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General Calculations Excerpt from PRYSMIAN'S *WIRE AND CABLE ENGINEERING GUIDE*

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Voltage Rating

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:

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 that 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 de-energizing the faulted section.

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 de-energized in a time not exceeding one hour. Also, they may be used when additional insulation strength over the 100 percent level category is desirable.

173 Percent Level - Cables in this category should be applied on systems where the time required to de-energize a grounded section is indefinite. Their use is recommended also for resonant grounded systems. Consult the cable manufacturer for insulation thicknesses.

In common with other electrical equipment, the use of cable is not recommended on systems where the ratio of the zero to positive sequence reactance of the system at the point of cable application lies between -1 and -40 since excessively high voltages may be encountered in the case of ground faults.

Voltage Regulation

Voltage regulation is often the limiting factor in the choice of either conductor or type of insulation. While the heat loss in the cable determines the maximum current it can safely carry without excessive deterioration, many circuits will be limited to currents lower than this in order to keep the voltage drop within permissible values. In this connection it should be remembered that the high voltage circuit should be carried as far as possible so that the secondary runs, where most of the voltage drop occurs, will be small.

The voltage drop percentage of a feeder circuit may be calculated by the following formulae:

$$V = (1 - \frac{V_L}{V_S}) \cdot 100$$

Where:

V = Voltage regulation in percent
V_L = Voltage across load
V_S = Voltage at source

And V_S is defined by the formula:

$$V_S = \sqrt{(V_L \cdot \cos\theta + R \cdot I)^2 + (V_L \cdot \sin\theta + X \cdot I)^2}$$

Where:

θ = Angle by which the load current lags the voltage across the load
$\cos\theta$ = Power factor of load
R = Total AC resistance of feeder
X = Total reactance of feeder
I = Load current

When the power factor angle is nearly the same as the impedance angle, that is:

$$\tan\theta \cong \frac{X}{R}$$

The voltage regulation equation above will reduce to the following formula:

$$(V_S - V_L) = RI \cdot \cos\theta + XI \cdot \sin\theta$$

The above formulas apply directly for single-phase lines when resistance and reactance are loop values and voltage is voltage between lines.

For three-phase circuits, use voltage to neutral and resistance and reactance of each conductor to neutral. This method will give the voltage drop to neutral. To obtain the voltage drop line-to-line, multiply the voltage drop by $\sqrt{3}$.

Note: The percent voltage drop is the same between conductors as from conductor to ground and should not be multiplied by $\sqrt{3}$.

Example:

3 single copper conductors, 5 kV cables in non-metallic conduit.

Size conductor	=	350 kcmil copper, 90
Insulation	=	90 mils
Jacket	=	70 mils
Overall diameter	=	1.13"
Voltage (V_S)	=	5,000 volts (3 phase)
Current (I)	=	460 amperes
Power Factor	=	0.8 (cos θ)
Length	=	2550 ft
Resistance	=	0.0308 ohms/1000 ft at 25°C 0.096 ohms or 2500 ft at 90°C
Reactance (X)	=	0.024 ohms/1000 ft (See section on conductor reactance) 0.072 ohms for 2500 ft including 20% random lay

$$V_S = \sqrt{(V_L \cdot \cos\theta + R \cdot I)^2 + (V_L \cdot \sin\theta + X \cdot I)^2}$$

$$\frac{5000}{\sqrt{3}} = \sqrt{[.8V_L + (.096 \cdot 460)]^2 + [.6V_L + (.072 \cdot 460)]^2}$$

Solving for V_L: V_L = 2,831.6 volts

Line-to-line voltage = 2831.6 $\sqrt{3}$ = 4904 V

Voltage Drop = 5000 - 4904 = 96 volts

Voltage Drop Percentage:

$$V = (1 - \frac{4904}{5000}) \cdot 100 = 1.92\%$$

Approximate Formula:

Voltage Drop = line to neutral
= R • I • cosθ + X • I • sinθ
= 0.096 • 460 • 0.8 + 0.072 • 460 • 0.6
= 35.3 + 19.8 = 55.1

Line-to-line drop = 55.1 · $\sqrt{3}$ = 95.4 V

Conductor Reactance

The reactance of any stranded or solid conductor can be calculated for a specific frequency, conductor size, and spacing. The following equation can be utilized to find the reactance of a given configuration by using the concept of geometric mean radius.

$$X = 2 \cdot \pi \cdot f \cdot \left(0.1404 \cdot \log_{10}\frac{g}{r} + 0.0153\right) \cdot 10^{-3}$$

Where:

X = Reactance in ohms/1000 ft
f = Frequency in Hertz
r = Radius of conductor
g = geometric mean radius between conductors and is given by the following formula:

$$g = \sqrt[n]{a \cdot b \cdot \ldots z_n}$$

Where:
n = number of conductors
a = distance from conductor a to b
b = distance from conductor b to c
z_n = distance from conductor n-1 to n

Using the equations above, a nomogram (a graphic representation that consists of several lines marked off to scale and arranged in such a way that by using a straightedge to connect known values on two lines an unknown value can be read at the point of intersection with another line) was constructed (the Nomogram is located at later in this document). This diagram can be used to determine the reactance of any solid or concentric stranded conductor. It covers spacing encountered for conduit wiring as well as for open wire circuits. Various modifications are necessary for use under special conditions is covered in notes on the nomogram. The reactances shown are for 60-Hertz operation.

