STO 01	5-25kV / .063
24 25	35kV / .065
25 X<>Y	46kV / .065
26 X<=Y?	69kV / .066
27 GTO 01	
28 46	
29 RCL 01	
30 X<=Y?	
31 GTO 02	
32 69	
33 RCL 01	
34 X<=Y?	
35 GTO 03	
36♦LBL 01	
37 .063	
38 GTO 05	
39♦LBL 02	
40 .065	
41 GTO 05	
42♦LBL 03	
43 .066	
44♦LBL 05	
45 RTN	
46♦LBL "TP"	Module for Maximum
47 "T2?: MAX"	Shield Temperture
48 PROMPT	
49 XEQ "VW"	
50 234	

STEP/KEY CODE	COMMENTS
51 +	
52 "T1?: OP"	Operating Shield Temperture
53 PROMPT	
54 XEQ "VW"	
55 234	$I=\frac{A}{\sqrt{E}}\sqrt{.030\log_{10}\left[\frac{t_2+\lambda}{t_1+\lambda}\right]}$
56 +	
57 /	
58 LOG	
59 .030	
60 *	
61 SQRT	
62 RCL 06	
63 RCL 04	
64 /	
65 *	
66 FIX 0	Fault Current
67 "AMPS= "	
68 XEQ "VW"	
69 STOP	
70♦LBL "CY"	Cycle Module
71 CF 29	
72 "CYCLES?"	Enter Time in Cycles
73 PROMPT	
74 XEQ "VW"	
75 60	(60HZ)
76 /	
77 FIX 4	
78 "T:SEC="	Display Seconds
79 XEQ "VW"	
80 SQRT	$\sqrt{t}$
81 STO 04	
82 FIX 0	
83 RTN	
84♦LBL "AR"	Area Module
85 SF 27	
86 "SELECT: A,B,C,D"	A = Wires
87 PROMPT	B = CU Tape (Worst Case)
88♦LBL A	
89 CF 27	
90 "NO. WIRES?"	C = CU Tape (Best Case)
91 PROMPT	
92 "DIA? MILS"	D = LC Shield
93 PROMPT	
94 X↑2	nds^2
95 *	
96 GTO "CMA"	
97♦LBL B	CU Tape (Worst Case)
98 CF 27	
99 "NO. TAPES?"	Number of Tapes
100 PROMPT	

STEP/KEY CODE	COMMENTS
101 "W? MIL"	Width of Tape, Mils
102 PROMPT	
103 "T? MIL"	Thickness of Tape, Mils
104 PROMPT	
105 *	
106 *	1.27 nwb
107 1.27	
108 *	
109 GTO "CMA"	
110◆LBL C	CU Tape (Best Case)
111 FIX 0	
112 CF 27	
113 100	
114 "% LAP?"	
115 PROMPT	
116 XEQ "VW"	4bdm $\sqrt{\dfrac{100}{2(100-L)}}$
117 -	
118 2	
119 *	
120 100	
121 X<>Y	
122 /	
123 SQRT	
124 "DM?"	ENTER D_m
125 PROMPT	
126 XEQ "VW"	
127 *	
128 "T:TAPE?"	Thickness, Mils
129 PROMPT	
130 XEQ "VW"	
131 *	
132 4	
133 *	
134 GTO "CMA"	
135◆LBL D	LC Shield
136 CF 27	Min O.D. EIS, Mils
137 "MIN:O.D:EIS?"	
138 PROMPT	
139 XEQ "VW"	
140 50	
141 +	
142 PI	$1.27\left[\pi(d +50)+B\right]b$
143 *	
144 "OVERLAP?:MIL?"	
145 PROMPT	
146 XEQ "VW"	
147 +	
148 "T?"	Thickness, Mils
149 PROMPT	
150 XEQ "VW"	
151 *	
152 1.27	
153 *	
154◆LBL "CMA"	CMA Module
155 "CMA="	
156 XEQ "VW"	
157 STO 06	
158 XEQ "VK"	
159 RCL 06	
160 *	
161 STO 00	
162 XEQ "CY"	$I = \dfrac{MA}{\sqrt{t}}$
163 RCL 00	
164 X<>Y	
165 /	
166 "AMPS="	
167 XEQ "VW"	
168 STOP	
169 END	

POSITIVE AND ZERO SEQUENCE IMPEDANCES OF CABLES

Robert W. Parkin

FUNCTION: Program determines the positive sequence reactance and the mutual reactance between the central conductor and metallic shield or sheath , and calculates the zero sequence impedance of a single or multi-conductor cable, based on three theoretical installation conditions:

1) Return current in sheath and grounded in parallel

2) All return current in sheath, none in ground

3) All return current in ground, none in sheath

ACCESSORIES: HP-41 CX or HP-41CV, Hewlett Packard Math Pac module is required for multiplication and division of complex impedance operations, printer is optional.

OPERATING LIMITS AND WARNINGS: None

REFERENCES:

[1] Electrical Transmission and Distribution Reference Book, Westinghouse Electric Corporation, Pittsburgh, 1964.

[2] Wagner, C.F., and R.D. Evans, Symmetrical Components, McGraw-Hill Book Co. N.Y. 1933

[3] Rome Cable UD Technical Manual, Third edition, Rome N.Y 13440

[4] Clarke, Edith, Circuit Analysis of A-C Power Systems, Vol. I John Wiley and Sons N.Y. 1950

SEQUENCE IMPEDANCE OF UNDERGROUND CABLES

Many primary distribution circuits involve a mixture of both overhead conductor and underground cable. Fault calculations for such circuits require a knowledge of the sequence impedances of the underground, as well as the overhead, portion of the circuits. This program deals with the sequence impedances and currents of underground cables.

The type of Cable insulation (continuous full-load temperature rating), cable spacing, earth resistivity, size of neutral (full or reduced), or type metallic shield or sheath affect the impedance of cables in single phase and three phase circuits.

The Insulation thickness has only minor effect on cable impedances when changed from 100% to 133% insulation levels. However, going from a reduced neutral to a full size has a significant effect for both positive and zero sequence impedance components.

On an overhead circuit, the neutral conductor has negligible effect on the positive and negative sequence components. This is not true for URD concentric neutral cable. When positive sequence currents flow in the phase conductors of this type circuit, circulating currents are induced in the nearby concentric neutrals which modify the positive and negative sequence components of the circuit. As the neutral size is increased, the effect becomes greater. In general, this means both positive,negative and zero sequence components should be recalculated for situations calling for three phase cable with full size neutrals.

When zero-sequence current flows along the phase conductors of a three-phase cable circuit, it must return in either the ground, or the sheaths, or in the parallel combination of both ground and sheaths. As zero-sequence flows through each conductor it encounters the a-c resistance of that conductor, and as it returns in the ground or sheaths it encounter the resistance of those paths. The zero-sequence current flowing in any one phase encounters also the reactance arising from conductor self-inductance,from mutual inductance of the return paths. Each of these inductive effects cannot always be identified individually from the equations to be used for reactance calculations because the theory of the earth return circuits, and use of one GMR to represent a parallel conductor group, present in combined form some of the fundamental effects contributing to total zero-sequence reactance. the resistance and reactance effects are dealt with so closely they are best dealt with simultaneously.

Cable sheaths are frequently bonded and grounded at several points, which allows much of zero-sequence return current to flow in the sheath. On the other hand when any of the other various devices used to limit sheath current are employed, much or all of the return current flow in the earth. The method of bonding and grounding, therefore has an effect on the zero-sequence impedance of the cable.

EARTH RESISTIVITY

A common value for earth resistivity used in calculating the impedances is 100 ohm meters. Since there can be a wide variation of earth resistivity from one geographical area to another it is of interest to estimate its effect on impedance. A change in earth resistivity does not affect the positive sequence impedance, but does affect the zero sequence impedance. An increase or decrease in value of earth resistivity from 100 ohm meters by a factor of ten produces approximate change of two percent in the magnitude of zero sequence impedance Zo. For a given cable, a large change in earth resistivity has a relatively small effect on Zo and its components.

Thus, using a value of 100 ohm meters for earth resistivity should give impedances sufficiently accurate for most situations.

Below is a table with earth resistivity values and other program parameters.

Earth Resistivity (meter-ohm)	Equivalent Depth of Earth Return,De Inches	feet	Equivalent Earth Resistance, re (ohms per mile)	Equivalent Earth Reactance, Xe (ohms per mile)
1	3.36 x 10^3	280	0.286	2.05
5	7.44 x 10^4	620	0.286	2.34
10	1.06 x 10^4	880	0.286	2.47
50	2.40 x 10^4	2000	0.286	2.76
100	3.36 x 10^4	2800	0.286	2.89
500	7.44 x 10^4	6200	0.286	2.89
1000	1.06 x 10^5	8800	0.286	3.31
5000	2.40 x 10^5	20000	0.286	3.60
10000	3.36 x 10^5	28000	0.286	3.73

USER INSTRUCTIONS

Size: 016

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "ZO",Z3","VW"		
4.	Check status		
5.	Initialize: XEQ "ZO"		
6.	Enter frequency of circuit in hertz	HZ	HZ ?
7.	Enter a-c resistance of one conductor in ohms per 1000 feet	Rac	Rac ?
8.	Enter a-c resistance of Earth return in ohms per 1000 feet	Re	Re ?
9.	Enter distance to equivalent Earth return path in inches (see table)	De	De ?
10.	Enter Geometric Mean Distance amoung conductors centers, inches	GMD	GMD ?
11.	Enter Geometric Mean Radius of conductor, inches	GMR	GMR ?
12.	Enter outside radius of sheath, inches	Ro	RO ?
13.	Enter inside radius of sheath, inches	Ri	RI?
14.	Enter resistance of metallic shield or sheath in ohms per 1000 feet	Rs	RS?
15.	Display mutual reactance between conductor and shield/sheath	-	XM =

STEP	INSTRUCTIONS	INPUT	DISPLAY
16.	Display positive sequence reactance in ohms per 1000 feet	-	X1 =
17.	Select cable assembly:	1 or 3	1/C:1 / 3/C:3
	1 = Single conductors		
	3 = Three conductor assembly (with common sheath)		
18.	Display Impedance of conductors in terms of impedance to zero sequence currents, ohms per 1000 ft	-	ZC =
19.	Display the impedance of the sheath, considering the presence of the earth return path but ignoring the presence of the conductor group. Given in terms of impedance to zero sequence currents in ohms per 1000 feet.	-	ZS =
20.	Display the mutual impedance between conductors and sheath, considering the presence of the earth return path which is common to both sheath and conductors, in zero-sequence terms, ohms per 1000 feet.	-	ZM =

[Display Calculation parameters in Rectangular form]

21.	Mutual impedance above; squared	-	ZM^2
Note:	U = Real Component		U =
	V = Imaginary Component		V =
22.	ZM^2/ZS		ZM^2/ZS:
			U =
			V =

STEP	INSTRUCTIONS	INPUT	DISPLAY
23.	Display total zero sequence impedance when both ground and sheath path exist in ohms per phase per 1000 feet	-	ZO: T: U = V =
24.	Display total zero sequence impedance when current returns in sheath only, with none in ground, ohms per 1000 feet	-	ZO: S: U = V =
	[Total Zero Sequence Impedance]		
	ZO:G = (ZC - Zm) + Zm		
25.	Zc - Zm		U = V =
27.	Display total zero sequence impedance when current returns in the ground only, ohms per 1000 feet		U = V =

Note: **[<u>Three</u> <u>Conductor</u>]**

Instructions are in the same format. Flag 03 will be set and display will show 3/C, where applicable.

SAMPLE PROBLEM

```
     XEQ "ZO"
HZ?
 60.0000
         RUN
Rac?
 .1678119
         RUN
Re?
 .0541    RU
           N
De?
 33600.0000
         RUN
GMD?
 1.1250    R
          UN
GMR?
 .1538    RU
           N
RO?
 .4980    RU
           N
RI?
 .5630    RU
           N
RS?
 .4860    RU
           N
XM= 0.0173
X1= 0.0458
1/:C:1 / 3/C:3?
         1.0000    RUN
Zc=0.2219 J0.7562
                   RUN
ZS=0.5401 J0.7277
                   RUN
ZM=0.0541 J0.7277
                   RUN
ZM↑2:
U=-0.5266
V=0.0787
ZM↑2/ZS:
U=-0.2766
V=0.5184
ZO:T:
U=0.4985
V=0.2377
ZO:S:
U= 0.6538
V= 0.0285
ZO:G:
U=0.1678
V=0.0285
U=0.2219
V=0.7562
```

Positive and Zero Sequence Impedance of Single (1/c) and Three Conductor (3/c) Cable

01◆LBL "ZO"	Intialize Then Enter Data:
02 CF 03	Frequency in Hertz
03 FIX 4	
04 "HZ?"	
05 PROMPT	
06 60	
07 /	f /60
08 STO 14	
09 "Rac?"	AC Resistance of One Conductor in Ohms per 1000 Feet (MFT)
10 PROMPT	
11 STO 13	
12 "Re?"	AC Resistance of Earth Return in Ohms per MFT
13 PROMPT	
14 STO 04	
15 +	
16 STO 05	
17 "De?"	Distance to Equivalent Earth Return Path, in Inches
18 PROMPT	
19 STO 01	
20 "GMD?"	Geometric Mean Spacing of Conductors
21 PROMPT	
22 STO 02	
23 X↑2	
24 "GMR?"	Geometric Mean Radius
25 PROMPT	
26 STO 03	$GMR_{3c} = \sqrt[3]{(GMR_{1c})\ (GMD_{3c})^2}$
27 *	
28 3	
29 1/X	
30 Y↑X	
31 STO 11	
32 XEQ 00	
33 STO 06	
34 RCL 04	
35 "RO?"	Outside Radius of Sheath
36 PROMPT	$\frac{rotri}{2} = pd$
37 "RI?"	Inside Radius of Sheath
38 PROMPT	pd= Pitch Diameter
39 +	
40 STO 15	
41 2	Calculate GMR_{3s}(Conducting Path Made Up of the 3 Sheaths in Parallel)
42 /	
43 RCL 02	
44 X↑2	
45 *	
46 3	$\sqrt[3]{(\frac{rotri}{2})\ (GMD_{3c})^2}$
47 1/X	
48 Y↑X	
49 STO 10	
50 XEQ 00	

51 STO 07	
52 "RS?"	Resistance of Metallic Shield or Sheath in Ohms per MFT
53 PROMPT	
54 STO 12	
55 RCL 04	Calculate Mutual Reactance
56 +	
57 STO 08	
58 RCL 02	$Xm = 0.05292 \log_{10} \frac{GMD}{pd}$
61 RCL 15	
62 /	
63 LOG	
64 .05292	
65 *	
66 ENTER↑	Display Xm in Ohms per MFT
67 "XM="	
68 XEQ "VW"	
69 3	
70 Y↑X	
71 STO 09	
72 RCL Y	
73 X↑2	Calculate Positive Sequence Reactance
74 RCL 12	
75 X↑2	
76 -	$0.05292 \log_{10} \frac{GMD_{3c}}{GMR_{1c}} - \frac{Xm^3}{Xm^2 - r_s^2}$
77 RCL 09	
78 X<>Y	
79 /	
80 ENTER↑	
81 RCL 02	
82 RCL 03	
83 /	
84 LOG	
85 .05292	
86 *	
87 RCL Y	
88 -	
89 "X1="	Display Positive Sequence Reactance Ohms per MFT
90 XEQ "VW"	
91 "1/:C:1 / 3/C:3?"	Enter Cable Assembly 1/c: 1 = Single Conductors
92 PROMPT	
93 3	3/c: 3 = Three Conductor Assembly (With Common Sheath)
94 X=Y?	
95 XEQ "Z3"	
96 "Zc="	
97 ARCL 05	
98 "⊢ J"	
99 ARCL 06	Zc and Zc (3/c) $= r_{ac} + re + j\ 0.15875\ f/60 \log_{10} \frac{De}{GMR_{3c}}$
100 AVIEW	
101 STOP	

STEP/KEY CODE	
102 "ZS="	
103 ARCL 08	$Z_s = r_s + re + j\ 0.15875\ f/60\ \log_{10} \frac{De}{GMR_{3s}}$
104 "⊢ J"	
105 ARCL 07	
106 AVIEW	
107 STOP	$Z_s\ 3/c = 3rs + re + j\ 0.15875\ f/60\ \log_{10} \frac{2De}{r_o + r_i}$
108 "ZM="	
109 ARCL 04	
110 "⊢ J"	
111 ARCL 07	$Zm = re + j\ 0.15875\ f/60\ \log_{10} \frac{De}{GMD_{3c - 3s}}$
112 AVIEW	
113 STOP	
114 "ZM↑2:"	$Zm\ 3/c = re + j\ 0.15875\ f/60\ \log_{10} \frac{2De}{r_o + r_i}$
115 AVIEW	
116 RCL 07	Calculate:
117 RCL 04	$Zo = Zc - \frac{Z^2m}{Zs}$
118 2	
119 XROM "Z↑N"	
120 RCL X	Display Z^2m Rectangular form U = Real
121 RCL Z	V = Imaginary
122 RCL Y	
123 RCL 07	
124 RCL 08	
125 "ZM↑2/ZS:"	$\frac{Z^2m}{Zs}$
126 AVIEW	
127 XROM "C/"	
128 RCL X	
129 STO 02	
130 RCL Z	
131 STO 09	
132 RCL 06	$Zc - \frac{Z^2m}{Zs}$
133 RCL 05	
134 RCL 09	
135 RCL 02	
136 "ZO:T:"	Total Zero Sequence Impedance When Both Ground and
137 AVIEW	Sheath Paths Exist in Ohms per Phase / MFT
138 XROM "C-"	
139 FS? 03	Flag 03 Set? Then Z3 (3/c) Module Was Called GOTO 01
140 GTO 01	Analyze Different Theoretical Installation Conditions
141 "ZO:S:"	
142 AVIEW	
143 RCL 12	ZO:S = If Current Returns in Sheath Only With None
144 RCL 13	In Ground, Ohms per MFT
145 +	
146 "U="	
147 XEQ "VW"	$rc + rs + j\ 0.15875\ f/60\ \log_{10} \frac{GMR_{3s}}{GMR_{3c}}$
148 RCL 10	
149 RCL 11	
150 /	
151 LOG	
152 .15875	
153 *	
154 RCL 14	
155 *	
156 "V="	
157 XEQ "VW"	

158◆LBL 02	If Current Return in the Ground Only: (1/c) (3/c)
159 "ZO:G:"	
160 AVIEW	
161 RCL 06	ZO:G = (Zc - Zm) + Zm
162 RCL 05	
163 RCL 07	
164 RCL 04	
165 XROM "C-"	
166 RCL X	
167 STO 02	
168 RCL Z	
169 RCL 02	
170 RCL 07	
171 RCL 04	
172 XROM "C+"	
173◆LBL 00	
174 RCL 01	Routine Used in Most Calculations
175 X<>Y	
176 /	$.15875 \; f/60 \; \log_{10} \frac{De}{GMR_{3c}}$
177 LOG	
178 .15875	
179 *	
180 RCL 14	
181 *	
182 RTN	
183◆LBL 01	
184 "3/C ZO:S:"	3/c ZO:S = If Current Returns in Sheath Only With None in Ground (3/c):
185 AVIEW	
186 RCL 12	
187 3	
188 *	
189 RCL 13	
190 +	$rc + 3_{rs} + j \; 0.15875 \; f/60 \; \log_{10} \frac{r_0 + r_i}{2\,(gmr_{3c})}$
191 "U="	
192 XEQ "VW"	
193 RCL 15	
194 RCL 11	
195 2	
196 *	
197 /	
198 LOG	
199 RCL 14	
200 *	
201 .15875	
202 *	
203 "V="	
204 XEQ "VW"	
205 GTO 02	
206 END	End

STEP/KEY CODE	COMMENTS
01♦LBL "Z3"	3/c Module
02 SF 03	
03 RCL 12	
04 3	
05 *	
06 RCL 04	
07 +	Used to Calculate
08 STO 08	
09 RCL 01	Zs 3/c and Zm 3/c
10 2	
11 *	
12 RCL 15	
13 /	
14 LOG	
15 RCL 14	
16 *	
17 .15875	
18 *	
19 STO 07	
20 "3/C:"	
21 AVIEW	
22 RTN	
23 .END.	End

DATA REGISTERS

00	Math		
01	De		
02	GMD		
03	GMR		
04	re (Zm Real)		
05	Zc real		
6	Zc j		
7	Zs Zm j		
8	Zs real		
9	Zm^2		
10	GMR 3s		
11	GMR 3c		
12	Rs		
13	Rac		
14	Frequency /60		
15	ro + ri		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
03		3/c	1/c

STATUS

SIZE 016 TOT. REG. ____ USER MODE
ENG ____ FIX 4 SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
None			

DIRECT CURRENT SHIELD RESISTANCE

Robert W. Parkin

FUNCTION: This Program calculates the d-c resistance of various metallic shields and sheaths at 25 degrees Celsius or at any operating temperature desired.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: None

REFERENCES:

[1] IPCEA PUB. NO. P-53-426 (second edition), NEMA PUB. NO. WC 50-1976.

[2] The Calculation of the Temperature Rise and Load Capability of Cable Systems, J.H. Neher, M.H. McGrath, ibid., vol. 76, Oct. 1957.

BASIC DEFINITION

METALLIC SHIELD: any non-magnetic metallic structure applied over the semiconducting insulation shield for the purpose of controlling and confining the electrostatic field. It may also serve as the neutral conductor.

SHIELD RESISTANCE

When the metallic shields of single conductor cables are bonded and grounded at multiple points, cable ampacities may be significantly reduced by the resultant circulating current losses. This is particularly true of spaced single conductor cables in the larger conductor sizes with lower resistance shields.

Metallic shield resistance is calculated to help determine an accurate ampacity rating of cable. The circulating current losses affect ampacity, and is influenced by the resistance of the metallic shield. This program provides a multi-source means of determining the d-c resistance of metallic shields and sheaths.

Three important observations of shield resistance on ampacity are given below:

1) For the smaller conductor sizes the variation of ampacity with shield resistance is relatively small.

2) For the larger conductor sizes, the variation of ampacity with shield resistance is relatively large.

3) The variation in ampacity with shield resistance for a given conductor size is a function of the slope of the loss ratio curve. In particular, the variation in ampacity increases as the shield resistance decreases except near the peak of the loss ratio curve. In general, the variation is greater for spaced than for trefoil configurations.

Calculation of d-c shield resistance at 25 degrees Celsius is determined from the formulas given with program documentation; corresponding program labels are:

LABEL	TYPE SHIELD
[A]	Concentric and Longitudinal applied crimped wire shield
[B]	Helical Applied Tape Shield (Open gap or intercalated)
[C]	Helical Applied and Overlapped Tape Shield
[D]	Longitudinally Folded Corrugated Tape Shield
[E]	Lead Sheath
[F]	Aluminum Sheath (61% IACS)

Nomenclature:

Rs = D-c resistance in micro-ohms per foot at 25 ^{o} C.

Af = Increase in tape shield length due to corrugations. A typical value for various tape shield thicknesses is 1.20.

B = Tape overlap. A typical value is 0.375" or 0.250"

d = Diameter of wire shield in inches.

Dis= Diameter over insulation shield in inches.

Dsm= Mean diameter of metallic sheath or shield in inches.

K = Factor for the increase in resistance of a helically applied overlapped copper tape shield due to contact resistance at the tape overlaps. K is normally 1 on cable as manufactured. With handling during installation, K will increase. After the cable has been in service and exposed to moisture and heat, a further increase in contact resistance may occur, particularly on uncoated copper tapes, and the contact resistance may approach infinity. For purposes of ampacity calculation and to insure that the cable will not be overheated soon after installation, a K value of 2 is suggested for use in helically applied overlapped tape shields.

l = Length of lay of shielding tape in inches.

Lf = Lay factor is the increase in length of wires due to helical application.

n = Number of wires

t = Thickness, inches

w = Width, inches

ps = Electrical resistivity, ohms - circular mil/foot. The electrical resistivity of copper, aluminum, and lead are as follows:

Material	**Resistivity at 25 ^{o}C**
Uncoated annealed copper (100% IACS)	10.575
Coated annealed copper ribbons and tape (98% IACS)	10.787
Coated annealed copper wire: (under 0.103 to 0.020 incl.,97.16% IACS)	10.878
(Under 0.290 to 0.103 incl., 96.16% IACS)	10.989
Aluminum (61% IACS)	17.345
Lead (7.84% IACS)	134.884

USER INSTRUCTIONS

Size 003

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "DCR","VW"		
4.	Check status		
5.	Initialize: XEQ "DCR"		
6.	Enter electrical resistivity of of shield component in ohms-circular mil/foot	Ps	PS ?
7.	Select type of shield/sheath	A-F	Select A-F

Label	Type Shield
A	Wire Shield
B	Copper Tape
C	Copper Tape(new)
D	LC Shield
E	Lead
F	Aluminum

STEP	INSTRUCTIONS	INPUT	DISPLAY
8.	Concentric and longitudinally applied crimped wire shield	A	
9.	Enter lay as multiple of diameter	Lay	LAY ?

STEP	INSTRUCTIONS	INPUT	DISPLAY
10.	Enter wire diameter, inches	Dia.	DIA ?
11.	Enter number of wires	N	N ?
12.	Display D-C shield resistance in micro-ohms per foot at 25 deg C	-	RS=
13.	D-C Resistance per kilometer		/KM
14.	Enter operating temperture degrees Celcius	T2	T2?
15.	D-C Shield resistance per foot @ T2	-	RS=
16.	D-C Resistance per kilometer (loop repeats for different T2 operating temperatures)		/KM
8.	**Helically applied tape shield - Open gap, butted or intercalated** (essentially infinite contact resistance)	**B**	**Select A-F**
9.	Enter mean diameter of metallic sheath or shield in inches	DSM	DSM ?
10.	Enter length of lay of shielding tape in inches	L	L ?
11.	Enter tape thickness in inches	T	T ?

STEP	INSTRUCTIONS	INPUT	DISPLAY
12.	Enter tape width inches	W	W ?
13.	Shield resistance displayed		RS =
14.	Same T2 loop		
8.	Helically applied and overlapped tape shield	C	Select A-F
9.	Enter factor for increase in resistance due to contact resistance at tape overlaps **1 = New Cable** **2 = Installed, aged**	K	K ?
10.	Enter mean diameter of shield, inches	DSM	DSM
11.	Enter tape thickness, inches	T	T ?
12.	Shield resistance displayed		RS=
13.	Same T2 loop		
8.	**Longitudinally folded corrugated tape shield**	**D**	**Select A-F**
9.	Enter increase in tape shield length due to corrugations. (typical value 1.20)	AF	AF ?

STEP	INSTRUCTIONS	INPUT	DISPLAY
10.	Enter diameter over insulation shield, inches	DIS	DIS ?
11.	Enter tape overlap, inches (typical value .250 - .375)	B	B ?
12.	Enter Tape thickness, inches	T	T ?
13.	Shield resistance displayed		RS =
14.	Same T2 loop		
8.	**Lead Sheath or Aluminum Sheath (61% IACS)**	**E or F**	**Select A-F**
9.	Enter mean diameter of sheath, inches	DSM	DSM ?
10.	Enter thickness, inches	T	T ?
11.	Shield resistance displayed		RS =
12.	Same T2 loop		

SAMPLE PROBLEM

```
   XEQ "DCR"
PS?
 10.7500
          RUN
SELECT: A-F
       XEQ A
LAY?
 9.0000    R
          UN
DIA?
 .0641     RU
           N
N?
 16.0000
          RUN
RS= 173.1965
/KM= 0.5683
T2?
      75.0000   RUN
RS= 206.5678
/KM= 0.6777
T2?
      80.0000   RUN
RS= 250.3490
/KM= 0.8214
T2?
```

```
               XEQ B
DSM?
       1.4200   RUN
L?
       6.0000   RUN
T?
        .0050   RUN
W?
       5.6000   RUN
RS= 375.7501
/KM= 1.2328
T2?
      50.0000   RUN
RS= 411.9496
/KM= 1.3516
T2?
```

```
               XEQ C
K?
       2.0000   RUN
DSM?
       1.4200   RUN
T?
        .0050   RUN
RS= 757.0423
/KM= 2.4839
T2?
```

```
               XEQ D
AF?
       1.2000   RUN
DIS?
       1.5600   RUN
B?
        .3750   RUN
T?
        .0100   RUN
RS= 186.5196
/KM= 0.6120
T2?
```

```
               XEQ E
DSM?
       1.6300   RUN
T?
        .0800   RUN
RS= 258.4356
/KM= 0.8479
T2?
```

DC Shield Resistance

STEP/KEY CODE	
01♦LBL "DCR"	
02 FIX 4	
03 234.5	Inferred Zero Resistance Temperture for Copper(λ)
04 STO 02	
05 "PS?"	Enter Electrical Resistivity in Ohms-Circular mil/foot
06 PROMPT	
07 STO 01	
08 SF 27	User Mode On
09 "SELECT: A-F"	Select Type Shield A,B,C,D,E,F
10 PROMPT	
11♦LBL A	A = Concentric and Longitudinally Applied Wire Shield
12 PI	
13 "LAY?"	Enter Lay as Multiple of the Diameter Over Wires
14 PROMPT	
15 /	$SF = \dfrac{1}{\cos \tan^{-1} \pi/\mathrm{lay}}$
16 ATAN	
17 COS	
18 1/X	
19 RCL 01	
20 *	
21 "DIA?"	Enter: Wire Diameter $\quad Rs = \dfrac{Ps\ Lf}{n\ d^2}$
22 PROMPT	
23 X↑2	
24 "N?"	Number of Wires
25 PROMPT	
26 *	
27 /	
28 GTO 00	
29♦LBL B	B = Helically Applied Tape Shield (∞ Contact Resistance)
30 "DSM?"	Enter Mean Diameter of Metallic Sheath or Shield in Inches
31 PROMPT	
32 PI	
33 *	
34 "L?"	Length of Lay of Shielding Tape in Inches
35 PROMPT	
36 /	
37 X↑2	$Rs = \dfrac{\pi Ps}{4wt}\sqrt{1 + \left(\dfrac{\pi\ Dsm}{L}\right)^2}$
38 1	
39 +	
40 SQRT	
41 STO 00	
42 RCL 01	
43 PI	
44 *	
45 "T?"	Thickness, Inches
46 PROMPT	
47 "W?"	Width, Inches
48 PROMPT	
49 *	
50 4	

STEP/KEY CODE	
51 *	
52 /	
53 RCL 00	
54 *	
55 GTO 00	
56◆LBL C	C = Helically Applied and Overlapped Tape Shield
57 "K?"	Enter: Factor for Increase in Resistance
58 PROMPT	1 = New Cable
59 RCL 01	2 = Installed, Used
60 *	
61 "DSM?"	Mean Diameter of Metallic Sheath or Shield in Inches
62 PROMPT	
63 "T?"	Thickness Inches
64 PROMPT	
65 *	$Rs = \frac{PsK}{4\ Dsm \cdot t}$
66 4	
67 *	
68 /	
69 GTO 00	
70◆LBL D	D = Longitudinally Folded Corrugated Tape Shield
71 "AF?"	Enter: Increase in Tape Shield Length Due to
72 PROMPT	Corrugations (Typical Value 1.20)
73 RCL 01	
74 *	
75 STO 00	
76 "DIS?"	Diameter Over Insulation Shield in Inches
77 PROMPT	
78 .05	
79 +	
80 PI	
81 *	
82 "B?"	Tape Overlap. Typical Value is 0.375 or 0.250 Inches
83 PROMPT	
84 +	
85 1.273	
86 *	Thickness, Inches
87 "T?"	
88 PROMPT	$Rs = \frac{Ps\ Af}{1.273\ [\pi (D_{is} + .05) + B]\ t}$
89 *	
90 RCL 00	
91 X<>Y	
92 /	
93 GTO 00	
94◆LBL E	E = Lead Sheath
95 236	
96 STO 02	
97 33.7	
98 "DSM?"	Mean Diameter of Lead Sheath in Inches
99 PROMPT	
100 "T?"	Thickness, Inches

STEP/KEY CODE	COMMENTS
101 PROMPT	Rs = $\frac{33.7}{Dsmt}$
102 *	
103 /	
104 GTO 00	
105◆LBL F	F = Aluminum Sheath
106 228.1	(61% IACS)
107 STO 02	
108 4.34	
109 "DSM?"	Mean Diameter of
110 PROMPT	Sheath in Inches
111 "T?"	Thickness, Inches
112 PROMPT	
113 *	Rs = $\frac{4.34}{Dsmt}$
114 /	
115◆LBL 00	
116 "RS="	Display Rs
117 XEQ "VW"	
118 STO 00	Dc Resistance in
119 .003281	Micrchms/Foot@25 C
120 *	
121 "/KM="	Same/Kilometer
122 XEQ "VW"	
123 "T2?"	Enter Operating
124 PROMPT	Temperture T2
125 RCL 02	
126 +	
127 RCL 02	Return Loop
128 25	
129 +	
130 /	
131 RCL 00	
132 *	
133 GTO 00	
134 END	End

DATA REGISTERS

00	Program		
01	PS		
02	λ		

STATUS

SIZE 003 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
Wire Shield	A		
CU Tape	B		
Cu Tape New	C		
LC Shield	D		
Lead	E		
Aluminum	F		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

A-C RESISTANCE OF CONDUCTORS

Robert W. Parkin

FUNCTION: This program determines the a-c resistance of conductors including skin and proximity effects.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: Largest conductor size up to 1500 kcmil.

REFERENCES:

[1] Underground Systems Reference Book, Edison Electric Institute.

[2] Anaconda Wire and Cable Handbook, Cablec Corporation

[3] ICEA S-66-524 NEMA Pub. No. WC-7

[4] National Bureau of Standards, Bulletin 169

A-C RESISTANCE

A conductor offers a greater resistance to the flow of alternating current than it does to direct current. The magnitude of the increase usually is expressed as an "ac/dc ratio". This ratio of a-c resistance to d-c resistance is almost unity for small conductors but increases proportionally with conductor size and conductivity.

The reasons for the a-c resistance increase is primarily due to skin effect which results in a decrease of current density toward the center of a cylindrical conductor (the current tends to crowd the surface to the surface).

A longitudinal element of the conductor near center is surrounded by more magnetic lines of force than is an element near the rim, hence the induced counter emf is greater in the center element. The net driving emf at the center is thus reduced with consequent reduction of current density.

For close spacings such as multi-conductor cables or several cables in the same conduit, there will be an additional apparent resistance due to proximity effect,the distortion of current distribution due to the magnetic effects of other nearby currents; hysteresis and eddy current losses in nearby ferromagnetic materials and induced losses in short circuited nearby non-ferromagnetic materials.

<u>SKIN EFFECT</u>

For isolated tubular conductors ranging from solid round wire to an infinitely thin tube the curves of Ewan [1] customarily are used. The skin effect ratio is shown in terms of the frequency in hertz, the conductor dimensions, inches, and the d-c resistance, ohms per 1000 feet.

For copper (and other non-magnetic materials), a parameter is given by:

$$x = 0.027678 \sqrt{f/Ro}$$

Where:

f = Frequency in hertz

Ro = Conductor d-c resistance at operating temperature, ohms per 1000 feet

The table on the following page is reproduced from the National Bulletin 169, and gives factors for skin effect ratio R/Ro as a function of x, where Ro is the d-c (zero frequency) resistance and R is the a-c resistance.

The nonuniform cross-sectional distribution of current also affects the inductance. The inductance is less than if the current density were uniform. The table of skin effect ratios therefore lists the inductance ratio L/Lo, where Lo is the inductance assuming uniform current density and L is the inductance due to a nonuniform current density.

The above formulae are independent of the number of strands for conductors up to about 1,500,000 circular mils. For larger conductors, other methods must be used for great accuracy.

PROXIMITY EFFECT

The flux linking a conductor (current) due to nearby current distorts the cross-sectional current distribution in the conductor in the same way as the flux from the current in the conductor itself. The latter effect is skin effect and has been discussed, the former is called proximity effect. The two effects are seldom separable in cable work and the combined effects are not directly cumulative.

The result of proximity effect in 3 - conductor cables ordinarily is to reduce slightly the effect of skin effect alone.

The further effect of proximity effect may be approximately calculated by:

$$\text{1- phase } fp = 4\left(\frac{GMR}{GMD}\right)^2 \left(\frac{R}{Ro} - 1\right)$$

$$\text{3- phase } fp = 6\left(\frac{GMR}{GMD}\right)^2 \left(\frac{R}{Ro} - 1\right)$$

Where:

R/Ro = the skin effect ratio

GMR = GMR of conductors

GMD = GMD of conductors

fp = the factor to account for proximity effect

Then the resistance of a conductor considering only skin effect and proximity effect is:

$$r = Ro \left(\frac{R}{Ro} + fp \right)$$

INTER-STRAND RESISTANCE

The effect of inter-strand resistance is of additional significance with regard to a-c resistance. If the current is (or can be) confined to the individual strands, skin effect will materially be reduced below that for an effectively solid conductor. The difference may be two percent or more.

TABLE III—RESISTANCE AND REACTANCE RATIO DUE TO SKIN EFFECT

x	R/R_o	L/L_o	x	R/R_o	L/L_o	x	R/R_o	L/L_o	x	R/R_o	L/L_o
0.0	1.00000	1.00000	2.9	1.28644	0.86012	6.6	2.60313	0.42389	17.0	6.26817	0.16614
0.1	1.00000	1.00000	3.0	1.31809	0.84517	6.8	2.67312	0.41171	18.0	6.62129	0.15694
0.2	1.00001	1.00000	3.1	1.35102	0.82975	7.0	2.74319	0.40021	19.0	6.97446	0.14870
0.3	1.00004	0.99998	3.2	1.38504	0.81397	7.2	2.81334	0.38933	20.0	7.32767	0.14128
0.4	1.00013	0.99993	3.3	1.41999	0.79794	7.4	2.88355	0.37902	21.0	7.68091	0.13456
0.5	1.00032	0.99984	3.4	1.45570	0.78175	7.6	2.95380	0.36923	22.0	8.03418	0.12846
0.6	1.00067	0.99966	3.5	1.49202	0.76550	7.8	3.02411	0.35992	23.0	8.38748	0.12288
0.7	1.00124	0.99937	3.6	1.52879	0.74929	8.0	3.09445	0.35107	24.0	8.74079	0.11777
0.8	1.00212	0.99894	3.7	1.56587	0.73320	8.2	3.16480	0.34263	25.0	9.09412	0.11307
0.9	1.00340	0.99830	3.8	1.60314	0.71729	8.4	3.23518	0.33460	26.0	9.44748	0.10872
1.0	1.00519	0.99741	3.9	1.64051	0.70165	8.6	3.30557	0.32692	28.0	10.15422	0.10096
1.1	1.00758	0.99621	4.0	1.67787	0.68632	8.8	3.37597	0.31958	30.0	10.86101	0.09424
1.2	1.01071	0.99465	4.1	1.71516	0.67135	9.0	3.44638	0.31257	32.0	11.56785	0.08835
1.3	1.01470	0.99266	4.2	1.75233	0.65677	9.2	3.51680	0.30585	34.0	12.27471	0.08316
1.4	1.01969	0.99017	4.3	1.78933	0.64262	9.4	3.58723	0.29941	36.0	12.98160	0.07854
1.5	1.02582	0.98711	4.4	1.82614	0.62890	9.6	3.65766	0.29324	38.0	13.68852	0.07441
1.6	1.03323	0.98342	4.5	1.86275	0.61563	9.8	3.72812	0.28731	40.0	14.39545	0.07069
1.7	1.04205	0.97904	4.6	1.89914	0.60281	10.0	3.79857	0.28162	42.0	15.10240	0.06733
1.8	1.05240	0.97390	4.7	1.93533	0.59044	10.5	3.97477	0.26832	44.0	15.80936	0.06427
1.9	1.06440	0.96795	4.8	1.97131	0.57852	11.0	4.15100	0.25622	46.0	16.51634	0.06148
2.0	1.07816	0.96113	4.9	2.00710	0.56703	11.5	4.32727	0.24516	48.0	17.22333	0.05892
2.1	1.09375	0.95343	5.0	2.04272	0.55597	12.0	4.50358	0.23501	50.0	17.93032	0.05656
2.2	1.11126	0.94482	5.2	2.11353	0.53506	12.5	4.67993	0.22567	60.0	21.46541	0.04713
2.3	1.13069	0.93527	5.4	2.18389	0.51566	13.0	4.85631	0.21703	70.0	25.00063	0.04040
2.4	1.15207	0.92482	5.6	2.25393	0.49764	13.5	5.03272	0.20903	80.0	28.53593	0.03535
2.5	1.17538	0.91347	5.8	2.32380	0.48086	14.0	5.20915	0.20160	90.0	32.07127	0.03142
2.6	1.20056	0.90126	6.0	2.39359	0.46521	14.5	5.38560	0.19468	100.0	35.60666	0.02828
2.7	1.22753	0.88825	6.2	2.46338	0.45056	15.0	5.56208	0.18822	∞	∞	0
2.8	1.25620	0.87451	6.4	2.53321	0.43682	16.0	5.91509	0.17649			

R/R_o = Resistance ratio due to skin effect.
L/L_o = Inductance ratio due to skin effect.
R = A-C resistance.
L = Inductance for nonuniform current density.
L_o = Inductance for uniform current density.
R_o = D-C (zero-frequency) resistance.
f = Frequency, cycles per second.
Reproduced from *National Bureau of Standards*, Bulletin 169.