Where regulation is an important consideration several factors should be kept in mind in order to obtain the best operating conditions.

Open wire lines have a high reactance. This may be improved by using parallel circuits but is much further reduced by using insulated cable. Three conductors in the same conduit have a lower reactance than conductors in separate conduits.

Single conductors should not be installed in individual magnetic conduit because of the excessive reactance.

Three conductors in magnetic conduit will have a somewhat higher reactance than cables in non-magnetic conduit.

The following table lists equations commonly used for determining various parameters of an electrical system where:

E = Phase-to-phase voltage
I = Current, in amperes
% Eff = Percent efficiency in decimals
pf = Power factor in decimals
kVA = Kilovolt-ampere
hp = Horsepower
kW = Kilowatts

Electrical Formulas for Determining Amperes, Horsepower, Kilowatts, and Kilovolt-Amperes

	ALTERNATING CURRENT		
Desired Data	**Single-Phase**	**Two-Phase* Four-Wire**	**Three-Phase (per phase)**
Amperes when kVA is known	$\frac{kVA \cdot 1000}{E}$	$\frac{kVA \cdot 1000}{2 \cdot E}$	$\frac{kVA \cdot 1000}{\sqrt{3} \cdot E}$
Amperes when kilowatts is known	$\frac{kW \cdot 1000}{E \cdot pf}$	$\frac{kW \cdot 1000}{2 \cdot E \cdot pf}$	$\frac{kW \cdot 1000}{\sqrt{3} \cdot E \cdot pf}$
Amperes when horsepower is known	$\frac{hp \cdot 746}{E \cdot \%Eff \cdot pf}$	$\frac{hp \cdot 746}{2 \cdot E \cdot \%Eff \cdot pf}$	$\frac{hp \cdot 746}{\sqrt{3} \cdot E \cdot \%Eff \cdot pf}$
Kilovolt-Amperes	$\frac{I \cdot E}{1000}$	$\frac{I \cdot E \cdot 2}{1000}$	$\frac{I \cdot E \cdot \sqrt{3}}{1000}$
Kilowatts	$\frac{I \cdot E \cdot pf}{1000}$	$\frac{I \cdot E \cdot 2 pf}{1000}$	$\frac{I \cdot E \cdot \sqrt{3} \cdot pf}{1000}$
Horsepower	$\frac{I \cdot E \cdot \%Eff \cdot pf}{746}$	$\frac{I \cdot E \cdot 2 \cdot \%Eff \cdot pf}{746}$	$\frac{I \cdot E \cdot \sqrt{3} \cdot \%Eff \cdot pf}{746}$

- In three-wire, two-phase balanced circuits, the current in the common conductor is $\sqrt{2}$ times that in either of the other conductors.

Shielding of Insulated Cables

Shielding should be considered for non-metallic covered cables operating at a circuit voltage above 2000 volts for single conductor cables and 5000 volts for assembled conductors with a common overall jacket.

Definition of shielding

Shielding of an electric power cable is the practice of confining the dielectric field of the cable to the insulation of the conductor or conductors. It is accomplished by means of strand and insulation shields.

Functions of Shielding

A strand shield is employed to preclude excessive voltage stress on voids between conductor and insulation. To be effective, it must adhere to or remain in intimate contact with the insulation under all conditions.

An insulation shield has a number of functions:

1. To confine the dielectric field within the cable.
2. To obtain symmetrical radial distribution of voltage stress within the dielectric, thereby minimizing the possibility of surface discharges by precluding excessive tangential and longitudinal stresses.
3. To protect cable connected to overhead lines or otherwise subject to induced potentials.
4. To limit radio interference.
5. To reduce the hazard of shock. This advantage is obtained only if the shield is grounded. If not grounded, the hazard of shock may be increased.

Use of Insulation Shielding

The use of shielding involves consideration of installation and operating conditions. Definite rules cannot be established on a practical basis for all cases. However, shielding should be considered for nonmetallic covered cables operating at a circuit voltage over 2000 where any of the following conditions exist:

1. Connection to aerial lines.
2. Transition from conducting to non-conducting environment.
3. Transition from moist to dry earth.
4. Dry soil, such as in the desert.
5. Damp conduits.
6. Where the surface of cable collects conducting materials.
7. Where electrostatic discharges are of low enough intensity not to damage cable but are sufficient in magnitude to interfere with radio or television reception.
8. Where safety to personnel is involved.

More specific information on requirements for shielding by cable type is provided in the following table.

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Operating Voltage Limits (kV) Above Which Insulation Shielding is Required

Power Cable - 100 and 133 Percent Insulation Level	
1. Single conductor (including assemblies of single conductors)	
a. With metallic sheath or armor	5kV
b. All others	2kV
2. Multiple conductors with common covering	
a. With discharge-resisting jacket	5kV
b. With non-discharge-resisting jacket	2kV
c. With metallic sheath or armor	5kV

Multiplying Factors for Equivalent Three-Phase Voltages for Single- or Two-Phase AC Systems or for DC Systems		
Single- and Two-Phase AC Systems* and DC Systems 5000 Volts or Less	Single- and Two-Phase AC Systems* Over 5000 Volts	
	One Side Grounded	Ungrounded and Midpoint Grounded
1	1.73	0.866

**** Where it is not definitely specified that a line operates as an isolated single- or two-phase system, it will be considered as a branch of a 100% insulation level three-phase circuit, and the rating will be the line-to-line voltage of this 100% insulation level three-phase circuit.***

Importance of Shielding

Where there is no metallic covering or shield over the insulation, the electric field will be partly in the insulation and partly in whatever lies between the insulation and ground. The external field, if sufficiently intense in air, will generate surface discharge and convert atmospheric oxygen into ozone, which may be destructive to rubber insulations and to protective jackets. If the surface of the cable is separated from ground by a thin layer of air and the air gap is subjected to a voltage stress, which exceeds the dielectric strength of air, a discharge will occur, causing ozone formation.

The ground may be a metallic conduit, a damp non-metallic conduit or a metallic binding tape or rings on an aerial cable, a loose metallic sheath, etc. Likewise, damage to non-shielded cable may result when the surface of the cable is moist, or covered with soot, soapy grease or other conducting film and the external field is partly confined by such conducting film so that the charging current is carried by the film to some spot where it can discharge to ground. The resultant intensity of discharge may be sufficient to cause burning of the insulation or jacket.

Where non-shielded non-metallic jacketed cables are used in underground ducts containing several circuits, which must be worked on independently, the external field if sufficiently intense can cause shock to those who handle or contact energized cable. In cases of this kind, it may be advisable to use shielded cable. Shielding used to reduce hazards of shock should have a resistance low enough to operate protective equipment in case of fault. In some cases, the efficiency of protective equipment may require proper size ground wires as a supplement to shielding. The same considerations apply to exposed installations where personnel who may not be acquainted with the hazards involved handle cables.

Grounding of the Insulation Shield

The insulation shield must be grounded at least at one end and preferably at two or more locations. This decreases the reactance to fault currents and increases human safety factor. It is recommended that the shield be grounded at cable terminations and at splices and taps. Stress cones should be made at all shield terminations.

The shield should operate at or near ground potential at all times. Frequent grounding of shields reduces the possibility of open sections on nonmetallic covered cable. Multiple grounding of shields is desirable in order to improve the reliability and safety of the circuit. All grounding connections should be made to the shield in such a way as to provide a permanent low resistance bond.

Using a mechanical clamp (such as a constant tension spring or a hose clamp) is usually adequate to secure the connection. In some instances, it may be preferable to solder the connection. 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 clamp, may be used to fasten the ends of the connection together. This combination will ensure a permanent low resistance, which will maintain contact even if the solder melts.

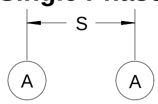
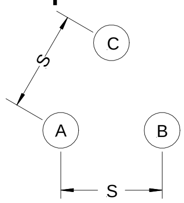
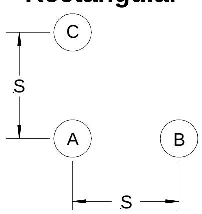
The wire or strap used to connect the cable shield ground connection to the permanent ground must be of adequate size to carry the fault current. Shielding which does not have adequate ground connection due to discontinuity of the shield or to improper termination may be more dangerous than non-shielded non-metallic cable and hazardous to life.

Shield Materials

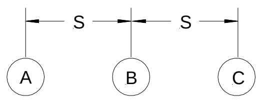
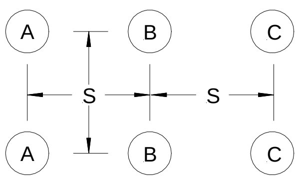
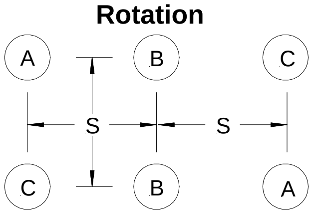
Two distinct types of materials are employed in constructing cable shields:

Nonmetallic shields - consist of either a conducting tape or a layer of conducting compound. The tape may be conducting compound, fibrous tape faced or filled with conducting compound, or conducting fibrous tape.

Metallic shield - should be nonmagnetic and may consist of tape, braid, concentric serving of wires, or a sheath.