USER INSTRUCTIONS

Size: 004

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "AC" "VW"		
4.	Check status		
5.	Initialize: XEQ "AC"		
6.	Enter DC resistance of conductor at 25 degrees C	Rdc	R: dc?
7.	Select type metal: **1 = Aluminum** **0 = Copper**		AL:1/CU:0
8.	Enter operating temperature in degreess celsius	T2	T2?
9.	Display D-C resistance at operating temperture	-	R2: dc =
10.	Enter frequency in Hertz	f	HZ ?
11.	Skin effect ratio, X	-	X =

TEP	INSTRUCTIONS	INPUT	DISPLAY
12.	Enter higher R/Ro (function of X)	High	R/RO: High
13.	Enter lower R/Ro	Low	R/Ro: Low
14.	Display actual R/Ro	-	R/RO =
15.	Enter GMR of conductor	GMR	GMR ?
16.	Enter GMD	GMD	GMD ?
17.	Select type circuit: **Single phase = 1** **Three phase = 3**	1 or 3	PH: 1/3 ?
18.	A-c resistance of conductor considering skin and proximity effects in ohms per 1000 feet		R: ac =
19.	A-c resistance above in ohms per kilometer		/KM =

NOTE: R/Ro = Resistance ratio due to skin effect

STEP/KEY CODE	COMMENTS
01◆LBL "AC"	AC Resistance of a Conductor Considering Skin and
02 FIX 4	Proximity Effects
03 "R:dc?"	
04 PROMPT	Enter D-C Resistance of Conductor at 25°C
05 STO 00	
06 "AL:1 / CU:0"	Select: 1 = Aluminum 0 = Copper
07 PROMPT	
08 X=0?	
09 GTO 00	
10 "T2?"	Enter Operating Temperature in Degrees C
11 PROMPT	Calculate Temperature Conversion:
12 228.1	
13 +	<u>For Aluminum</u>:
14 253.1	
15 GTO 04	$R_2 = R_1 \left(\frac{228.1 + T_2}{228.1 + T_1}\right)$
16◆LBL 00	
17 "T2?"	
18 PROMPT	<u>For Copper</u>:
19 234.5	
20 +	$R_2 = R_1 \left(\frac{234.5 + T_2}{234.5 + T_1}\right)$
21 259.5	
22◆LBL 04	
23 /	
24 RCL 00	
25 *	
26 "R2:dc="	Display Dc Resistance at Operating Temperature
27 XEQ "VW"	
28 STO 00	
29 "HZ?"	Enter Frequency in Hertz
30 PROMPT	
31 RCL 00	Calculate Skin Effect Ratio
32 /	
33 SQRT	$X = 0.027678 \sqrt{f/R_o}$
34 .027678	
35 *	
36 "X="	Display x Parameter
37 XEQ "VW"	
38 FRC	
39 10	Input Higher and Lower R/R_o Value for Interpolation (see table)
40 *	
41 FRC	
42 10	
43 *	
44 STO 02	
45 "R/RO: HIGH?"	Enter Higher R/Ro (By X)
46 PROMPT	
47 "R/RO: LOW?"	Enter Lower R/Ro (By X)
48 PROMPT	
49 STO 01	Take Difference and Interpolate
50 -	
51 10	
52 /	
53 RCL 02	
54 *	

STEP/KEY CODE	COMMENTS
55 RCL 01	
56 +	
57 FIX 5	
58 "R/RO="	Display Actual R/Ro
59 XEQ "VW"	
60 RCL 00	
61 *	
62 STO 01	Calculate Proximity Effect
63 "GMR?"	Enter Geometric Mean Radius
64 PROMPT	
65 "GMD?"	Enter Geometric Mean Spacing of the Conductors
66 PROMPT	
67 /	
68 X↑2	
69 RCL 01	$\left(\frac{GMR}{GMD}\right)^2$ (R/Ro -1)
70 RCL 00	
71 /	
72 1	
73 -	
74 *	
75 STO 02	
76 "PH: 1 / 3?"	Select Circuit: 1 = Single Phase
77 PROMPT	3 = Three Phase
78 3	
79 X=Y?	<u>1 - Phase</u> $f_p = 4 \left(\frac{GMR}{GMD}\right)^2$ (R/Ro - 1)
80 GTO 02	
81 RCL 02	
82 6	<u>3 - Phase</u> $f_p = 6 \left(\frac{GMR}{GMD}\right)^2$ (R/Ro - 1)
83 *	
84 STO 03	
85 GTO 03	rac = Ro (R/Ro + f_p)
86◆LBL 02	
87 RCL 02	
88 4	
89 *	
90 STO 03	
91◆LBL 03	
92 RCL 01	
93 RCL 00	
94 /	
95 RCL 03	
96 +	Resistance of Conductor Considering Skin Effect
97 RCL 00	and Proximity Effect
98 *	
99 "R:ac="	
100 XEQ "VW"	rac in Ohms per MFT and in Ohms per Kilometer
101 3.281	
102 *	
103 "/KM="	
104 XEQ "VW"	
105 END	

f_p = Factor to Account for Proximity Effect
Ro = Conductor d-c Resistance at Operating Temperature

R/Ro = Resistance Ratio Due to Skin Effect

SAMPLE PROBLEM

```
      XEQ "AC"
R:dc?
 .1680      RU
             N
AL:1 / CU:0
 1.0000      R
            UN
T2?
 20.0000
           RUN
R2:dc= 0.164
7
HZ?
        60.0000    RUN
X= 0.5283
R/RO: HIGH?
         1.0067    RUN
R/RO: LOW?
        1.00320    RUN
R/RO= 1.00419
GMR?

       .127286    RUN
GMD?
       1.36000    RUN
PH: 1 / 3?
       3.00000    RUN
R:ac= 0.16540
/KM= 0.54266
```

DATA REGISTERS

00	DC Resistance		
01	R/RO Low		
02	Interpolate		
03	Proximity Factor		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

STATUS

SIZE 004 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
None			

VOLTAGE REGULATION AND VOLTAGE DROP

Robert W. Parkin

FUNCTION: This program determines the percent voltage drop of a line (e.g., a feeder) with respect to the receiving end voltage, and the difference between the sending end and the receiving end voltage of a section of cable.

ACCESSORIES: HP-41 CX, or HP-41 CV, printer optional.

OPERATING LIMITS AND WARNINGS: Values given apply directly for single phase lines when resistance and reactance are loop values and voltage is voltage between the lines. For three phase circuits, use the voltage to neutral and the resistance and reactance of each conductor to neutral. To obtain voltage drop line-to-line , multiply voltage drop by $\sqrt{3}$. The percent voltage drop is the same between conductors as from conductor to ground, and should not be multiplied by $\sqrt{3}$.

REFERENCES:

[1] Electric Power Distribution Engineering, Turan Gonen.
[2] Anaconda Wire and Cable Engineering Handbook,Cablec Corp
[3] Standard Handbook for Electrical Engineers, Fink and Beaty.
[4] Voltage Regulation of Cables Used for Low-Voltage A-C Distribution, H.R. Searing and E.R. Thomas - AIEE Transactions, Vol. 52.
[5] Voltage Ratings for Electric Power Systems and Equipment, ANSI C84.1 -1977.
[6] Westinghouse Electric Corp: Electric Utility Engineering Reference Book - Distribution Systems, vol. 3, East Pittsburgh, Pa. 1965.

BASIC DEFINITIONS

Voltage regulation: the percent voltage drop of a line with respect to the receiving end voltage

Voltage drop: the difference between the sending end and the receiving end voltage of a line.

Nominal voltage: the nominal value assigned to a line or apparatus or a system of a given voltage class.

Rated voltage: the voltage at which performance and operating characteristics of apparatus are referred.

Service voltage: the voltage measured at the ends of the service entrance apparatus.

Utilization voltage: the voltage measured at the ends of an apparatus.

Base voltage: the reference voltage, usually 120 V.

Maximum voltage: the largest 5- min average voltage

Minimum voltage: the smallest 5-min voltage

Voltage spread: the difference between the maximum and minimum voltages, without voltage dips due to motor starting.

In general, the primary objective of an electrical distribution system is to provide power users with a supply voltage compatible with their utilization equipment and freedom from interruptions. An ideal electric system provides constant voltage to all users under all loading conditions. However it is economically impractical to attempt such an ideal system approach. A common practice among utilities is to stay with preferred voltage levels and ranges of variation for satisfactory operation as set forth by the American National Standards Institute (ANSI).

Supplying either a too-high steady state voltage or a too-low steady state voltage is detrimental to the operation of electrical equipment. The nominal voltage standards for a majority of the electric utilities in the United States to serve residential and commercial customers are:

1. **120/240 -V three wire single phase**
2. **240/120 -V four wire three phase delta**
3. **208Y/120-V four wire three phase wye**
4. **480Y/277-V four wire three phase wye**

Voltage on a distribution circuit varies from a maximum value at the customer nearest to the source to a minimum value at the end of the circuit. The voltage limits given below are classified as "favorable zone" ranges for secondary voltage systems.

	Voltage Limits		
	At point of delivery		at point of utilization
Nominal voltage class	Maximum	Minimum	Minimum
120/240-V and 240-V / 120-V 3 phase delta	126/252	114/228	110/220
208Y/120-V 3 phase	218Y/126	197Y/114	191Y/110
408Y/277-V 3 phase	504Y291	456Y/263	440Y/254

Voltages outside of these limitations move into a tolerable or extreme-emergency zone.

Voltage regulation is often the limiting factor in the choice of either conductor type or insulation. While heat loss in the cable determines the maximum current it can carry without deterioration, it is often necessary to limit current to an even lower value because of excessive voltage drop. This problem is usually confined to high current, secondary or distribution circuits. For this reason it is advantageous to carry the primary circuit as close to the load before transforming; so that the voltage drop in the secondary runs, where most of the voltage drop occurs will be small.

The voltage drop of a cable is determined as follows:

$$VR\ (\%\ \text{Regulation}) = \frac{|Vs| - |VL|}{|VL|} \times 100$$

Where:

VR = Voltage regulation in percent

VL = Voltage across load

Vs = Voltage at source

$$Vs = (VL \cos\theta + R\ I)^2 + (VL \sin\theta + X\ I)^2$$

Where:

O = Angle by which the current lags the voltage across the load (cos O = power factor of load)

R = Total a-c resistance of cable

I = Load current

Approximate formula for voltage drop:

$$\mathbf{(Vs - VL) = R\ I \cos\theta + X\ I \sin\theta}$$

This formula is satisfactory where the power factor angle is nearly the same as the impedance angle. It is exact when they are equal, i.e.; tan O = X/R.

The National Electric Code recommends maximum voltage drops of 3% for for power loads and 1% for lighting or combined lighting power loads.

There are numerous ways to improve voltage regulation and keeping distribution circuit voltages within permissible limits. The complete list is given by Lokay [6] as:

1. Use generator voltage regulators
2. Application of voltage-regulating equipment in the distribution substations.
3. Applications of capacitors in the distribution substation
4. Balancing of the loads on the primary feeders
5. * Increasing of feeder conductor size
6. Changing of feeder sections from single phase to multi-phase
7. Transferring of loads to new feeders
8. Installing of new substations and primary feeders
9. Increasing of primary voltage levels
10. Application of voltage regulators out on the primary feeders
11. Application of shunt capacitors on the primary feeders
12. Application of series capacitors on the primary feeders

The selection of a technique or techniques depends upon the particular system requirement.

* Using a larger conductor reduces the resistance and is effective in the case of direct current or unity - power- factor a-c. In general, however, power distribution is accomplished with a-c at power factors less than unity. In this case, it is necessary also to consider reducing the reactance. This is accomplished by reducing the conductor spacing (for open wiring) or by dividing circuits (in conduit),e.g.; by using twin circuits, of # 4/0 AWG instead of a single circuit 500 kcmil and properly arranging conductor configuration, it is possible to reduce the voltage regulation about 30%.

Practically, where voltage regulation is important, it is desirable to avoid the use of spaced open wiring and to consider divided circuits for conductor sizes over 500 kcmil.

USER INSTRUCTIONS

Size: 004

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "VR" VW"		
4.	Check status		
5.	Initialize: XEQ "VR"		
6.	Enter Voltage at load	VL	VL?
7.	Enter total a-c resistance of cable	Rac	Rac?
8.	Enter load current	I	I?
9.	Enter angle by which current lags the voltage across the load, degrees	angle	∢ ?
10.	Enter total Reactance of conductor	X	X ?
11.	Voltage at source		VS =
12.	Voltage drop in percent		VR =

Voltage Regulation

STEP / KEYCODE	COMMENTS
01♦LBL "VR"	
02 "VL?"	Enter Voltage at Load
03 PROMPT	
04 STO 00	
05 "Rac?"	Enter Total A-C Resistance of Cable
06 PROMPT	
07 "I?"	Enter Load Current
08 PROMPT	
09 STO 01	
10 *	
11 "∡?"	Enter Angle by Which the Current Lags the Voltage Across the Load
12 PROMPT	
13 STO 02	
14 COS	
15 RCL 00	$(VL \cos \theta + RI)^2$
16 *	
17 +	
18 X↑2	
19 STO 03	
20 "X?"	Enter Total Reactance of Cable
21 PROMPT	
22 RCL 01	
23 *	
24 RCL 02	
25 SIN	
26 RCL 00	
27 *	$V_s = \sqrt{(VL \cos \theta + RI)^2 + (VL \sin \theta + XI)^2}$
28 +	
29 X↑2	
30 RCL 03	
31 +	
32 SQRT	Display Source Voltage, V_S
33 "VS="	
34 XEQ "VW"	
35 RCL 00	$VR = \frac{100\ (VS - VL)}{V_L}$
36 -	
37 "V:DROP="	
38 XEQ "VW"	Voltage Drop, Line to Neutral in volts $(V_S - V_L)$
39 100	
40 *	
41 RCL 00	
42 /	Voltage Regulation In Percent
43 "VR="	
44 XEQ "VW"	
45 END	

STEP/KEY CODE COMMENTS

SAMPLE PROBLEM

```
            XEQ "VR"
VL?
      240.0000    RUN
Rac?
         .0356    RUN
I?
      200.0000    RUN
∠?
       36.8000    RUN
X?
         .0281    RUN
VS= 249.0678
V:DROP= 9.0678
VR= 3.7783
```

DATA REGISTERS

00	VL		
01	I		
02	θ		
03	$(VL\cos\theta + RI)^2$		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

STATUS

SIZE 004 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY

INDUCTIVE REACTANCE AND INDUCTANCE IN CABLES

Robert W. Parkin

FUNCTION: This program determines the series inductive reactance to neutral of cables in conduit, direct bury, or in air for single and three phase circuits, and the inductance in cable for single and multi-conductor cables.

ACCESSORIES: HP-41 CX, or HP-41 CV, printer optional.

OPERATING LIMITS AND WARNINGS: None

REFERENCES:

[1] Aluminum Electrical Conductor Handbook

[2] Anaconda Wire and Cable Engineering Handbook,

[3] Electric Power Transmission, Woodruff. Standard Handbook for Electrical Engineers, Fink and Beaty.

INDUCTIVE REACTANCE: The inductance and consequently, the inductive reactance of a cable is a function of its geometry and its physical relationship to other cables. General equations and configurations are given with program documentation.

Reactance depends on:

1 - Size of conductor
2 - Spacing between it and other current carrying conductors
3 - Position of conductors in relation to other conductors
4 - Frequency of current
5 - Presence of magnetic materials close to the conductor

Reactance is reduced by:

1 - Placing conductors close together
2 - Non-magnetic raceways (instead of steel)

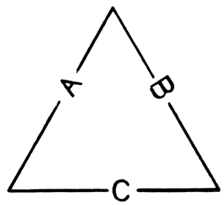
Geometric Mean Radius (or self GMD) of Solid and Stranded Conductors can be determined by the following table. The GMR is merely a mathematical convenience and is not an intrinsically useful physical concept.

Conductor Stranding	GMR, mils
solid	0.3894004 d
7- wires	0.3627837 d
12-wire	0.3803203 d
19-wire	0.3788277 d
27-wire	0.3866393 d
37-wire	0.3840227 d
61-wire	0.3860303 d
91-wire	0.3871463 d
127-wire	0.3877845 d
169-wire	0.3881861 d
217-wire	0.3884543 d
271-wire	0.3887594 d

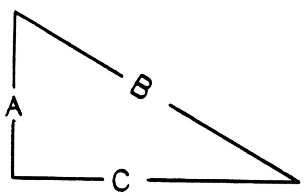
Where: d = diameter of conductor, mils

Geometric Mean Distance (GMD) Equivalent conductor spacing.

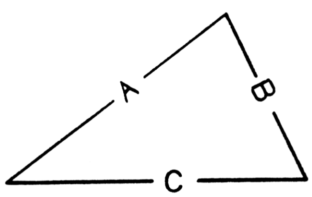
1. Equilateral Triangular $\qquad$ GMD = A=B=C



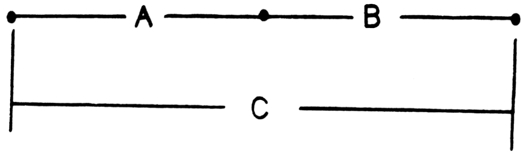
2. Right Angle Triangle $\qquad$ GMD = 1.123 A when A=C



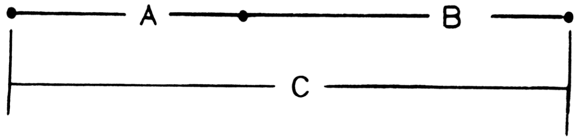
3. Unequal Triangular $\qquad$ GMD = $\sqrt[3]{A \times B \times C}$



4. Symmetrical Flat $\qquad$ GMD = 1.26 A $\quad$ A=B



5. Unsymmetrical Flat $\qquad$ GMD = $\sqrt[3]{A \times B \times C}$



Program is based on the following formulas, symbol notations are given with program documentation.

1. Inductive reactance in ohms per 1000 feet at loop for single phase two conductor concentric URD cable, 60 hertz.

$$XL = 0.5292 \log_{10} (D2/D1) + 0.0115 (1/2 + D1^2 / 3 * D2^2)$$

2. Inductive reactance ohms to neutral per 1000 feet for URD and UD cables direct bury or in non-magnetic duct, three phase , 60 hertz.

$$XL = 0.05292 \log_{10} GMD / GMR$$

3. Inductive reactance in ohms per 1000 feet of circuit for single phase (two wire) circuit direct bury in air or non-magnetic duct.

$$XL = 0.10584 \log_{10} S / GMR$$

Note 1: For frequencies other than 60 hertz , multiply by f/60.

Note 2: For magnetic conduit implement the following corrections:

Single conductor - Increase 50% for magnetic effect and random lay

Multiple cables - Use the following multiplying factors for round cables:

Conductor size kcmil -up to	**Multiplying factor**
250	1.149
300	1.146
350	1.140
400	1.134
500	1.122
600	1.111
700	1.100
750	1.095

INDUCTANCE: The inductance relationships used in predicting the performance of power transmission systems often involve the effects of stranded and bundled conductors operating in parallel as well as single phase systems coordinated with polyphase systems. The current carrying conductors of a phase are considered mathematically as a cylindrical shell of current of radius called self geometric mean radius of the phase or GMR. The mutual distance between the current in a particular phase and the other (return) currents in the other phase are replaced by the mutual geometric mean distance to the return or GMD. The inductance of all phases may be balanced by transposing the conductors over the length of the transmission line, so that each phase occupies all positions equally in the length of the line. Inductance in multi-conductor cables is essentially the same as for other arrangements of conductors; the equation is:

$$L = 0.1404 \log_{10} \frac{GMD}{GMR} \times 10^{-3}$$

Where: L = Inductance in henries to neutral per 1,000 feet

GMD = Distance between centers of conductors, inch

GMR = GMR of conductor, inch

MUTUAL INDUCTANCE: When two independent circuits are in proximity to each other, a change in current in one is accompanied by a change in its magnetic field, which induces an electromotive force in the other. In single conductor, metallic-covered cables, current flowing in the conductor will produce, by mutual conductance, an emf in the sheath. If by any means the sheath forms part of a closed circuit, current will flow in the sheath. The inductance in the sheath is expressed by:

$$Lm = 0.1404 \log_{10} \frac{GMD}{rm}$$

Where :

Lm = Inductance in henries to neutral per 1,000 feet

rm = Mean sheath radius, inch

USER INSTRUCTIONS

Size: 005

MODE: Single Phase, Concentric Neutral Wires

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "XL","VW","AV"		
4.	Check status		
5.	Initialize: XEQ **"XL"**		
6.	Enter Geometric mean radius of center conductor,inches.	GMR	GMR? Inch
7.	Select Type Circuit: **1 = Single phase** **3 = Three phase**	1	Phase:1/3?
8.	Are concentric neutrals used? **Y = Yes** **N = No**	Y	CNW? Y?N
9.	Enter diameter of conductor,inches	D1	D1=?
10.	Enter diameter under neutral wires, inches	D2	D2=?
11.	Inductive reactance in ohms per 1000 feet	-	XL/MFT=
12.	Inductive reactance in ohms per kilometer	-	XL/KM=

MODE: [Single Phase, Without Concentric Neutral Wires]

STEP	INSTRUCTIONS	INPUT	DISPLAY
8.	Are concentric neutrals used? **Y = YES** **N = No**	N	CNW? Y/N
9.	Enter spacing between conductor centers, inches	S	S = ? Inch
10.	Inductive reactance per 1000 feet		XL/MFT=
11.	Inductive reactance per kilometer		XL/KM=

MODE: [Three Phase]

STEP	INSTRUCTIONS	INPUT	DISPLAY
9.	Enter geometric mean Distance of cables,inches	GMD	GMD?:Inch
10.	Inductive reactance per 1000 feet	-	XL/MFT=
11.	Inductive reactance per kilometer	-	XL/KM=

USER INSTRUCTIONS

Size:000

MODE: Single and Multiconductors

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "LL", "VW"		
4.	Check status		
5.	Initialize: XEQ **"LL"**		
6.	Enter Geometric Mean Distance of conductors, inches.	GMD	GMD?
7.	Select Type Conductor:	1 or 0	MC:1/1C:0
	1 = Multiconductor		
	0 = Single Conductor		
8.	Enter GMR, inches	GMR	GMR?
9.	Display Inductance in henries to neutral per 1000 feet.	-	L =
	[For Multiconductors]		
7.	Select 0	0	MC:1/1C:0
8.	Enter Mean Sheath radius in inches	Rm	RM?
9.	Display Inductance in henries to neutral per 1000 feet	-	L =

Inductive Reactance

STEP/KEY CODE	COMMENTS
01◆LBL "XL"	
02 FIX 4	
03 "GMR? INCH"	Enter Geometric Mean Radius of Solid or Stranded Conductor in Inches
04 TONE 5	
05 PROMPT	
06 XEQ "AV"	
07 STO 00	Enter:
08 "PHASE: 1 / 3?"	1 = Single Phase
09 PROMPT	
10 1	3 = Three Phase
11 X=Y?	
12 GTO 01	
13 GTO 02	
14◆LBL 01	
15 "Y"	
16 ASTO Y	
17 "CNW?: Y/N"	Concentric Neutral Wires?
18 AVIEW	
19 AON	Y = Yes
20 STOP	
21 AOFF	N = No
22 ASTO X	
23 X=Y?	
24 GTO 03	
25 GTO 04	
26◆LBL 03	Single Phase URD,CNW
27 "D1=?"	D_1 = Diameter of Center Conductor Inches
28 PROMPT	
29 STO 03	
30 X↑2	
31 "D2=?"	D_2 = Diameter Under Neutral, Inches
32 PROMPT	
33 STO 04	
34 X↑2	
35 3	$0.05292 \log_{10}(D_2/D_1) + 0.0115\left(1/2 + \frac{D_1^2}{3D_2^2}\right)$
36 *	
37 /	
38 .5	
39 +	
40 .0115	
41 *	
42 RCL 04	
43 RCL 03	
44 /	
45 LOG	
46 .05292	
47 *	
48 +	
49 XEQ 05	
50◆LBL 04	
51 "S=? INCH"	Single Phase
52 PROMPT	
53 XEQ "AV"	Enter S = Spacing Between Conductor Centers, Inches
54 RCL 00	
55 /	
56 LOG	
57 .10584	$0.10584 \log_{10} S/GMR$
58 *	
59 XEQ 05	
60◆LBL 02	
61 "GMD=?INCH"	3 Phase Cables: Enter:Geometric Mean Distance of Cables,Inches
62 PROMPT	
63 XEQ "AV"	
64 RCL 00	
65 /	$0.05292 \log_{10} GMD/GMR$
66 LOG	
67 .05292	
68 *	
69◆LBL 05	
70 "XL/MFT="	Inductive Reactance in Ohms per 1000 Feet
71 XEQ "VW"	
72 3.281	
73 *	
74 "XL/KM="	Inductive Reactance in ohms per Kilometer
75 XEQ "VW"	
76 STOP	
77 END	End
01◆LBL "AV"	View Module For Printer Display
02 CF 21	
03 FC? 55	
04 RTN	
05 SF 21	
06 ACA	
07 ACX	
08 ADV	
09 RTN	
10 .END.	

SAMPLE

```
            XEQ "XL"
GMR? INCH
          .1940    RUN
     GMR? INCH 0.1940
PHASE: 1 / 3?
         1.0000    RUN
CNW?: Y/N
Y                  RUN
D1=?
          .5120    RUN
D2=?
         1.1100    RUN
XL/MFT= 0.0243
XL/KM=  0.0799

            XEQ "XL"
GMR? INCH
          .1940    RUN
     GMR? INCH 0.1940
PHASE: 1 / 3?
         1.0000    RUN
CNW?: Y/N
N                  RUN
S=? INCH
         1.4300    RUN
       S=? INCH 1.4300
XL/MFT= 0.0918
XL/KM=  0.3013

            XEQ "XL"
GMR? INCH
          .1940    RUN
     GMR? INCH 0.1940
PHASE: 1 / 3?
         3.0000    RUN
GMD=?INCH
         1.4300    RUN
       GMD=?INCH 1.4300
XL/MFT= 0.0459
XL/KM=  0.1506
```

DATA REGISTERS

00	GMR		
01	Not Used		
02	Not Used		
03	D1		
04	D2		

STATUS

SIZE 005 TOT. REG. ____ USER MODE
ENG ____ FIX 4 SCI ____ ON ____ OFF ✓
DEG ____ RAD ____ GRAD ____

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY

STEP/KEY CODE	COMMENTS
Inductance in Cable	
01◆LBL "LL"	
02 "GMD?"	Geometric Mean
03 PROMPT	Distance in Inches
04 STO 00	
05 "MC:1 /1C:0"	1=Multiconductor 0=Single Conductor
06 PROMPT	
07 X=0?	
08 GTO 00	
09 "GMR?"	Geometric Mean
10 PROMPT	Radius of Conductor
11◆LBL 01	Inches
12 RCL 00	
13 X<>Y	$L=0.1404 \log \frac{GMD}{GMR} \times 10^{-3}$
14 /	
15 LOG	
16 .1404	$L = 0.1404 \log_{10} \frac{GMD}{r_m}$
17 *	
18 1 E-3	Displays Inductance
19 *	in Henrys to
20 ENG 3	Neutral per 1000
21 "L="	Feet
22 XEQ "VW"	
23 STOP	
24◆LBL 00	
25 "RM?"	Enter Mean Sheath
26 PROMPT	Radius, Inches
27 GTO 01	
28 .END.	

DATA REGISTERS

00	GMD		

SAMPLE

```
                XEQ "LL"
GMD?
               1.43  RUN
MC:1 /1C:0
                  0  RUN
RM?
              1.288  RUN
L= 6.377-06

                XEQ "LL"
GMD?
               1.43  RUN
MC:1 /1C:0
                  1  RUN
GMR?
               .194  RUN
L= 121.8-06
```

STATUS

SIZE 001 TOT. REG. ____ USER MODE
ENG ✓ FIX ____ SCI ____ ON ____ OFF ✓
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

DIELECTRIC CHARACTERISTICS OF CABLES

Robert W. Parkin

PROGRAM: "DC"

FUNCTION: This program covers the general dielectric characteristics associated with insulated power cables. Capacitance, Charging Current, Dielectric Loss, Capacitive Reactance, and Insulation Resistance of the cable are calculated. The values derived can be applied in the other electrical programs.

ACCESSORIES: HP-41 CX or CV, printer optional

OPERATING LIMITS AND WARNINGS: None

REFERENCES: CABLEC Corp, Essex Underground Cable Engineering Handbook, Bartnikas/McMahon, Engineering Dielectrics.

PROGRAM DESCRIPTION AND PARAMETERS

Many factors affect the dielectric properties of an insulated cable; among them being the permittivity (dielectric constant), power factor, leakage current, dielectric strength, impulse strength and operating temperature. Both Cross-Linked Polyethylene (XLPE) and Ethylene Propylene Rubber (EPR) insulating compounds exhibit good electrical properties. However, EPR insulated cables have higher dielectric losses proportional to rated circuit voltage as compared to XLPE.

DIELECTRIC CONSTANT: The permittivity, dielectric constant, or specific inductive capacity of any material used as a dielectric is equal to the ratio of a materials capacitance to the capacitance using a vacuum as the dielectric medium. The permittivity of dry air is approximately equal to one. The dielectric constant is an indicator of chemical or physical changes of the dielectric material; values are given with program documentation.

DIELECTRIC STRENGTH: The ultimate dielectric strength of a material is determined by the voltage at which it breaks down. The stress in volts/mil at which this occurs depends on the thickness of the insulation, temperature, frequency, waveform of the testing voltage and the method of application. The time for which the voltage is applied is important; most dielectrics will withstand a much higher voltage for brief periods. Dielectric strength is reduced when it is operated at high temperatures or if moisture is present.

POWER FACTOR: (or Tangent Delta) is a measure of the loss angle in the dielectric. The cable dielectric is an imperfect capacitor of high resistance and capacitive reactance. Therefore, the current passing through the dielectric leads the voltage across the dielectric by almost 90 degrees. The cosine of this angle is the power factor. Typical power factor values for dielectrics are:

Material	Power Factor
HMWPE	0.01%
XLPE	0.1%
TR-XLP	0.5%
EPR	1.0%

Power factor varies with temperature, voltage, water absorption and age of insulation, and is used to determine the dielectric loss dissipated as heat in the insulation, expressed in watts/ft. of cable.

CAPACITANCE: from the viewpoint of electrokinetics is the property of an electric system comprising insulated conductors and associated dielectrics which determines for a given time rate of change of potential difference between th conductors, the displacement currents in the system.

Capacitance in cable can be calculated by:

$$C = \frac{7.354 \times 10^{-3} \times K}{\log_{10} D/d}$$

Where:

C = Capacitance in microfarads per 1000 ft. (MFT)

K = Dielectric Constant

D = Diameter over Insulation

d = Diameter over conductor

CHARGING CURRENT: Where extremely long primary circuits are involved (apprx. 10 miles or more), lower cable capacitance may be required to reduce the 60 cycle charging currents; Which could account for an appreciable voltage drop. This can be accomplished by increasing the cable insulation thickness, thereby reducing cable capacitance. The charging current can be calculated as follows:

$$I = \frac{2\,PI\,f\,C\,E}{1000}$$

Where:

I = Charging current in amperes

E = Circuit voltage to ground, kV

f = Frequency in cycles per second

C = Electrostatic Capacitance in microfarads

DIELECTRIC LOSS: The power dissipated by a dielectric is computed from the general formula:

$$W = 2\,PI\,f\,K\,C\,n\,e^{2}\,Fp \times 10^{-6}$$

Where:

K = Dielectric Constant

f = Frequency, cycles per second

C = Capacitance of insulation per foot, one conductor to neutral when K = 1, in micro-microfarads

n = Number of conductors in cable

e = Voltage, conductor to neutral, kV

Fp = Power factor of insulation, expressed as decimal

W = Dielectric Loss in watts/ft.

INSULATION RESISTANCE: Is the volume d-c resistance measured in terms of surface resistivity in megohms per 1000 feet at 15.6 degrees C. It is useful in estimating leakage current when d-c proof testing cables after installation.

$$R = k \text{ Log } D/d$$

Where:

R = Insulation Resistance in Megohms/MFT

k = k constant (see table with program)

D = Diameter over insulation

d = Diameter over conductor

USER INSTRUCTIONS

Size: 006

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "DC","VW"		
4.	Check status		
5.	Initialize: XEQ "DC"		
6.	Enter dielectric constant	e	e?
7.	Enter diameter over insulation	D	D?
8.	Enter diameter over ESS	d	d?
9.	Capacitance in Microfarads/MFT		C:MFT =
10.	Capacitance in Microfarads/km		C:/KM =
11.	Enter voltage to ground, kV	Vg	Vg?
12.	Charging current in Amperes/MFT		AMPS =
13.	Enter power factor as decimal	PF	N?
14.	Number of conductors	N	
15.	Dielectric loss watts/foot		W/FT =
16.	Capacitive Reactance		Xc =
17.	Enter K constant	K	K?
18.	Insulation Resistance in Megohms/MFT @ 15.6 degrees C.		IR=

Dielectric Characteristics

STEP/KEY CODE	COMMENTS
01♦LBL "DC"	
02 FIX 4	*Enter Dielectric
03 "e?"	Constant
04 PROMPT	
05 STO 01	
06 .007354	
07 *	
08 "D?"	Enter Diameter Over
09 PROMPT	Insulation
10 "d?"	
11 PROMPT	Enter Diameter Over
12 /	ESS
13 LOG	
14 STO 00	$C = \frac{7.354 \times 10^{-3} \times \epsilon}{\log_{10} D/d}$
15 /	
16 STO 03	
17 "C:MFT="	
18 XEQ "VW"	Capacitance in Micro-
19 3.281	farads/1000 Feet
20 *	
21 "C:/KM="	Capacitance in Micro-
22 XEQ "VW"	farads/Kilometer
23 "VG?"	
24 PROMPT	Enter Circuit Voltage
25 STO 02	to Ground in KV
26 376.99	($2\pi f$) @ 60HZ
27 *	
28 RCL 03	
29 *	
30 1 E3	$\frac{2\pi f\, CVg}{1000}$
31 /	
32 "AMPS="	
33 XEQ "VW"	Charging Current in
34 7.354	Amperes/MFT

* Typical Values of ϵ (SIC)

PVC	3.5-8.0
EPR	2.8-3.5
Polyethylene	2.3
XLPE	2.3-6.0

STEP/KEY CODE	COMMENTS
35 RCL 00	C, When ϵ =1
36 /	
37 "PF?"	Enter Power
38 PROMPT	Factor of Di-
39 *	electric as a
40 376.99	Decimal
41 *	
42 "N?"	Enter Number of
43 PROMPT	Conductors in
44 *	Cable
45 RCL 02	
46 X↑2	$W = 2\pi f \epsilon\, Cne^2 P_F \times 10^{-6}$
47 *	
48 RCL 01	
49 *	
50 1 E-6	
51 *	
52 "W/FT="	Dielectric Loss
53 XEQ "VW"	in Cable Insulation
54 376.99	in Watts/Foot
55 RCL 03	
56 *	
57 1/X	$X_C = -\frac{1}{2\pi f\, C}$
58 CHS	
59 "Xc= "	Capacitive Reactance
60 XEQ "VW"	
61 "K?"	
62 PROMPT	Enter K Constant
63 RCL 00	For the Insulation
64 *	
65 FIX 0	
66 "IR="	Insulation Resis-
67 XEQ "VW"	tance in Megohms
68 END	1000ft
	@ 15.6°C (60°F)

$$IR = K \log_{10} D/d$$

K = Specfic Insulation Resistance in Meg-ohms/1000

Typical Values of K

Synthetic Rubber, Heat and Moisture Resisting 75C......2000
EP Insulation.................20000
Polyethylene..................50000
PVC...........................2000
Crossed Linked Polyethylene...20000

SAMPLE PROBLEM

```
     XEQ "DC"
e?
 2.3000     R
            UN
D?
 1,080.0000
           RUN
d?
 392.0000
           RUN
C:MFT= 0.038
4
C:/KM= 0.1261
VG?
      20.2000   RUN
AMPS= 0.2926
PF?
        .0010   RUN
N?
       1.0000   RUN
W/FT= 0.0059
Xc= -0.0690
K?
  20,000.0000   RUN
IR= 8,803.
```

STATUS

SIZE 006 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY

DATA REGISTERS

00	log D/d		
01	Dielectric Constant		
02	Vg-Voltage to Ground kv		
03	Capacitance		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

Section Two

Polymer Insulated Cable Design

SOLID DIELECTRIC CABLE DESIGN

Robert W. Parkin

PROGRAM: "CD"

FUNCTION: This program designs control, secondary, and Medium-high voltage power distribution cables rated from 600V to 138kV. Outer diameters, component thicknesses, and weights are displayed in accordance with industry standards and codes, i.e.; AEIC, ICEA, NEMA, UL, NEC, EPRI, AND IEEE. Original dimensions can be employed for custom cable designs. Drawings, tables, and example cables specifications are included in this section.

ACCESSORIES: HP-41 CX, or HP-41 CV model with extended memory functions module, printer optional, recommend card reader or wand to load in data.

OPERATING LIMITS AND WARNINGS: Enter AWG sizes 1/0, 2/0, 3/0, and 4/0 as 10,20,30, or 40. Maximum number of wires in control cables is 20 wires per cable. System voltage adders are incorporated up to 69kV, if above 69kV adders can be entered manually.

REFERENCES: are given in back

PROGRAM DESCRIPTION AND PARAMETERS

This program covers the construction and design of cables for use on the following Utility and Industrial Systems:

1) **Medium Voltage Primary Distribution (5-138 kV)**

2) **Low Voltage Secondary Distribution (600 V)**

3) **Control and Instrumentation (0-2000 V)**

The user should recognize that many options exist and should consider all circuit parameters in the selection and design of the cable. As a minimum, the following system characteristics should be specified in cable specifications assuming a 60 hertz a-c circuit:

1) Normal operating voltage between phases or, if direct current, between conductors.

2) Number of phases and conductors. If series street lighting, give the open circuit voltage and state whether system is operated with or without protection.

3) Cable insulation level (100% or 133%) or grounded or ungrounded circuit.

4) Minimum temperature at which cable will be installed.

5) Maximum conductor temperatures for normal (continuous), emergency, and short circuit operation.

6) Description and conditions of installation.

The following component thicknesses and diameters are displayed in accordance with AEIC and ICEA: center conductor; strands and diameter, extruded strand and insulation shield, and outer jackets over single or multi-conductor assemblies. The user has the option of overriding any industry standard value and entering original input values.

This allows the designer to construct an accurate and complete cable in accordance with industry standards or internal specifications.

SPECIFICATIONS

1. Association of Edison Illuminating Companies (AEIC)
51 East St., New York, N.Y. 10017

CS5-87 (XLPE)	**5-35 kV**
CS6-87 (EPR)	**5-69 kV**
CS7-87 (XLPE)	**46-138 kV**

Covers: Shielded Power Cables for outside plant utility service. Outlines qualification tests for cable core and insulation, with the addition of a thermomechanical type test for jacketed cables to determine electrical performance characteristics.

2. Insulated Cable Engineers Association (ICEA)
National Electrical Manufacturers Association (NEMA)
2101 L Street, N.W., Washington D.C. 20037

S-66-524 (XLPE)	**NEMA WC-7**
S-68-516 (EPR)	**NEMA WC-8**
S-61-402 (PE)	**NEMA WC-5**

Covers: Processes, materials, properties and testing of power cables rated from 0 through 35kV. NEMA standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for its particular need.

SPECIFICATIONS

3. Underwriters Laboratories (UL)
1285 Walt Whitman Road, Melville, L.I., N.Y. 11747

UL 1072 (XLPE & EPR)

Note: UL is a nationally recognized product testing and certifying organization.

1072 Covers: Processes, materials, properties and testing of shielded and non-shielded cable rated 5 - 35kV, with emphasis on adequate safeguards for personnel and property. Type MV-90, MV-75, MC cable, "Sunlight Resistant", "For CT Use", and "Oil Resistant" cables included; these do not cover URD/UD power cables that have concentric neutral wires.

4. United States Department of Agriculture
Rural Electrification Administration
Washington D.C. 20250

REA 50-70 (U-1)

REA U-2 (600V Underground Cable)

REA maintains a system of bulletins that contains construction standards and specifications for materials and equipment which are applicable to electric system facilities constructed by REA electric borrowers in accordance with the REA loan contract.

Covers: REA Bulletin 50-70 (U-1) is the REA specification for Primary Underground Power Cable rated 15 kV and 25 kV. It contains REA's requirements relative to the purchase of underground power cables by REA electric borrowers. The requirements in bulletin 50-70 (U-1) are minimum requirements and are based primarily on specifications of national standard organizations, i.e., AEIC and ICEA.

SPECIFICATIONS

5. The National Electric Code (NEC)

Covers: 0-35 kV wire and cable, and is recognized as the legal criterion of safe electrical design and installation.

Note: Any wire or cable to be used in a NEC installation must carry a listing from a nationally recognized laboratory, of which UL is most predominant. When a cable type from a manufacturer is submitted to UL for testing, and passes the appropriate tests, it is assigned a specific listing which designates the type of installation in which the cable may be used. The most common UL standards and types for 600V - 2000V rated cables are given below:

Cable Listing	UL Reference Pub.	Voltage	Cable Type
USE	854	600V	Underground Service
UF	493	600V	Underground Feeder
NM	719	600V	Nonmetallic sheathed
TC	1277	600V	Tray cable
MC	1072	600V-35kV	Metal Clad
RHH (90 C)	44	600V-2 kV	Heat resistant rubber
RHW (75 C)	44	600V-2 kV	Moisture and heat resistant rubber
THW (75 C)	83	600V	Moisture and heat Resistant thermoplastic
THHN (90 C)	83	600V	Heat resistant TP
XHHW (90 C)	44	600V	Moisture and heat Resistant XL polymer
VW-1	44	600V	Pass vertical flame test

SPECIFICATIONS

The following summary of NEC letter-designations used for describing insulations and cable constructions may be helpful for understanding specifications that include NEC abbreviations. This summary relates only to power cables of the usual kinds. There are limitations and exceptions, so the abbreviations must be used with caution. Refer to NEC for full information.

INSULATION MATERIALS

R = Rubber (natural or synthetic)

T = Thermoplastic

X = XLPE, i.e., XHHW

FEP= Fluorinated ethylene propylene

HEAT-RESISTANT QUALITY

H = Suitable for 75C

HH= Suitable for 90C (except XHHW dry)

Without "H" = Suitable for 60C.

MOISTURE AND OIL RESISTANT QUALITY

Without "W"= Usually suitable for dry locations.

W = Usually suitable for wet and dry locations.

M = Usually suitable for oily conditions (machine-tool circuits).

Do not confuse with "M" for metal as part of MC (metal-clad).

Note: Listed separately by Underwriters Laboratories (UL) and governed by separate articles in the National Electric Code, AC and MC cables overlap a great deal both structurally and functionally. The numbers and sizes of conductors permitted in MC cable completely overlap and include the range permitted in AC cable. AC cable typically has 2,3 or 4 copper conductors in sizes ranging from 14 AWG through 1 AWG. MC cable may have multiple conductors, commonly from 18 AWG (copper) or 6 AWG (aluminum) up to 2000 kcmil.

CABLE DESIGN AND MATERIALS

Power, control or instrumentation cables use similar designs and materials determined by operating voltage, insulation level, installation conditions, wet or dry locations etc.

600V, low voltage power cables are generally rated at 600V regardless of the use voltage, whether 120,240,277,480, or 600V. The selection of 600V power cable is oriented more to physical rather than to electrical service requirements. Resistance to forces such as crush, impact, and abrasion becomes a predominant factor, although good electrical properties for wet locations are also needed.

Material Data for components utilized by these programs are required only if weights are desired. Set flag 05 activities "weight mode" and will execute weight modules "WGT" and "SG" which require the specific gravity of extruded components.

A generalized specific gravity table for common compounds used in the industry today is given below.

	Material		Specific Gravity g/cm^3
INSULATIONS:	EPR		1.19
	XLPE	UC 4201	0.92
	TRXLP	UC 4202	0.92
SHIELDS:	ESS	UC 0581	1.14
	EIS	UC 0691	1.14
METALS:	LEAD		11.37
	* COPPER		8.89
	** ALUMINUM		2.703
JACKETS:	PVC		1.35
	LDPE		0.93
	HDPE		0.96
	SCPE	UC 7707	1.12

* When worked and annealed
** Hard Drawn

CONDUCTORS

Program Selection of Conductors

Select type of phase conductor:

Label	Conductor Type
A	**Solid Aluminum**
B	**Compact Class B strand**
C	**Compressed Class B strand**

Input the conductor in kcmil or AWG size ; the diameter and number of strands per conductor are then displayed.

NOTE: # 1/0 Input as 10
2/0 Input as 20
3/0 Input as 30
4/0 Input as 40

Any conductor diameter not stored in the program can be entered manually (in inches).

CONDUCTOR PROPERTIES

Copper and aluminum are the metals employed for the transmission and distribution of electrical energy.

COPPER: Copper is the best practical conductor of heat and electricity. When used as conductors for underground cable it is soft-drawn - annealed , and can be either uncoated (bare) or tin or lead alloy coated per ASTM B 33 or B 189. When metal coatings are applied to copper the electrical resistance of the wire or strand is increased.

The electrical properties of concern are electrical resistivity and conductivity. The volume resistivity of annealed bare copper is 10.371 ohms cir-mil/ft. at 20°C. The resistivity of metal coated copper varies according to wire diameter and the temperature coefficients of resistance.

ALUMINUM: Aluminum is widely used and consists of 1350 EC Alloy available as full hard per ASTM B230 and intermediate tempers per ASTM B609:

TEMPER DESIGNATION

[1]	**H24**	**annealed 1/2 hard**
	H26	**annealed 3/4 hard**
	H14	**drawn 1/2 hard**
	H16	**drawn 3/4 hard**
	H19	**drawn full hard**

Its conductivity is about two-thirds that of copper. Compared with a copper wire of the same physical size, aluminum wire has 61% conductivity of copper IACS., 45% of the tensile strength, and 33% of the weight. An aluminum conductor must be 100/61 = 1.64 times as large as copper wire in cross section to have the same conductivity. Equivalent Aluminum AWG size are two sizes larger than copper i.e. #4/0 AWG aluminum is equivalent to a # 2/0 AWG copper. This does not apply to kcmil sizes.

The volume resistivity of hard drawn aluminum is 17.002 ohms cmil/ft.

Conductor Classes

Conductors are classified as solid or stranded. A solid conductor is a single conductor of solid circular section. (Commonly sized 1/0 and below for aluminum). A stranded conductor is composed of a group of wires helically applied around each successive layer in opposite lay starting from one central wire to six, to 12, to 18 ... etc. This progression of six additional wires in each layer will produce a conductor of any diameter. The same size wire is used in each layer. This method makes the cable as flexible as possible thus facilitating bending. The weight and resistance increase of a stranded conductor versus a solid is approximately 2%.

The nominal direct current resistance in ohms per 1000 feet at 25^{o}C of solid and concentric lay stranded conductors are taken from ICEA S-66-524 Table 2-4. Nominal conductor diameters are from table 2-7, and weights of conductors are from Table 0-2.

CONDUCTOR TYPES

Solid Conductors: Provides an excellent water block and smooth circumference for Aluminum power cable conductors. Drawn at imtermiediate tempers either 1/2 or 3/4 hard per ASTM B 609. Conductors larger than a 4/0 must be stranded.

Compressed Stranding: This is the most common conductor configuration. The outer conductor diameter is compressed to 97% of the regular concentric round diameter per ASTM B231 for aluminum and ASTM B8 for copper. This compression of the conductor strands blocks the penetration of the extruded strand shield from flowing in the outer interstice of the strand and thereby making it easily removable in the field.

Compact Stranding: The outer conductor diameter is compacted (each stranded layer) to approximately 90% of concentric conductor diameters per ASTM B496 for aluminum and ASTM B400 for copper. This reduced conductor size results in an overall cable diameter proportionally lower and smooth outer surface for following applied components. Compacting does produce however a harder conductor especially in the case of copper.

Strandfill: The interstand area within the conductor can be filled with a semiconducting, polymeric material during the stranding process. The strandfill compound is designed to prevent water from penetrating the stranded cable conductor during storage, installation, splicing, and termination the cable. This eliminates the possibilities of water being trapped in the conductor given rise to electrochemical trees which could cause premature failure.

The strandfill material should be compatible with all cable components and exhibit testing characteristics in accordance with ICEA procedures.

Consideration should be given to 7 wire strands (#2 AWG) as solid aluminum; which would serve as the best type of water block.

SEMI-CONDUCTING SHIELDING

Conventional semi-conducting shielding consists of an extruded thermosetting polymer material with conductive carbon black dispersed in the polymer material to achieve the require semiconducting properties. Voids and protrusions at the Insulation interface should comply with AEIC requirements.

The significant electrical property of semiconducting materials is volume resistivity. ICEA defines volume resistivity as a maximum of 500 ohm-meters at room temperature.

Conductor or Strand Shield: A strand shield eliminates excessive voltage stress in voids between the conductor and insulation, thus eliminating the stress concentration at the individual strand, and presents a smooth electrode to the inner surface of the insulation.

It may be a conducting non-metallic tape, conducting compound or a combination of both. An extruded conducting compound is preferable to eliminate irregularities introduced by lapped tapes.

CONDUCTOR SHIELD

The extruded strand shield (ESS) thickness per AEIC are as follows:

[2]

Conductor Size AWG or kcmil	Conductor Shield Thickness (mils) Minimum Point	Minimum Average
8-4/0	12	15
250- 500	16	20
600-1000	20	25
1001 and larger	24	30

For compact round conductors having a diameter eccentricity tolerance verified by measurement of 0-2 mils before covering, the conductor shielding thickness may be 50 percent of Table C1 values if stated by manufacturer at time of quotation. Also, criteria for conductor shield protrusions per C.1.3 are 5 and 5 mils respectively.

INSULATION SHIELD

The insulation shield system consists of two parts. The first is a non-metallic covering directly over the insulation. The second Part is a non-magnetic metal component directly over or embedded in the non metallic covering.

NEC Section 310-6 contains rules on insulation shielding that must be observed. Solid dielectric insulated conductors operated above 2000V in permanent installations must have an ozone-resistant insulation and be shielded. However, non-shielded insulated conductors listed by a nationally recognized test laboratory are permitted for use up to 8000V under the condition given in Section 310-6 of NEC.

In general, shielding should be applied for non-metallic covered cables operating at a circuit voltage above 2000V for single conductor cable and 5000V for multi-conductor with common overall jacket.

There are three principal functions of an insulated shield.

1. To obtain symmetrical radial stress distribution within the insulation and to eliminate, for practical purposes, tangential and longitudinal stresses on the surface of the insulation or jacket.

2. To provide a definite capacitance to ground for the insulated conductor, thereby presenting a uniform surge impedance and minimizing the reflection of voltage waves within the cable run.

3. To reduce the hazard of shock and danger to life and property.

Insulation shield thickness per AEIC is given below:

[1]

Calculated Minimum Diameter Over Insulation (inches)	For Cables With or Without and Overall Jacket Insulation Shield Thickness (mils)			
	Nominal Value	Minimum Point	Maximum Point	Maximum Indent
0 -1.000	40	30	70	15
1.001-1.500	50	40	85	15
4.501-2.000	70	55	100	20
2.001-and larger	70	55	115	20

Note 1: The minimum point does not apply to locations under the metallic shield indent.

Note 2: Nominal thickness represents the value used to calculate diameters measured over the insulation shield.

METAL COMPONENT

The metallic portion or the insulation shield serves as a current carrying medium to carry charging and leakage currents. In some cases, the shield may be required to carry more than the cable charging current. Fault or short circuit current can be carried with larger types of shielded depending on the duration of the fault and the time cycles per second. Program "ST" designs shields for short circuit current durations.

The types of shields available are given below:

1. **Copper wire shield helically applied**

   a) **#16 AWG and smaller referred to as wire shield**

   b) **#14, #12, #10, #9, and #8 AWG referred to as concentric neutrals**

2. **Copper tape helically applied with overlap**

3. **Longitudinally applied and corrugated tape (LC)**

4. **Sheaths (lead sheath)**

5. **Flat strap neutrals**

6. **combination of wire and tape**

7. **Corrugated drain wires longitudally embedded in an extruded outer jacket (CPE)**

Concentric Neutral Conductors

Concentric neutral conductors should consist of a number of copper wires meeting the chemical requirements of ASTM B5 and the resistivity,tensile, and elongation requirements of ASTM B3 for uncoated wires, ASTM B 33 for tin coated wires or ASTM B189 for lead alloy coated wires. The diameter and tolerance of these wires shall comply with ICEA S-66-524 section 7.1.5.

Program "CN" covers sizing of concentric neutral wires. URD cables are single phase and normally have the same current carrying capacity as the central phase conductor, and UD cables carry 1/3 the current as they are employed in three phase circuits.

It is recommended to encapsulate an overall jacket over Bare uncoated copper neutral wires. To prevent concentric neutral corrosion; which can cause reduction or even complete loss of cross-section, affecting the cable neutral ampacity, fault current capability, voltage drop, and metallic shield capability that lead to reduced service life and accelerated replacement of the cable.

INSULATION

The extruded dielectric is the most important component of a cable, as it serves the primary function of containing the voltage within the cable system. The most common solid dielectric insulation materials in use today for medium voltage cables are Cross-Linked Polyethylene (XLPE) and varieties of Ethylene Propylene Rubber (EPR). Some general characteristic properties are given below:

Cross-Linked Polyethylene (XLPE, XHHW): This insulation is listed in NEC as Type XHHW and also suitable for underground service entrance (USE), and is classified as thermosetting, 90 C operating temperature, rated from 600V to 138kV. It has seen over 20 years utility service, demonstrates strong resistance to thermal deformation, has excellent electrical and physical aging properties, and is light-weight. It is also environmental safe, and Least costly compared to TRXLP and EPR.

If operated increasingly under overload conditions, thermal expansion becomes a problem and can lead to cable degradation and failure when the insulation is susceptible to corona.

Tree Retardant Cross-Linked Polyethylene (TRXLPE): Has the same general properties as XLPE, except is mineral filled (non-carbon) to retard tree growth within the cable. TRXLP is superior to cables with standard XLPE in accelerated water tests and breakdown strength (AEIC water tree test). Slightly higher cost, with approximately six years field service. Its Dielectric strength is slightly reduced as compared to XLPE.

Ethylene Propylene Rubber (EPR): This insulation consists substantially of ethylene-propylene copolymer (EPM) or ethylene-propylene terpolymer (EPDM). It is UL approved and is recognized under the RHH-RHW type. EPR is a very highly filled material, in that most contain no more than 50% of the base ethylene propylene copolymer. The balance of the EP material consists of carefully selected and treated clays,cross-linking agents, antioxidants and possibly, filling materials to enhance flame-retardance or some property which is of interest to the compounder. Since the EP is highly filled its electrical properties are not as good as XLPE, however, these properties are quite acceptable for the purpose to which the cable is applied and the methods in which the cable is manufactured. It has higher dielectric losses than XLPE, affecting higher voltage distribution systems, and has approximately 20 years field service, more flexibility and superior physical characteristics at high temperature, and is normally more costly. Recent studies have shown that EPR insulations are 30% more efficient than XLPE in dissipating heat, particularly at the emergency overload temperature. EPR is also more flexible than XLPE over a wide range of temperatures, having a modulus at 100% extension only 60% as large as XLPE's. Greater flexibility in a wide range of climates means it can be installed easily and cost-effectively with smooth, reliable splices and terminations. These advantages are very important in areas where cable must be installed in extremely cold weather.

Insulation thicknesses in accordance with ICEA S-66-524 (XLPE) and S-68-516 (EPR) for cables rated **2000 volts and less:**

Rated Circuit Voltage Phase-to-Phase	**Conductor Size AWG or kcmil**	**Single Cable**	**Multiple and Single with Outer Jacket**
0-600V	#14 - #9	45	30
	#8 - #2	60	45
	#1 - 4/0	80	55
	225- 500	95	65
	525-1000	110	80
601- 2000V	#14 - #9	60	45
	#8 - #2	70	55
	#1 - 4/0	90	65
	225- 500	105	75
	525-1000	120	90

Insulation thickness in accordance with ICEA S-66-524 (XLPE) for **Type A,B,C,D Control Cables:**

Conductor Size AWG	**300 Volts**	**600 Volts**	**1000 Volts**
#20 - #18	20	25	---
#16	20	25	45
#14	25	30	45
#12 - #9	--	30	45

ICEA S-68-516 covers composite insulation thicknesses, and UL 854 and UL 44 cover 600V and 2000V single and multi-conductor cables.

NOTE: The minimum thickness at any point should not be less than 90 percent of the minimum average values given above.

Insulation thicknesses per AEIC CS5,CS6, and CS7 are given below:

Rated Voltage Phase to Phase kV	Conductor Size AWG or kcmil	Minimum Average Insulation Thickness Mils	
		A	B
5	8 to 1000	90	115
	Above 1000	140	140
8	6 to 1000	115	140
	Above 1000	175	175
15	2 to 1000	175	220
	Above 1000	220	220
25	1 to 2000	260	320
28	1 to 2000	280	345
35	1/0 to 2000	345	420
46	4/0 to 2000	445	580
69	500 to 2000	650	-
115	750 to 3000	800	-
138	750 to 3000	850	-

Note 1: For 25kV 133%, ICEA specifies a greater thickness of 345 mils versus 320.

Note 2: For cables intended for three-phase systems, the Rated Voltage is expressed in terms of phase-to-phase voltage. For cables intended for other systems, it should be expressed in suitable terms that will make clear the voltages involved.

Note 3: Ratings for above; CS5-87 5-35kV, CS6-87 5- 69kV, CS7-87 46-138kV.

Note 4: The selection of the cable insulation level to be used in a particular installation shall be made on the basis of the applicable phase-to-phase voltage and the general system category as outlined below.

a. **100 Percent Level** - Cables in this category may be applied where the system is provided with relay protection such that ground faults will be cleared as rapidly as possible, but in any case within one minute. While these cables are applicable to the great majority of cable installations which are on grounded systems, they may also be used on other systems for which the application of cables is acceptable, provided the above clearing requirements are met in completely deenergizing the faulted section.

b. **133 Percent Level** - This insulation level corresponds to that formerly designated for ungrounded systems. Cables in this category may be applied in situations where the clearing time requirements of the 100 percent level category cannot be met, and yet there is adequate assurance that the faulted section will be deenergized in a time not exceeding one hour. Also, they may be used when additional insulation strength over the 100 percent level category is desirable.

Note 5: It is recommended that the minimum size conductor be in accordance with Table B1. For cables or conditions of service where mechanical stresses govern, such as in submarine cables or long vertical risers, these minimum conductor sizes may not provide sufficient strength.

JACKETS AND SHEATHS

Outer jackets can be applied to protect the cable core from physical damage and impede corrosion of metallic shields or neutral wires.

Some of the general properties associated with jacket materials are given below:

PVC - Polyvinyl Chloride
LDPE - Low Density Polyethylene
LLDPE - Linear Low Density Polyethylene
HDPE - High Density Polyethylene
MDPE - Medium Density Polyethylene
SCPE - Semiconducting Polyethylene
CSP - Chlorosulfonated Polyethylene
CPE - Chlorinated Polyethylene

TYPE	PROPERTIES
1. PVC	Thermoplastic, excellent resistance to oils, gasoline acids, alkalis and moisture. Good flame and sunlight resistance, low cost. Physical requirements comply with section 4.4.1 in ICEA S-66-524.
2. Polyethylene, Black	
a) LDPE	Same as PVC except has reduced resistance to petroleum products fire, and lower melting point. Physical Requirements comply with section 4.4.2 of ICEA, and ASTM Standard D 1248 for classifications, types, and grades. i.e, Type I, Category 4, Grades E4, E5, J1.
b) LLDPE	Same as LDPE with Greater tensile and tear strength and higher impact and abrasion resistance. Also has improved low and high temperature performance.

c) **HDPE**	Superior mechanical and physical properties, has excellent abrasion resistance, and can be used as an outer jacket or coilable duct. ASTM D 1248 Type III Category 5 Class C, Grades are associated with the appropriate type, class and category designations. Medium density PE material is Type II.
d) **SCPE**	Properties are given in ICEA S-68-516 Table 7.6-7 and ICEA S-66-524 as Type I and II requirements. Material used should have excellent stress crack resistance, volume resistivity, and compatibility with other cable materials. Compared to insulating LDHMWPE materials, an increase in cost from 20 to 30% usually applies and the carbon black content will cause the jacket to absorb water at a faster rate. Electrical contact with the ground along the cables entire length places the cable at local ground potential at all points; and should be treated as such.
3) **CSP (Hypalon)**	Thermoset, highly resistant to abrasion, impact, oil and ozone, and provides excellent flexibility, and high Cost. Properties comply to section 4.4.10 of S-68-516.
4) **Neoprene**	Thermoset provides excellent resistance to high temperatures, tears. Mechanical abrasion and moisture. Very flexible with high cost.
5) **CPE**	Thermoplastic (or thermoset), same properties as Hypalon with better flame resistance, low temperature performance, low coefficient of friction. Physical properties comply to section 4.4.7 of S-68-516.

JACKET COMPARISONS

	PVC	LDPE	HDPE	Hypalon	Neoprene	CPE
Abrasion Resistance	G	F-G	E	G	G	G
Flame Resistance	G	P	P	G	G	G
Moisture Resistance	G	E	E	G-E	G	G
Oil Resistance	G	F-G	F-G	G	G	G-E
Low Temperature Flexibility	P-G	G-E	E	F	F-G	F-G
Sunlight Resistance	G-E	E	E	E	G	G-E
Acid Resistance	G-E	G-E	G-E	E	G	E
Alkali Resistance Sodium Hydroxide (Lye) Potassium Hydroxide (Potash) Calcium Hydroxide (Lime)	G-E	G-E	G-E	E	G	G-E
Paraffinic Hydrocarbons Gasoline Kerosene	G	P-F	P-F	P	P	P
Aromatic Hydrocarbons Benzol Tolul	P-F	P	P	F	P-F	F
Halogenated Hydrocarbons Chloroform Carbon Tetrachloride Methylene Chloride	P	P	P	P	P	P
Alcohol Resistance Isopropyl Wood Grain	F	E	E	G	F	G
Relative Cost	2	1	3	6	4	5

E - Excellent

G - Good

F - Fair　　1 - Lower

P - Poor　　6 - Higher

CPE resins can be compounded with other materials to produce either thermoplastic or thermoset jacketing materials. Low halogen containing thermoplastic CPE compounds have attained prominence in cable jacketing applications. These materials compare quite favorably with thermoset jacketing materials, such as CSP in virtually all of the critical performance characteristics including its fire resistant properties.

An excellent IEEE guide for the selection of power cable jackets [14] is available.

The thicknesses of outer jackets are given in the following tables in accordance with ICEA S-66-524 and S-68-516.

Outer jackets that are extruded to fill the area between concentric neutral wires are referred to as encapsulating jackets. The program displays the sleeved on outer jacket thickness with a double beep; if no jacket is required enter zero, if an encapsulated jacket is required, use the thickness given in the table below in accordance with ICEA S-66-524 section 7.1.6.1:

Diameter Over Concentric Wires	**Minimum Average Jacket Thickness**
0 - 1.500"	50 mils
Over 1.500"	80 mils

The minimum spot thickness will be 80% of the minimum average value.

The encapsulated jacket material (either semiconducting or insulating) should be free stripping from the concentric neutral wires and insulation shield.

For phase or circuit identification outer polyethylene jackets can have colored stripes (primary cable normally red) extruded into the jackets. The width of these stripes will depend on the circumference of the cable and should be equally spaced 120 degrees apart for three stripes, and 90 degrees apart for four.

METALLIC SHEATHS

Sheaths are generally defined as the protective covering of a cable core which includes at least one metallic component. ICEA defines "jacket" as a continuous nonmetallic covering and "sheath" as a continuous metallic covering. Lead sheathing is still used to protect paper insulated cables and on some solid dielectric cables for maximum protection in underground manhole and tunnel, or underground duct distribution systems subject to flooding. While not as resistant to crushing loads as interlocked armor, its very high degree of corrosion and moisture resistance makes lead attractive in the above applications. The refined lead used should be produced from lead-bearing materials meeting the requirements of ASTM specification B29.

INTERLOCKED ARMOR

Where added mechanical protection is required, armored cable may be utilized. Interlocked armors made from galvanized steel, or aluminum are widely used. Where corrosion and moisture resistance are required in addition to mechanical protection, an overall jacket of extruded material may be used. The use of interlocked galvanized steel armor must be avoided on single-conductor a-c power circuits due to high hysteresis and eddy current losses. This effect, however is minimized in three conductor cables with armor overall and with aluminum armor on single-conductor cables.

NONSHIELDED CABLES

Nonshielded cables rated 2001 to 5000 Volt are mainly used under conditions where shields cannot be adequately grounded, or where space is inadequate for proper termination of the shielding system. ICEA S-66-524 table 3-1, and sections 7.5 and 7.6 cover the requirements for non-shielded cables. Nonshielded cables without protective coverings should have a carbon black pigmented insulation which is resistant to sunlight.

If the cable is Type MV listed per UL 1072 having interlocked aluminum or steel armor, a grounding conductor should be placed within the cable assembly sized in accordance with table 20.1. Tables 12.1 and 12.2 give the insulation thicknesses for nonshielded cables rated 5000 or 8000 Volt at the desired percent level catagory.

JACKET MINIMUM AVERAGE WALL -OVER LEAD SHEATH OR ARMOR TABLE

MIN DIA OF LAST OPER. (MINIMUM)	MIN DIA OF LAST OPER. (MAXIMUM)	(MIN AVG WALL) FOR JACKET OVER LEAD SHEATH	(MIN AVG WALL) FOR JACKET OVER ARMOR
0.000	0.750	.050	.050
0.751	1.500	.065	.050
1.501	2.250	.080	.060
2.251	3.000	.095	.075
3.001	9.999	.110	.085

JACKET MINIMUM AVERAGE WALL -STANDARD TABLE

MIN DIA OF LAST OPER. (MINIMUM)	MIN DIA OF LAST OPER. (MAXIMUM)	JACKET OVERALL FOR SINGLE OR MULTICONDUCTOR	(MIN AVG WALL) FOR JACKET UNDER ARMOR	(MIN AVG WALL) OVER SINGLE IN MULTICONDUCTOR
0.000	0.249	.045	.045	.015
0.250	0.425	.045	.045	.025
0.426	0.700	.060	.045	.030
0.701	1.500	.080	.060	.050
1.501	2.500	.110	.080	.080
2.501	9.999	.140	.110	.000

LEAD SHEATH WALL DIMENSIONS TABLE

MIN DIA OF LAST OPER. (MINIMUM)	MIN DIA OF LAST OPER. (MAXIMUM)	(MIN AVG WALL) NO JACKET ON 1/C CABLE	(MIN AVG WALL) JACKET ON 1/C CABLE
0.000	0.425	.045	.045
0.426	0.700	.065	.055
0.701	1.050	.080	.070
1.051	1.500	.095	.085
1.501	2.000	.110	.095
2.001	3.000	.125	.110
3.001	9.999	.140	.125

INTERLOCKED ARMOR THICKNESS TABLE

LAST OPER MIN DIA (MINIMUM)	LAST OPER MIN DIA (MAXIMUM)	ARMOR THICKNESS STEEL	ARMOR THICKNESS ALUMINUM
0.000	1.500	0.020	0.025
1.501	9.999	0.025	0.030

FACTORY TEST VOLTAGES

Medium Voltage AEIC

RATED VOLTAGE (KV)	INSUL LEVEL PERCENT	MIN AVG WALL	AC VOLTAGE (KV)	DURATION IN MINUTES	DC VOLTAGE (KV)	DURATION IN MINUTES
005	100	.090	018	5	035	15
005	133	.115	023	5	045	15
008	100	.115	023	5	045	15
008	133	.140	028	5	055	15
015	100	.175	035	5	070	15
015	133	.220	044	5	080	15
023	100	.295	044	5	110	15
025	100	.260	052	5	100	15
025	133	.345	069	5	125	15
027	100	.275	055	5	126	15
028	100	.280	056	5	105	15
028	133	.345	069	5	125	15
035	100	.345	069	5	125	15
035	133	.420	084	5	155	15
046	100	.445	089	5	165	15
046	133	.580	116	5	215	15

MEDIUM VOLTAGE TEST FOR ICEA S-68-524 AND UL1072

RATED VOLTAGE (KV)	INSUL LEVEL PERCENT	MIN EXT LEVEL (KV)	MIN AVG WALL	AC VOLTAGE (KV)	DURATION IN MINUTES	DC VOLTAGE (KV)	DURATION IN MINUTES
005	100	04	.090	13	5	000	00
005	133	05	.090	13	5	000	15
008	100	06	.115	18	5	045	15
008	133	08	.140	22	5	045	15
015	100	11	.175	27	5	070	15
015	133	15	.215	33	5	080	15
025	100	19	.260	38	5	100	15
025	133	26	.345	49	5	125	15
028	100	21	.280	42	5	105	15
035	100	26	.345	49	5	125	15

Table 2-7

Nominal Diameters for Copper and Aluminum Conductors

Conductor Size		Nominal Diameters*					
			Concentric Lay Stranded				
		Solid	Compact	Compressed	Class B	Class C	Class D
AWG	kcmil	Inch	Inch	Inch	Inch	Inch	Inch
22	0.812	0.0253	...	...	...	...	...
20	1.02	0.0320	...	...	...	...	...
19	1.29	0.0359	...	...	...	...	...
18	1.62	0.0403	...	...	...	...	...
17	2.05	0.0453	...	...	...	...	...
16	2.58	0.0508	...	...	...	...	...
15	3.26	0.0571	...	0.0629	0.0648	...	...
14	4.11	0.0641	...	0.0704	0.0727	0.0735	0.0735
13	5.18	0.0720	...	0.0792	0.0816	0.0825	0.0826
12	6.53	0.0808	...	0.0888	0.0915	0.0925	0.0931
11	8.23	0.0907	...	0.0998	0.103	0.104	0.104
10	10.38	0.1019	...	0.112	0.116	0.117	0.117
9	13.09	0.1144	...	0.126	0.130	0.131	0.132
8	16.51	0.1285	0.134	0.141	0.146	0.148	0.148
7	20.82	0.1443	...	0.158	0.164	0.166	0.166
6	26.24	0.1620	0.169	0.178	0.184	0.186	0.186
5	33.09	0.1819	...	0.200	0.206	0.208	0.209
4	41.74	0.2043	0.213	0.225	0.232	0.234	0.235
3	52.62	0.2294	0.238	0.252	0.260	0.263	0.264
2	66.36	0.2576	0.268	0.283	0.292	0.296	0.297
1	83.69	0.2893	0.299	0.322	0.332	0.333	0.333
1/0	105.6	0.3249	0.336	0.361	0.372	0.374	0.374
2/0	133.1	0.3648	0.376	0.406	0.418	0.420	0.420
3/0	167.8	0.4096	0.423	0.456	0.470	0.471	0.472
4/0	211.6	0.4600	0.475	0.512	0.528	0.529	0.530
	250	0.5000	0.520	0.558	0.575	0.576	0.576
	300	0.5477	0.570	0.611	0.630	0.631	0.631
	350	0.5916	0.616	0.661	0.681	0.681	0.682
	400	0.6325	0.659	0.706	0.728	0.729	0.729
	450	0.6708	0.700	0.749	0.772	0.773	0.773
	500	0.7071	0.736	0.789	0.813	0.814	0.815
	550	...	0.775	0.829	0.855	0.855	0.855
	600	...	0.813	0.866	0.893	0.893	0.893
	650	...	0.845	0.901	0.929	0.930	0.930
	700	...	0.877	0.935	0.964	0.965	0.965
	750	...	0.908	0.968	0.998	0.999	0.998
	800	...	0.938	1.000	1.030	1.032	1.032
	900	...	0.999	1.061	1.094	1.093	1.095
	1000	...	1.060	1.117	1.152	1.153	1.153
	1100	...	...	1.173	1.209	1.210	1.211
	1200	...	...	1.225	1.263	1.264	1.264
	1250	...	...	1.251	1.289	1.290	1.290
	1300	...	...	1.275	1.314	1.316	1.316
	1400	...	...	1.323	1.365	1.365	1.365
	1500	...	...	1.370	1.412	1.413	1.413
	1600	...	...	1.415	1.459	1.460	1.460
	1700	...	...	1.459	1.504	1.504	1.504
	1750	...	...	1.480	1.526	1.527	1.527
	1800	...	...	1.502	1.548	1.548	1.549
	1900	...	...	1.542	1.590	1.590	1.591
	2000	...	...	1.583	1.632	1.632	1.632

* Diameters in millimeters shall be obtained by multiplying the above values in inches by 25.4.

Nominal Direct Current Resistance in Ohms Per 1000 Feet** at 25°C (77°F) of Solid and Concentric Lay Stranded Conductor

Conductor	Solid			Concentric Lay Stranded*				
Size	Aluminum	Copper		Aluminum	Copper			
AWG or kcmil		Uncoated	Coated	Class, B, C, D	Uncoated	Coated		
					Class B, C, D	Class B	Class C	Class D
22	27.1	16.5	17.2	27.4	16.7	17.9	...	...
20	16.9	10.3	10.7	17.3	10.5	11.1	...	...
19	13.5	8.20	8.52	13.7	8.33	8.83	...	...
18	10.7	6.51	6.76	10.9	6.67	7.07	...	...
17	8.45	5.15	5.35	8.54	5.21	5.52	...	...
16	6.72	4.10	4.26	6.85	4.18	4.43	...	...
15	5.32	3.24	3.37	5.41	3.30	3.43	...	...
14	4.22	2.57	2.67	4.31	2.63	2.73	2.79	2.83
13	3.34	2.04	2.12	3.41	2.08	2.16	2.21	2.22
12	2.66	1.62	1.68	2.72	1.66	1.72	1.75	1.75
11	2.11	1.29	1.34	2.15	1.31	1.36	1.36	1.39
10	1.67	1.02	1.06	1.70	1.04	1.08	1.08	1.11
9	1.32	0.808	0.831	1.35	0.825	0.856	0.856	0.874
8	1.05	0.640	0.659	1.07	0.652	0.678	0.678	0.680
7	0.833	0.508	0.522	0.851	0.519	0.538	0.538	0.538
6	0.661	0.403	0.414	0.675	0.411	0.427	0.427	0.427
5	0.524	0.319	0.329	0.534	0.325	0.338	0.339	0.339
4	0.415	0.253	0.261	0.424	0.258	0.269	0.269	0.269
3	0.329	0.201	0.207	0.336	0.205	0.213	0.213	0.213
2	0.261	0.159	0.164	0.266	0.162	0.169	0.169	0.169
1	0.207	0.126	0.130	0.211	0.129	0.134	0.134	0.134
1/0	0.164	0.100	0.102	0.168	0.102	0.106	0.106	0.106
2/0	0.130	0.0794	0.0813	0.133	0.0810	0.0842	0.0842	0.0842
3/0	0.103	0.0630	0.0645	0.105	0.0642	0.0667	0.0669	0.0669
4/0	0.0819	0.0500	0.0511	0.0836	0.0510	0.0524	0.0530	0.0530
250	0.0694	...	...	0.0707	0.0431	0.0448	0.0448	0.0448
300	0.0578	...	...	0.0590	0.0360	0.0374	0.0374	0.0374
350	0.0495	...	...	0.0505	0.0308	0.0320	0.0320	0.0320
400	0.0433	...	...	0.0442	0.0269	0.0277	0.0280	0.0280
450	0.0385	...	...	0.0393	0.0240	0.0246	0.0249	0.0249
500	0.0347	...	...	0.0354	0.0216	0.0222	0.0224	0.0224
550	...	...	...	0.0321	0.0196	0.0204	0.0204	0.0204
600	...	...	...	0.0295	0.0180	0.0187	0.0187	0.0187
650	...	...	...	0.0272	0.0166	0.0171	0.0172	0.0173
700	...	...	...	0.0253	0.0154	0.0159	0.0160	0.0160
750	...	...	...	0.0236	0.0144	0.0148	0.0149	0.0150
800	...	...	...	0.0221	0.0135	0.0139	0.0140	0.0140
900	...	...	...	0.0196	0.0120	0.0123	0.0126	0.0126
1000	...	...	...	0.0177	0.0108	0.0111	0.0111	0.0112
1100	...	...	...	0.0161	0.00981	0.0101	0.0102	0.0102
1200	...	...	..	0.0147	0.00899	0.00925	0.00934	0.00934
1250	...	...	...	0.0141	0.00863	0.00888	0.00897	0.00897
1300	...	...	...	0.0136	0.00830	0.00854	0.00861	0.00862
1400	...	...	...	0.0126	0.00771	0.00793	0.00793	0.00801
1500	...	...	...	0.0118	0.00719	0.00740	0.00740	0.00747
1600	...	...	...	0.0111	0.00674	0.00694	0.00700	0.00700
1700	...	...	...	0.0104	0.00634	0.00653	0.00659	0.00659
1750	...	...	...	0.0101	0.00616	0.00634	0.00640	0.00640
1800	...	...	...	0.00982	0.00599	0.00616	0.00616	0.00622
1900	...	...	...	0.00931	0.00568	0.00584	0.00584	0.00589
2000	...	...	...	0.00885	0.00539	0.00555	0.00555	0.00560
2500	...	...	...	0.00715	0.00436	0.00448	...	...
3000	...	...	...	0.00596	0.00363	0.00374	...	...
3500	...	...	...	0.00515	0.00314	0.00323	...	...
4000	...	...	...	0.00451	0.00275	0.00283	...	...
4500	...	...	...	0.00405	0.00247	0.00254	...	...
5000	...	...	...	0.00364	0.00222	0.00229	...	...