Cable Geometry Configuration	*Induced Sheath Voltage Formulae (µV to Neutral per ft)*	*Metallic Shield Loss Formulae for Solidly Grounded Shields*	*Where:*
Single Phase  	*Phase A:* IX_M	*Phase A:* $I^2R_S\cdot\left[\frac{(X_M)^2}{(R_S)^2+(X_M)^2}\right]$ *Total Loss:* $2I^2R_S\cdot\left[\frac{(X_M)^2}{(R_S)^2+(X_M)^2}\right]$	P = R_S / Y Q = R_S / Z
Equilateral  	*Phase A, B & C:* IX_M	*Phase A, B & C:* $I^2R_S\cdot\left[\frac{(X_M)^2}{(R_S)^2+(X_M)^2}\right]$ *Total Loss:* $3I^2R_S\cdot\left[\frac{(X_M)^2}{(R_S)^2+(X_M)^2}\right]$	
Rectangular  	*Phase A & C:* $\frac{I\cdot\sqrt{3\cdot Y^2+\left[X_M-\left(\frac{A}{2}\right)\right]^2}}{2}$ *Phase B:* IX_M	*Phase A & C:* $I^2\cdot R_S\cdot\left[\frac{(P^2+3Q^2)\pm 2\sqrt{3}\cdot(P-Q)+4}{4\cdot(P^2+1)\cdot(Q^2+1)}\right]$ *Phase B:* $I^2\cdot R_S\cdot\frac{I}{Q^2+1}$ *Total Loss:* $3I^2\cdot R_S\cdot\left[\frac{P^2+Q^2+2}{2\cdot(P^2+1)\cdot(Q^2+1)}\right]$	Y = x_M + A/2 Z = x_M - A/6

Formulae continued on Next Page.

Cable Geometry Configuration	*Induced Sheath Voltage Formulae (µV to Neutral per ft)*	*Loss Formulae for Solidly Grounded Metallic Sheaths*	*Where:*
Flat 	*Phase A & C:* $\frac{I\cdot\sqrt{3\cdot Y^2+\left(X_M-A\right)^2}}{2}$ *Phase B:* IX_M	*Phase A & C:* $I^2\cdot R_S\cdot\left[\frac{\left(P^2+3Q^2\right)\pm2\sqrt{3}\cdot(P-Q)+4}{4\cdot\left(P^2+1\right)\cdot\left(Q^2+1\right)}\right]$ *Phase B:* $I^2\cdot R_S\cdot\frac{I}{Q^2+1}$ *Total Loss:* $3I^2\cdot R_S\cdot\left[\frac{P^2+Q^2+2}{2\cdot\left(P^2+1\right)\cdot\left(Q^2+1\right)}\right]$	Y = x_M + A Z = x_M - A/3
2-Circuit, No Phase Rotation 	*Phase A & C:* $\frac{I\cdot\sqrt{3\cdot Y^2+\left[X_M-\left(\frac{B}{2}\right)\right]^2}}{2}$ *Phase B:* $I\cdot\left(X_M+\frac{A}{2}\right)$		Y = x_M + A + B/2 Z = x_M + A/3 - B/6
2-Circuit, Phase Rotation 	*Phase A & C:* $\frac{I\cdot\sqrt{3\cdot Y^2+\left[X_M-\left(\frac{B}{2}\right)\right]^2}}{2}$ *Phase B:* $I\cdot\left(X_M+\frac{A}{2}\right)$		Y = x_M + A - B/2 Z = x_M + A/3 - B/6

$x_M = 2\pi f\ (0.1404\ \log_{10}(S/r_m))\ \mu\Omega/ft$

$A = 2\pi f\ (0.1404\ \log_{10}(2))\ \mu\Omega/ft$

$B = 2\pi f\ (0.1404\ \log_{10}(5))\ \mu\Omega/ft$

$R_S = \rho/(8r_m t)\ \mu\Omega/ft$

R_S = Metallic Shield Resistance (µΩ/ft)

t = Metallic Tape Thickness (inches)

f = Frequency (Hz)

S = Center to Center Spacing of Cables (inches)

r_m = Metallic Shield Mean Radius (inches)

I = Conductor Current (amperes)

ρ = Metallic Shield Resistivity at 50°C (Ωcmil/ft)

ρ Values (Ωcmil/ft)

Overlapped Copper Tape	30
Overlapped Brass Tape	70
Overlapped Monet Tape	2500
Overlapped Ambrac Tape	350
Lead Sheath	150
Aluminum Sheath	20
Aluminum Interlocked Armor	28
Galvanized Steel Interlocked Armor	70
Galvanized Steel Armor Wire	102
Aluminum (5052 Alloy)	30

Splices and Terminations

The insulation shields must be removed completely at splices and terminations, otherwise excessive leakage current and flashover will result. Auxiliary nonmetallic conducting shields may adhere to the insulation, so that the use of a 100 grit aluminum oxide cloth (or similar material) may be required to assure removal of the conducting material from the insulation surface (See pages 28 - 30 for generalized discussion of cable preparation for splicing and terminating).

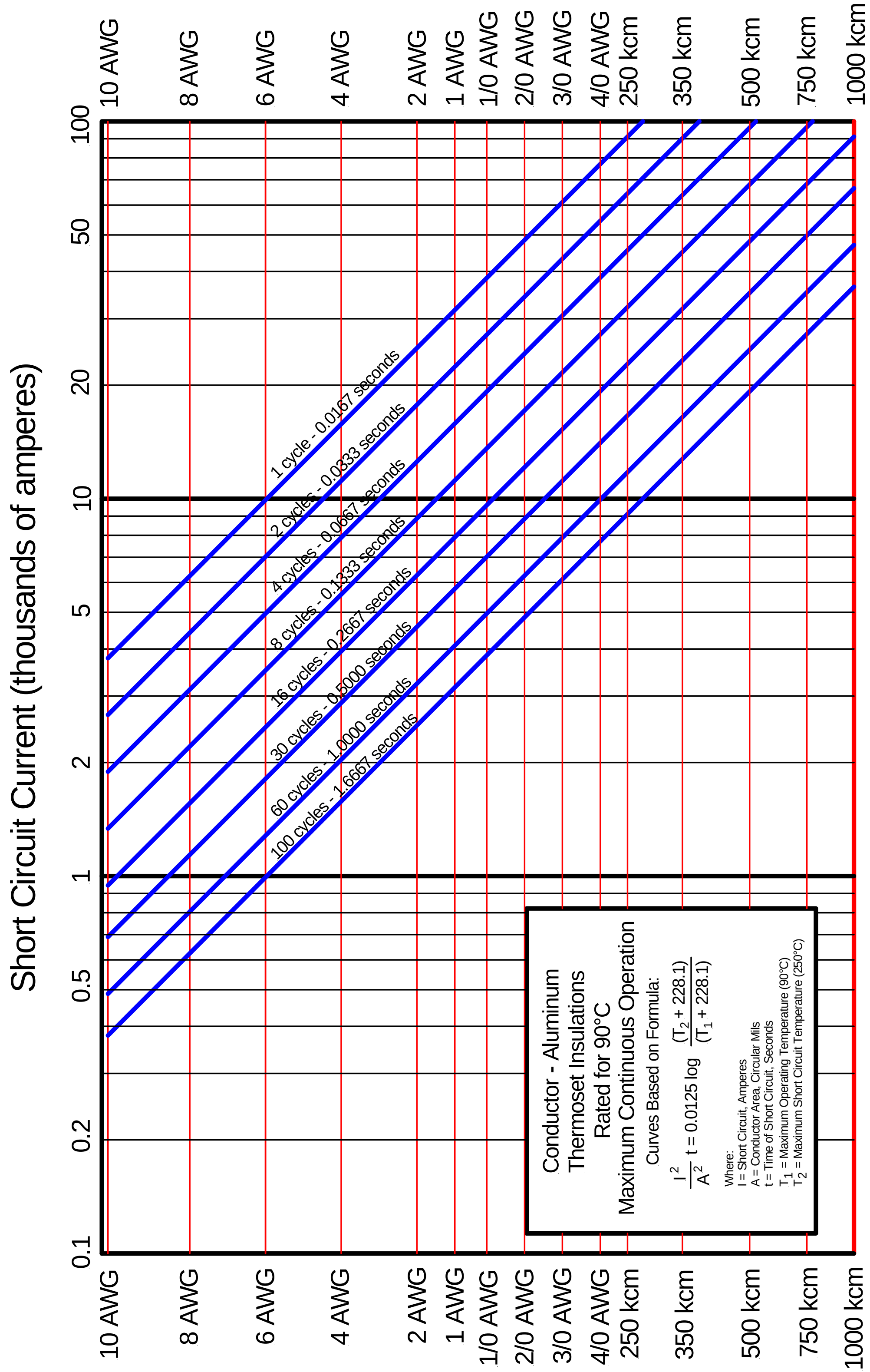
Short-Circuit Currents for Insulated Cable Conductors