* Concentric lay stranded includes compressed and compact conductors.

** Resistance values in milliohms per meter shall be obtained by multiplying the above values by 3.28.

Table O-2

Concentric Stranded Class B Aluminum and Copper Conductors

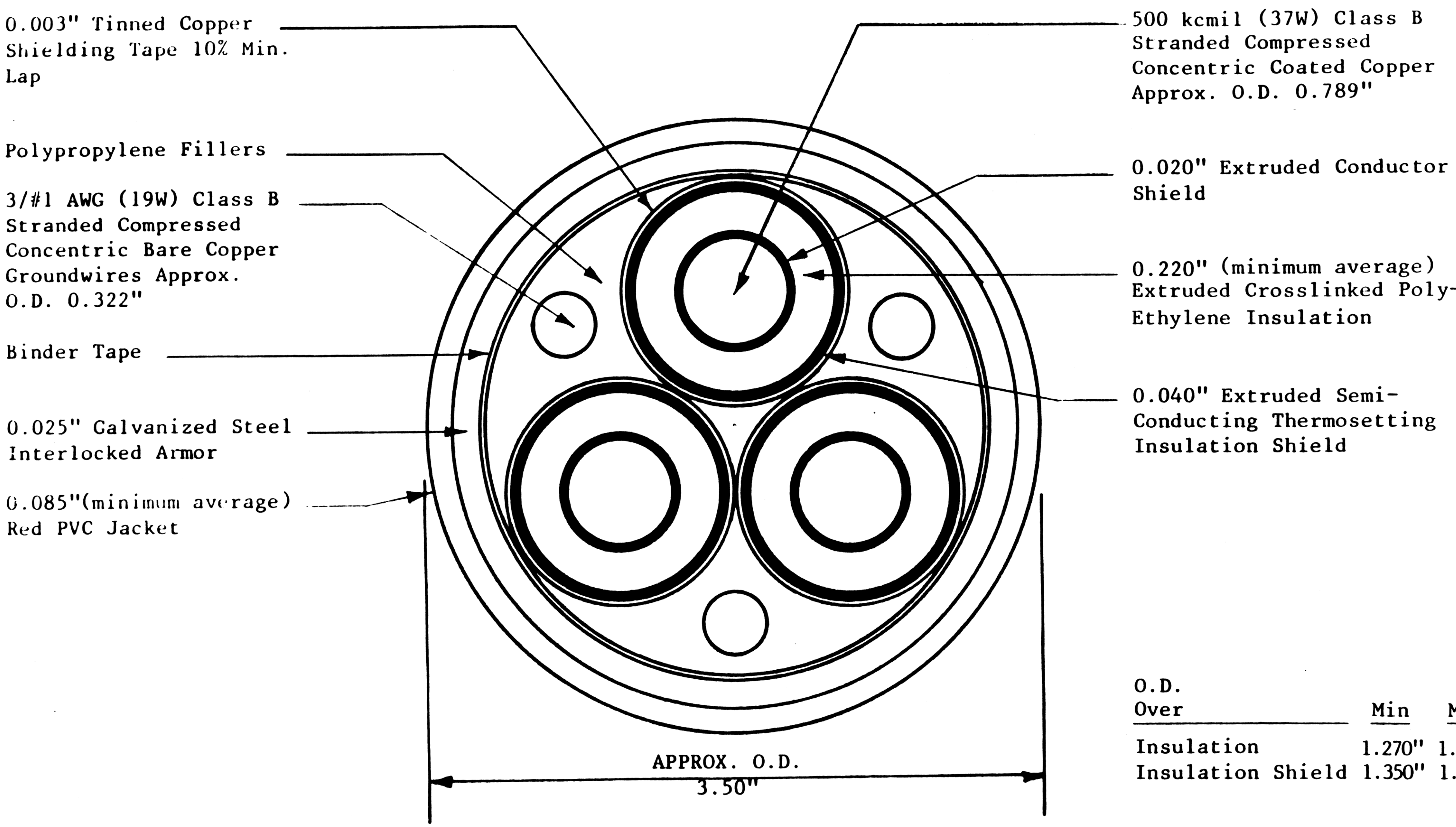
Conductor Size, AWG or kcmil	Number of Strands	Approximate Diameter of Each Strand		Approximate Outside Diameter		Approximate Weight			
						Aluminum		Copper	
		mils	mm	inches	mm	Pounds per 1000 Feet	g/m	Pounds per 1000 Feet	g/m
22	7	9.6	0.244	0.029	0.737	...	...	1.975	2.941
20	7	12.1	0.307	0.036	0.914	...	...	3.154	4.705
19	7	13.6	0.345	0.041	1.04	...	...	3.974	5.922
18	7	15.2	0.386	0.046	1.17	...	...	5.015	7.462
17	7	17.2	0.437	0.052	1.32	...	...	6.324	9.429
16	7	19.2	0.488	0.058	1.47	...	...	7.974	11.86
15	7	21.6	0.549	...	...	...	...	9.959	14.98
14	7	24.2	0.615	...	...	...	...	12.68	18.88
13	7	27.2	0.691	...	...	...	...	16.01	23.82
12	7	30.5	0.775	...	...	6.13	9.12	20.16	30.00
11	7	34.3	0.871	...	...	7.72	11.5	25.49	37.80
10	7	38.5	0.978	...	...	9.75	14.5	32.06	47.71
9	7	43.2	1.10	...	...	12.3	18.3	40.42	60.14
8	7	48.6	1.23	...	...	15.5	23.1	51.0	75.9
7	7	54.5	1.39	...	...	19.5	29.1	64.2	95.7
6	7	61.2	1.56	...	...	24.6	36.7	80.9	121
5	7	68.8	1.75	...	...	31.1	46.2	102	152
4	7	77.2	1.96	...	...	39.2	58.3	129	192
3	7	86.7	2.20	...	...	49.4	73.5	162	242
2	7	97.4	2.47	...	...	62.3	92.7	205	305
1	19	66.4	1.69	...	...	78.6	117	259	385
1/0	19	74.5	1.89	...	...	99.1	147	326	485
2/0	19	83.7	2.13	...	...	125	186	411	611
3/0	19	94.0	2.39	...	...	157	234	518	771
4/0	19	105.5	2.68	...	...	199	296	653	972
250	37	82.2	2.09	...	...	235	349	772	1150
300	37	90.0	2.29	...	...	282	419	925	1380
350	37	97.3	2.47	...	...	329	489	1080	1610
400	37	104.0	2.64	...	...	376	559	1236	1840
450	37	110.3	2.80	...	...	422	629	1390	2070
500	37	116.2	2.95	...	...	469	699	1542	2300
550	61	95.0	2.41	...	...	517	768	1700	2530
600	61	99.2	2.52	...	...	563	838	1850	2760
650	61	103.2	2.62	...	...	610	908	2006	2990
700	61	107.1	2.72	...	...	657	978	2160	3220
750	61	110.9	2.82	...	...	704	1050	2316	3450
800	61	114.5	2.91	...	...	751	1120	2469	3680
900	61	121.5	3.09	...	...	845	1260	2780	4140
1000	61	128.0	3.25	...	...	939	1400	3086	4590
1100	91	109.9	2.79	...	...	1032	1540	3394	5050
1200	91	114.8	2.92	...	...	1126	1680	3703	5510
1250	91	117.2	2.98	...	...	1173	1750	3859	5740
1300	91	119.5	3.04	...	...	1220	1820	4012	5970
1400	91	124.0	3.15	...	...	1313	1960	4320	6430
1500	91	128.4	3.26	...	...	1408	2100	4632	6890
1600	127	112.2	2.85	...	...	1501	2240	4936	7350
1700	127	115.7	2.94	...	...	1596	2370	5249	7810
1750	127	117.4	2.98	...	...	1643	2440	5403	8040
1800	127	119.1	3.02	...	...	1691	2510	5562	8270
1900	127	122.3	3.11	...	...	1783	2650	5865	8730
2000	127	125.5	3.19	...	...	1877	2790	6176	9190

DECIMAL EQUIVALENTS OF FRACTIONS

1/64	.015625	33/64	.515625
1/32	.03125	17/32	.53125
3/64	.046875	35/64	.546875
1/16	.0625	9/16	.5625
5/64	.078125	37/64	.578125
3/32	.09375	19/32	.59375
7/64	.109375	39/64	.609375
1/8	.125	5/8	.625
9/64	.140625	41/64	.640625
5/32	.15625	21/32	.65625
11/64	.171875	43/64	.671875
3/16	.1875	11/16	.6875
13/64	.203125	45/64	.703125
7/32	.21875	23/32	.71875
15/64	.234375	47/64	.734375
1/4	.250	3/4	.750
17/64	.265625	49/64	.765625
9/32	.28125	25/32	.78125
19/64	.296875	51/64	.796875
5/16	.3125	13/16	.8125
21/64	.328125	53/64	.828125
11/32	.34375	27/32	.84375
23/64	.359375	55/64	.859375
3/8	.375	7/8	.875
25/64	.390625	57/64	.890625
13/32	.40625	29/32	.90625
27/64	.421875	59/64	.921875
7/16	.4375	15/16	.9375
29/64	.453125	61/64	.953125
15/32	.46875	31/32	.96875
31/64	.484375	63/64	.984375
1/2	.500	1	1.000

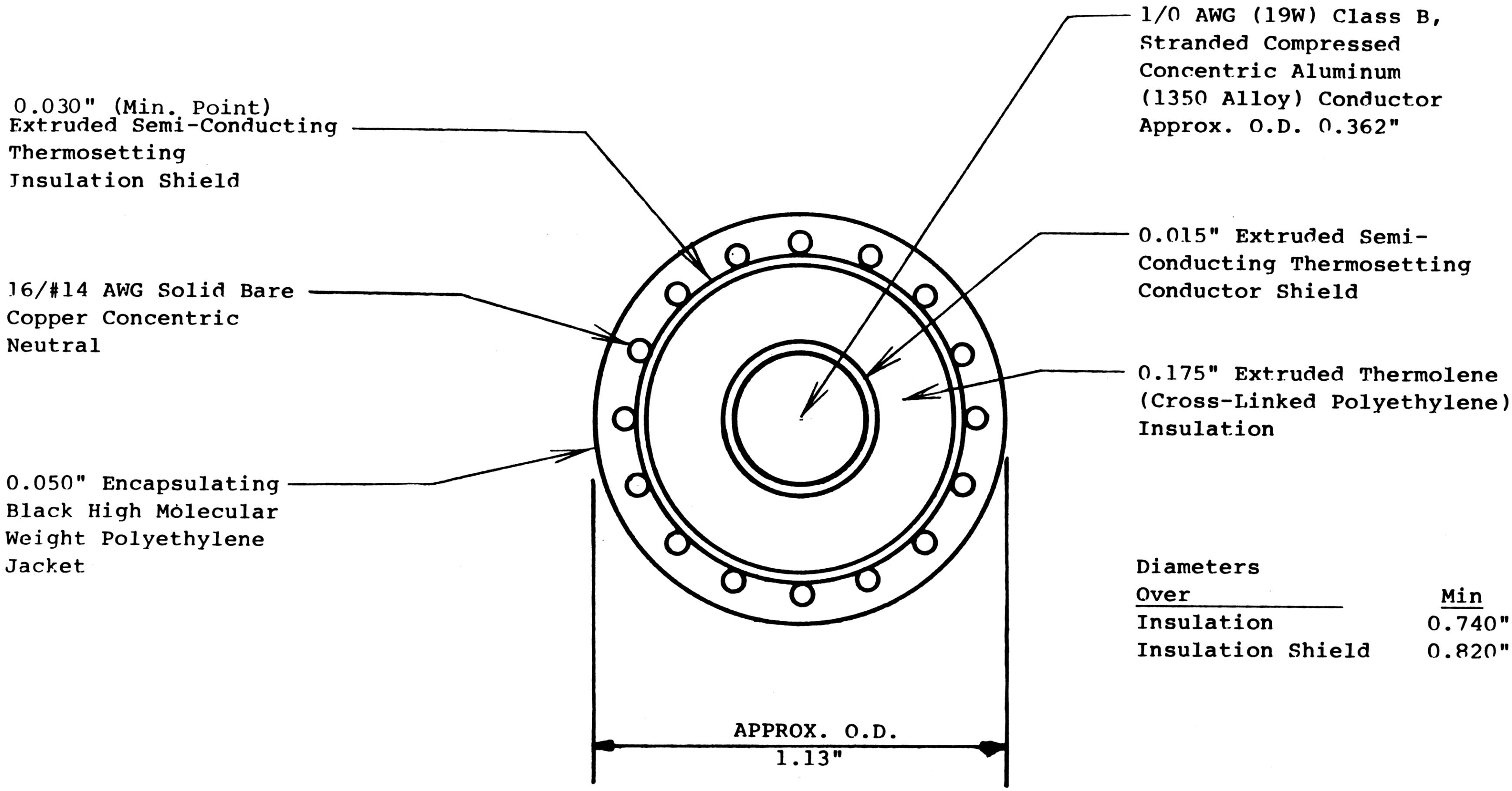
INCHES IN DECIMAL OF A FOOT

1/16	3/32	1/8	3/16	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1	2	3	4	5	6	7	8	9	10	11
.0052	.0078	.0104	.0156	.0208	.0260	.0313	.0417	.0512	.0625	.0729	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167



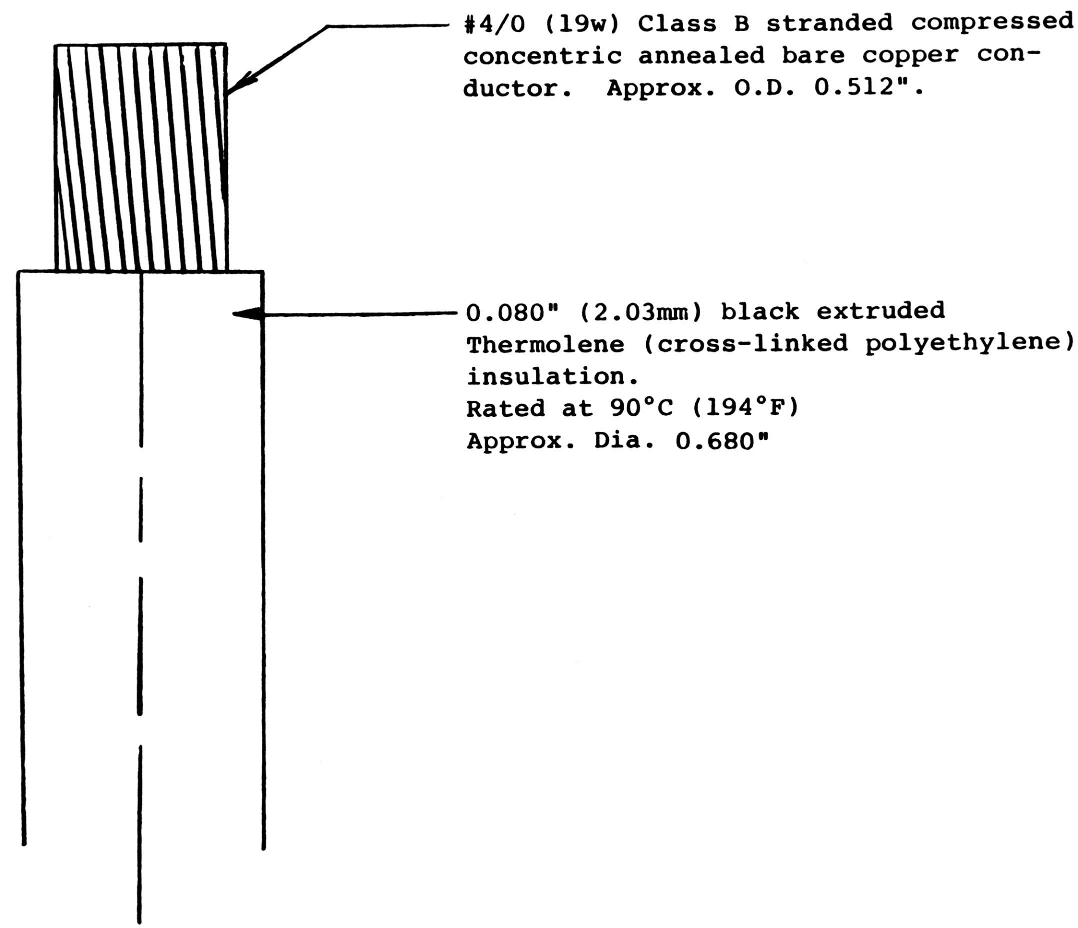
O.D. Over	Min	Max
Insulation	1.270"	1.330"
Insulation Shield	1.350"	1.450"

THREE CONDUCTOR
500 KCMIL COATED COPPER, CROSS-LINKED POLYETHYLENE INSULATION, SHIELDED, WITH GROUNDWIRES, GALVANIZED STEEL INTERLOCKED ARMOR, PVC JACKET 15 KV 133% INSULATION LEVEL PER ICEA S-66-524 AEIC CS5-82, UL 1072 TYPE MV-90



Diameters Over	Min	Max
Insulation	0.740"	0.800"
Insulation Shield	0.820"	0.920"

SINGLE CONDUCTOR
1/0 AWG ALUMINUM, CROSSLINKED
POLYETHYLENE INSULATION,
SHIELDED, JACKETED, 15KV 100%
INSULATION LEVEL, PER ICEA
S-66-524 AEIC CS5-87



Single Conductor
600 V rated in accordance with
ICEA S-66-524

CABLE SPECIFICATIONS

This example specification section is intended to be used as a basis for the development of individual specifications, or in the preparation of specifications for a particular project. In either case, these guide specifications must be edited to fit the conditions of use and adapted to a particular cable size, or group.

For a specification that covers a group of cables, it is advisable to incorporate a table or chart in the back of the specification to outline or reiterate specific construction details and parameters. Assigning an item code number also helps identify individual cables, especially items with similar constructions; i.e., same item with reduced neutral, or same item triplexed or parallel.

Ideally a specification should relate the performance desired and expected from the product. To avoid writing a specification that precludes the implementation of good, sound manufacturing techniques, or the use of compatible, good materials (maybe better), is the responsibility of the specification writer.

The specification writer should analyze available data to prove the need for a particular requirement. Should a limiting or restricting requirement be offered for inclusion in a specification; supporting data should be solicited and carefully examined before that requirement is in fact, included. This simple step will reduce the proliferation of specification requirements which do little more than reduce technically sound, and competitive offerings from cable manufacturers.

600V UL TYPE TC
POWER AND CONTROL TRAY CABLE

Multiconductor power cable rated 600 volts, 90 C normal continues **for critical circuits in tray application** UL listed as Type TC.

Conductor: Bare copper Class B strand per ICEA S-68-516, Part 2.

Insulation: Shall be Type II Ethylene Propylene in accordance with ICEA S-68-516, Part 3.7. Thickness shall be per Table 3-1.

Fillers: (optional) Shall be suitable nonhygroscopic fillers.

Grounding Conductors: Shall be bare copper Class B per ICEA S-68-516, Part 2. Size shall be in accordance with UL 1277, Part 6.

Cabling Insulated conductors shall be assembled per ICEA S-68-516, Part 5.

Overall Cable Jacket: Shall be Chlorosulphonated polyethylene per ICEA S-68-516, Part 4 or Chlorinated Polyethylene (CPE) meeting the following physical requirements:

Tensile Strength, min.	1400 psi	
Elongation, min.	150%	
Air Oven Test	Percent of Original	
168 hours at 121 C	Tensile	85
	Elongation	50

Identification: Individual conductors shall be UL listed as VW-1 and colored or printed by the sequence detailed in Table L-2 of ICEA S-66-524. Surface printing on the overall jacket shall be a contrasting color consisting of manufacturer's name, locatin, cable type, cable size, and voltage rating.

Tests: Finished cable shall be tested in accordance with ICEA S-68-516 and shall meet UL 1277 flame test.

Documentation: Manufacturere shall furnish certified test reports showing compliance with electrical requirements of ICEA S-68-516 and UL 1277 flame test.

Standards: Cable and materials shll meet the following standards, most recent editins, as cited herein:

ICEA S-68-516
UL 1277
ICEA S-66-524 (Color Code only).

600V SINGLE CONDUCTOR POWER CABLE

Single conductor, copper power cable, rated 600 volts, 90 C normal operating, 130 C emergency, 250 C short circuit. UL listed Type RHHH, RHW, USE and VW-1. For critical circuits.

Conductor: Bare copper class B strand per ICEA S-68-516, Part 2.

Separator Tape: If required, shall be of an opaque Mylar tape, applied between conductor and insulation material.

Insulation: Ethylene propylene rubber per ICEA S-68-516, Part 3. Thickness shall be in accordance with ICEA S-68-516, Table 3-1.

Jacket: If required, shall be chlorosulfonated polyethylene in accordance with ICEA S-68-516, Part 4.4.9.

Identification: Cable shall be surface printed with a contrasting color consisting of the manufacturer's name, location, cable size, cable type and voltage rating.

Finished Cable Tests: Manufacturer shall furnish certified test reports showing compliance with ICEA S-68-516, Part 3 and UL 44.

Listings: Finished cable shll be UL listed as Type RHH, RHW, USE, and VW-1 rated. Size 250 MCM and larger shll be listed "For CT Use".

Standards: Cable and materials shall meet the following standards, most recent editions as cited herein:

UL 44, Eleventh Ed., Rev. May 83.

SPECIFICATION FOR 5kV THROUGH 35kV SHIELDED POWER CABLE

1.Ø SCOPE

1.1 This specification covers single conductor Solid Dielectric TRXLPE insulated power cable for use on a single phase or three phase 15 kV 6Ø Hertz grounded neutral system.

1.2 The cable shall be suitable for use in wet and dry locations in underground conduits or ducts and direct earth burial.

1.3 Finished cable shall be UL listed as Type MV-9Ø and Sunlight Resistant.

1.4 The insulation level shall be 133%.

2.Ø GENERAL

The cable specified herein shall meet the requirements of the latest edition of AEIC Specification CS-5, UL 1Ø72, and ICEA Standard S-66-524. Where a difference between this specification and others referenced herein exist, this specification shall govern. The cable and all its components shall be designed to operate satisfactorily at a normal temperature of 9Ø degrees C conductor, an emergency temperature of 13Ø degrees C conductor and short circuit temperature of 25Ø degrees C.

3.Ø CONDUCTOR

A. Copper conductor (when specified), shall be uncoated soft drawn-annealed,Class B compressed concentric lay strand in accordance with ASTM Standard B3.

B. Aluminum conductor shall be Class B compressed concentric lay stranded EC 135Ø Alloy, H19 temper in accordance with ASTM Standard B23Ø. If a solid aluminum conductor is specified the intermediate temper shall be 1/2 or 3/4 hard per ASTM B6Ø9.

3.2 The inner interstices of the stranded conductor shall be continuously filled with a semi-conducting compound so as to render the conductor incapable of transmitting moisture. The compound shall be flexible and stable under the conditions imposed by cable operation according to the test requirements per ICEA No. P-XX-61Ø, "Guide for performance of a Longitudinal Water Penetration Resistance Test for Sealed Conductors" and be fully compatible with the conductor, conductor shield and insulation.

4.Ø CONDUCTOR SHIELD

4.1 The conductor shield shall be extruded and the material used shall be a conducting, thermosetting polymer that is compatible with the underlying conductor metal and the overlying insulation.

4.2 The conductor shield shall be thoroughly bonded to the overlying insulation and shall be tight fitting, yet strippable from the underlying conductor.

4.3 The thickness of the extruded conductor shield shall be in accordance with AEIC CS5 or AEIC C56.

5.Ø INSULATION

5.1 The insulation shall be unfilled, clean tree retardant crosslinked polyethylene (TRXLPE). It shall be applied at the same time as the conductor and insulation shields and cured or crosslinked simultaneously with those components.

5.2 The minimum average insulation thickness shall be 22Ø mils.

5.3 The insulation shall comply with the requirements of the latest editions of AEIC CS5 and ICEA S-66-524.

6.Ø INSULATION SHIELD

6.1 The cable shall have extruded directly over the insulation a semi-conducting, thermoset polymer in accordance with AEIC CS5.

6.2 The extruded insulation shield shall adhere tightly yet be readily strippable from the underlying insulation and shall be compatible with all materials with which it comes in contact. The tension required to strip the insulation shield shall be in accordance with AEIC CS5.

6.3 The average thickness of the extruded shielding material shall be in accordance with AEIC CS5.

7.0 METALLIC SHIELD

7.1 Metallic shielding component shall be in accordance with ICEA S-66-524 as a minimum requirement.

7.2 Fault current sizing (if applicable) will be specified with request for quotation.

8.0 JACKET

8.1 An outer black PVC jacket meeting the requirements of ICEA section 4 shall be provided, extruded over the mylar separator tape if drain wires are supplied or extruded directly over the copper tape shield.

8.2 The jacket shall be of smooth and uniform composition and free of porosity, holes, cracks, blisters, or other imperfections.

9.0 IDENTIFICATION OF CABLE

Cable shall have identification according to UL 1072 Type MV-90 with a sequential footage marker. The sequential number shall be printed every 2 feet.

10.0 CABLE REELS

10.1 The cable shall be shipped on non-returnable wood reels in lengths specified in the Quotation Request.

10.2 The reel drum diameter shall be in accordance with NEMA Publication No. WC 26-1984.

10.3 The inner drum end of the cable, when allowed to project through the flange of the reel, shall be protected to avoid injury to the cable or cable seal.

11.Ø IDENTIFICATION OF REEL

Reel shall have identification according to AEIC CS-5 (latest edition).

12.Ø PACKING, SEALING AND SHIPPING

12.1 Each end of each lengths of cable shall be durably sealed before shipment to prevent entrance of moisture.

12.2 The cable shall be placed on the reels in such a manner that it will be protected from injury during shipment. Care shall be taken to prevent the reeled cable from becoming loose. Each end of the cable shall be firmly and properly secured to the reel.

12.3 The reels shall be covered with suitable material to provide physical protection for the cables during transit and during ordinary handling operations and storage.

12.4 Reels shall be securely blocked in position so that they will not shift during transit.

13.Ø TESTS AND TEST REPORTS

13.1 All tests indicated in this specification shall be performed in accordance with the test procedures as described in ICEA Standard S-66-524 and AEIC CS-5 (latest edition) as applicable.

13.2 An X-Y recording of the apparent discharge (ADC) level of each reel, tested in accordance with procedure described in AEIC CS-5 (latest edition), shall become a part of the certified test reports specified in 13.3 of this Specification.

13.3 The Manufacturer shall furnish a copy of a certified test report of tests covered in this specification and of all non-listed standard tests.

14.Ø QUALIFICATION TYPE TESTS

14.1 The manufacturer shall have on file a copy of the latest AEIC qualification test report that represents the cable being supplied. A change in compound material would require re-qualification and new reports should be submitted.

SPECIFICATION FOR 15kV RATED URD CABLE

1.Ø SCOPE

1.1 This specification covers single conductor Solid Dielectric TRXLPE insulated underground residential distribution (URD) cable for use on a single phase 15 kV 6Ø Hertz grounded neutral system.

1.2 The cable shall be suitable for use in wet and dry locations in underground conduits or ducts and direct earth burial.

1.3 The insulation level shall be 133%.

2.Ø GENERAL

The cable specified herein shall meet the requirements of the latest edition of AEIC Specification CS-5 and ICEA Standard S-66-524. Where a difference between this specification and others referenced herein exist, this specification shall govern. The cable and all its components shall be designed to operate satisfactorily at a normal temperature of 9Ø degrees C conductor, an emergency temperature of 13Ø degrees C conductor and short circuit temperature of 25Ø degrees C.

3.Ø CONDUCTOR

A. Copper conductor (when specified), shall be uncoated soft drawn-annealed,Class B compressed concentric lay strand in accordance with ASTM Standard B3.

B. Aluminum conductor shall be Class B compressed concentric lay stranded EC 135Ø Alloy, H19 temper in accordance with ASTM Standard B23Ø. If a solid aluminum conductor is specified the intermediate temper shall be 1/2 or 3/4 hard per ASTM B6Ø9.

3.2 The inner interstices of the stranded conductor shall be continuously filled with a semi-conducting compound so as to render the conductor incapable of transmitting moisture. The compound shall be flexible and stable under the conditions imposed by cable operation according to the test requirements per ICEA No. P-XX-61Ø, "Guide for performance of a Longitudinal Water Penetration Resistance Test for Sealed Conductors" and be fully compatible with the conductor, conductor shield and insulation.

4.Ø CONDUCTOR SHIELD

4.1 The conductor shield shall be extruded and the material used shall be a conducting, thermosetting polymer that is compatible with the underlying conductor metal and the overlying insulation.

4.2 The conductor shield shall be thoroughly bonded to the overlying insulation and shall be tight fitting, yet strippable from the underlying conductor.

4.3 The thickness of the extruded conductor shield shall be in accordance with AEIC CS5 or AEIC C56.

5.Ø INSULATION

5.1 The insulation shall be unfilled, clean tree retardant crosslinked polyethylene (TRXLPE). It shall be applied at the same time as the conductor and insulation shields and cured or crosslinked simultaneously with those components.

5.2 The minimum average insulation thickness shall be 22Ø mils.

5.3 The insulation shall comply with the requirements of the latest editions of AEIC CS5 and ICEA S-66-524.

6.Ø INSULATION SHIELD

6.1 The cable shall have extruded directly over the insulation a semi-conducting, thermoset polymer in accordance with AEIC CS5.

6.2 The extruded insulation shield shall adhere tightly yet be readily strippable from the underlying insulation and shall be compatible with all materials with which it comes in contact. The tension required to strip the insulation shield shall be in accordance with AEIC CS5.

6.3 The average thickness of the extruded shielding material shall be in accordance with AEIC CS5.

7.Ø CONCENTRIC NEUTRAL

7.1 A concentric neutral conductor shall be tightly applied over the extruded semi-conducting insulation shield. It shall meet the requirements in accordance to ICEA S-66-524 Section 7.1.5.

7.2 The cable shall be supplied with a full neutral concentric conductor.

7.3 The concentric neutral conductor shall consist of bare soft drawn copper wires.

8.Ø JACKET

8.1 The cable shall have an encapsulating outer jacket to cover the concentric neutral conductor and fill the spaces between the wires, and be free stripping from the extruded insulation shield and concentric neutral wires.

8.2 The jacket shall be of smooth and uniform composition and free of porosity, holes, cracks, blisters, or other imperfections.

8.3 The jacket material shall be Linear Low Density Polyethylene and it shall meet the applicable requirements specified in ICEA Publication S-66-524 Section 4.4.2. The jacket thickness shall be per ICEA S-66-524 Section 7.1.6.1.

9.Ø IDENTIFICATION OF CABLE

Cable shall have identification according to AEIC CS-5 (latest edition) and a sequential footage marker. The sequential number shall be printed every 2 feet.

1Ø.Ø CABLE REELS

1Ø.1 The cable shall be shipped on non-returnable wood reels in lengths specified in the Quotation Request.

1Ø.2 The reel drum diameter shall be in accordance with NEMA Publication No. WC 26-1984.

1Ø.3 The inner drum end of the cable, when allowed to project through the flange of the reel, shall be protected to avoid injury to the cable or cable seal.

11.Ø IDENTIFICATION OF REEL

Reel shall have identification according to AEIC CS-5 (latest edition).

12.Ø PACKING, SEALING AND SHIPPING

12.1 Each end of each lengths of cable shall be durably sealed before shipment to prevent entrance of moisture.

12.2 The cable shall be placed on the reels in such a manner that it will be protected from injury during shipment. Care shall be taken to prevent the reeled cable from becoming loose. Each end of the cable shall be firmly and properly secured to the reel.

12.3 The reels shall be covered with suitable material to provide physical protection for the cables during transit and during ordinary handling operations and storage.

12.4 Reels shall be securely blocked in position so that they will not shift during transit.

13.Ø TESTS AND TEST REPORTS

13.1 All tests indicated in this specification shall be performed in accordance with the test procedures as described in ICEA Standard S-66-524 and AEIC CS-5 (latest edition) as applicable.

13.2 An X-Y recording of the apparent discharge (ADC) level of each reel, tested in accordance with procedure described in AEIC CS-5 (latest edition), shall become a part of the certified test reports specified in 13.3 of this Specification.

13.3 The Manufacturer shall furnish a copy of a certified test report of tests covered in this specification and of all non-listed standard tests.

14.Ø QUALIFICATION TYPE TESTS

14.1 The manufacturer shall have on file a copy of the latest AEIC qualification test report that represents the cable being supplied. A change in compound material would require re-qualification and new reports should be submitted.

REFERENCES

[1] ICEA S-66-524 NEMA PUB. NO. WC-7, ICEA S-68-516, NEMA PUB. NO. WC-8 for XLPE and EPR wire and cables.

[2] AEIC CS5, CS6, CS7 for XLPE and EPR shielded power cables.

[3] Electric Cables Materials and Constructions, J.L. Steiner

[4] National Electrical Code 1987, NFPA Publ.

[5] Standard Handbook for Electrical Engineers, Fink and Beaty

[6] Material Data Sheet, Union Carbide

[7] Aluminum Electrical Conductor Handbook, The Aluminum Assc.

[8] Underground Systems Reference Book, Edison Electric Institute.

[9] UL 1072 Medium Voltage Power Cables

[10] Specification REA U-1

[11] ASTM Standard D 1248, Standard Specifications for Polyethylene Plastics Molding and Extrusion Materials

[12] ASTM Standards: B230, B231, B406, B3, B8

[13] ASTM Standards: B33, B189, B29.

[14] Guide for Selecting and Testing Jackets for Cables, IEEE-ANSI Standard 532-1982,1983.

[15] Guide for Selection and Design of Aluminum Sheaths for Cables, IEEE/ANSI Standard 635,1980.

[16] EPR-Based URD Insulation:"A Question of Confidence" Morton Browm.

[17] IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants, STD 141-1976

DATA REGISTER LOADING INSTRUCTIONS

An example is given below on how to load data in main memory to a data file in extended memory. Note, that a data file contains two data header registers along with the data registers.

The following procedure can be applied to load desired data registers:

DATA REGISTER	FUNCTION
* "STC", "STA", "SAL"	Weights
"A", "B", "C"	Conductor diameters
"AWG"	AWG diameters
* "CTD"	Control Cable Factors

* Optional

STEP	INSTRUCTION	EXAMPLE
1.	Execute size	XEQ 025
2.	Load data by card or enter manually into main memory	18 Registers (05-022)
3.	Put file name in alpha	"C"
4.	Enter 20 (18+2)	20
5.	Create data file	XEQ CRFLD
6.	Put file name in alpha	"C"
7.	Enter index value (05.022 +1)	05.023
8.	Move data to data file	XEQ "SAVERX"

USER INSTRUCTIONS

MODE: Medium Voltage Without Component Weights

SIZE: 026

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "CD", "TT", "MN", "kV", "IS", "ESS", "JK". **Optional Programs:** Control: "CT" Secondary: "VV" Weights: "WGT", "SG" Weight Components: "CNW", "FS", "LC", "CU", "JKT", "CW"		
4.	Clear Flag 05		
5.	Initialize: XEQ **"CD"**		Select A,B,C
6.	Select conductor type: **A = Solid** **B = Compact** **C = Compressed**	A,B,C	
7.	Enter conductor size in AWG or kcmil.Note: 1/0 = 10, 2/0 = 20 3/0 = 30, 4/0 = 40.	AWG or kcmil	AWG?:KCMIL?
8.	Number of strands and Diameter of Conductor, mils.		XXW O.D=
9.	Enter system voltage rating, kV. (displayed only if conductor size is greater than 4/0 AWG).	kV	kV? kV=
10.	Display/Enter adder (enter if voltage rating over 69kV), mils.		0,10,15,or 20

STEP	INSTRUCTIONS	INPUT	DISPLAY
11.	Extruded Strand Shield thickness per AEIC; R/S or enter desired ESS thickness, mils.	* ESS	ESS/AEIC= ESS=
12.	Enter Insulation Thickness, mils	INSL	INSL?
13.	Diameters over insulation Minimum ---- Maximum, mils	-	XXXX---XXXX
14.	Extruded Insulation Shield Thickness (nominal) per AEIC; R/S or enter desired EIS, mils.	* EIS	AEIC= EIS=
15.	Diameters over EIS Minimum ---- Maximum, mils	-	XXXX---XXXX
16.	Enter AWG wire size #8 AWG - #24 AWG **Note: Enter zero if no concentric wires apply**	AWG or zero	AWG?
17.	Minimum Diameter over Wires in inches.	-	MIN=
18.	Enter Adder for Tape Shields, Separator tapes, LC shield, Metallic Sheaths, in mils	Adder	Adder?
19.	Display outer Jacket Thickness for sleeved on (non-encapsulating) type jackets per ICEA. R/S, or enter desired thickness, mils. (See comment on last page) **NOTE: Enter zero if non - Jacketed construction.**	* JKT	JKT:ICEA=

STEP	INSTRUCTIONS	INPUT	DISPLAY
20.	Diameters over outer jacket (or Metallic shield/sheath) if non-jacketed, mils. **Minimum ---- Maximum**	-	XXXX---XXXX
21.	Display Circumscribed Nominal Triplexed O.D. of 3 Single cables, inches.	-	3/C O.D=
22.	Enter Adder for Binder tapes, or Sheaths mils.	Adder	ADDER?
23.	Display Minimum O.D over Adder Component. inches	-	MIN =
24.	Overall Outer Jacket thickness per ICEA for multiconductor cables without Metallic armor, mils. R/S, or enter desired thickness.	* JKT	JKT:ICEA=
25.	Overall Nominal Diameter of complete multiconductor assembly, inches.	-	3/C O.D =
26.	Display Maximum Diameter of Ground Wire that can fit in the outer Interstice of the cable, inches.	-	MX.GW.DIA=

* Input only where applacable

NOTE: Encapsulating Jacket thickness per ICEA is 50 mils when the minimum O.D given in step 17 is less than or equal to 1.5", and 80 mils if greater than 1.5" (over concentric neutral wires).

USER INSTRUCTIONS

MODE: Medium Voltage With Component Weights

SIZE: 026

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "CD", "TT", "MN", "kV", "IS", "ESS", "JK"."WGT" "SG" **Optional Programs:** Control: "CT" Secondary: "VV" Weights: "WGT", "SG" Weight Components: "CNW", "FS", "LC", "CU", "JKT", "CW"		
4.	**SET Flag 05**	**SF 05**	
5.	Initialize: XEQ **"CD"**		Select A,B,C
6.	Select conductor type: **A = Solid** **B = Compact** **C = Compressed**	A,B,C	
7.	Enter conductor size in AWG or kcmil.**Note: 1/0 = 10, 2/0 = 20 3/0 = 30, 4/0 = 40**	AWG or **kcmil**	AWG?:KCMIL?
8.	Number of strands and Diameter of Conductor, mils.		XXW O.D=
9.	Enter system voltage rating, kV. (displayed only if conductor size is greater than 4/0 AWG).	kV	kV? kV=
10.	Display/Enter adder (enter if voltage rating over 69kV), mils.	*	0,10,15,or 20

STEP	INSTRUCTIONS	INPUT	DISPLAY
11.	Select Type Metal: **1 = Aluminum** **2 = Copper**	1 or 0	AL:1 / CU:0
12.	Weight per 1000 Feet of ESS and Metal Conductor, lbs.	-	WT/MFT=
13.	Extruded Strand Shield thickness per AEIC; R/S or enter desired ESS thickness, mils.	* ESS	ESS/AEIC= ESS=
14.	Enter Insulation Thickness, mils	INSL	INSL?
15.	Diameters over insulation **Minimum ---- Maximum, mils**	-	XXXX---XXXX
16.	Enter Specific Gravity of Insulation.	SG	SG?
17.	Weight of Insulation Compound per 1000 ft, lbs.	-	XXX.XX LB
18.	Extruded Insulation Shield Thickness (nominal) per AEIC; R/S or enter desired EIS, mils.	* EIS	AEIC= EIS=
19.	Diameters over EIS **Minimum ---- Maximum, mils**	-	XXXX---XXXX
20.	Enter Specific Gravity of EIS	SG	SG?
21.	Weight of EIS compound/MFT	-	XXX.XX LB
22.	Recall Register 25 to display total core weight at this point	RCL 25	XXX.XX LB
23.	Enter AWG wire size #8 AWG - #24 AWG **Note:** Enter zero if no concentric wires apply	AWG or zero	AWG?
24.	Minimum Diameter over Wires in inches.	-	MIN=
25.	Enter Adder for Tape Shields, Separator tapes, LC shield, Metallic Sheaths, in mils	Adder	Adder?