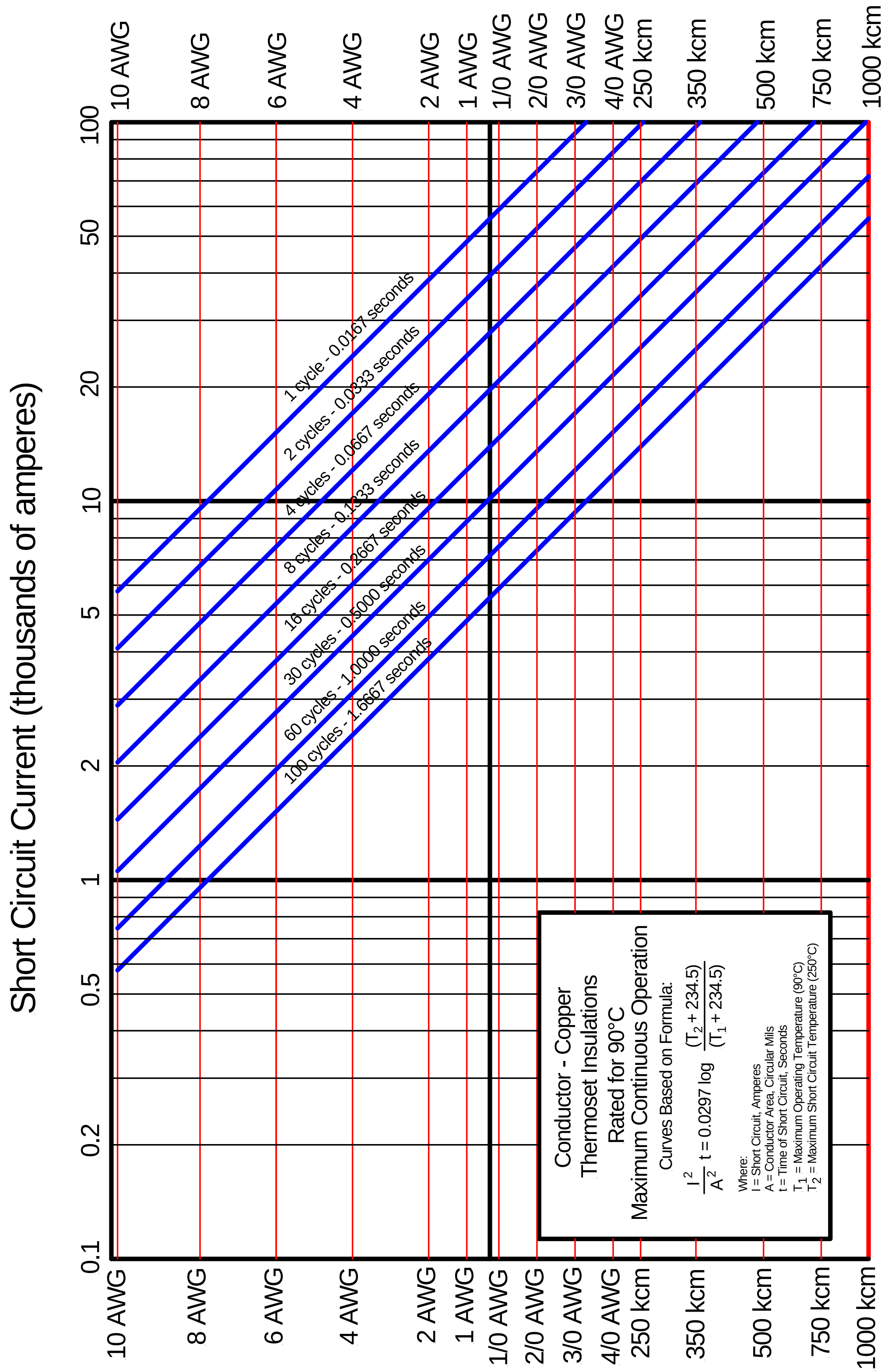
Steady increases in kVA capacity of power distribution systems have resulted in possible short circuit currents of such magnitude that the resulting high conductor temperature may seriously damage the conductor insulation. As a guide in preventing such serious damage, maximum allowable short circuit temperatures that damage the insulation to a slight extent only, have been established for the various insulations as follows (based on ICEA P-32-382):

Thermoplastic Compound	150°C
Rubber and Varnished Cloth	200°C
Impregnated Paper	200°C
Thermoset Compound	250°C

The charts on the following pages show the currents, which, after flowing for the times indicated, will produce these maximum temperatures for the given conductor sizes.

These charts are for copper or aluminum conductors operating at 90°C or 105°C with thermoset insulations. For other, less common charts, reference ICEA P-32-382. The system short circuit capacity, the conductor cross-sectional area and the circuit breaker opening time should be such that these maximum allowable short circuit currents are not exceeded.


Short Circuit Current (thousands of amperes)
0.1
0.2
0.5
1
2
5
10
20
50
100
10 AWG
8 AWG
6 AWG
4 AWG
2 AWG
1 AWG
1/0 AWG
2/0 AWG
3/0 AWG
4/0 AWG
250 kcm
350 kcm
500 kcm
750 kcm
1000 kcm
1 cycle - 0.0167 seconds
2 cycles - 0.0333 seconds
4 cycles - 0.0667 seconds
8 cycles - 0.1333 seconds
16 cycles - 0.2667 seconds
30 cycles - 0.5000 seconds
60 cycles - 1.0000 seconds
100 cycles - 1.6667 seconds
Conductor - Aluminum
Thermoset Insulations
Rated for 90°C
Maximum Continuous Operation
Curves Based on Formula:
$\frac{I^2}{A^2} t = 0.0125 \log \frac{(T_2 + 228.1)}{(T_1 + 228.1)}$
Where:
I = Short Circuit, Amperes
A = Conductor Area, Circular Mils
t = Time of Short Circuit, Seconds
T_1 = Maximum Operating Temperature (90°C)
T_2 = Maximum Short Circuit Temperature (250°C)