26.	Display outer Jacket Thickness for sleeved on (non-encapsulating) type jackets per ICEA. R/S, or enter desired thickness, mils. **NOTE:** Enter zero if non - Jacketed construction.	* JKT	JKT:ICEA=
27.	Diameters over outer jacket (or Metallic shield/sheath) if non-jacketed, mils. **Minimum ---- Maximum**	-	XXXX---XXXX
28.	Display Circumscribed Nominal Triplexed O.D. of 3 Single cables, inches.	-	3/C O.D=
29.	Enter Adder for Binder tapes, or Sheaths mils.	Adder	ADDER?
30.	Display Minimum O.D over Adder Component. inches	-	MIN =
31.	Overall Outer Jacket thickness per ICEA for multiconductor cables without Metallic armor, mils. R/S, or enter desired thickness.	* JKT	JKT:ICEA=
32.	Overall Nominal Diameter of complete multiconductor assembly, inches.	-	3/C O.D =
33.	Display Maximum Diameter of Ground Wire that can fit in the outer Interstice of the cable, inches.	-	MX.GW.DIA=

* Input only if applicable

NOTE: Encapsulating Jacket thickness per ICEA is 50 mils when the minimum O.D given in step 24 is less than or equal to 1.5"and 80 mils if greater than 1.5" (over concentric neutral wires).

USER INSTRUCTIONS

MODE: TRPX & QUAD 600V Secondary Cables

SIZE: 026

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "CD", "TT", "MN", "kV", "IS", "ESS", "JK", "VV". **Optional Programs:** Control: "CT" Secondary: "VV" Weights: "WGT", "SG" Weight Components: "CNW", "FS", "LC", "CU", "JKT", "CW"		
4.	Clear Flag 05		
5.	Initialize: XEQ "CD"		Select A,B,C
6.	Select conductor type: A = Solid B = Compact (Class B) C = Compressed (Class B)	A,B,C	
7.	Enter Phase Conductor size in AWG or kcmil.Note: 1/0 = 10, 2/0 = 20 3/0 = 30, 4/0 = 40.	AWG or kcmil	AWG?:KCMIL?
8.	Number of strands and Diameter of Conductor, mils.		XXW O.D=
9.	Enter system voltage rating, kV. (displayed only if conductor size is greater than 4/0 AWG).	kV	kV? kV=

STEP	INSTRUCTIONS	INPUT	DISPLAY
10.	Extruded Strand Shield thickness per AEIC; Enter Zero	0	ESS/AEIC= ESS=0
11.	Select type of Cable: 0 = Control 1 = Secondary	1	CT:0 / SC:1?
12.	Enter Insulation Thickness, mils	INSL	INSL?
13.	Nominal Diameter over insulation in mils.	-	NOM =
14.	Enter Neutral Conductor size AWG or kcmil.	AWG or kcmil	AWG/:KCMIL?
15.	Number of strands and diameter of conductor.	-	XXW: O.D=
16.	Enter Insulation Thickness of Neutral Conductor (zero if bare).	INSL	INSL?
17.	Nominal O.D of Neutral Cable.	-	NOM=
18.	Choose Assembly: 1 = Triplexed 0 = Quadruplexed	1 or 0	TX:1 / QD:0
20.	Nominal O.D. over complete Triplexed or Quadruplexed Assembly.	-	NOM: O.D=

USER INSTRUCTIONS

MODE: Control & Instrumentation Cables

SIZE: 026

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "CD", "TT", "MN", "kV", "IS", "ESS", "JK", "CT". **Optional Programs:** Control: "CT" Secondary: "VV" Weights: "WGT", "SG" Weight Components: "CNW", "FS", "LC", "CU", "JKT", "CW"		
4.	Clear Flag 05		
5.	Initialize: XEQ "CD"		Select A,B,C
6.	Select conductor type: A = Solid B = Compact (Class B) C = Compressed (Class B)	A,B,C	
7.	Enter Conductor size in AWG or kcmil.Note: 1/0 = 10, 2/0 = 20 3/0 = 30, 4/0 = 40.	AWG or kcmil	AWG?:KCMIL?
8.	Number of strands and Diameter of Conductor, mils.		XXW O.D=
9.	Enter system voltage rating, kV. (displayed only if conductor size is greater than 4/0 AWG).	kV	kV? kV=

STEP	INSTRUCTIONS	INPUT	DISPLAY
10.	Extruded Strand Shield thickness per AEIC; Enter Zero	0	ESS/AEIC= ESS=0
11.	Select type of Cable: 0 = Control 1 = Secondary	0	CT:0 / SC:1?
12.	Enter Insulation Thickness, mils	INSL	INSL?
13.	Nominal Diameter over insulation in mils.	-	NOM =
14.	Enter number of conductors in assembly.	N	NO:CDTR?
15.	Enter adder for Binder or separator tapes, mils.	ADDER	ADDER?
16.	Minumum O.D. over binder tape	-	MIN=
17.	Outer jacket thickness per ICEA. R/S, or enter desired thickness, mils.	*	JKT:ICEA= M/C O.D=
18.	Minimum Diameter over complete assembly.	-	MIN =

* Input only if applicable

USER INSTRUCTIONS

MODE: Manual Input of Conductor Diameters

SIZE: 026

STEP	INSTRUCTIONS	INPUT	DISPLAY
ROM STEP 7			
8.	After BEEP, enter diameter of conductor in inches.	dia.	DIA:INCH?
9.	Display Diameter of Conductor		OW O.D=
10.	Select Metal:	1 or 0	AL:1/CU:0
11.	Enter weight of metal conductor and ESS.	WT	WT/MFT?
12.	Enter estimated O.D over ESS	O.D	EST.O.D:ESS?

Continue to next step in appropriate program

PRINTER ROUTINES

```
01♦LBL "VW"
02 CF 21
03 FC? 55
04 GTO 01
05 SF 21
06 ACA
07 SF 12
08 ACX
09 PRBUF
10 TONE 5
11 CF 12
12 RTN
13♦LBL 01
14 ARCL X
15 AVIEW
16 TONE 5
17 STOP
18 RTN
19 END
```

```
01♦LBL "AV"
02 CF 21
03 FC? 55
04 RTN
05 SF 21
06 ACA
07 ACX
08 ADV
09 RTN
10 END
```

SAMPLE PROBLEM

```
    XEQ "CD"
SELECT: A,B,
C:
         XEQ C
AWG?: KCMIL?
        1000   RUN
AWG?: KCMIL? 1000
61W O.D=1117

KV?
   25     RUN
KV? 25KV
           10
ESS/AEIC=25
          RUN
ESS=25

INSL?
  260     RUN
INSL? 260 MILS
1695---1755

AEIC= 70
          RUN
EIS= 70
1835---1935

AWG?
   12     RUN
AWG?  12
MIN = 1.995
ADDER?
   16     RUN
ADDER? 16 MILS
JKT:ICEA=110
          RUN
JKT=  110 MILS
2235---2385

3/C O.D=4.98
ADDER?
         30   RUN
ADDER? 30 MILS
MIN = 5.010
          RUN
JKT:ICEA=140
          RUN
JKT=  140 MILS
3/C O.D=5.32
MX.GW.DIA=1.152
```

```
    XEQ "CD"
SELECT: A,B,
C:
         XEQ C
AWG?: KCMIL?
        1000   RUN
AWG?: KCMIL? 1000
61W O.D=1117

KV?
   35     RUN
KV? 35KV
           15
AL: 1 / CU:
0
    0     RUN
WT/MFT=3154
          RUN
ESS/AEIC=25
          RUN
ESS=25

INSL?
  345     RUN
INSL? 345 MILS
1870---1930

SG?
 .920     RUN
699.57 LB
          RUN
AEIC= 70
          RUN
EIS= 70
2010---2110

SG?
 1.140     RU
            N
225.48 LB
          RUN
AWG?
 12.00     RU
            N
AWG?  12.00
MIN = 2.170
ADDER?
   16     RUN
ADDER? 16 MILS
JKT:ICEA=110
          RUN
JKT=  110 MILS
2410---2560
```

```
3/C O.D=5.36
ADDER?
         30   RUN
ADDER? 30 MILS
MIN = 5.385
          RUN
JKT:ICEA=140
          RUN
JKT=  140 MILS
3/C O.D=5.69
MX.GW.DIA=1.236
```

SAMPLE PROBLEM

```
    XEQ "CD"
SELECT: A,B,
C:
          XEQ C
AWG?: KCMIL?
          14   RUN
AWG?: KCMIL? 14
7W O.D=70

ESS/AEIC=15
    0     RUN
ESS=0
CT: 0 / SC:
1?
    0     RUN
INSL?
   30     RUN
INSL?  30 MILS
NOM:OD=0.130
NO. CDTR?
          12   RUN
NO. CDTR? 12
ADDER?
          20   RUN
ADDER? 20
MIN = 0.560
JKT:ICEA=60
          RUN
JKT=  60 MILS
M/C: OD:
MIN = 0.680
```

```
    XEQ "CD"
SELECT: A,B,
C:
          XEQ C
AWG?: KCMIL?
          40   RUN
AWG?: KCMIL? 40
19W O.D=512

ESS/AEIC=15
    0     RUN
ESS=0
CT: 0 / SC:
1?
    1     RUN
INSL?
   60     RUN
INSL? 60 MILS
NOM:OD=0.638
AWG?: KCMIL?
          10   RUN
AWG?: KCMIL? 10
19W O.D=362

INSL?
   60     RUN
INSL? 60 MILS
NOM:OD=0.488
TX:1 / QD: 0
          1    RUN
M/C O.D:
NOM:OD=1.276
```

DATA REGISTERS FOR WEIGHTS #2 AWG - 1000 kcmil

COPPER STRAND	ALUMINUM STRAND	ALUMINUM Solid
STC	**STA**	**SAL**
R05= 2.3200220	R05= 2.3200077	R05= 2.2920068
R06= 1.3590273	R06= 1.3590092	R06= 1.3230085
R07= 10.4000342	R07= 10.4000115	R07= 10.3590106
R08= 20.4440429	R08= 20.4440143	R08= 20.3990133
R09= 30.4950539	R09= 30.4950178	R09= 30.4440166
R10= 40.5570680	R10= 40.5570226	R10= 40.5000210
R11= 250.6040798	R11= 250.6040261	
R12= 300.6570954	R12= 300.6570311	
R13= 350.7071112	R13= 350.7070361	
R14= 400.7531271	R14= 400.7530411	
R15= 450.7971427	R15= 450.7970459	
R16= 500.8371582	R16= 500.8370509	
R17= 600.9251900	R17= 600.9250613	
R18= 700.9952215	R18= 700.9950712	
*R19= 1.0282373	R19= 0.0000000	
*R20= 1.1793154	R20= 0.0000000	
	* R21= 1.0280761	
	* R22= 1.1791007	

NOTE: Solid Copper not Applicable

* Direct Access Registers
Conductor Size in Program

CONFIGURATION

X X X . Y Y Y . Z Z Z Z

Conductor Size AWG/ kcmil

Estimated O.D. of Conductor and ESS.

Net Weight of Metal Conductor and ESS.

DATA REGISTERS: Diameter Values, Configuration: Conductor Size, Diameter, Strand

A = Solid

```
R05=   14.064
01
R06=   12.081
01
R07=   9.1140
1
R08=   8.1280
1
R09=   6.1620
1
R10=   4.2040
1
R11=   2.2580
1
R12=   1.2890
1
R13=   10.325
01
R14=   20.365
01
R15=   30.410
01
R16=   40.460
01
R17=   250.50
001
R18=   350.59
201
R19=   400.63
301
R20=   500.70
701
R21=   0.0000
0
R22=   0.0000
0
```

B = Compact Class B

```
R05=   0.0000
0
R06=   0.0000
0
R07=   0.0000
0
R08=   8.1340
7
R09=   6.1690
7
R10=   4.2130
7
R11=   2.2680
7
R12=   1.2991
9
R13=   10.336
19
R14=   20.376
19
R15=   30.423
19
R16=   40.475
19
R17=   250.52
037
R18=   350.61
637
R19=   400.65
937
R20=   500.73
637
R21=   750.90
861
R22=   1.0606
1
```

C = Compressed Strand Class B

```
R05=   14.070
07
R06=   12.089
07
R07=   9.1260
7
R08=   8.1410
7
R09=   6.1780
7
R10=   4.2250
7
R11=   2.2830
7
R12=   1.3221
9
R13=   10.362
19
R14=   20.406
19
R15=   30.456
19
R16=   40.512
19
R17=   250.55
837
R18=   350.66
137
R19=   400.70
637
R20=   500.78
937
R21=   750.96
861
R22=   1.1176
1
```

DATA REGISTERS

Concentric Neutral and Drain Wire Diameters
(Two Times Wire Diameter)

AWG

```
R05=   8.257
R06=   9.229
R07=   10.204
R08=   11.181
R09=   12.162
R10=   13.144
R11=   14.128
R12=   15.114
R13=   16.102
R14=   17.091
R15=   18.081
R16=   19.072
R17=   20.064
R18=   22.051
R19=   24.040
```

Control Cable Multiple Factors
(Up To 20 Conductors Per Cable)

CTD

```
R05=   2.2000
R06=   3.2155
R07=   4.2414
R08=   5.2700
R09=   6.3000
R10=   7.3000
R11=   8.3310
R12=   9.3610
R13=   10.400
0
R14=   11.400
0
R15=   12.415
5
R16=   13.424
0
R17=   14.441
4
R18=   15.455
0
R19=   16.470
0
R20=   17.500
0
R21=   18.500
0
R22=   19.500
0
R23=   20.531
0
```

STEP/KEY CODE	COMMENTS
01◆LBL "CD"	"Cable Design"
02 CF 03	Initialize
03 CF 04	
04 SF 27	
05 "SELECT: A,B,C:"	Choose Conductor Type
06 TONE 0	
07 PROMPT	
08◆LBL A	Solid (Aluminum)
09 SF 03	
10 "A"	
11 GTO "QQ"	
12◆LBL B	Compact Strand
13 "B"	
14 GTO "QQ"	
15◆LBL C	Compressed Strand
16 "C"	(Class B)
17◆LBL "QQ"	
18 CF 01	
19 0	
20 SEEKPTA	
21 05.023	Index Value for Data
22 GETRX	Registers
23◆LBL "EA"	
24 5	
25 STO 04	
26 FIX 0	
27 CF 27	Initialize Counter
28 CF 02	
29 CF 29	
30 CF 12	
31 "AWG?: KCMIL? "	Enter Conductor Size in AWG or kcmil
32 TONE 8	Note: 1/0 Enter 10
33 PROMPT	2/0 Enter 20
34 STO 03	
35 XEQ "VA"	Direct Address for
36 STO 00	1000 kcmil
37 1 E3	
38 X=Y?	
39 GTO 06	
40◆LBL 00	
41 RCL 04	Indirect Recall
42 22	to find Diameter and
43 X=Y?	Number of Strands in
44 GTO 03	Conductor
45 RDN	
46 RCL IND X	
47 INT	
48 RCL T	
49 X=Y?	
50 GTO 02	
51 1	
52 ST+ 04	
53 GTO 00	
54◆LBL 02	Take Fraction of
55 RCL L	Data Value
56 FRC	

STEP/KEY CODE	COMMENTS
57 GTO 05	Diameter not in
58◆LBL 03	Register Enter
59 BEEP	Manually
60 "DIA: INCH?"	
61 PROMPT	
62 GTO 05	
63◆LBL 06	
64 RCL 22	
65◆LBL 05	
66 1 E3	
67 *	
68 ENTER↑	
69 INT	
70 STO 00	
71 RCL Y	
72 FRC	
73 100	
74 *	
75 SF 12	Display Diameter
76 CLA	and Number of Wires
77 ARCL X	
78 "⊢W O.D= "	
79 ARCL 00	
80 AVIEW	
81 TONE 5	
82 FC? 21	
83 STOP	
84 RCL 00	
85 FS? 55	
86 ADV	
87 514	Greater Than 4/0?
88 X>Y?	Enter Voltage
89 GTO 07	
90 XEQ "KV"	Adders for Voltage
91 VIEW X	Rating
92 ST+ 00	Add to Core Diameter
93◆LBL 07	
94 FS? 01	If Set GOTO 600V/
95 GTO "VV"	Control -
96 SF 12	Low Voltage Cable
97 FS? 05	
98 XEQ "WGT"	XEQ Component Weight
99 TONE 9	Strand Shield
100 TONE 9	Thickness in Mils.
101 XEQ "ESS"	No Strand Shield (0)
	Automatically Goes
102 X=0?	to low Voltage
103 GTO "VV"	
104 FS? 55	
105 ADV	
106 2	
107 *	Enter Insulation
108 RCL 00	Thickness Mils
109 +	Store Thickness in
110 "INSL?"	REG 23 (t) for
111 PROMPT	Weight
112 STO 23	

STEP/KEY CODE	COMMENTS
113 XEQ "AV"	Display
114 2	
115 *	
116 +	
117 XEQ "TT"	Round-Off per ASTM
118 CLA	
119 ARCL X	
120 STO 00	
121 FS? 02	Above 35kv?
122 XEQ "HV"	HV Deltas for Insula-
123 60	tion
124♦LBL "DD"	
125 +	
126 XEQ "MT"	Display Diameter Min/
127 FS? 05	Max
128 XEQ "SG"	Weight of Extrusion
129 SF 12	Component
130 FIX 0	
131 XEQ "IS"	Insulation Shield
132 "AEIC= "	Thickness per AEIC
133 ARCL X	
134 AVIEW	
135 TONE 8	
136 STOP	Can Override AEIC
137 "EIS= "	Enter EIS
138 ARCL X	
139 STO 23	For Weight Calc
140 AVIEW	
141 2	
142 *	
143 ST+ 00	
144 RCL 00	
145 CLA	
146 ARCL X	
147 FS? 02	Above 35kv?
148 XEQ "VH"	HV Deltas EIS
149 100	
150♦LBL "CC"	
151 +	
152 XEQ "MT"	
153 STO 04	Store Max O.D.
154 FS? 05	
155 XEQ "SG"	
156 "AWG"	
157 0	
158 SEEKPTA	
159 05.020	
160 GETRX	
161 5	Indirect Access Loop
162 STO 01	for AWG Diameter
163♦LBL 10	
164 "AWG? "	
165 PROMPT	Enter Concentric
166 ENTER↑	Neutral or Drain Wire
167 X=0?	Size(#8-#24 AWG.)
168 GTO 14	
169 XEQ "VA"	
170♦LBL 01	Enter 0 if No Wire
171 RCL 01	
172 20	
173 X=Y?	
174 GTO 10	
175 RDN	
176 RCL IND	Indirect Recall
X	Find Diameter of
177 INT	Wire
178 RCL T	
179 X=Y?	
180 GTO 11	
181 1	
182 ST+ 01	
183 GTO 01	
184♦LBL 11	
185 RCL L	
186 FRC	Take Fraction of
187 1 E3	Data Value
188 *	
189♦LBL 08	
190 ST+ 00	
191 RCL 00	
192 XEQ "MN"	Display Min. O.D.
193 FC? 21	Over Wire
194 STOP	
195♦LBL 14	
196 "ADDER?"	Enter Adder to
197 PROMPT	Core for Tapes
198 ST+ 04	
199 XEQ "AV"	
200 ST+ 00	
201 XEQ "JK"	1/c Jacket
202 X=0?	Thickness
203 GTO 12	Displayed per
204 2	ICEA (Can Over-
205 *	ride)
206 ST+ 00	
207 RCL 00	
208 XEQ "TT"	
209 STO 00	
210 CLA	
211 ARCL X	
212 150	
213 +	
214 XEQ "MT"	
215 STO 04	+/-75 Mil Spread
216 75	
217 -	
218 STO 02	
219 GTO 13	Store Max O.D.
220♦LBL 12	
221 RCL 00	
222 XEQ "TT"	Nominal 1/c Dia-
223 CLA	meter
224 STO 00	Non-Jacketed
225 ARCL X	
226 100	
227 +	
228 XEQ "MT"	+/- 50 Mil
229 50	
230 -	
231 STO 02	

STEP/KEY CODE	COMMENTS
232◆LBL 13	Nominal 1/c Diameter
233 RCL 02	
234 2.155	
235 *	Triplexed O.D.
236 XEQ "MC"	
237 "ADDER?"	Display for 3/c Enter Adder for Tapes or Armor
238 PROMPT	
239 XEQ "AV"	
240 +	
241 CF 12	Overall Jacket Thickness Displayed Per ICEA
242 XEQ "MN"	
243 STO 00	
244 STOP	
245 XEQ "JK"	
246 2	
247 *	
248 25	
249 +	
250 RCL 00	
251 +	Extrusion Adder
252 XEQ "MC"	
253 RCL 04	
254 1 E3	Display 3/c O.D. Max O.D. 1/c
255 /	
256 .483	
257 *	
258 FIX 3	Interstice Check
259 "MX.GW.DIA="	
260 ARCL X	Display Maximum Ground Wire Diameter in Outer Interstice
261 AVIEW	
262 END	End

DATA REGISTERS

00	Program Use		
01	Program Use		
02	1/c Diameter		
03	Program Use		
04	Max O.D. 1/c		
05–22	Data Register See Separate Listings		
23	t=thickness in weight		
24	d (weight) ESS EST O.D.		
25	Core Weight (Total)		

STATUS

SIZE 024 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____ AUTO ✓

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
SOLID	A		
COMPACT	B		
STRAND	C		
EA	E		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
01	C	600V/ Control Cable	Med-High kV
02	C	Above 35kV	Below 35 kV
03	C	Solid Cdtr.	Strand Cdtr.
04	C	Copper	Aluminum
05	--	With Weights	Without Weights
12	C	Print Double Wide	Normal Print
21	C	Printer on/off	Disables Printer
27	C	Turns on User Mode	Turns Off User Mode
29	C	Digit Group On	Digit Group Off
55	C	Printer Exists	No Printer

STEP	KEY CODE	COMMENTS
01	♦LBL "VV"	600V Secondary Module
02	FS? 01	Control Cable = 0
03	GTO 00	Secondary Cable = 1
04	"CT: 0 /	
	SC: 1?"	
05	PROMPT	
06	X=0?	
07	XEQ "CT"	
08	♦LBL 00	
09	SF 12	
10	"INSL?"	
11	PROMPT	Enter Insulation Thickness of Phase Conductor (or Neutral
12	XEQ "AV"	Second Time Around) in mils
13	2.1	
14	*	
15	RCL 00	
16	+	
17	XEQ "NM"	2.1 x (Nominal Multiple)
18	X↑2	
19	FS? 01	
20	GTO 01	
21	STO 02	
22	SF 01	
23	GTO "EA"	Back to CD at Label EA to Select Neutral Size
24	♦LBL 01	
25	STO 04	
26	"TX:1 /	
	QD: 0"	
27	PROMPT	
28	X=0?	Triplex = 1
29	GTO 19	
30	RCL 02	Quadruplex = 0
31	2	
32	*	
33	RCL 04	
34	+	
35	3	
36	/	
37	SQRT	Average Circumscribed Outer Diameter
38	2.155	
39	*	
40	GTO 20	
41	♦LBL 19	Triplex
42	RCL 02	
43	3	$\frac{(a + (2 \times b))^2 * 2 + c}{3} * 2.155$
44	*	
45	RCL 04	
46	+	
47	4	Quadruplex
48	/	
49	SQRT	
50	2.414	$\frac{(a + (2 \times b))^2 * 3 + c}{4} * 2.414$
51	*	
52	♦LBL 20	
53	CF 01	
54	"M/C O.D	a = Phase Conductor (dia)
	:"	b = Insulation Thickness (mils)
55	AVIEW	c = Neutral Diameter(Bare or with insulation)
56	XEQ "NM"	
57	.END.	

STEP/KEY CODE	COMMENTS
01◆LBL "CT"	Control Cable Module
02 "CTD"	
03 0	
04 SEEKPTA	
05 05.024	Index Value
06 GETRX	Load Register with
07 SF 12	Multiple Factors up
08 "INSL? "	to 24 Cables per
09 PROMPT	Conductor
10 XEQ "AV"	
11 2	
12 *	
13 RCL 00	
14 +	
15 STO 00	
16 XEQ "NM"	
17◆LBL 00	
18 5	
19 STO 04	
20 "NO. CDTR?"	Enter Number of Conductors in Cable
21 PROMPT	
22 XEQ "VA"	
23 STO 02	
24◆LBL 01	
25 RCL 04	
26 24	
27 X=Y?	
28 GTO 00	Recall Indirect Loop
29 RDN	
30 RCL IND X	
31 INT	
32 RCL 02	
33 X=Y?	
34 GTO 03	
35 1	
36 ST+ 04	
37 GTO 01	
38◆LBL 03	
39 RCL L	
40 FRC	

STEP/KEY CODE	COMMENTS
41 10	Enter Adder for
42 *	Tapes or Armor
43 RCL 00	
44 *	
45 "ADDER?"	
46 PROMPT	
47 XEQ "VA"	
48 +	
49 STO 00	
50 XEQ "MN"	
51 XEQ "JK"	Jacket Thickness
52 2	per ICEA
53 *	
54 RCL 00	
55 +	
56 "M/C: OD:"	Display Minimum Nominal O.D. of
57 AVIEW	Cable
58 XEQ "MN"	
59 END	

STEP	KEY CODE	COMMENTS	STEP	KEY CODE	COMMENTS

Rounds Off Numbers When Called in Accordance With ASTM Standards:

Last Digit:

0,1,2 → 0

3,4,5,6,7 → 5

8,9,10 → 10

```
01♦LBL "TT"
02 ENTER↑
03 INT
04 100
05 /
06 FRC
07 10
08 *
09 FRC
10 10
11 *
12 STO 01
13 X<>Y
14 RCL Y
15 -
16 STO 03
17 RCL 01
18 7
19 X<>Y
20 X>Y?
21 GTO 01
22 GTO 02
23♦LBL 01
24 10
25 RCL 01
26 X=Y?
27 GTO 03
28 RCL 01
29 1
30 +
31 STO 01
32 GTO 01
33♦LBL 02
34 STO 01
35 7
36 X<>Y
37 X<=Y?
38 RCL 01
39 2
40 X<>Y
41 X>Y?
42 GTO 04
43 GTO 05
44♦LBL 04
45 5
46 RCL 01
47 X<=Y?
48 GTO 06
49 GTO 07
50♦LBL 06
51 5
52 RCL 01
53 X=Y?
54 GTO 03
55 RCL 01
56 1
57 +
58 STO 01
59 GTO 06
60♦LBL 07
61 5
62 RCL 01
63 X=Y?
64 GTO 03
65 RCL 01
66 1
67 -
68 STO 01
69 GTO 07
70♦LBL 05
71 STO 01
72 X=0?
73 GTO 03
74 1
75 -
76 GTO 05
77♦LBL 03
78 RCL 03
79 +
80 RTN
81 END
```

STEP	KEY CODE	COMMENTS	STEP	KEY CODE	COMMENTS

```
01♦LBL "MN"      Display and View
02 XEQ "TT"      Modules
03 SF 12
04 FIX 3
05 1 E3
06 /
07 "MIN = "      Display "Min="
08 ARCL X
09 AVIEW
10 TONE 5
11 1 E3
12 *
13 FIX 0
14 RTN
15♦LBL "NM"      Display "Nom:OD="
16 1 E3
17 /
18 SF 12
19 FIX 3
20 "NOM:OD=
"
21 ARCL X
22 AVIEW
23 CF 12
24 1 E3
25 *
26 FIX 0
27 TONE 5
28 FS? 55
29 RTN
30 RTN
31♦LBL "AV"      View With "Mils"
32 CF 21
33 FC? 55
34 RTN
35 SF 21
36 ACA
37 ACX
38 CF 12
39 " MILS"
40 ACA
41 SF 12
42 PRBUF
43 RTN
44♦LBL "VA"      Display for Printer
45 CF 21         if Attached
46 FC? 55
47 RTN
48 SF 21
49 ACA
50 ACX
51 PRBUF
52 RTN
```

```
53♦LBL "MC"      3/c Display
54 FIX 2
55 1 E3
56 /
57 SF 12
58 "3/C O.D
="
59 ARCL X
60 AVIEW
61 TONE 5
62 1 E3
63 *
64 CF 12
65 FIX 0
66 FC? 21
67 STOP
68 RTN
69♦LBL "MT"      Display Space
70 "├---"        Bar
71 ARCL X
72 AVIEW
73 TONE 6
74 FS? 55
75 ADV
76 FS? 55
77 RTN
78 STOP
79 RTN
80 END
```

STEP	KEY CODE	COMMENTS
01	♦LBL "KV"	Kilovolt Adder Module
02	"KV? "	
03	PROMPT	
04	ARCL X	
05	"├KV"	
06	AVIEW	
07	STO 01	15kv = 10mils
08	15	
09	X<>Y	
10	X<=Y?	
11	GTO 01	
12	28	
13	RCL 01	25kv = 10mils
14	X<=Y?	
15	GTO 02	
16	35	
17	RCL 01	28kv = 10mils
18	X<=Y?	
19	GTO 03	35kv = 15mils
20	69	
21	RCL 01	69kv = 20mils
22	X<=Y?	
23	GTO 04	
24	"ADD? 69 ↑"	Greater Than 69kv Enter Adder Manually
25	PROMPT	
26	SF 02	
27	GTO 05	
28	♦LBL 01	
29	0	
30	GTO 05	
31	♦LBL 02	
32	10	
33	GTO 05	
34	♦LBL 03	
35	15	
36	GTO 05	
37	♦LBL 04	
38	SF 02	
39	20	
40	♦LBL 05	
41	RTN	
42	END	

STEP	KEY CODE	COMMENTS
01	♦LBL "IS"	Insulation Shield Thickness per AEIC See Table
02	RCL 00	
03	1 E3	
04	X<>Y	
05	X<=Y?	
06	GTO 01	
07	1500	
08	RCL 00	
09	X<=Y?	
10	GTO 02	
11	GTO 03	
12	♦LBL 01	
13	40	
14	GTO 04	
15	♦LBL 02	
16	50	
17	GTO 04	
18	♦LBL 03	
19	70	
20	♦LBL 04	
21	RTN	
22	♦LBL "HV"	
23	80	
24	GTO "DD"	
25	♦LBL "VH"	
26	120	
27	GTO "CC"	
28	END	

STEP/KEY CODE	COMMENTS	STEP/KEY CODE	COMMENTS

Jacket

Module Automatically Selects Outer Extruded Jacket Thickness For Shielded Single Cable and Outer Jacket For Mutiple Cable Assemblies in Accordance With ICEA S - 66 - 524, S - 68 - 516

```
01◆LBL "JK"
02 RCL 00
03 425
04 X<>Y
05 X<=Y?
06 GTO 01
07 700
08 RCL 00
09 X<=Y?
10 GTO 02
11 1500
12 RCL 00
13 X<=Y?
14 GTO 03
15 2500
16 RCL 00
17 X<=Y?
18 GTO 04
19 140
20 GTO 06
21◆LBL 01
22 45
23 GTO 06
24◆LBL 02
25 60
26 GTO 06
27◆LBL 03
28 80
29 GTO 06
30◆LBL 04
31 110
32◆LBL 06
33 "JKT:ICE
A="
34 ARCL X
35 AVIEW
36 STOP
37 "JKT= "
38 XEQ "AV"
39 RTN
40 .END.
```

Calculated Diameter of Cable Under Jacket	Jacket Thickness
Inches	Mils
0.425 or Less	45
0.426 - 0.700	60
0.701 - 1.500	80
1.501 - 2.500	110
2.501 and Larger	140

Display Jacket Thickness per ICEA

Override Stop to Enter Different Thickness i,e, Encapsulated, Zero, (non Jacketed) Larger or Smaller

Extruded Strand Shield Thickness in Accordance with AEIC

```
01◆LBL "ESS
"
02 RCL 00
03 512
04 X<>Y
05 X<=Y?
06 GTO 01
07 789
08 RCL 00
09 X<=Y?
10 GTO 02
11 1117
12 RCL 00
13 X<=Y?
14 GTO 03
15 30
16 GTO 04
17◆LBL 01
18 15
19 GTO 04
20◆LBL 02
21 20
22 GTO 04
23◆LBL 03
24 25
25◆LBL 04
26 "ESS/AEI
C="
27 ARCL X
28 AVIEW
29 TONE 9
30 STOP
31 "ESS="
32 ARCL X
33 AVIEW
34 RTN
35 .END.
```

Conductor Size AWG or kcmil	Strand Shield Thickness (Mils)
8 - 4/0	15
250 - 500	20
600 - 1000	25
1001 and Larger	30

STEP	KEY CODE	COMMENTS
01	♦LBL "SG"	Specific Gravity for Extrusion Weights
02	RCL 23	
03	1 E3	
04	/	
05	2.1	
06	*	
07	RCL 24	Determines Weight of Extrusion Component
08	STO Z	
09	+	(Insulation, EIS, Leadsheath, Outer Sleeved on Jacket)
10	FIX 3	
11	RND	
12	STO 24	
13	X↑2	
14	RCL Y	$W = (D^2 - d^2)(340.2 \times S.G.)$
15	X↑2	
16	-	
17	"SG?"	
18	PROMPT	
19	340.2	
20	*	
21	*	In Pounds
22	FIX 2	
23	CLA	
24	ARCL X	
25	"⊢ LB"	
26	AVIEW	
27	ST+ 25	
28	STOP	
29	RTN	
30	END	

STEP	KEY CODE	COMMENTS
01	♦LBL "WGT"	<u>Weight Module</u>
02	"AL: 1 / CU: 0"	Set Flag 05 Actuates This Weight Module for Cable Core (Metal CDTR, ESS, Insulation, EIS)
03	TONE 9	
04	PROMPT	
05	X=0?	
06	GTO 15	
07	FS? 03	
08	GTO 23	
09	"STA"	
10	GTO "GWT"	
11	♦LBL 23	Metal Conductor Aluminum or Copper Solid or Strand
12	"SAL"	
13	GTO "GWT"	
14	♦LBL 15	
15	FS? 03	
16	GTO "WGT"	
17	SF 04	
18	"STC"	
19	♦LBL "GWT"	
20	0	
21	SEEKPTA	Index Value to Load Data Register 1000 kcmil and 750 kcmil Direct Access
22	05.023	
23	GETRX	
24	5	
25	STO 04	
26	1 E3	
27	RCL 03	
28	X=Y?	
29	GTO 18	
30	750	
31	X=Y?	
32	GTO 21	
33	♦LBL 16	
34	RCL 04	
35	22	
36	X=Y?	
37	GTO 24	Loop to Find Conductor Weight
38	RDN	
39	RCL IND X	
40	INT	
41	RCL 03	
42	X=Y?	
43	GTO 20	
44	1	
45	ST+ 04	
46	GTO 16	
47	♦LBL 20	
48	RCL L	
49	FRC	
50	♦LBL 17	
51	1 E3	
52	*	
53	ENTER↑	
54	INT	
55	1 E3	
56	/	
57	STO 24	
58	RCL Y	Displays Weight of Conductor and ESS
59	FRC	
60	1 E4	
61	*	
62	STO 25	
63	"WT/MFT="	
64	ARCL X	
65	AVIEW	
66	TONE 4	
67	STOP	
68	RTN	
69	♦LBL 24	Enter Data if Not in Register
70	BEEP	
71	"WT/MFT?"	
72	PROMPT	
73	STO 25	
74	"EST. O. D. ESS?"	
75	PROMPT	
76	STO 24	
77	RTN	
78	♦LBL 21	
79	FS? 04	
80	GTO 22	
81	RCL 21	
82	GTO 17	
83	♦LBL 22	
84	RCL 19	
85	GTO 17	
86	♦LBL 18	
87	FS? 04	
88	GTO 19	
89	RCL 22	
90	GTO 17	
91	♦LBL 19	
92	RCL 20	
93	GTO 17	
94	STOP	
95	END	

Cylindrically Sleeved on Component Weights

```
01♦LBL "CW"
02 CF 27
03 "DIAM L.          Enter Diameter of Last Operation
O.=?"
04 PROMPT
05 STO 00
06 2.1
07 "T?"              Input Thickness of Extruded Component in Inches
08 PROMPT
09 *
10 +
11 X↑2
12 RCL 00
13 X↑2
14 -
15 340.2
16 *
17 "S.G.=?"          Input Specfic Gravity of Material to be Used
18 PROMPT
19 *
20 FIX 2
21 "WGT="            Displays Weight of Component Per MFT
22 ARCL X
23 AVIEW
24 STOP
25 .END.
```

$$W = [\ (\ D + 2.1\ (T))^2 - D^2\ ] \quad x \quad (340.2 \ x \ S.G)$$

Where:

D = Diameter of Last Operation

T = Thickness in Inches

S.G. = Specfic Gravity

340.2 = Conversion Factor

Weight of Concentric Neutral Wires

STEP/KEY CODE	COMMENTS
01♦LBL "CNW"	
02 CF 27	Deactivate User Mode
03 PI	
04 "LAY?"	
05 PROMPT	Input Lay as a Mutiple of the Estimated O.D. Over the Concentric Neutral
06 /	
07 ATAN	
08 COS	
09 1/X	
10 "WIRE WT?"	
11 PROMPT	Input the Weight Per MFT of One Neutral Wire
12 *	
13 "NO WIRES?"	
14 PROMPT	Input the Number of Wires to be Used
15 *	
16 FIX 2	
17 "WGT="	Displays the Weight of the Neutral Wire Per MFT
18 ARCL X	
19 AVIEW	
20 "STOP"	
21 END	

$W = N \times W \times S.F.$

Where:

N = Number of Wires

W = Weight of One Wire

S.F. = Secant Factor

$$= \frac{1}{\cos(\tan^{-1}(\frac{\pi}{Lay}))}$$

Weight of Concentric Neutral Flat Straps

STEP/KEY CODE	COMMENTS
01♦LBL "FS"	
02 CF 27	Deactivate User Mode
03 PI	
04 "LAY?"	
05 PROMPT	Input Lay as a Multiple of the Estimated O.D. Over the Flat Straps
06 /	
07 ATAN	
08 COS	
09 1/X	
10 "T?"	
11 PROMPT	Input the Thick-ness of One Strap Strap
12 "WIDTH=?"	
13 PROMPT	
14 *	
15 3850.06	
16 *	
17 *	
18 "NO STRAPS=?"	Input the Number of Straps
19 PROMPT	
20 *	
21 FIX 2	
22 "WGT="	Displays the Weight of the Flat Straps Per MFT
23 ARCL X	
24 AVIEW	
25 STOP	
26 .END.	

$W = N \times W \times S.F.$

Where:

N = Number of Straps

S.F. = Weight Factor of CU

$$= \frac{1}{\cos(\tan^{-1}(\frac{\pi}{lay}))}$$

W = Weight of One Stra

$= T \times W \times WF \times 1.273$

Where: T = Thickness

W = Width

W.F. = Weight Factor of CU = 3024.4

1.273 = 4/ Conversion Factor to Square Mils

Weight of Longitudinally Applied Copper Tape

STEP/KEY CODE	COMMENTS
01♦LBL "LC"	
02 CF 27	
03 "DIA: L.O. MAX?"	Input the Max Average Diameter of the Last Operation
04 TONE 8	
05 PROMPT	
06 PI	
07 *	
08 .6	
09 +	
10 FIX 3	
11 "WIDTH="	Displays the Width of the Tape - Inches
12 ARCL X	
13 AVIEW	
14 STOP	
15 4625	
16 *	
17 "T?"	
18 PROMPT	Input the Corrugated Tape Thickness - Inches
19 *	
20 FIX 1	
21 "WGT="	Displays the Weight of Corrugated Tape Per MFT
22 ARCL X	
23 AVIEW	
24 STOP	
25 END	

Weight = W x 4625 x t

Where:

W = Width = D + .6

4625 = Conversion Factor

t = Corrugated Tape Thickness

D = Max. O.D. of Last Operation

Enter All Dimensions in Inches

Weight of Helically Applied Copper Tape

STEP/KEY CODE	COMMENTS
01♦LBL "CU"	
02 CF 27	
03 "THICK:INCH?"	
04 PROMPT	Enter the Tape Thickness-Inches
05 STO 00	
06 8.89	
07 *	
08 PI	
09 *	
10 433.5	
11 *	
12 "EST.DIA:LO?"	
13 PROMPT	Enter Estimated Diameter of the Last Operation Under Tape
14 ENTER↑	
15 RCL 00	
16 +	
17 *	
18 STO 01	
19 1	
20 ENTER↑	
21 "OVERLAP?"	
22 PROMPT	Enter Nominal Percent of Overlap
23 ENTER↑	
24 5	
25 +	
26 100	
27 /	
28 -	
29 1/X	
30 RCL 01	
31 *	
32 FIX 2	
33 "T:WT="	Weight of Copper Tape in MFT
34 ARCL X	
35 AVIEW	
36 STOP	
37 END	

$$W = 433.5 \times S.G. \times T \times x(D + T) \times \left(\frac{1}{1 - \frac{L}{100}}\right)$$

Where:

L = Overlap

433.5 = Conversion Factor

S.G. = Specific Gravity

T = Thickness of Tape

D = Estimated Diameter Under Tape

Weight of Encapulating Jackets

```
 01♦LBL "JKT
"
 02 CF 27
 03 "S.G.="
 04 PROMPT          Enter Specfic Gravity of Compound
 05 340.2
 06 *
 07 STO 00
 08 "D=?"
 09 PROMPT          Enter Estimated O.D. Over Jacket in Inches
 10 X↑2
 11 "d=?"
 12 PROMPT
 13 X↑2
 14 -
 15 *
 16 RCL 00
 17 3024.4
 18 /
 19 "NEUT WG        Input Weight of Neutral Wires
T?"
 20 PROMPT
 21 *
 22 -
 23 FIX 2
 24 "WGT="          Weight of Encapsulating Jacket Per MFT
 25 ARCL X
 26 AVIEW
 27 STOP
 28 END
```

$$W = [(D^2 - d^2)\ WF_1] - \left(\frac{WF_1}{WF_2}\ W_1\right)$$

Where:

W = Jacket Weight Per MFT

D = Estimated O.D. Over Jacket in Inches

d = Estimated O.D. Under Neutral in Inches

WF_1= Weight Factor for Jacket Compound(S.G. x 340.2)

WF_2= Weight Factor for Neutral Wires(S.G. x 340.2)

W_1= Weight of Neutral Wires Per MFT

USER INSTRUCTIONS

Size:000

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "COV"		
4.	Check status		
5.	Initialize: XEQ "COV"		
6.	Enter Lay of Wires as multiple of O.D.	Lay	Lay?
7.	Enter number of wires or straps	N	No.Wires?
8.	Enter width of wires or straps in inches	W	W:Inch
9.	Enter maximum O.D. over Insulation shield	Max O.D.	MAX:OD:EIS?
10.	Percent coverage of wires or Straps displayed		% =

STEP/KEY CODE COMMENTS

STEP/KEY CODE	COMMENTS
01♦LBL "COV"	% Coverage of Wire or Straps over Insulation Shield
02 PI	
03 "LAY?"	Enter Lay
04 PROMPT	Multiple (6-10 times)
05 /	
06 ATAN	
07 COS	Secant Factor $\frac{1}{\cos \tan^{-1} \pi/\text{Lay}}$
08 1/X	
09 "NO. WIRES?"	Enter number of Wires or Straps
10 PROMPT	
11 *	
12 "W: INCH?"	Width in Inches
13 PROMPT	
14 *	
15 "MAX:OD:EIS?"	Max. O.D. over EIS
16 PROMPT	
17 PI	
18 *	
19 /	$K = \frac{F_s \; NW}{D}$
20 100	
21 *	
22 FIX 0	
23 "%= "	
24 ARCL X	
25 AVIEW	
26 STOP	
27 END	

K = % coverage
F_s= Secant Factor
N = Number of Wires
W = Width of Wires
D = O.D. (Max) over EIS

```
    XEQ "COV"
LAY?
     7
NO. WIRES?
    32
W: INCH?
 .0808

MAX:OD:EIS?
   .98
%= 92
```

METALLIC SHIELDING CONSTRUCTIONS

Robert W. Parkin

PROGRAM: "MS"

FUNCTION: This program covers the metal shield component of URD/UD and power cables; specifically wire shields. If a copper tape shield is used it must be at least 2.5 mils thick in accoradance with ICEA S-66-524. Wires , straps, or sheaths should be copper and have a total area at any cross section of at least 5000 circular mils per inch (0.1 mm^2 /mm) of insulated conductor diameter. Metal tapes, wires, straps, and sheaths may be used in combination providing they are compatible.

The program first displays the minimum cross-sectional area required per ICEA S-64-524 and the number of wires needed. Then a comparison of the first group of wires "1W" can be made, to determine how many wires are needed to equal the cross-sectional area of the original group.

ACCESSORIES: HP-41 CX, CV printer optional

OPERATING LIMITS AND WARNINGS: None

REFERENCES: ICEA S-66-524

USER INSTRUCTIONS

Size:001

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "MS", "VW"		
4.	Check status		
5.	Initialize: XEQ "MS"		
6.	Enter O.D. over the insulation, inches.	O.D.	O.D.:INSL?
7.	Display minimum cross-sectional area required, per ICEA in circular mils.		CMA=
8.	Enter CSA of copper wire in circular mils	CMIL	CMIL?
9.	Display minimum number of copper wires for cable.		XX.X WIRES
10.	Enter first wire size in circular mils.	1:CSA	1W:CMIL?
11.	Enter number of wires	N	N?
12.	CSA Displayed		CMA=
13.	Second size: Enter CSA	2:CSA	2W:CMIL?
14.	Display number of wires		XX.X Wires
15.	Back to step 13 for comparison of different wire sizes		2W:CMIL?

SAMPLE PROBLEM

```
     XEQ "MS"
O.D: INSL?
  1.5     RUN
CMA= 7500.0
CMIL?
          812.0    RUN
9.2 WIRES



                   RUN
1W: CMIL?
         1290.0    RUN
N?
           36.0    RUN
CMA= 46440.0
2W: CMIL?



         1620.0    RUN
28.7 WIRES

                   RUN
2W: CMIL?
         2580.0    RUN
18.0 WIRES



              XEQ "MS"
O.D: INSL?
            1.5    RUN
CMA= 7500.0
CMIL?
         2580.0    RUN
2.9 WIRES
```

STEP/KEY CODE	COMMENTS
01◆LBL "MS"	Metallic Shielding
02 FIX 1	
03 "O.D: INSL?"	Enter O.D. Over Insulation in Inches
04 PROMPT	
05 5000	
06 *	
07 "CMA="	Minimum Cross-Sectional Area Required
08 XEQ "VW"	
09 "CMIL?"	Enter Desired Shield Wire Cross Section in Circular Mils
10 PROMPT	
11 /	
12 CLA	
13 ARCL X	
14 "⊢ WIRES "	Displays Number of Wires Needed
15 AVIEW	
16 STOP	
17 "1W: CMIL?"	Enter New or Original Wire in Cmil For Comparison to Second Wire Size
18 PROMPT	
19 "N?"	
20 PROMPT	
21 *	
22 STO 00	
23 "CMA="	Area Displayed
24 XEQ "VW"	
25◆LBL 00	
26 TONE 9	
27 RCL 00	
28 "2W: CMIL?"	Enter Next Wire Size in Cmil
29 PROMPT	
30 /	
31 CLA	
32 ARCL X	Number of Wire Needed For Second Wire Size
33 "⊢ WIRES "	
34 AVIEW	
35 STOP	Return to 2W: For Next Size Wire
36 GTO 00	

DATA REGISTERS

00	CSA Number of Wires IW		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

STATUS

SIZE 001 TOT. REG. ____ USER MODE
ENG ____ FIX 1 SCI ____ ON ____ OFF ✓
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
None			

CONCENTRIC NEUTRAL WIRE SIZES AND SELECTION

Robert W. Parkin

PROGRAM: "NL"

FUNCTION: This program covers two-conductor concentric neutral underground distribution cables (URD/UD), consisting of an insulated central conductor and one copper concentric conductor applied helically over the insulation shield. URD/UD cables are intended for use on single phase and three phase primary underground distribution systems operating at 2001 through 35000 volts phase to phase.

Given the area in kcmil and type metal (copper or aluminum) for the phase conductor, the number of concentric neutral wires to equal the conductivity of the phase conductor (full neutral) is displayed, and continues in reduced neutral sizes, i.e., 1/3, 1/6, 1/9 etc., for that conductor.

ACCESSORIES: HP-41 CX or CV, printer optional

OPERATING LIMITS AND WARNINGS: Use the coverage program "COV" to insure that the number of wires applied for a full neutral can fit around the circumference of the cable under the wires.

REFERENCES: ICEA S-66-524

USER INSTRUCTIONS

Size: 004

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "NL","VW"		
4.	Check status		
5.	Initialize: XEQ "NL"		
6.	Enter Phase Conductor size in kcmil	Phase CDTR	kcmil?
7.	Enter Concentric Neutral wire size in kcmil	kcmil	AWG?
8.	Select Type Metal of Phase Conductor: 1 = Aluminum 2 = Copper	1 or 2	AL:1/CU:0
9.	Display Number of Wires for full neutral capacity		FULL=
10.	Number of wires required for 1/3 neutral		/3=
11.	Number of wires for 1/6 1/9, 1/12, etc. - Press R/S to stop if printer is connected.		/6=

SAMPLE PROBLEM

```
    XEQ "NL"
KCMIL?
 1000.0     R
            UN
AWG?
 4.11     RUN
AL:1 / CU:0
  1.0     RUN
FULL= 148.4
/3=49.5 WIRES
              RUN
/6=16.5 WIRES
              RUN
/9=5.5 WIRES
              RUN
/12=1.8 WIRES
```

```
    XEQ "NL"
KCMIL?
 750.0      RU
             N
AWG?
 6.53     RUN
AL:1 / CU:0
  0.0     RUN
FULL= 114.9
/3=38.3 WIRES
              RUN
/6=12.8 WIRES
              RUN
/9=4.3 WIRES
        XEQ "NL"
KCMIL?
       750.0  RUN
AWG?
       10.38  RUN
AL:1 / CU:0
         0.0  RUN
FULL= 72.3
/3=24.1 WIRES
              RUN
/6=8.0 WIRES
```

```
    XEQ "STP"
CMA?
 40,479.0
          RUN
T?
        20.0  RUN
W?
       160.0  RUN
CMA:FS= 4,074.2
9.9 STRAPS
              RUN
T?
        25.0  RUN
W?
       160.0  RUN
CMA:FS= 5,092.8
7.9 STRAPS
              RUN
T?
        30.0  RUN
W?
       150.0  RUN
CMA:FS= 5,729.4
7.1 STRAPS
              RUN
T?
        22.0  RUN
W?
       160.0  RUN
CMA:FS= 4,481.7
9.0 STRAPS
```

Concentric Neutral Wire Selection

STEP/KEY CODE	COMMENTS
01◆LBL "NL"	
02 0	Clear Register 02
03 STO 02	
04 FIX 1	
05 CF 29	
06 "KCMIL?"	Enter Phase
07 PROMPT	Conductor Size in
08 STO 00	kcmil
09 "AWG?"	Enter Concentric
10 PROMPT	Neutral Size Wire
11 STO 01	in kcmil
12 "AL:1 / CU:0"	Select Metal:
13 PROMPT	1 = Aluminum
14 X=0?	2 = Copper
15 GTO 00	
16 RCL 00	If Aluminum Multiply
17 .61	0.61 Times CMA
18 *	(Adjust for Conduc-
19 STO 00	tivity)
20◆LBL 00	
21 RCL 00	
22 RCL 01	
23 /	Display Number of
24 "FULL="	Wires for Full
25 XEQ "VW"	Conductivity
26◆LBL 01	
27 RCL 00	
28 3	
29 ST+ 02	Register 02-Store
30 /	Neutral Capacity
31 STO 00	
32 RCL 01	
33 /	
34 STO 03	
35 CLA	
36 FIX 0	
37 "/"	
38 ARCL 02	
39 "⊢="	
40 FIX 1	Display Number of
41 ARCL 03	Wires for 1/3,1/6,
42 "⊢ WIRES"	1/9 etc.
43 AVIEW	
44 STOP	
45 GTO 01	Return to 01
46 END	

DATA REGISTERS

00	Phase kcmil		
01	CNW's kcmil		
02	Neutral Capacity		
03	Display CNW's		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
29		Digit Grouping	

FLAT STRAP NEUTRALS

Robert W. Parkin

PROGRAM: "STP"

FUNCTION: This program determines helical flat strap neutral arrangements, given the equivalent cross-sectional area required.

The best type of metallic shield or sheath to provide the most copper, (and conductance) with the smallest overall cable diameter is helically applied flat straps. These straps can be sized for service as a full or reduced neutral and carry fault currents while providing mechanical protection to the cable itself.

Tinning the wires in accordance with ASTM B33 is common, and will increase the electrical resistance of the straps. For added protection against physical damage or corrosion an overall sleeved on or encapsulated jacket can be applied.

ACCESSORIES: HP-41 CX or CV, printer optional

OPERATING LIMITS AND WARNINGS: Use the coverage program "COV" to insure that the number of straps applied can fit around the circumference of the cable.

REFERENCES

[1] ASTM B272 Copper Flat Products with Finished (rolled or Drawn) Edges (Flat Wire and Strip)

[2] ASTM B33, ASTM B189

[3] ICEA S-66-524, NEMA WC-7

USER INSTRUCTIONS

Size: 001

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "STP","VW"		
4.	Check status		
5.	Initialize: XEQ **"STP"**		
6.	Enter effective cross-sectional area required in circular mils **NOTE: Aluminum conductors; multiply by .61 if copper straps are used**	CMA	CMA ?
7.	Enter thickness of strap in mils	T	T ?
8.	Enter width of strap in mils	W	W ?
9.	Equivalent cross-sectional area of one strap	-	CMA:FS =
10.	Display number of straps needed	-	X.X Strap
11.	Loop to re-enter thickness and width for different size strap	T	T ?

STEP / KEYCODE COMMENTS

Flat Strap Neutrals

STEP / KEYCODE	COMMENTS
01♦LBL "STP"	Enter Effective Copper Equalvalent, Cross-Sectional Area Required
02 FIX 1	
03 "CMA?"	
04 PROMPT	
05 STO 00	Enter Thickness of Strap in Mils
06♦LBL 01	
07 "T?"	
08 PROMPT	
09 "W?"	Enter Width of Strap in Mils
10 PROMPT	
11 *	
12 1.2732	
13 *	Display CSA of One Flat Strap
14 "CMA:FS="	
15 XEQ "VW"	
16 RCL 00	Display Number of Straps Required
17 X<>Y	
18 /	
19 CLA	
20 ARCL X	
21 "⊢ STRAPS"	Loop to Re-enter t and W
22 TONE 9	
23 AVIEW	
24 STOP	
25 GTO 01	End
26 .END.	

METRIC STRAND CONDUCTOR DESIGN

Robert W. Parkin

PROGRAM: This program determines areas and diameters for compressed and compact concentric strand conductors in metric units. Standard and non-standard conductor sizes can be entered. Dimensions are given in metric units (mm^2) and American Wire Gauge (circular mils).

For concentric class B strand, the individual strands are all equal in size, and consist of successive helical layers that correspond to the aggregate of wires; which is 7,19,37,61,91,127, or 169 wires.

Formulas applied are given with program documentation.

ACCESSORIES: HP-41 CX or CV, printer optional.

OPERATING LIMITS AND WARNINGS: Maximum number of wires can be 169.

REFERENCES: Underground Systems Reference Book, Edison Electric Institute.

USER INSTRUCTIONS

Size: 004

MODE: COMPRESSED CONDUCTOR

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "MET" "VW"		
4.	Check status		
5.	Initialize: XEQ "MET"		
6.	Enter cross section in mm^2	MM^2	MM^2
7.	Circular mil area displayed		CM =
8.	Select type conductor 0 = Compact 1 = Compressed	1	CMT:0/CPS:1
9.	Enter number of wires in conductor (7,19,37,61, 91,127,169)	N	No. Wires?
10.	Diameter of one wire		DIA:1W=

STEP	INSTRUCTIONS	INPUT	DISPLAY
11.	**Diameter of conductor, mils**		**D:MIL =**
12.	**Diameter of conductor, mm**		**D:MM =**

MODE: [COMPACT CONDUCTOR]

STEP	INSTRUCTIONS	INPUT	DISPLAY
8.	Select type conductor 0 = Compact 1 = Compressed	0	CMT:0/CPS:1
9.	Enter area A1, of known compact conductor in circular mil	A1	A? CM
10.	Enter diameter of known compact conductor in inches	Dia. D1	D1? Inch
11.	Diameter of conductor in inches		DIA =
12.	Diameter of conductor in mm		DIA: MM =

STEP/KEY CODE	COMMENTS
01♦LBL "MET"	Metric Conductor Strand Design
02 FIX 1	
03 "MM↑2?"	Enter Cross Section
04 PROMPT	in mm^2
05 1973.55	
06 *	
07 STO 03	Cir-mil Equivalent
08 "CM="	Select Type:
09 XEQ "VW"	0 = Compact Strand
10 "CMT:0 / CPS:1"	1 = Compressed Strand
11 PROMPT	
12 X=0?	
13 GTO 00	
14 "NO. WIRES?"	Enter Number of Wires in Conductor,
15 PROMPT	(7,19,37,61,91,127,169)
16 STO 00	
17 1/X	
18 RCL 03	
19 *	Dia 1W $\sqrt{\text{cmil}\ \frac{1}{\text{No.of Wire}}}$
20 SQRT	
21 STO 01	
22 "DIA:1W="	Diameter of Individual Wires
23 XEQ "VW"	
24 XEQ "LY"	
25 RCL 01	
26 RCL 02	Compressed .97 Times
27 *	
28 .97	
29 *	
30 "D:MIL="	Conductor Diameter in
31 XEQ "VW"	Mils
32 .0254	
33 *	
34 "D:MM="	Conductor Diameter in
35 XEQ "VW"	mm
36 STOP	
37♦LBL 00	
38 RCL 03	Enter Area (A^1) of
39 "A1?: CM"	Compact Conductor Known
40 PROMPT	
41 /	
42 SQRT	
43 "D1?: INCH"	Enter Diameter of Known Compact Conductor
44 PROMPT	
45 *	
46 FIX 3	
47 "DIA="	Diameter in Inches
48 XEQ "VW"	
49 1 E3	$D_2 = \sqrt{\frac{A_2}{A_1}} \quad D_1$
50 *	
51 .0254	
52 *	
53 "DIA:MM="	

STEP/KEY CODE	COMMENTS
54 XEQ "VW"	Module to
55 STOP	Determine Total
56♦LBL "LY"	Number of Layers
57 RCL 00	Across Conductor
58 7	
59 X<>Y	
60 X=Y?	
61 GTO 01	
62 19	
63 RCL 00	
64 X=Y?	
65 GTO 02	
66 37	
67 RCL 00	
68 X=Y?	
69 GTO 03	
70 61	
71 RCL 00	
72 X=Y?	
73 GTO 04	
74 91	
75 RCL 00	
76 X=Y?	
77 GTO 05	
78 127	
79 RCL 00	
80 X=Y?	
81 GTO 06	
82 169	
83 RCL 00	
84 X=Y?	
85 GTO 07	
86♦LBL 01	
87 3	
88 GTO 08	
89♦LBL 02	
90 5	
91 GTO 08	
92♦LBL 03	
93 7	
94 GTO 08	
95♦LBL 04	
96 9	
97 GTO 08	
98♦LBL 05	
99 11	
100 GTO 08	
101♦LBL 06	
102 13	
103 GTO 08	
104♦LBL 07	
105 15	
106♦LBL 08	
107 STO 02	
108 RTN	
109 STOP	

```
   XEQ "MET"
MM↑2?
 150.0       RU
              N
CM= 296,032.
5
CMT:0 / CPS:1
            1.0    RUN
NO. WIRES?
           37.0    RUN
DIA:1W= 89.4
D:MIL= 607.3
D:MM= 15.4
```

```
             XEQ "MET"
MM↑2?
          150.0    RUN
CM= 296,032.5
CMT:0 / CPS:1
            0.0    RUN
A1?: CM
      300,000.0    RUN
D1?: INCH
           .570    RUN
DIA= 0.566
DIA:MM= 14.382
```

DATA REGISTERS

00	No. Wires		
01	Diameter 1W		
02	Layers		
03	CM		

STATUS

SIZE____ TOT. REG.____ USER MODE
ENG____ FIX____ SCI____ ON____ OFF____
DEG____ RAD____ GRAD____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

STEP/KEY CODE COMMENTS

```
 01◆LBL "MM"          Conversion Factors
 02 CF 27
 03 .0254             mm to mil
 04 *
 05 STOP
 06◆LBL "MIL
"
 07 CF 27             mil to mm
 08 .0254
 09 /
 10 STOP
 11◆LBL "CM"
 12 1973.5            mm^2 to kcmil
 13 *
 14 1000
 15 /
 16 STOP
 17◆LBL "MT"          meter to feet
 18 CF 27
 19 3.281
 20 *
 21 STOP
 22◆LBL "KG"          Kilogram to pounds
 23 2.205
 24 *
 25 CF 27
 26 STOP
 27◆LBL "CML
"
 28 CF 27             CM to mil
 29 .00254
 30 *
 31 STOP
 32 END
```

Metric Conversion Chart

Metric Conversion Chart AWG/Metric Preferred sizes of conductors

AWG/MCM	mm²	circ mills
·2000		2 000 000
	+1000	1 970 000
·1750		1 750 000
	+ 800	1 580 000
·1500		1 500 000
·1250		1 250 000
	+ 630	1 240 000
·1000		1 000 000
	+ 500	987 000
	+ 400	789 000
· 750		750 000
· 600		600 000
	+ 300	592 000
· 500		500 000
	+ 240	474 000
· 400		400 000
	+ 185	365 000
· 350		350 000
· 300		300 000
	+ 150	296 000
· 250		250 000
	+ 120	237 000
· 4/0		211 600
	+ 95	187 000
3/0		167 000
	+ 70	138 000
· 2/0		133 100
· 1/0		105 600
	+ 50	98 700
1		83 690
	+ 35	69 100
· 2		66 360
3		52 620
	+ 25	49 300
· 4		41 740
	+ 16	31 600
· 6		26 240
	+ 10	19 700
· 8		16 510
	+ 6.0	11 800
· 10		10 380
	+ 4.0	7 890
· 12		6 530
	+ 2.5	4 930
· 14		4 110
	+ 1.5	2 960
· 16		2 580
	+ 1.0	1 970
	0.90	1 773
· 18		1 620
	0.80	1 576
	+ 0.75	1 480
	+ 0.60	1 182
· 20		1 020
	+ 0.50	987
· 22		640
· 24	+ 0.20	404
· 26		253
· 28		159
· 30		100
32	.05	64.0
· 34		39.7
36	.02	25.0
38		16.0
· 40	.005	9.61

+Metric (IEC 228) preferred size · American Wire Gauge preferred sizes

Section Three

Installation Programs and Guidelines

PULLING TENSIONS AND INSTALLATION GUIDELINES FOR CABLE

Robert W. Parkin

PROGRAM: "PUL" "TEN"

FUNCTION: This program determines the maximum allowable pulling tensions and lengths of extruded solid dielectric power cables. Sidewall bearing pressures on the cable are displayed for curved pulls along with the Clearance, Jam Ratio, and Percent Fill. Four cable configurations can be selected and nine forms of pulling directions are provided.

ACCESSORIES: HP-41CX or CV, printer optional

OPERATING LIMITS AND WARNINGS: A Maximum of four cables per pull can be applied. The shift key should be used to select the lower case labels a,b,c,d when selecting the configuration of cable in duct, and the upper case A-I for individual installing sections.

PROGRAM DESCRIPTION AND PARAMETERS

The manner in which cable is installed greatly influences not only the immediate cost but also the operational reliability and service continuity of the cable system. Although different cable constructions may demonstrate varying degrees of resistance to physical damage, current technology does not provide damage proof insulated conductors. Installation subjects cables to the highest mechanical stresses they will ever be exposed to, therefore, extreme care should be exercised while handling and installing cable.

The program covers four cable configurations in duct:

- **a) Single**
- **b) Triangular**
- **c) Cradled**
- **d) Diamond**

And Nine forms of pulling directions:

- **A) Straight**
- **B) Horizontal Bend**
- **C) Slope Up**
- **D) Slope Down**
- **E) Vertical Dip**
- **F) Convex Up**
- **G) Convex Down**
- **H) Concave UP**
- **I) Concave Down**

Each program module corresponds to the lower and upper case local label outlined above. Prompts are called sequentially and only if applicable to that section of the installation, keeping input data for each pull section to a minimum. After T2 and sidewall load (if applicable) are displayed the program will loop to re-select the next installing section, using the previous T2 as T1 until the installation layout is completed.

A diagram of the installation should be used in conjunction with the program to determine the best procedure, or re-design of the layout. Both directions of pulling should be evaluated, since the tensions and corresponding sidewall pressures will not be equal for both directions of installation in most cases.

The calculations to determine the forces on a cable as it is pulled into a duct depends on several parameters:

Conduit Fill	**Weight Correction Factor**
Clearance	**Cable Diameter and Weight**
Jam Ratio	**Configuration**
Friction	**Bending , Training**
Sidewall Load	**Maximum Tension**

CONDUIT FILL: Conduit fill mainly affects heat dissipation, ampacity, and installation forces. The NEC regulates the maximum number of conductors that may be pulled into rigid metal conduit, rigid non-metallic conduit, intermediate metal conduit, electrical metallic tubing, flexible metal conduit, and liquid-tight flexible metal conduit.

For round conductors and equal diameter cables, percent fill is calculated:

$$\% \text{ Fill} = [d/D]^2 \, n * 100\%$$

where: D = inside diameter of duct

d = overall diameter of a single conductor cable

The number of conductors permitted in a particular size of conduit is covered in the NEC chapter nine, given below. The table displays the maximum cable cross-sectional area as a percentage of internal conduit or duct area.

[6]

	Number of Cables				
	1	2	3	4	over 4
Cables (not lead covered)	53	31	40	40	40
Cables Lead Covered	55	30	40	38	35

Bigger than minimum conduit should generally be used to provide some measure of spare capacity for load growth, and in many cases the conduit should be upsized considerably to allow for future installation of anticipated large size conductors.

Fill also affects the ampacity rating of the enclosed cables. Consult the NEC Article 310 to determine the influence that the selected fill has on circuit ampacity.

The dimensions of standard high density polyethylene conduit is given below.

High Density Polyethylene Conduit Dimensions (Inches)

Nominal Size	Nominal O.D.	Nominal I.D.	* Min. Drum
3/4	1.050	0.920	-
1	1.315	1.155	-
1 1/4	1.660	1.448	-
1 1/2	1.900	1.656	36
2	2.375	2.065	42
2 1/2	2.875	2.469	48

* Recommended Minumum drum diameter on shipping reel.

CABLE CLEARANCE: In applications where the NEC limits do not apply, it is necessary to calculate the clearance between the cables and the inside top of the conduit to ensure that the cable can be pulled through.

[1] It is recommended that the calculated clearance be not less than 0.5 inches. A lesser clearance, as low as 0.25 inches may be acceptable for essentially straight pulls. The clearance should be adequate to accommodate the pulling eye or grip which will be used in the cable pull.

The clearance for each configuration is displayed first for each operation as "CL=". Formulas for clearance are shown in the program documentation.

JAM RATIO: Jamming is the wedging of cables in a conduit only when three (3) cables lay side by side in the same plane. Compute this using the nominal (or maximum) overall outer diameter of the cable (d) and 1.05 times the inside diameter of the conduit (D). A proper ratio of D/d must be maintained to avoid a 3/1 ratio.

The program will display this ratio, and then a "JAM" or "NO JAM" message. The "JAM" message will sound a warning BEEP if the ratio is between 2.8 - 3.2. Within this range jamming might occur because of slight ovality in bends that increase I.D. to give a jam ratio of 3.0. Serious jamming can probably be avoided if the ratio is less than 2.8. If D/d is less than 2.5, jamming is impossible because cables will be confined to a triangular configuration which also reduces electrical losses, but check the clearance to make sure the cable will fit.

FRICTION: The dynamic coefficient of friction between a cable and conduit can vary from 0.25 to 1.050 depending on the number of cables, type outer covering of cable, type conduit material installation temperature and of course type of pull and lubricant. This factor is generally divided with sidewall bearing pressures less than, or greater than 150 lbs/ft.

The value of 0.5 is used as a general value for lubricated cables being pulled into conduit or ducts without other cables. 0.15 for cables being pulled over ball or roller bearing rollers in cable trays, 0.4 for cables being pulled over rollers/sheaves without roller or ball bearing. Higher installation temperatures cause the coeffient of friction to be higher for cables having a non-metallic jacket.

NOTE: Once a cable installation has begun, if possible, pulling should continue until completed. Once stopped, restarting will require pulling tension to be increased to overcome frictional and inertial resistance.

[3] **Recomended Basic Dynamic Coefficients of Friction**

Duct Material	**Cable Jacket Material**	**One Cable/Duct** * **75 F**	**20 F**	**Three Cables/Duct 75 F**
PVC	XLPE	0.40	0.40	0.60
	PE	0.40	0.35	0.45
	PVC	0.50	0.25	0.60
	N	0.90	0.55	1.50
	CN	0.40	0.40	--
	Pb	0.25	0.25	--

Straight pulls and bends with bearing pressure less than 150 lb/ft with soap and water base luricants.

[7] **SIDEWALL LOAD:** The cable Sidewall load (or bearing pressure) is the radial force exerted on the cables as is being pulled through a curved section.

For a single cable in conduit pulls:

$$SWL = T/R$$

Cradled formation three conductors:

$$SWL = (3\ Wc - 2)\ T/\ (3R)$$

In triangular formation:

$$SWL = Wc\ T\ /\ (2R)$$

For four cables in diamond configuration:

$$SWL = (Wc - 1)\ \ T/R$$

Where:

SWL = Sidewall bearing pressure on cable with greatest radial bend in lbs / ft

T = Maximum combined tension of cables for multiple cable pulls or tension on one cable for single cable pulls when exiting the bend in pounds

R = Inner radius of conduit bend

Wc = Weight correction factor for multiple cable pulls

It should be noted that the T/R ratio is independent of the angular change of direction produced by the conduit bend. It depends on the tension out of the bend and the bend radius, with the effective radius taken as the inside of the bend. If a limit is exceeded the bend radius can be satisfied by increasing the radius of the bend.

The following maximum sidewall loads are generally considered good installation practice:

Cable Type	SWL (lb / ft)
600V nonshielded control	300
600V and 1kV EP power	500
Medium Voltage EPR and XLPE	500
Interlocked Armor	300

Sidewall bearing pressure on the cable can be kept to a minimum by obsevering these guidelines:

(1) Keep conduit runs as straight as possible

(2) Make the bend radius as large as possible

(3) Keep offsets to a minimum

(4) Where elbows or bends are unavoidable, locate the cable feed-in point as close to the bend as possible so that pulling tension at the bend is low.

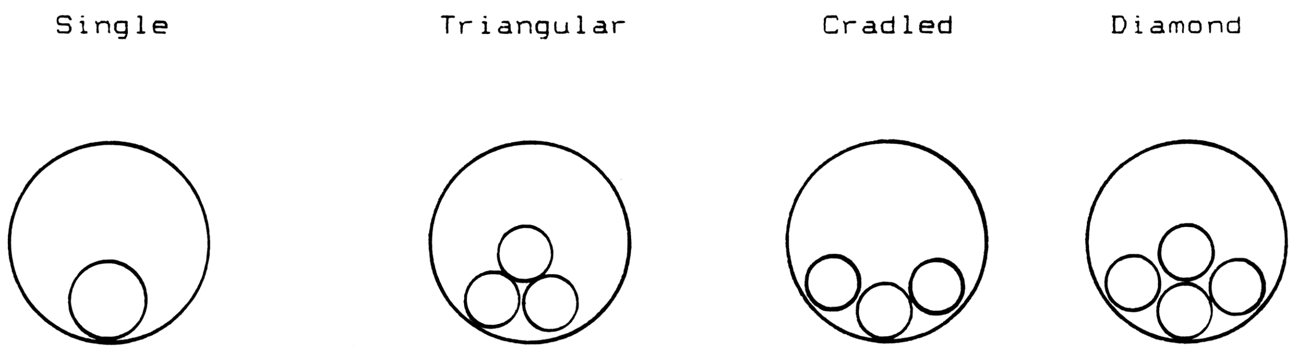
WEIGHT: Use the total weight per unit length of cables being pulled. Triplexed cables will weigh more than parallel cables. For triplexed cables multiply the weight of a single cable by 3.009 for the total weight of assembly.

WEIGHT CORRECTION FACTOR: This takes into account the uneven forces placed on the cables while being pulled through the conduit, due to the geometric configuration of the cables. This imbalance results in additional frictional drag on the cables during the pull, effectivly increasing the weight of the cable. Formulas applied are shown with program documentation.

The weight correction factor for a single cable is unity.

CONFIGURATION: The configuration of the cable as it lays in the duct directly affects drag. Four configurations are given in the program and shown below. The cradled configuration is assumed to result from pulling cables from individual reels in parallel with D/d greater than 2.5. This is also called the parallel configuration. The triangular configuration results from the cables being triplexed, or parallel cables in a conduit less than 2.5. Use cradled for paralleled cables with D/d greater than 2.5.

Cable Configuration in Conduit



MINIMUM BENDING RADIUS OF CABLES: There are two different forms of bends that place stresses on cables:

- Cables under tension (Bending)

- Cables not under tension (Training)

For both training and bending, computations are to be based on the inside radius. These limits do not apply to conduit bends, sheaves or other curved surfaces around which the cable may be pulled under tension while being installed.

The minimum bending radius as a multiple of Cable Diameter for both single and multiple conductor cables rated up to and including 35kV are as follows, based on these conditions:

- **Single or multiple conductors**
- **Non-shielded cabled**
- **Without lead sheath**
- **Wire shielded cables**

MINIMUM BENDING RADIUS

[4]

Thickness of Cable Insulation (mils)	Overall Diameter of Cable, Inches 1.000 and less	1.001 to 2.000	2.001 and over
155 or less	4	5	6
170 - 310	5	6	7
325 & over	-	7	8

Single conductor tape shielded cables have a minimum bending radius of 12 times the overall diameter. For multiple assemblies and multiplexed cables having individual tape shields, the minimum bending radius is the same as for a single conductor or seven times the overall diameter, whichever is greater. For assemblies having an overall tape shield over the multi-conductor assembly, the minimum bending radius is 12 times the overall diameter of the cable.

For multi-conductor interlocked armor cables, except tape shielded cables: Per above table but not less than seven times the O.D.

MAXIMUM TENSIONS: The metallic phase conductors are the tensile members of a cable. Thus all pulling forces must ultimately be transferred to them, unless the cable is of custom design having special tension members.

The maximum allowable pulling tension applied to a cable varies with:

- The number of cables
- Size and type of conductor
- Number of conductors
- Method of attachment between pulling line and cable

1) Cables with pulling eyes or bolts should not exceed:

Where Tm is the maximum allowable tension, in pounds,

$$Tm = B \times n \times A$$

A = Conductor area in circular mils
n = Number of conductors
B = Conductor Tension Constant

[5]

Material	**Cable Type**	**Temper**	**B**
Copper	All	Soft drawn	0.008
Aluminum	Power	Hard	0.008
Aluminum	Power	3/4 Hard	0.006
Aluminum	Power	"AWM"	0.005
Aluminum	URD (solid)	Soft(1/2 hard)	0.003
All	Thermocouple		0.008

Three-quarter hard aluminum is allowed for power cable. AWM is required for UL labeled 600V aluminum solid wired #8 AWG and smaller; it may be used in larger sizes. Soft is sometimes used for large solid aluminum. AWM is a UL designated aluminum.

NOTE: Do not consider area of neutral or ground conductors in the cable when calculating maximum pulling tensions.

In pulling three single conductors, a value of n equal to two is recommended since two of the conductors may sustain the total pulling tension in a triangular configuration, and one of the conductors may sustain more than 50 percent of the total tension in a cradled arrangement. The maximum tension for a single conductor cable should not exceed 5000 lb., and the maximum tension for two or more conductors should not exceed 6000lb even though calculations may yield higher values.

2) **Basket Grip:** The maximum tension on copper or aluminum conductors should not exceed 1000 lb. per grip or the value calculated with $T_m = B \times n \times A$, whichever is smaller. The limit applies to a single conductor cable, a multi-conductor cable with a common jacket, two or more twisted cables or parallel cables using a basket grip. Use n = 2 for three grips, one per conductor to determine the maximum allowable tensions. Do not pull on metal sheaths or armors - pull on their phase conductors. If the basket grip is applied to the metal conductor then the limits of tension on the conductor apply. If the basket grip is applied over the insulated cable then a tension up to 1000 lb. is allowed per grip.

All of the limits are applicable to all pulls and the installation of cables shall not cause the limits to be exceeded. In particular, cable pulling tension must not exceed the smaller of these values:

- Allowable Tension on Conductor
- Allowable Tension on Pulling Device
- Allowable Sidewall Loads

NOTE (1): Extreme care must be observed in the storage, movement, and set-up of non-returnable wood and steel reels. Cable reels must be rolled on smooth and firm surface that is clean and free of debris that could damage the cable. Fork-lifts should approach the reels from the side and never come in contact with the cable. Arrows on the flange should indicate the direction of roll which should always be in the direction opposite to the cable wind on the reel. This prevents loosening of the cable turns on the reel, which may cause problems during installation.

(2) Reel back tensions and braking during a pull should be monitored, and kept within allowable limits. Braking of the reel should be done only to prevent an overrun when the pull is slowed or stopped, or on steep down-hill runs or vertical drops where cable weight is enough to overcome cable - duct friction.

This program offers nine forms of pulling directions, which can be selected via the programable assigned alpha keys, A through I; providing subdivision of specific pulling sections. The sketches provided show the pulling directions. The formulas associated with each direction gives the cumulative tension T2 on the loading end of the cable as it exits from a specific section when T1 is the tension in the cable entering that section. Each section can be used as many times as needed.