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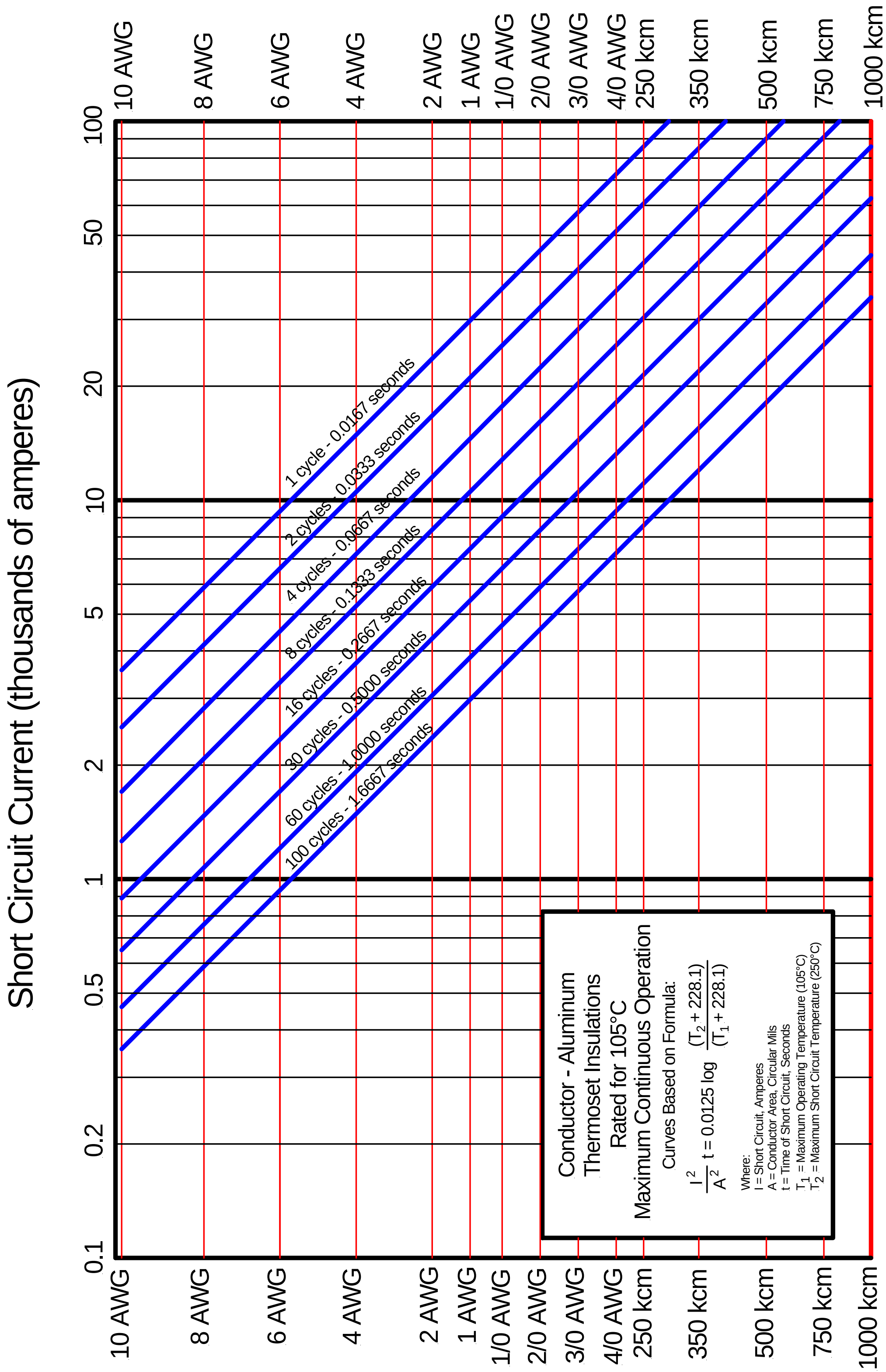