DEFINITION OF SYMBOLS

Symbol	Definition	Units
T1	Incoming cable tension	Pounds
T2	Outgoing cable tension	Pounds
R	Inside radius of conduit bend	Feet
W	Total weight of cables in duct	lbs/foot
θ	Angle subtended by bend for curved sections, or angle of slope measured from horizontal for inclined planes	Radians
K	Effective coefficient of friction	----
L	Length of cable in section	Feet
D'	Depth of dip from horizontal axis	Feet
2S	Horizontal length of dip section	Feet

REFERENCES

[1] [3] EPRI EL-333-CM-CCM,V2 Cable - Pulling Guidelines for Solid Dielectric Cables Feb 1984

[2] [5] Anaconda (CABLEC CORP) Cable Installation Manual

[4] Insulated Cable Engineers Association Pub no. S-66-514, National Electrical Manufactuers Association Pub no. WC-8-1984, and WC-26 Wire and Cable Packaging 1984

[6] National Electric Code 1984

[7] R.C. Rifenburg "Pipe-line design for pipe-type Feeders" AIEE, pp 1275-1288, Dec 1953

[8] Underground Systems Reference Book, Edison Electric Institute, 1957

CABLE INSTALLATION DATA

By: ______________________ DATE: __________

USER: Name ______________________

Cable Installation Address ______________________

INSTALLER: Company ______________________

Site Supervisor ______________________

DESIGNER: Company ______________________

Individual ______________________ __________

PURCHASER: Company __________ Order # __________ Mfgr. __________ Order # __________

Phase Cable Type __________ Voltage ______ Size ______ #/ϕ ____ #/Duct ____ Reel # ______

Grounded (Neutral) Cable Type __________ Voltage ______ Size ______ #/ϕ ____ #/Duct ____ Reel # ______

Grounding Cable Type __________ Size ______ #/ϕ ____ #/Duct ____ Reel # ______

WHEN: Manufactured ______ Delivered ______ Installed ______ Energized ______

ENVIRONMENT: ☐ wet ☐ air ☐ raceway ☐ indoor ☐ hazardous
☐ dry ☐ underground ☐ no raceway ☐ outdoor ☐ ambient temp. ______

RACEWAY: Type __________ Material __________ Inside Dimensions __________

CABLE END: 1: Termination ☐ indoor ☐ outdoor gn lead size __________

mfgr & type ______________________

Lightning or Surge Arrestor - feet of wire from arrestor to cable end __________

mfgr & type ______________________

2: Termination ☐ indoor ☐ outdoor gn lead size __________

mfgr & type ______________________

Lightning or Surge Arrestor - feet of wire from arrestor to cable end __________

mfgr & type ______________________

SPLICE: 1. ☐ straight ☐ Y ☐ T ☐ transition, mfgr & type __________ gn lead size __________
2. ☐ straight ☐ Y ☐ T ☐ transition, mfgr & type __________ gn lead size __________

INSTALLATION: pulling rope - material __________ size ______

puller - type __________

lubricant - mfgr & type __________

dynamometer - mfgr __________ range ______

☐ eyes
☐ basket grip
☐ serving
how many grips ____
☐ cabled ☐ parallel
type ______

TESTING: (attach data sheet): when & who __________ ins. resistance: volt ______ time ______

cleaning solvent (brand & type) __________ dc hi voltage: volt ______ time ______

corona suppression (lugs, etc) __________ ac hi voltage: volt ______ time ______

SKETCH: **[Put on back or separate sheet] - Include all bends such as offsets, and vertical sections as shown in Pulling Calculation Input, page 46. Indicate where reels were set-up, size of boxes or manholes, location of splices or taps.**

CIRCUIT: Identity __________ Length (source to load) __________

Source: Volt ______ Hz ______ kVA ______ ☐ gr ☐ ungr ☐ Δ ☐ Y ☐ 1 phase ☐ 3 phase

Fault ______ AMPS

Overcurrent Protection: ☐ circuit breaker type __________

☐ clearing time (sec) ϕ ______ gn ______

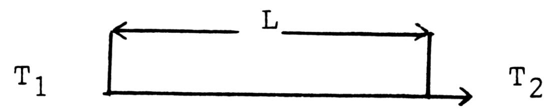
Loads: load factor ______ power factor ______

type: motor: type, size, how started

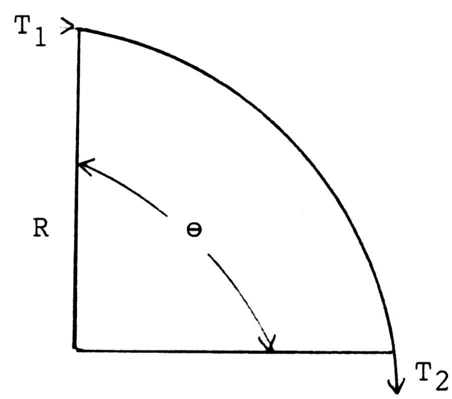
transformers, capacitors, furnaces, lighting fixtures: size, type, connection

all: gn/ungn, Δ/y, 1ϕ/3ϕ, amps: running, full load

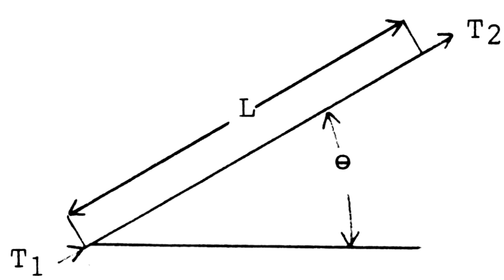
A. Straight Pull



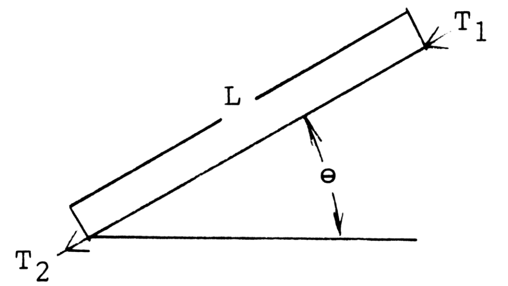
B. Horizontal Bend Pull



C. Slope - Upward Pull

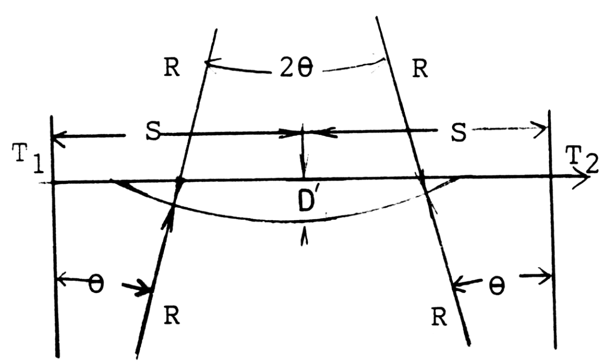


D. Slope-Downward Pull



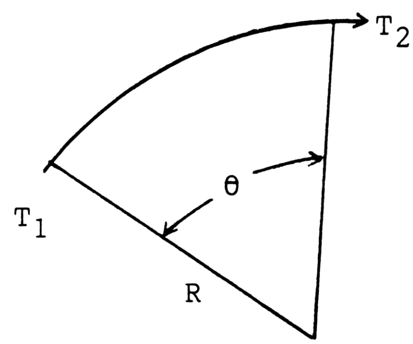
E. Vertical Dip Pull - (Small Angle)

Where D' is Small Compared to S (i.e. $\tan\theta/2 = \sin\theta/2 = D'/S$)



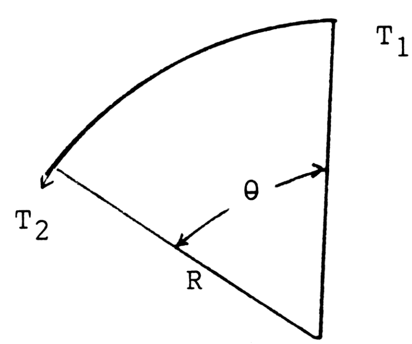
F. Convex Bend - Upward Pull

For Angle θ Measured From Vertical Axis



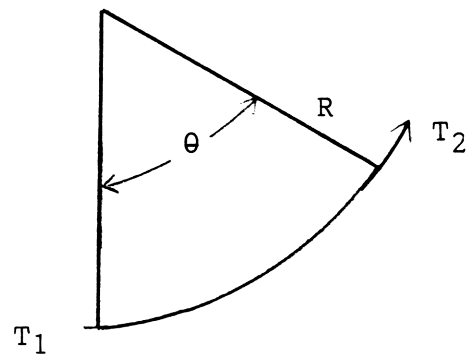
G. Convex Bend - Downward Pull

For Angle θ Measured From Vertical Axis



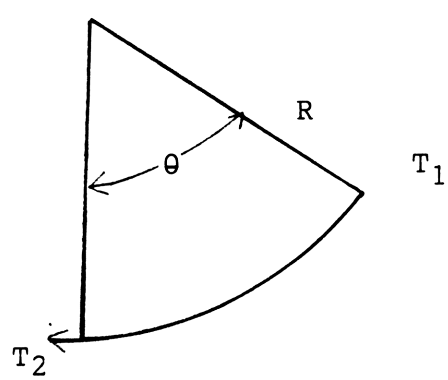
H. Concave Bend - Upward Pull

For Angle θ Measured From Vertical Axis



I. Concave Bend - Downward Pull

For Angle θ Measured From Vertical Axis



USER INSTRUCTIONS

Size: 017

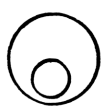
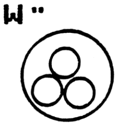
STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect Printer if a hardcopy is desired. R/S after each display if no printer attached.		
2.	Set Printer switch to manual or normal mode.		
3.	Load programs "PUL" AND "VW"		
4.	Check Status		
5.	Initialize: XEQ **"PUL"**		D?
6.	Enter I.D. of Duct	D	d?
7.	Enter nominal O. D. of Cable	d	Select:abcd
8.	Choose cable confguration **a = Single** **b = Triangular** **c = Cradled** **d = Diamond**	shift a,b,c,d	
9.	Display Clearance		CL =
10.	Display Jam Ratio		JR = "No Jam" or "Jam"
11.	Enter number of cables	N	N?
12.	Display Percent Fill		% Fill =
13.	Enter coefficient of friction	F	F?
14.	Enter section of incoming cable tensions. T1, Pounds.	T1	T1?
15.	Enter weight of cable per foot	W	W/Ft?

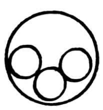
STEP	INSTRUCTIONS	INPUT	DISPLAY
16.	Select Pull layouts **A = Straight Pull** **B = Horizontal Bend** **C = Slope Upward** **D = Slope Downward** **E = Vertical Dip** **F = Convex Bend Up** **G = Convex Bend Down** **H = Concave Bend Up** **I = Concave Bend Down** Input data depends on the layout selected, (straight,curved, or dip pulls).Each module will loop back to step 16 after displaying T2 and SWL (if applicable).	"A-I"	Select:A-I
17.	Straight Pulls: Enter length of section, feet	"A,C,D" L	L?
18.	Section outgoing cable tension		T2 =
19.	Select next Pull (step 16)		Select: A-I
20.	**Curved Pulls:**	"B,F,G, H,I	
21.	Enter inside radius of conduit bend.	R	R?
22.	Enter angle in degrees	O	? DEG
23.	T2 Displayed		T2 =
24.	Sidewall Load displayed		SWL =
25.	Select next Pull (Step 16)		Select:A-I
26.	Vertical Dip:	"E"	
27.	Enter depth of dip from horizontal axis, feet	D'	D?FT
28.	Enter horizontal length of dip section, feet.	S	S?
29.	T2 Displayed		T2 =
30.	SWL Displayed		SWL =
31.	Select next Pull (Step 16)		Select:A - I

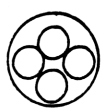
SAMPLE PROBLEM

```
   XEQ "PUL"
D?
 5.65     RUN
d?
 1.26     RUN
SELECT:abcd
        XEQ c
CL= 4.4
JR= 4.5
NO JAM
              RUN
N?
        3.0   RUN
%FILL=  15
F?
        .45   RUN
T1?
        100   RUN
W/FT?
       4.25   RUN
SELECT: A-I
            XEQ A
L?
        200   RUN
T2= 524.51
SELECT: A-I
            XEQ B
R?
       6.00   RUN
∡? DEG.
      90.00   RUN
T2= 1149.90
SWL= 84.93
SELECT: A-I
            XEQ C
L?
      80.00   RUN
T2= 1489.90
SELECT: A-I
            XEQ D
L?
     100.00   RUN
T2= 1064.90
```

```
SELECT: A-I
            XEQ E
D? FT
       3.00   RUN
S?
      40.00   RUN
T2= 1437.52
SWL= 4.78
SELECT: A-I
            XEQ F
R?
       6.00   RUN
∡? DEG.
      45.00   RUN
T2= 2152.78
SWL= 159.01
SELECT: A-I
            XEQ G
R?
       6.00   RUN
∡? DEG.
      90.00   RUN
T2= 4704.21
SWL= 347.46
SELECT: A-I
            XEQ H
R?
       6.00   RUN
∡? DEG.
      30.00   RUN
T2= 6106.62
SWL= 451.04
SELECT: A-I
            XEQ I
R?
       6.00   RUN
∡? DEG.
      15.00   RUN
T2= 6955.14
SWL= 513.72
SELECT: A-I
```

STEP / KEYCODE	COMMENTS	
01◆LBL "PUL"		
02 RAD		
03 FIX 1	Intialize	
04 CF 01		
05 CF 02		
06 CF 03		
07 CF 04		
08 CF 05	Enter: Inside Diameter of Conduit, Inches	
09 "D?"		
10 PROMPT		
11 STO 00		
12 "d?"	Nominal Outside Diameter of Single Conductor,Inches	
13 PROMPT		
14 STO 01		
15 -		
16 STO 02		
17 SF 27	Select Cable Configuation in Conduit:	
18 "SELECT: abcd"	(Use Shift For Uppercase(a,b,c,d)	
19 PROMPT		a = Single Cable
20◆LBL a		
21 XEQ "CR"	Single	b = 3 Cables Triangular
22 1	Clearance = D - d	
23 STO 04	Weight Correction	c = 3 Cables Cradled
24 SF 01	Factor = 1	
25 XEQ "JAM"	Find Jam Ratio	d = 4 Cables Diamond
26 XEQ "TEN"	XEQ Tension Module	
27◆LBL 01		
28 FS? 05	Find Sidewall Loading Pressure	
29 GTO 00		
30 RCL 06		
31 RCL 08		
32 /		
33 "SWL="	SWL = T/R	
34 XEQ "VW"	Return to Next Pull	
35 GTO 00		
36◆LBL b	 Triangular	
37 SF 02		
38 1		
39 RCL 01		
40 RCL 02		
41 /		
42 X↑2		
43 -		
44 SQRT		
45 STO 03		
46 RCL 02	$CR = \frac{D}{2} - 1.366d + \frac{1}{2}(D - d)\sqrt{1 - (\frac{d}{D - d})}$	
47 *		
48 .5		
49 *		
50 RCL 00		

STEP / KEYCODE	COMMENTS
51 2	
52 /	
53 RCL 01	
54 1.366	
55 *	
56 -	
57 +	
58 XEQ "CR"	Display Clearance
59 RCL 03	
60 1/X	$Wc = 1/\sqrt{1-[d/(D-d)]^2}$
61 STO 04	
62 XEQ "JAM"	
63 XEQ "TEN"	
64◆LBL 02	
65 FS? 05	Straight Pull?
66 GTO 00	
67 RCL 04	
68 RCL 06	
69 *	
70 RCL 08	
71 2	$SWL = W_c\ T\ /\ (2R)$
72 *	
73 /	
74 "SWL="	
75 XEQ "VW"	Display and Return
76 GTO 00	
77◆LBL c	
78 SF 03	<u>Cradled</u>
79 1	
80 RCL 01	
81 RCL 02	
82 2	
83 *	
84 /	
85 X↑2	
86 -	
87 SQRT	
88 RCL 02	
89 2	
90 /	$CR = \frac{D}{2} - \frac{d}{2} + \frac{D-d}{2}\sqrt{1-\left[\frac{d}{2(D-d)}\right]^2}$
91 *	
92 RCL 00	
93 2	
94 /	
95 RCL 01	
96 2	
97 /	
98 -	
99 +	
100 XEQ "CR"	

STEP / KEYCODE	COMMENTS
101 RCL 01	
102 RCL 02	
103 /	
104 X↑2	$Wc = 1 + 4/3\ [d/(D - d)\ ]^2$
105 1.3333	
106 *	
107 1	
108 +	
109 STO 04	
110 XEQ "JAM"	
111 XEQ "TEN"	
112◆LBL 03	
113 FS? 05	
114 GTO 00	
115 RCL 04	
116 3	
117 *	$SWL = (3Wc - 2)\ [\ T/\ (3R)\ ]$
118 2	
119 -	
120 RCL 06	
121 RCL 08	
122 3	
123 *	
124 /	
125 *	
126 "SWL="	Display and Return
127 XEQ "VW"	
128 GTO 00	
129◆LBL d	 Diamond
130 SF 04	
131 RCL 02	
132 RCL 01	
133 X↑2	
134 2	$CR = (\ D - d\ ) - \frac{2d^2}{(D-d)}$ with $\frac{D}{d} \leqslant 3$
135 *	
136 RCL 02	
137 /	
138 -	
139 XEQ "CR"	
140 RCL 01	
141 RCL 02	
142 /	
143 X↑2	$Wc = 1 + 2\ [d/(D - d)\ ]^2$
144 2	
145 *	
146 1	
147 +	
148 STO 04	
149 XEQ "JAM"	
150 XEQ "TEN"	

STEP / KEYCODE	COMMENTS	
151◆LBL 04		
152 FS? 05		
153 GTO 00		
154 RCL 04		
155 1	SWL = (Wc - 1) T/R	
156 -		
157 RCL 06		
158 RCL 08		
159 /		
160 *		
161 "SWL="		
162 XEQ "VW"		
163 GTO 00		
164◆LBL "TEN"	<u>Pulling Tension Module</u>	
165 "F?"	Enter Coefficient of Friction	
166 PROMPT		
167 RCL 04		
168 *		
169 STO 03		
170 "T1?"	Enter Incoming Cable Tension, Pounds	
171 PROMPT		
172 STO 06		
173 "W/FT?"	Enter Total Weight of Cables in Conduit, Pounds/ft	
174 PROMPT		
175 STO 07		
176◆LBL 00	Return Label	
177 CF 05		
178 SF 27	Select Pull and Bend Configuations	
179 "SELECT: A-I"		
180 TONE 9		A = Straight Pull
181 PROMPT		
182◆LBL A	Straight Pull	B = Horizontal Bend Pull
183 SF 05	$T_1 \longrightarrow T_2$	C = Slope Upward Pull
184 RCL 07		
185 RCL 03		
186 *		D = Slope Downward Pull
187 "L?"	Enter Length of	
188 PROMPT	Cable In Section	E = Vertical Dip Pull
189 *		
190 RCL 06	$T_2 = T_1 + WKL$	F = Convex Bend Up
191 +		
192 XEQ "T2"		G = Convex Bend Down
193◆LBL B	<u>Horizontal Bend Pull</u>	
194 XEQ "BD"		H = Concave Bend Up
195 RCL 10		
196 RCL 03		I = Concave Bend Down
197 *		
198 XEQ "SINH"		
199 RCL 08		
200 RCL 07		

T_2 = Section Outgoing Cable Tension, Pounds

STEP / KEYCODE	COMMENTS
201 *	
202 X↑2	
203 RCL 06	
204 X↑2	
205 +	
206 SQRT	$T_2 = T_1 \cosh K\theta + \sqrt{T_1^2 + (WR)^2} \sinh K\theta$
207 *	
208 RCL 10	
209 RCL 03	
210 *	
211 XEQ "COSH"	
212 RCL 06	
213 *	
214 +	Display T2
215 XEQ "T2"	
216♦LBL C	<u>Slope Upward Pull</u>
217 SF 05	
218 RCL 10	
219 COS	
220 RCL 03	
221 *	$T_2 = T_1 + LW(\sin\theta + K\cos\theta)$
222 RCL 10	
223 SIN	
224 +	
225 RCL 07	
226 *	
227 "L?"	Enter Length of Section
228 PROMPT	
229 *	
230 RCL 06	
231 +	
232 XEQ "T2"	
233♦LBL D	<u>Slope Upward Pull</u>
234 SF 05	
235 RCL 10	
236 COS	
237 RCL 03	
238 *	
239 STO 16	
240 RCL 10	
241 SIN	
242 RCL 16	$T_2 = T_1 - LW(\sin\theta - K\cos\theta)$
243 -	
244 RCL 07	
245 *	
246 "L?"	
247 PROMPT	
248 *	
249 RCL 06	
250 X<>Y	
251 -	
252 XEQ "T2"	Display T_2

Vertical Dip Pull

STEP / KEYCODE	COMMENTS
253♦LBL E	
254 "D? FT"	Enter Depth of Dip From Horizontal Axis,Feet
255 PROMPT	
256 STO 11	
257 2	
258 *	
259 "S?"	Enter Horizontal Length of Dip Section,Feet
260 PROMPT	
261 STO 12	
262 /	$\theta = \frac{2D}{S}$
263 STO 10	
264 RCL 12	
265 X↑2	
266 RCL 11	
267 4	$R = \frac{S^2}{4D}$
268 *	
269 /	
270 STO 08	
271 RCL 07	
272 *	RW
273 STO 13	
274 RCL 03	
275 RCL 10	$K\theta$
276 *	
277 STO 14	
278 E↑X	
279 1	$T = T_1 \; e^{k\theta} + RW(e^{k\theta} - 1)$
280 -	
281 RCL 13	
282 *	
283 RCL 14	
284 E↑X	
285 RCL 06	
286 *	
287 +	
288 RCL 13	For $T > RW$
289 X<>Y	
290 X<=Y?	
291 GTO 05	$T_2 = T_1 \; e^{4k\theta} + RW[e^{4k\theta} - 2e^{3k\theta} + 2e^{k\theta} - 1]$
292 RCL 14	
293 4	
294 *	
295 E↑X	
296 RCL 14	
297 3	
298 *	
299 E↑X	
300 2	
301 *	
302 -	
303 RCL 14	
304 E↑X	
305 2	
306 *	

STEP / KEYCODE	COMMENTS
307 1	
308 -	
309 +	
310 RCL 07	For $T \leqslant RW$
311 *	
312 RCL 08	
313 *	
314 RCL 14	
315 4	
316 *	
317 E↑X	
318 RCL 06	
319 *	
320 +	
321 XEQ "T2"	$T_2 = T_1 + WK2S$
322♦LBL 05	
323 RCL 12	
324 2	
325 *	
326 RCL 03	
327 *	
328 RCL 07	
329 *	
330 RCL 06	
331 +	
332 XEQ "T2"	
333♦LBL F	
334 XEQ "BD"	<u>Convex Bend Upward Pull</u>
335 1	
336 RCL 14	
337 -	
338 RCL 10	
339 COS	
340 +	
341 1	
342 RCL 03	
343 X↑2	
344 -	
345 *	
346 STO 09	$T_2 = T_1 e^{k\theta} + \frac{WR}{1 + K^2} [2Ke^{k\theta}\sin\theta + (1-k^2)(1-e^{k\theta}\cos\theta)$
347 RCL 14	
348 RCL 03	
349 *	
350 2	
351 *	
352 RCL 10	
353 SIN	
354 *	
355 RCL 09	
356 +	
357 STO 16	
358 XEQ "WR"	
359 RCL 16	
360 *	
361 RCL 14	
362 RCL 06	
363 *	
364 +	
365 XEQ "T2"	

```
366♦LBL G
367 XEQ "BD"
368 XEQ "CB"
369 RCL 14
370 RCL 06
371 *
372 +
373 XEQ "T2"
```

<u>Convex Bend-Downward Pull</u>

$$T_2 = T_1 e^{k\theta} + \frac{WR}{1 + k^2} [2K \sin \theta - (1-k^2)(e^{k\theta} - \cos \theta)]$$

```
374♦LBL H
375 XEQ "BD"
376 XEQ "CB"
377 RCL 14
378 RCL 06
379 *
380 X<>Y
381 -
382 XEQ "T2"
```

<u>Concave Bend Upward Pull</u>

$$T_2 = T_1 e^{k\theta} - \frac{WR}{1 + k^2} [2K \sin \theta - (1-k^2)(e^{k\theta} - \cos \theta)]$$

```
383♦LBL I
384 XEQ "BD"
385 RCL 14
386 RCL 03
387 *
388 2
389 *
390 RCL 10
391 SIN
392 *
393 STO 00
394 1
395 RCL 03
396 X↑2
397 -
398 1
399 ENTER↑
400 RCL 14
401 RCL 10
402 COS
403 *
404 -
405 *
406 RCL 00
407 +
408 STO 16
409 XEQ "WR"
410 RCL 16
411 *
412 RCL 14
413 RCL 06
414 *
415 X<>Y
416 -
417 XEQ "T2"
```

<u>Concave Bend Down</u>

$$T_2 = T_1 e^{k\theta} - \frac{WR}{1 + k^2} [2Ke^{k\theta} \sin \theta + (1-k^2)(1-e^{k\theta} + \cos \theta)]$$

STEP / KEYCODE	COMMENTS
418♦LBL "JAM"	<u>Jam Module</u>
419 RCL 00	
420 RCL 01	$D/d < 2.8$
421 /	
422 "JR="	
423 XEQ "VW"	Jam Ratio 2.8 - 3.2 Leaves Serious Possibility
424 2.8	of Cables Jamming
425 X>Y?	
426 GTO 06	
427 RCL Y	
428 3.2	$D/d > 3.2$
429 X<=Y?	
430 GTO 06	Display "Jam" if Within 2.8-3.2 With Warning Beep
431 "JAM"	
432 AVIEW	
433 BEEP	
434 STOP	
435 GTO 07	
436♦LBL 06	
437 "NO JAM"	Display "No Jam"
438 AVIEW	
439 TONE 9	
440 STOP	
441♦LBL 07	
442 RCL 01	
443 RCL 00	
444 /	
445 X↑2	
446 "N?"	Enter Number of Cables
447 PROMPT	
448 *	
449 100	
450 *	
451 FIX 0	
452 "%FILL="	% Fill = $[d/D]^2 \; n \cdot 100\%$
	(For Round Conduits, and Equal Diameter Cables)
453 XEQ "VW"	
454 RTN	
455♦LBL "CR"	
456 CF 27	
457 "CL="	Clearance Display
458 XEQ "VW"	
459 RTN	
460♦LBL "SINH"	Sinh Module
461 STO 00	
462 E↑X-1	
463 RCL 00	
464 E↑X	
465 /	
466 RCL 00	Sinh = $1/2\ [e^x - 1 + \frac{e^x - 1}{e^x}]$
467 E↑X-1	
468 +	
469 2	
470 /	
471 RTN	

STEP / KEYCODE	COMMENTS
472◆LBL "BD"	Bend Module
473 "R?"	
474 PROMPT	Enter Inside Radius of Conduit Bend, Feet
475 STO 08	
476 "∡? DEG."	Enter Angle Subtended by Bend for Curved Sections or Angle of Slope Measured From Horizontal for Inclined Planes,Degrees
477 PROMPT	
478 D-R	
479 STO 10	
480 RCL 03	
481 *	
482 E↑X	$e^{k\theta}$
483 STO 14	
484 RTN	
485◆LBL "T2"	T2 Module
486 FIX 2	Round to 2 Digits
487 RND	
488 STO 06	
489 "T2="	
490 XEQ "VW"	
491 FS? 01	Return to Configuation for SWL
492 GTO 01	
493 FS? 02	
494 GTO 02	
495 FS? 03	
496 GTO 03	
497 FS? 04	
498 GTO 04	
499◆LBL "COSH"	$\text{COSH X} = \dfrac{e^{x} + e^{-x}}{2}$
500 E↑X	
501 ENTER↑	
502 1/X	
503 +	
504 2	
505 /	
506 RTN	
507◆LBL "WR"	WR Module
508 RCL 08	
509 RCL 07	
510 *	
511 RCL 03	$\dfrac{WR}{1+K^2}$
512 X↑2	
513 1	
514 +	
515 /	
516 RTN	

STEP/KEY CODE	COMMENTS
517◆LBL "CB"	<u>Bend Module</u>
518 RCL 10	
519 SIN	
520 RCL 03	
521 2	
522 *	
523 *	
524 1	
525 RCL 03	
526 X↑2	
527 -	
528 RCL 14	
529 RCL 10	
530 COS	
531 -	
532 *	
533 -	
534 XEQ "WR"	
535 *	
536 STO 15	
537 RTN	
538 END	End

STATUS Auto

SIZE 017 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
Straight	A	Concave Up	H
Horizontal	B	Concave Down	I
Slope Up	C		
Slope Down	D	Single	a
Vertical Dip	E	Triangular	b
Convex Up	F	Cradle	c
Convex Down	G	Diamond	d

DATA REGISTERS

00	D		
01	d		
02	D - d		
03	K (eff)		
04	WC		
05	Not Used		
06	T1		
07	Weight		
08	R		
09	Calculations		
10	θ Radius		
11	D^1		
12	S		
13	WR		
14	$K\theta + e^{k\theta}$		
15	CB - Calc.		
16	Calculations		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
01	C	Single	
02	C	Triangular	
03	C	Cradled	
04	C	Diamond	
05	C	Straight Pull	Bend

PACKAGING OF WIRE AND CABLE

Robert W. Parkin

FUNCTION: This program determines the total capacity of round wire or cable that a given reel size can accommodate; based on total length and/or weight capacity of the reel. Cable diameter, flange diameter, traverse width, and drum diameter are the required inputs for length capacity, and cable and reel weights are optional inputs if the total packaging weight is required.

A safety factor incorporated into the program provides a clearance of two-inches, or one cable diameter, whichever is larger. A series of four tones will sound to alert the user that the drum diameter is to small, and needs to be checked from Table 3-1.; excessive or extreme bending can be detrimental to cable.

The program is in two sections; the first part calculates the total footage and weight capacity (optional). The second isolates the calculation parameters and uses less stringent nesting factors and gives the total footage capacity by adding each successive layer. The clearance and footage in the last outer layer are the most important factors to observe when utilizing the successive layer method. The footage of each layer on the reel, summation of layers, number of turns across the traverse, number of layers, footage per turn in the outer layer, and the clearance left between the outer layer of cable and outer edge of reel flange are displayed. If weights are of no concern enter zero at appropriate prompts.

ACCESSORIES: HP-41CX or CV, printer optional

OPERATING LIMITS AND WARNINGS: Accuracy of this program is dependent on an evenly wound reel, constant cable diameter, and circular drums and flanges on reels. A multiple of 14 (on line 36) is initially set in the program for drum diameter checks. Selected reel sizes should be in accordance with NEMA WC-26 requirements to insure that the minimum bend radius for the cable is not exceeded and to allow adequate flange support in the reel design.

REFERENCES:

[1] NEMA Publication No. WC-26 for Wire and Cable
[2] Pulling Tensions and Installation Guidelines for Cable. R.W. Parkin

The formula for calculating footage capacities of reels for round cable is shown as follows. A 5 percent nesting factor and 95 percent traverse utilization have been built into the formula. Therefore, cables <u>must be wound evenly</u> to obtain uniformity, compactness, and the nesting of successive turns and layers.

$$\frac{\pi}{12}\left[\left(\frac{A - 2X - B}{1.9 \times D}\right)^{*} \times 0.95 \times D + B\right] \times \left(\frac{A - 2X - B}{1.9 \times D}\right)^{*} \times \left(\frac{C}{D} - 1\right)^{*}$$

*Take integer of whole number

A = Flange Diameter (inches)

B = Drum Diameter (inches)

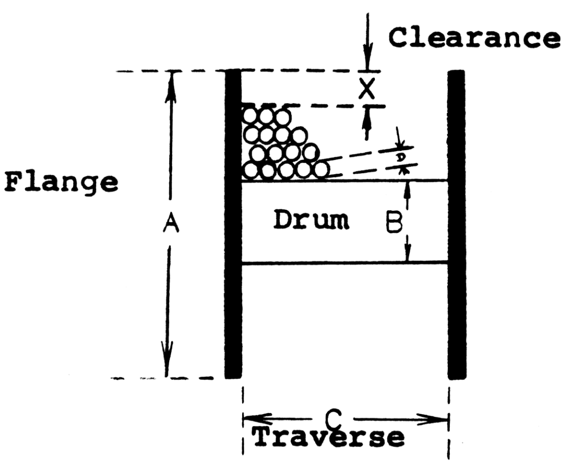
C = Traverse Width (inches)

D = Cable estimated diameter (inches)

X = Clearance between outer layer of cable and outer edge of reel flange.

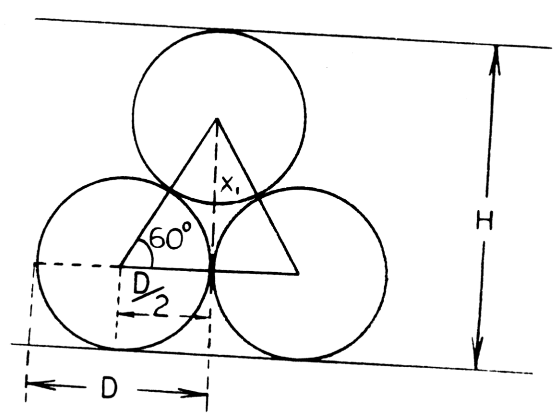
Note: For Triplexed cable D=2.155 x 0.D of single (circumscribed diameter)

For paralleling no special allowance need be made.



Maximum nesting factor as determined by geometric center spacing of cables.

$H = D + X_1$



$H = D + X_1$

$\tan 60° = \frac{X_1}{\frac{D}{2}}$

$X_1 = \tan \times \frac{D}{2}$

$X_1 = 1.73 \times \frac{D}{2}$

$X_1 = 0.866D$

$H = D + 0.866D$

$H = 1.866D$

Max nesting factor = 1.866/2
= 93%

FORMULAS FOR SECOND PART OF PROGRAM

1. Number of Layers (n)

$$n = \frac{A - (B + 2X)}{1.9 \times D} \;*$$

*INTEGER

2. Clearance (X)

$$X = \frac{A - B}{2} - (n \times D)$$

3. Footage/turn in outer layer (FOL)

$$FOL = [B + (2D \times n \times 0.95)] \frac{\pi}{12}$$

4. Number of Turns (NT)

$$NT = \frac{C}{D} - 1$$

5. Footage per layer (FL)

$$\left\{B + [D(2\,ni - 1)]\right\} \frac{\pi}{12} \times NT$$

6. $\Sigma FL \quad \sum_{i=1}^{n} FL$

Where:

A = Flange Dia
B = Drum Dia
C = Traverse
D = Cable O.D.
x = Clearance

n = No. of Layers
FOL = Foctage/Turn in outer layer
NT = No. of turns
FL = Footage per layer
ΣFL = Summation of Layers (Total reel capacity)

NOTE: The above equations apply for single cables having an even layer wind. Triplexed and Parallel assemblies should use only the first Program with the circumscribal O.D. for Triplexed cables and a 0.89 reduction factor of total length for Parallel cables.

NON RETURNABLE WOOD REELS

FLANGE	TRAV	DRUM	O.A.W.	REEL SPEC	REEL WEIGHT (LBS.)	WEIGHT CAPACITY (LBS.)
24	12	10	14.0	NEMA	20.0	350
24	18	10	20.0	NEMA	22.0	525
27	18	12	21.0	NEMA	31.0	700
30	18	12	21.0	NEMA	37.0	950
32	24	14	28.0	NEMA	52.0	1500
36	24	17	28.0	NEMA	93.0	2000
40	24	17	28.0	NEMA	108.0	2500
42	26	18	30.0	NEMA	120.0	3000
45	28	21	32.0	NEMA	140.0	3500
50	32	24	37.0	NEMA	212.0	4800
54	32	28	36.5		240.0	5600
54	30	24	34.5		236.0	5600
58	32	28	37.0	NEMA	274.0	6500
60	32	28	36.5		290.0	6600
66	36	36	41.5	NEMA	468.0	7000
72	36	28	42.5		590.0	8000
72	36	36	41.5	NEMA	608.0	8000
72	48	36	54.5	NEMA	653.0	8000
78	48	42	54.5	NEMA	733.0	9000
84	45	42	51.5	NEMA	892	10000
84	54	48	60.5	NEMA	910.0	10000
90	45	42	51.5	NEMA	985	15000
90	54	48	60.5	NEMA	1140.0	15000
96	54	56	60.5	NEMA	1240.0	15000
96	54	48	60.5		1140.0	15000
104	50	48	56.5		1250.0	15000

REEL SELECTION -RM STEEL TABLE

FLANGE	TRAVERSE	DRUM	O.A.W.	REEL SPEC	REEL WEIGHT	WEIGHT CAPACITY	CLEARANCE INCHES	ARBOR HOLE MIN	ARBOR HOLE MAX
048	24	24	31.0		0225.0	004200	2.0	3.00	3.25
054	32	32	39.0		0295.0	006100	2.0	3.00	3.25
060	32	32	39.0		0345.0	008000	2.0	3.00	3.25
066	32	36	41.0	NEMA	0355.0	007680	2.0	3.00	3.25
066	36	40	42.0		0390.0	010200	2.0	3.00	3.25
072	36	40	45.0	NEMA	0500.0	010260	2.0	3.00	3.25
078	36	48	43.0		0690.0	014200	2.0	3.00	3.25
084	36	42	45.0		0730.0	013600	2.0	5.37	5.37
084	48	56	55.0		0905.0	015000	2.0	3.00	3.25
096	56	48	64.5		1700.0	030000	2.0	5.75	5.75

REEL SELECTION -RMT STEEL TABLE

FLANGE	TRAVERSE	DRUM	O.A.W.	REEL SPEC	REEL WEIGHT	WEIGHT CAPACITY	CLEARANCE INCHES	ARBOR HOLE MIN	ARBOR HOLE MAX
084	36	42	45.0	NEMA	0730.0	013600	2.0	5.00	5.25
084	45	42	55.0	NEMA	0865.0	017000	2.0	5.00	5.25
090	45	42	55.0	NEMA	1100.0	021000	2.0	5.00	5.25
090	54	56	64.0	NEMA	1200.0	020000	2.0	5.00	5.25
096	45	42	56.0		1600.0	020000	2.0	5.75	5.75
096	54	56	66.1		1700.0	020000	2.0	5.75	5.75
096	60	42	71.0	NEMA	1700.0	026000	2.0	5.00	5.25
096	60	56	71.0	NEMA	1800.0	026000	2.0	5.00	5.25

Table 3-1
MINIMUM DRUM DIAMETERS OF REELS FOR CABLES

Type of Cable	Minimum Drum Diameter as a Multiple of Outside Diameter† of Cable — Type of Insulation — Paper: Solid and Gas	Paper: Oil Filled	Varnished Cloth	Extruded
A. Single and multiple conductor nonmetallic covered cable				
1. Nonshielded and wire shielded, including cables with concentric wires:				
a. 0–2000 volts	14	—	14	10
b. Over 2000 volts;				
(1) Nonjacketed with concentric wires	—	—	—	14
(2) All others	14	—	14	12
2. Tape shielded	14	—	14	14
B. Single- and multiple-conductor metallic-covered cable:				
1. Tubular metallic sheathed;				
a. Lead	14	14*	14	14
b. Aluminum;				
(1) Outside diameter—1.750″ and less	25	25	25	25
(2) Outside diameter—1.751″ and larger	30	30	30	30
2. Wire armored	16	18	16	16
3. Flat tape armored	16	18	16	16
4. Corrugated metallic sheathed	16	18	14	14
5. Interlocked armor	14	18	14	14
C. Multiple single conductors cabled together without common covering, including self-supporting cables				
The circumscribing overall diameter shall be multiplied by the factor given in item A or B and then by the reduction factor at the right	0.85	—	0.85	0.75
D. Combinations				
For combinations of the types described in items A, B and C, the highest factor for any component type shall be used.				
E. Single- and multiple conductor cable in coilable nonmetallic duct				
Outside diameter of duct, inches—0.0 -0.50	—	—	—	26
0.51–1.00	—	—	—	24
1.01–1.25	—	—	—	22
1.26–1.50	—	—	—	21
Over 1.50	—	—	—	20

† Outside Diameter—

1. When metallic-sheathed cables are covered only by a thermosetting or thermoplastic jacket, the "outside diameter" is the diameter over the metallic sheath itself. In all other cases, the outside diameter is the diameter outside of all the material on the cable in the state in which it is to be wound upon the reel.
2. For "flat-twin" cables (where the cable is placed upon the reel with its flat side against the drum), the minor outside diameter shall be multiplied by the appropriate factor to determine the minimum drum diameter.
3. The multiplying factors given for item E refer to the outside diameter of the duct.

* For single-conductor cables with more than 500 mils of insulation, this factor is 18.

USER INSTRUCTIONS

Size: 011

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "REEL","AV","VW".		
4.	Check status		
5.	Initialize: XEQ "REEL"		
6.	Enter total weight of cable(s) Per 1000 Feet or zero.	WGT	W/MFT?
7.	Enter nominal diameter of cable, for triplexed cables use circumscribed O.D. of assembly: (2.155 x single O.D), inches.	O.D	CABLE O.D?
8.	Enter Flange Diameter, inches.	F	FLANGE?
9.	Enter Traverse Width, inches.	T	TRAV?
10.	Enter Drum Diameter, inches.	D	DRUM?
11.	Total Footage Reel can hold.	-	FT =
12.	Enter Shipping Length, feet.	SL	SL?
13.	Total Weight of Shipping Length.	-	XXXX LBS
14.	Enter Weight of reel, pounds.	-	REEL: WT?
15.	Total Package Weight (reel and shipping length).	-	T:WT =

STEP	INSTRUCTIONS	INPUT	DISPLAY
	DISPLAY:		
16.	Flange/Drum ratio	-	F/D =
17.	Number of Layers	-	NL =
18.	Clearance	-	CL =
19.	Footage/Turn in outer layer.	-	FOL =
20.	Number of Turns.	-	NT =
21.	Footage per layer.	-	1 = 2 = 3 = 4 = etc.
22.	Summation of Layers.		ΣFL =
23.	Total Weight for summation of layers.	-	XXX LBS
24.	Enter Shipping Length.	SL	SL?
25.	Total Weight for shipping length.	-	XXXX LBS
	OPTIONS:		
1.	To select different reel size using the same cable O.D. and weight: XEQ "RT" Enter Flange, etc	F	FLANGE?
2.	To print out reel size and cable O.D. load and XEQ "RD"		

SAMPLE PROBLEM

```
  XEQ "REEL"
W/MFT?
 1580     RUN
CABLE: O.D?
 1.86     RUN
FLANGE?
   72     RUN
TRAV?
   36     RUN
DRUM?
   36     RUN
FT=  2,201.
SL?
       2,000.   RUN
3,160. LBS
REEL: WT?
         400.   RUN
T:WT= 3,560.
F/D=  2.0
NL=  9.0
CL=  1.3
FOL= 17.8
NT=  18
1 = 182
2 = 200
3 = 218
4 = 236
5 = 253
6 = 271
7 = 289
8 = 307
9 = 325
ΣFL=  2281
3604 LBS
SL?
          2000   RUN
3160 LBS
```

```
              XEQ "RT"
FLANGE?
            78    RUN
TRAV?
            48    RUN
DRUM?
            42    RUN
FT=   3,274.
SL?
        3,000.    RUN
4,740. LBS
REEL: WT?

          500.    RUN
T:WT= 5,240.
F/D=  1.9
NL=  9.0
CL=  1.3
FOL= 19.3
NT=  25
1 = 285
2 = 309
3 = 333
4 = 357
5 = 381
6 = 406
7 = 430
8 = 454
9 = 478
ΣFL=  3433
5425 LBS
SL?
          3000    RUN
4740 LBS
```

STEP/KEY CODE	COMMENTS
01♦LBL "REEL"	
02 FIX 0	Initialize
03 CF 27	
04 SF 12	
05 CF 29	
06 "W/MFT?"	Prompt for Weight
07 TONE 9	of Cable/1000 ft.
08 PROMPT	
09 STO 08	
10 "CABLE: O.D?"	Enter Cable O.D. in
11 PROMPT	Inches
12 STO 03	
13 FIX 0	
14 2	
15 X<=Y?	$X \leqslant 2$? Then CL = 2
16 GTO 05	
17 GTO 04	
18♦LBL 04	If $X > 2$ Then
19 STO 04	CL = Cable O.D.
20 GTO "RT"	
21♦LBL 05	
22 RCL 03	
23 STO 04	
24♦LBL "RT"	Return Label for
25 CF 27	New Reel
26 "FLANGE?"	Enter Flange Diameter
27 PROMPT	
28 STO 00	
29 "TRAV?"	Traverse Width
30 PROMPT	
31 STO 02	
32 "DRUM?"	Drum Diameter
33 PROMPT	
34 STO 01	
35 RCL 03	Multiple Drum Check
36 14	(14 Times)
37 *	
38 RCL 01	
39 X<=Y?	
40 BEEP	4 Tone Series Warning
41♦LBL "FT"	
42 RCL 00	Total Footage
43 RCL 04	Calculation
44 2	
45 *	
46 RCL 01	
47 +	
48 -	
49 RCL 03	
50 1.9	

STEP/KEY CODE	COMMENTS
51 *	
52 /	
53 INT	$\frac{A - 2x - B}{1.9 \times D}$
54 STO 06	
55 .95	
56 *	
57 RCL 03	
58 *	$0.95 \times D + B$
59 RCL 01	
60 +	
61 .2618	$\pi/12$
62 *	
63 RCL 02	
64 RCL 03	$\frac{C}{D} - 1$
65 /	
66 1	
67 -	
68 INT	
69 *	
70 SF 12	
71 RCL 06	
72 *	
73 FIX 0	
74 SF 29	Reel Capacity in
75 "FT= "	Feet
76 XEQ "VW"	
77 XEQ "SL"	Shipping Length
78 "REEL:WT?"	Enter Reel Weight
79 PROMPT	
80 +	
81 "T:WT="	Total Weight of
82 XEQ "VW"	Cable and Reel
83 CF 29	
84 RCL 00	
85 RCL 01	
86 /	
87 2.5	
88 X<=Y?	
89 BEEP	Flange/Drum < 2.5
90 RCL Y	
91 FIX 1	
92 "F/D= "	
93 XEQ "VW"	
94 RCL 06	Number of Layers
95 "NL= "	
96 XEQ "VW"	
97♦LBL "CL"	Calculate
98 RCL 00	Clearance
99 RCL 01	
100 -	

STEP/KEY CODE	COMMENTS
101 2	
102 /	
103 RCL 06	$X = \frac{A-B}{2} - (n \times D)$
104 RCL 03	
105 *	
106 -	
107 FIX 1	
108 "CL= "	
109 XEQ "VW"	
110♦LBL "FOL"	Footage Per Turn in Outer Layer
111 RCL 06	
112 .95	
113 *	
114 RCL 03	
115 2	$[B + (2D \times n \times 0.95)] \frac{\pi}{12}$
116 *	
117 *	
118 RCL 01	
119 +	
120 .2618	
121 *	
122 "FOL="	
123 XEQ "VW"	
124♦LBL "NT"	Number of Turns
125 RCL 02	
126 RCL 03	NT = C/D - 1
127 /	
128 1	
129 -	
130 FIX 0	
131 STO 05	
132 "NT= "	
133 XEQ "VW"	
134♦LBL "FLI"	Footage Per Layer Calculation
135 0	
136 STO 10	
137 FIX 0	
138 1	Initialize
139♦LBL 01	
140 STO 07	
141 2	
142 *	
143 1	
144 -	
145 RCL 03	$B = [D(2n_i - 1)] \frac{\pi}{12} \times NT$
146 *	
147 RCL 01	
148 +	
149 .2618	
150 *	

STEP/KEY CODE	COMMENTS
151 RCL 05	
152 *	
153 ST+ 10	
154 CLA	
155 ARCL 07	Append n
156 "⊢ = "	
157 ARCL X	
158 AVIEW	
159 TONE 8	
160 RCL 06	
161 RCL 07	Loop
162 X=Y?	
163 GTO 02	
164 RCL 07	
165 1	
166 +	
167 GTO 01	
168♦LBL 02	
169 RCL 10	Summation of Layers
170 "ΣFL= "	
171 XEQ "VW"	
172 XEQ "WT"	
173♦LBL "SL"	Shipping Length
174 "SL?"	
175 PROMPT	
176 XEQ "WT"	
177 RTN	
178♦LBL "WT"	Weight
179 RCL 08	
180 1 E3	
181 /	
182 RCL Y	
183 *	
184 CLA	
185 ARCL X	
186 "⊢ LBS"	
187 AVIEW	
188 FC? 21	
189 STOP	
190 RTN	
191 END	

Reel Calculation
Short Form

```
01♦LBL "REE
L"
02 FIX 0
03 CF 27
04 CF 29
05 "CABLE O
D?"
06 PROMPT
07 STO 03
08 2
09 X<=Y?
10 GTO 05
11 GTO 04
12♦LBL 04
13 STO 04
14 GTO 06
15♦LBL 05
16 RCL 03
17 STO 04
18♦LBL 06
19 FIX 3
20 "CL= "
21 ARCL X
22 AVIEW
23♦LBL "RT"
24 CF 27
25 "FLANGE?
"
26 PROMPT
27 STO 00
28 "TRAV?"
29 PROMPT
30 STO 02
31 "DRUM?"
32 PROMPT
33 STO 01
34 RCL 03
35 14
36 *
37 RCL 01
38 X<=Y?
39 BEEP
40♦LBL "FT"
41 RCL 00
42 RCL 04
43 2
44 *
45 RCL 01
46 +
47 -
48 RCL 03
49 1.9
50 *
51 /
52 INT
53 STO 06
54 .95
55 *
56 RCL 03
57 *
58 RCL 01
59 +
60 .2618
61 *
62 RCL 02
63 RCL 03
64 /
65 1
66 -
67 INT
68 *
69 SF 12
70 RCL 06
71 *
72 FIX 0
73 "FT= "
74 ARCL X
75 AVIEW
76 TONE 0
77 CF 12
78 END
```

STEP/KEY CODE

Print Out
Reel and O.D.

```
01◆LBL "RD"
02 FIX 0
03 SF 12
04 RCL 00
05 ACX
06 RCL 02
07 ACX
08 RCL 01
09 ACX
10 PRBUF
11 RCL 03
12 FIX 2
13 "O.D= "
14 ARCL X
15 AVIEW
16 STOP
17 END
```

DATA REGISTERS

00	Flange		
01	Drum		
02	Traverse		
03	Cable O.D.		
04	Clearance		
05	No. of Layers ( )		
06	No. of Layers		
07	Layers N =i		
08	Weight/MFT		
09	Not Used		
10	Accumulated Summation of Layers		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
12		Double Wide Print	
27		User Mode On	User Mode Off
29		Digit Grouping	

STATUS

SIZE____ TOT. REG.____ USER MODE Auto
ENG____ FIX ____ SCI ____ ON ____ OFF ____
DEG____ RAD____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
RT			
RD			

MECHANICAL DESIGN OF OVERHEAD SPANS

Robert W. Parkin

FUNCTION: This program determines the unit tensions for the conductor, mid-point and apparent sag, horizontal weight spans, pull-off angles and relative or absolute elevations for overhead transmission line or distribution circuits. In addition the distance measured vertically from any point in the conductor to a straight line between its two points of support can be found by inputting the distance from the first structure. English or metric units may be used.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: None

REFERENCES:

[1] Sag Calculations for Suspended Wires, P.H. Thomas Trans. AIEE, 1911, vol 30, p 2229

[2] Computer Aids Weight-on-Line Solutions, Transmission and Distribution, November, 1978

[3] Standard Handbook for Electrical Engineers, Fink and Beaty, Eleventh Edition

[4] National Electrical Safety Code, ANSI Pub. No. C2

[5] NEMA WC-8, ICEA S-68-516

Conductor Loads

Overhead span design consists of determining the sag at which the conductor should be elevated so that heavy winds, accumulations of ice and snow, and low temperatures will not stress the conductor beyond the elastic limit, and possibly cause a serious permanent stretch, or result in fatigue failures from continued vibrations. The conditions of span design can be divided into three sections:

1) **The sag in a span resulting from a conductor of a given weight at a given tension (or the reverse).**

2) **The sags or tensions resulting from unequal spans or differences in elevation of supports**

3) **The sags resulting from changes in loading or temperature**

Determination of Ice and Wind Loading

The geographical location of aerial sites determines the ice and wind loading affects on overhead conductors and cables. In the U.S.A, three districts for standard loading conditions are specified in the National Electric Safety Code. The loading's for the various districts are as follows:

Loading District	Heavy	Medium	Light
Radial thickness of ice (inches)	1/2	1/4	0
Horizontal wind pressure (lbs./sq.ft.)	4	4	9
Temperature (F)	0	15	30
Constant k (lbs./ft)	0.31	0.22	0.05

The resultant weight of loaded cables is calculated as follows:

i = Weight of ice loading (lbs./ft)

t = Thickness of ice (inches)

D = Diameter of cable (inches)

$i = 1.24\ t\ (D + t)$

h = Force due to wind (lbs/ft.)

P = Horizontal wind pressure (lbs./sq. ft.)

$$h = \frac{P\ (D+2t)}{12}$$

w'= Weight of unloaded cable

w''= Vertical weight of loaded cable

$$w'' = w' + i$$

The loaded cable weight of the cable is the resultant of the vertical and horizontal weights plus the proper constant.

w''' = Resultant weight of loaded cables

$$w''' = \sqrt{(w' + i)^2 + h^2} + k$$

Messenger Sizes

Different types and sizes of messengers consist of either composite stranded copper and copper clad steel in accordance with ASTM B 229, Grade 30 EHS stranded copper clad steel in accordance with ASTM B 228, stranded aluminum clad steel in accordance with ASTM B 416, stranded aluminum alloy conductors (AAAC) in accordance with ASTM B 399, or composite stranded aluminum and aluminum clad steel (ACSR/AW) in accordance with ASTM B 549.

The messenger sizes for copper clad steel is given in ICEA S-68-516 Table 7.3-4 and for ACSR/AW in Table 7.3-5. For other types of messenger, consult the manufacturer. Messenger size should be based on normal stringing tensions of 60 F (15.6 C) not exceeding 30 percent of the ultimate strength and a maximum tension not exceeding 50 percent of the ultimate strength for heavy loading conditions (1/2 inch(12.7 mm) ice, 4 lb./sq. ft. (192 Pa) wind force, 0 degrees F (-17.8 C)). For further information, see the National Electrical Safety Code.

Program Parameters

The program will calculate the following information about the span catenary:

1. Mid-point of the span or low point of sag in feet or meters.

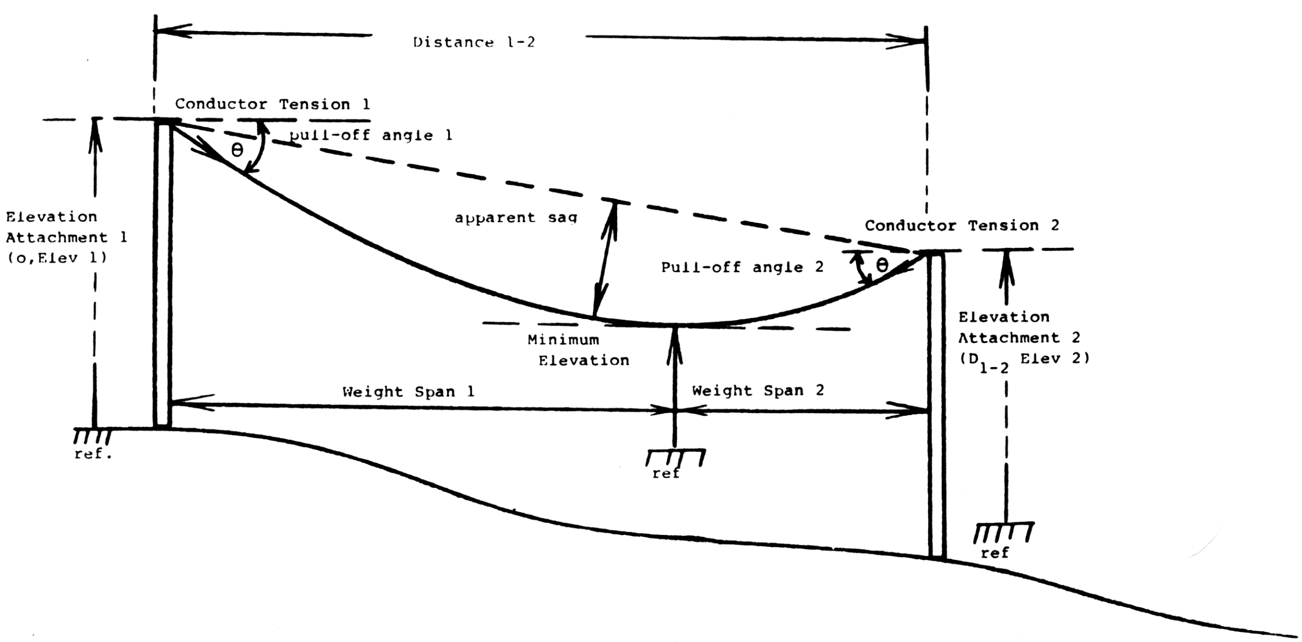
2. Apparent sag of span; the maximum departure of the wire in a given span from the straight line between the two points of support of the span, in feet or meters.

3. Conductor tension at both supporting structures in pounds or kilograms.

4. Weight spans for both supporting structures in feet or meters. This is the length of the conductor from the lowest elevation of the catenary curve to the attachment point. The value will be positive if the low point lies to the right of the structure attachment point, and negative if to the left.

5. Conductor pull-off angle at both supporting structures in degrees or radians.

The drawing below is given for reference.



Program Algorithms

The principal formulas used for computation are based on catenary formulas used in the unit-span dimensions. The equation $Y = P \cosh (X/P) - P$ is used, where X and Y are rectangular coordinates on the catenary with the orgin at the catenary low point and P is equal to the conductor horizontal tension/conductor weight per foot. Axis translation is performed to allow input of attachment 1 at (0,ELEV 1) and attachment 2 at (D_{1-2},ELEV 2).

Conductor tension = $PW \cosh (- D_{1-2}/ 2P)$
where P is determined by iteration

$$\text{Span midpoint} = x_m = P \sinh^{-1} \left[\frac{\text{ELEV 2} - \text{ELEV 1}}{2P \sinh (D_{1-2}/2P)} \right]$$

Attachment 1 catenary location = $x_1 = x_m - D_{1-2} / 2$

Y translation = $Y_t = \text{ELEV 1} - [P \cosh (x_1/P) - P]$

Minimum elevation = ELEV 1 $- Y_t$

Apparent sag = $P \cosh (x_1/P) + (\text{ELEV2}-\text{ELEV 1}/2) + A [P \sinh^{-1} (A) - x_m] - P \cosh [(P \sinh^{-1} (A) / P)]$

where $A = \text{ELEV2} - \text{ELEV 1}/ D_{1-2}$

Weight span structure 1 = $-P \sinh (x_1 / P)$

Conductor tension structure 1 = $PW \cosh (x_1 / P)$

Conductor pull-off angle str. 1 = $\text{Tan}^{-1} (\sinh (x_1/P))$

Weight span structure 2 = $-P \sinh (x_1 + D_{1-2} / P)$

Conductor tension structure 2 = $PW \cosh (x_1 + D_{1-2} /P)$

Conductor pull-off angle structure 2 = $- \text{Tan}^{-1} (\sinh (x_1 + D_{1-2}) /P)$

Elevation at any point x=D = $P \cosh (x1 +D/P) - P + Y_c$

SAMPLE PROBLEM

```
      XEQ "SAG"
TEN: -SAG?
 3,470.00
          RUN
WT/FT?
 2.712

HGT: 1?
 40.00

DIST. 1-2?
 150.00

HGT: 2?
 52.00

MIN HGT= 39.
71
MAX. SAG= 2.21
WT.S1=-27.02
T1= 3,464.80
∡1= 1.21
WT.S2=-177.58
T2= 3,497.35
∡2=-7.92


                 XEQ C
DIST?
            50.00    RUN
HGT= 42.04
TOP EL?
            30.00    RUN
CL= 12.04
```

```
      XEQ "SAG"
TEN: -SAG?
 7,556.00
          RUN
WT/FT?
 1.66     RUN
HGT: 1?
 758.00     R
           UN
DIST. 1-2?
 741.00     R
           UN
HGT: 2?
 801.00     R
           UN
MIN HGT= 756
.72
MAX. SAG= 15.16
WT.S1= 107.69
T1= 7,532.99
∡1=-1.36
WT.S2=-635.38
T2= 7,604.37
∡2=-7.97


                 XEQ C
DIST?
           356.00    RUN
HGT= 763.52
TOP EL?
           653.00    RUN
CL= 110.52
```

```
      XEQ "SAG"
TEN: -SAG?
-20.00      RU
             N
WT/FT?
 1.66     RUN
HGT: 1?
 758.00     R
           UN
DIST. 1-2?
 741.00     R
           UN
HGT: 2?
 801.00     R
           UN
MIN HGT= 753
.73
MAX. SAG= 20.00
WT.S1= 171.40
T1= 5,718.87
∡1=-2.85
WT.S2=-572.28
T2= 5,790.25
∡2=-9.44
```

USER INSTRUCTIONS

Size:010

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "SAG"		
4.	Check status (for metric input set to radian mode)		
5.	Initialize: XEQ **"SAG"**	A	
6.	Enter conductor tension in pounds (or kilograms) for a level span at the desired loading condition; or enter maximum sag in feet (or meters) in the span. **This should be entered as a negative number.**	Ten or -sag	TEN: - SAG?
7.	Enter conductor weight per foot in pounds (or kg/m) at the desired loading condition.	wt./ft.	WT/FT?
8.	Enter height in feet (or meters) of one conductor attachment. This can be either the actual sea level elevation for use with the installation layout or an elevation relative to the other attachment.	HGT: 1	HGT: 1?
9.	Enter horizontal distance in feet (or meters) between the two attachment points.	Dist 1-2	DIST 1-2?
10.	Enter height of other attachment location in feet (or meters).	Hgt 2	HGT: 2?
11.	Display minimum conductor height (low point on catenary) in feet or meters.	-	MIN HGT=
12.	Display apparent sag in span in feet (or meters)	-	MAX SAG=

STEP	INSTRUCTIONS	INPUT	DISPLAY
13.	Display weight span on structure 1 in feet or meters	-	WT.S1=
14.	Display conductor tension at structure 1 in pounds or kg	-	T1=
15.	Display pull-off angle at structure 1 in degrees or radians.	-	/ 1=
16.	Display weight span on structure 2 in feet or meters.	-	WT.S2=
17.	Display conductor tension at structure 2 in pounds or kg.	-	T2=
18.	Display pull-off angle at structure 2 in degrees or radians.	-	/ 2=
19.	Press C to find conductor elevation at a distance from structure 1, (user mode should be on; if not "XEQ" C)	C	
20.	Enter Distance from structure in feet or meters.	Dist	DIST?
21.	Display height of conductor at above distance in feet or meters.	-	HGT=
22.	Enter top elevation of structure located under conductor in feet or meters.	-	TOP EL?
23.	Display clearance over structure in feet or meters.	-	CL=

STEP/KEY CODE	COMMENTS
01♦LBL "SAG"	
02♦LBL A	Initialize
03 SF 27	
04 FIX 2	
05 CF 04	
06 "TEN.⊢SAG?"	Enter Tension
07 PROMPT	
08 STO 01	
09 "WT/FT?"	Weight of Cable/ft
10 PROMPT	
11 STO 02	
12 "HGT: 1?"	Height of 1
13 PROMPT	
14 STO 03	
15 "DIST. 1-2?"	Distance from 1-2
16 PROMPT	
17 STO 04	
18 "HGT: 2?"	Height of 2
19 PROMPT	
20 STO 05	
21 RCL 01	Tension or Sag?
22 X>0?	Set flag 04 for Sag
23 GTO 01	
24 SF 04	
25 CHS	Estimate P
26 1/X	
27 RCL 04	
28 X↑2	$P = \frac{D_{1-2}{}^{**2}}{8 * Sag}$
29 *	
30 8	
31 /	
32 STO 06	
33 GTO 03	
34♦LBL 04	Reference Calculated Sag to Actual Sag
35 CHS	
36 STO 00	
37 RCL 01	
38 -	
39 ABS	Tolerance
40 .01	
41 X>Y?	Yes?
42 CF 04	
43 RCL 00	
44 RCL 01	Improve Estimation
45 /	
46 ST* 06	Tension Known
47 GTO 03	
48♦LBL 01	
49 RCL 01	$P = \frac{T}{W}$
50 RCL 02	

STEP/KEY CODE	COMMENTS
51 /	
52 STO 06	Loop to get P
53♦LBL 02	
54 RCL 04	
55 2	
56 /	
57 RCL 06	$T = PW\cosh(-\frac{D1-2}{2P})$
58 /	
59 CHS	
60 XEQ 31	
61 RCL 06	
62 *	
63 RCL 02	Adjust P if Necessary
64 *	
65 STO 00	
66 RCL 01	
67 -	
68 ABS	
69 1 E-3	
70 X>Y?	
71 GTO 03	
72 RCL 01	
73 RCL 00	
74 /	
75 ST* 06	
76 GTO 02	
77♦LBL 03	Compute Xm, X1
78 RCL 04	
79 2	
80 /	
81 RCL 06	
82 /	
83 XEQ 30	
84 RCL 06	
85 *	
86 2	
87 *	
88 1/X	
89 RCL 05	
90 RCL 03	
91 -	
92 *	
93 XEQ 32	
94 RCL 06	Xm
95 *	
96 STO 07	
97 RCL 04	
98 2	
99 /	
100 -	

STEP/KEY CODE	COMMENTS
101 STO 08	X_1 Calculation Begins
102 RCL 08	
103 XEQ 20	
104 RCL 06	
105 -	Minimum Elevation
106 RCL 03	
107 -	
108 CHS	
109 STO 09	
110 "MIN HGT ="	Yt
111 XEQ "VW"	
112 RCL 05	Maximum Sag
113 RCL 03	
114 -	
115 RCL 04	
116 /	
117 ENTER↑	
118 XEQ 32	
119 RCL 06	
120 *	
121 STO 00	
122 RCL 07	
123 -	
124 *	
125 RCL 00	
126 XEQ 20	
127 -	
128 RCL 05	
129 RCL 03	
130 -	
131 2	
132 /	
133 +	
134 RCL 08	
135 XEQ 20	
136 +	
137 FS? 04	
138 GTO 04	Iteration loop
139 "MAX. SAG="	
140 XEQ "VW"	
141 RCL 08	Weight Span
142 RCL 06	Structure 1
143 /	
144 XEQ 30	
145 RCL 06	
146 *	
147 CHS	
148 "WT.S1="	
149 XEQ "VW"	
150 RCL 08	
151 XEQ 20	Tension at
152 RCL 02	Structure 1
153 *	
154 "T1="	
155 XEQ "VW"	
156 RCL 08	
157 RCL 06	Pull-off angle
158 /	at Structure 1
159 XEQ 30	
160 ATAN	
161 "∡1="	Weight Span
162 XEQ "VW"	of Structure 2
163 RCL 08	
164 RCL 04	
165 +	
166 RCL 06	
167 /	
168 STO 00	
169 XEQ 30	
170 RCL 06	
171 *	
172 CHS	
173 "WT.S2="	
174 XEQ "VW"	Tension at
175 RCL 00	Structure 2
176 XEQ 31	
177 RCL 06	
178 *	
179 RCL 02	
180 *	
181 "T2="	
182 XEQ "VW"	Pull off angle
183 RCL 00	at Structure 2
184 XEQ 30	
185 ATAN	
186 CHS	
187 "∡2="	
188 XEQ "VW"	
189 RTN	
190◆LBL C	
191 "DIST?"	Calculate
192 PROMPT	Elevation given
193 RCL 08	Distance from
194 +	Structure 1
195 XEQ 20	
196 RCL 06	
197 -	
198 RCL 09	
199 +	
200 "HGT="	Display Height of Cable

STEP/KEY CODE	COMMENTS
201 XEQ "VW"	Enter Maximum
202 "TOP EL? "	Elevation of Structure 1
203 PROMPT	
204 -	
205 "CL="	Display Clearance
206♦LBL "VW"	
207 FS? 04	
208 RTN	View Module
209 CF 21	
210 FC? 55	
211 GTO 09	
212 SF 21	
213 XEQ "ACA "	
214 SF 12	
215 XEQ "ACX "	
216 XEQ "PRB UF"	
217 TONE 5	
218 CF 12	
219 RTN	
220♦LBL 09	
221 ARCL X	
222 AVIEW	
223 TONE 5	
224 STOP	
225 RTN	
226♦LBL 20	$P*\cosh(\frac{x\ req}{P})$
227 RCL 06	
228 /	
229 XEQ 31	
230 RCL 06	
231 *	
232 RTN	
233♦LBL 30	Sinh
234 E↑X	
235 ENTER↑	
236 1/X	
237 -	
238 2	
239 /	
240 RTN	
241♦LBL 31	Cosh
242 E↑X	
243 ENTER↑	
244 1/X	
245 +	
246 2	
247 /	
248 RTN	
249♦LBL 32	A sinh
250 ENTER↑	
251 X↑2	
252 1	
253 +	
254 SQRT	
255 +	
256 LN	
257 END	

STEP/KEY CODE COMMENTS

DATA REGISTERS

00	Program		
01	Tension or -Sag		
02	wt/ft cable		
03	Height at 1		
04	Dist. 1-2		
05	Height at 2		
06	P		
07	Xm		
08	X 1		
09	Yt		

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES
04	C	Ro1= -Sag	Ro1=Tension
12	C	Print Wide	Normal Print
21	C	Printer on	Printer Disables
27	S	User Mode On	User Mode Off
55	C	Printer Exist	No Printer

STATUS

SIZE 010 TOT. REG. 73 USER MODE
ENG ____ FIX 2 SCI ____ ON ____ OFF ____
DEG x RAD ____ GRAD ____

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY
Start	A		
Clearance	C		

D-C HIGH POTENTIAL TESTING OF MEDIUM VOLTAGE CABLES

Robert W. Parkin

FUNCTION: This program determines the D-C test voltages for medium-high voltage power cables during installation or after installation, (before the cable is placed in regular service). Recommended maintenance test values for cables in service is determined, given the time in years. Results are based on AEIC CS5, CS6, and CS7 specifications for XLPE and EPR cables rated 5kV through 138 kV.

ACCESSORIES: HP-41 CX or HP-41CV, printer optional

OPERATING LIMITS AND WARNINGS: Medium voltage shielded power cables rated 5kV through 138 kV. The significance of D-C high voltage tests on nonshielded and non-metallic-sheathed cable is dependent upon the environment in which it is installed; as the characteristics of the return circuits are unknown. The environment must carefully be considered or test results may not be significant, and can possibly damage the cable insulation.

REFERENCES:

[1] Association of Edison Illuminating Companies (AEIC) CS5-87, CS6-87, CS7-87

[2] IEEE Guide for Making High-Direct- Voltage Tests on Power Cable Systems in the Field.

[3] Cable Installation Manual, Anaconda (Cablec Corporation)

[4] NEMA WC-7, ICEA S-66-524 AND NEMA WC-8, ICEA S-68-516

[5] The National Electric Code, 1987 NFPA

INSTALLATION AND MAINTENANCE PROOF TESTING

The primary tests for cables are continuity checks and the testing of the insulation system. All cables, including power, lighting, instrumentation, communication, and fire protection circuits should be insulation resistance (IR) tested. All power cable circuits above 600V should also be d-c high potential tested. These tests must be made after the cable is installed and both ends terminated with the proper terminator, be it a lug for low voltage cable, or a stress cone, pothead, or cable terminator for medium-high voltage cable.

Installation proof or acceptance testing is important in that it provides assurance that no damage has occurred during installation or in the handling after leaving the factory.

Maintenance proof testing on a regular schedule assures trouble free operation by detecting incipient failures or gradual deterioration of cable characteristics. Faults or near faults which are located during maintenance testing may be repaired while the cable is out of service, thereby eliminating service interruptions. It is recommended that all medium-high voltage cables be given installation proof tests followed by regularly scheduled maintenance tests at intervals of from three to five years, depending on the type of circuit.

HIGH VOLTAGE D-C TESTING

The most common method of proof testing utilizes a high voltage d-c power supply and equipment for measuring the leakage current of the cable. Because of the size and weight of test transformers and equipment, it is not practical to employ a-c testing at field locations. The use of direct current to detect incipient failures or deterioration also avoids the harmful heating, corona effects and severe burning usually associated with a-c testing. Because of the low currents involved in d-c testing, the equipment for energizing long lengths of cable is relatively small and portable enough for field testing.

During the test, interpretation of current time curves provides considerable information regarding overall cable performance. Leakage current is dependent on the circuit capacitance, which is dependent on the insulation material, cable construction and more importantly, the circuit length. The initial current is high, and gradually seeks a steady, lower value for a good cable. If the current does not decrease, or falls and then rises, failure or weakness in the system in indicated.

The user should understand how to operate the particular test set being used, and follow safe, stringent and well documented test procedures. More information on testing procedures can be obtained from the cited references.

Table 1 below lists the factory d-c test voltages per AEIC required for input into the program; it should be noted that these levels are higher than those recommended by NEMA WC7 and WC 8 for XLPE and EPR cables.

Table 1

RATED VOLTAGE Kv	INSULATION 100%	INSULATION 133%	DC TEST VOLTAGES, kV 100%	DC TEST VOLTAGES, kV 133%
5	90	115	35	45
8	140	140	45	55
15	175	220	70	80
25	260	320	100	120
28	280	345	105	125
35	345	420	125	155
46	445	580	165	215
69	650	-	240	-
115	800	-	300	-
138	850	-	315	-

NOTE: Conductor sizes for rated voltages and notations in the cable design section for insulation thicknesses all apply.

USER INSTRUCTIONS

Size:001

STEP	INSTRUCTIONS	INPUT	DISPLAY
1.	Connect printer if a hardcopy is desired. R/S after each display if no printer is attached.		
2.	Set printer switch to manual or normal mode.		
3.	Load programs "DCT", "VW"		
4.	Check status		
5.	Initialize: XEQ **"DCT"**		
6.	Enter factory D-C test voltage from table 1 in kV.	DC	d.cTEST:V-KV
MODE: During Installation, input 0			
7.	Is the test being performed during or after installation? Enter: **0 = DC Test during installation** **1 = DC Test performed after and before cable is placed in regular service**	0	DRG.0/ AFT:1?
8.	For input 0 (during installation): Display DC test voltage in kV	-	d.c: KV =
9.	Display duration of test for five consecutive minutes.	-	5 Min.

STEP	INSTRUCTIONS	INPUT	DISPLAY
MODE: After Installation - input 1			
7a.	Is the test being performed during or after installation? Enter: **0 = DC Test during installation** **1 = DC Test performed after and before cable is placed in regular service**	1	DRG.O/ AFT:1?
8a.	For input 1, after installation and before cable is placed in regular service. Display DC test voltage in kV.	-	d.c: KV =
9a.	Display duration of test for fifteen consecutive minutes	-	15 Min.
MODE: Cable completely installed and placed in service.			
10.	Cable has been placed in service for how many years?	years	SVC: YEARS?
11.	Display DC Proof test voltage in kV for cable placed in service. Based on 65% within the first five years , and after that time period 40 % of DC test Voltage.	-	d.c: KV =
12.	Time duration for cable placed in service - 5 Min.	-	5 MIN.

STEP / KEYCODE	COMMENTS
01♦LBL "DCT"	DC High Potential Testing
02 FIX 0	Intialize
03 TONE 9	
04 "d.c.TEST:V-KV?"	Enter Factory d-c Test Voltage in kV
05 PROMPT	
06 STO 00	
07 "DRG:0 / AFT:1?"	0 = Test during Installation
08 PROMPT	1 = Test After and Before Cable is Placed in Regular Service
09 X=0?	
10 GTO 03	
11 RCL 00	
12 .80	After: 80% for 15 Consecutive Minutes
13 *	
14 "d.c: KV ="	
15 XEQ "VW"	
16 "15 MIN."	
17 AVIEW	
18 STOP	
19 GTO 01	
20♦LBL 03	
21 RCL 00	During: 75% for Five Consecutive Minutes
22 .75	
23 *	
24 "d.c: KV ="	
25 XEQ "VW"	
26 "5 MIN."	
27 AVIEW	
28 STOP	
29♦LBL 01	
30 "SVC: YEARS?"	Placed in Service for How Long in Years
31 PROMPT	
32 5	
33 X<>Y	
34 X<=Y?	
35 GTO 02	After Five Years 40%
36 RCL 00	
37 .40	
38 *	
39 GTO 06	
40♦LBL 02	
41 RCL 00	Within 5 Years 65%
42 .65	
43 *	
44♦LBL 06	
45 "d.c: KV ="	
46 XEQ "VW"	
47 "5 MIN."	
48 AVIEW	
49 STOP	
50 END	

SAMPLE PROBLEM

```
   XEQ "DCT"
d.c.TEST:V-K
V?
   80      RUN
DRG:0 / AFT:
1?
    0      RUN
d.c: KV= 60
5 MIN.
           RUN
SVC: YEARS?
         6    RUN
d.c: KV= 32
5 MIN.
```

```
           XEQ "DCT"
d.c.TEST:V-KV?
           80    RUN
DRG:0 / AFT:1?
            1    RUN
d.c: KV= 64
15 MIN.
                 RUN
SVC: YEARS?
            3    RUN
d.c: KV= 52
5 MIN.
```

DATA REGISTERS

00	DC Test- kV		

STATUS

SIZE 001 TOT. REG. ____ USER MODE
ENG ____ FIX ____ SCI ____ ON ____ OFF ____
DEG ____ RAD ____ GRAD ____

FLAGS

#	INIT S/C	SET INDICATES	CLEAR INDICATES

ASSIGNMENTS

FUNCTION	KEY	FUNCTION	KEY

SOFTWARE AND HARDWARE

User support questions and software can be obtained by contacting:

MCM SOFTWARE COMPANY
123 Lewis Court
Washingtonville, N.Y. 10992 U.S.A
Attn. Robert Parkin

SECTION ONE: ELECTRICAL PROGRAMS

1. CABLE SYSTEM AMPACITIES
2. INDUCED SHIELD VOLTAGES AND LOSSES
3. CABLE EMERGENCY OVERLOAD CAPABILITIES
4. SHORT CIRCUIT RATINGS FOR PHASE CONDUCTORS
5. SHORT CIRCUIT RATINGS OF METALLIC SHIELDS
6. POSITIVE AND ZERO SEQUENCE IMPEDANCES OF CABLES
7. DIRECT CURRENT SHIELD RESISTANCE
8. A-C RESISTANCE OF CONDUCTORS
9. VOLTAGE REGULATION AND VOLTAGE DROP OF CABLES
10. INDUCTIVE REACTANCE AND INDUCTANCE IN CABLES
11. DIELECTRIC CHARACTERISTICS OF CABLES

30 cards $25.00

SECTION TWO: **<u>POLYMER INSULATED CABLE DESIGN</u>**

12. PRIMARY CABLE DESIGN

13. TRIPLEXED AND QUADRUPLEXED SECONDARY CABLE DESIGN

14. CONTROL AND INSTRUMENTATION CABLE DESIGN

15. PERCENT COVERAGE OF CONCENTRIC WIRES OR STRAPS

16. METALLIC SHIELDING CONSTRUCTIONS

17. CONCENTRIC NEUTRAL WIRE SIZES AND SELECTION

18. FLAT STRAP NEUTRALS

19. METRIC STRAND CONDUCTOR DESIGN

20. METRIC CONVERSION FACTORS FOR CABLES

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21. PULLING TENSIONS AND INSTALLATION GUIDELINES FOR CABLE

22. PACKAGING OF WIRE AND CABLE

23. MECHANICAL DESIGN OF OVERHEAD SPANS

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14 Cards ....$ 15.00

HP-41 hardware can be obtained by contacting :

EduCALC Mail Store
27953 Cabot Road
Laguna Niguel, CA 92677 U.S.A

APPENDIX

APPENDIX

APPENDIX