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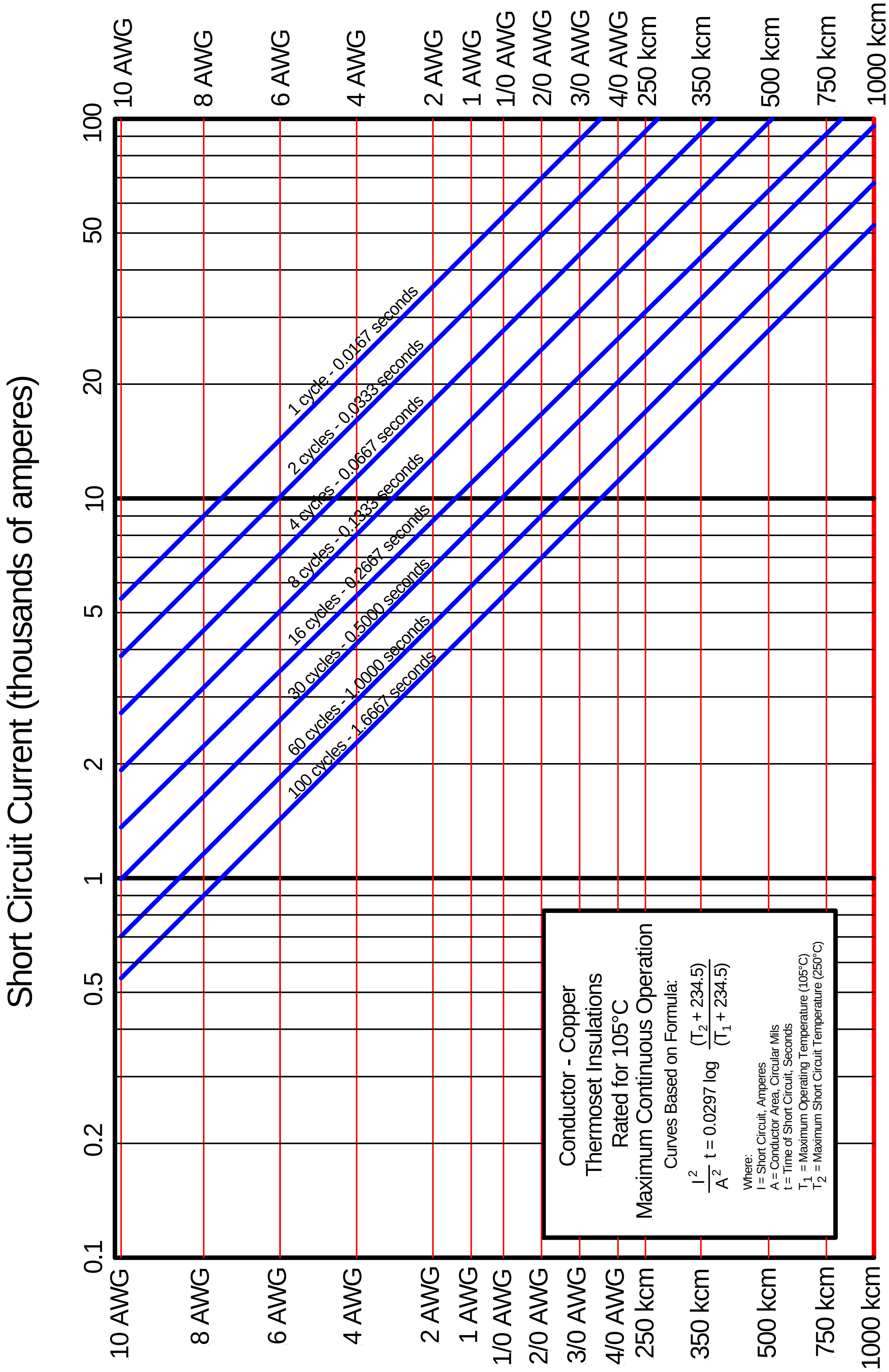
Short Circuit Current (thousands of amperes)
0.1
0.2
0.5
1
2
5
10
20
50
100
10 AWG
8 AWG
6 AWG
4 AWG
2 AWG
1 AWG
1/0 AWG
2/0 AWG
3/0 AWG
4/0 AWG
250 kcm
350 kcm
500 kcm
750 kcm
1000 kcm
1 cycle - 0.0167 seconds
2 cycles - 0.0333 seconds
4 cycles - 0.0667 seconds
8 cycles - 0.1333 seconds
16 cycles - 0.2667 seconds
30 cycles - 0.5000 seconds
60 cycles - 1.0000 seconds
100 cycles - 1.6667 seconds
Conductor - Copper
Thermoset Insulations
Rated for 105°C
Maximum Continuous Operation
Curves Based on Formula:
$\frac{I^2}{A^2}$ t = 0.0297 log $\frac{(T_2 + 234.5)}{(T_1 + 234.5)}$
Where:
I = Short Circuit, Amperes
A = Conductor Area, Circular Mils
t = Time of Short Circuit, Seconds
T_1 = Maximum Operating Temperature (105°C)
T_2 = Maximum Short Circuit Temperature (250°C)

Shield Short Circuit Current Formula

The following simplified formula may be used to calculate allowable sheath currents (based on ICEA P-45-482):

1. The maximum time that a given short-circuit current can flow in a given shield or sheath, or

2. The maximum short-circuit current that can flow in a given shield or sheath for a given time, or

3. The effective cross-sectional area of a shield or sheath needed to withstand a given short-circuit current for a given time.

$$I = \frac{MA}{\sqrt{\frac{N}{60}}}$$

Where:

I = Short circuit current, amperes
A = Shield Area in cmils
N = Number of cycles
M = See Tables on next page

The final temperature the shield or sheath can reach without damaging the adjacent materials limits allowable shield or sheath currents. This limiting temperature is defined in ICEA P-45-482 as the variable "T2". Various values of "T2" are listed below. For greater detail in regards to the calculation please refer to ICEA P-45-482.

Values of T_2, Maximum Allowable Shield or Sheath Transient Temperature

Cable Material in Contact with Shield or Sheath	T_2 (°C)
Crosslinked (thermoset)	350*
Thermoplastic	200
Impregnated Paper	200
Varnished Cloth	200

* ***For lead (Pb) sheaths this temperature is limited to 200°C.***

NOTE: The material in contact with the shield or sheath shall limit the temperature of the shield or sheath. For example, a cable having a crosslinked semi-conducting shield under the metallic shield and a crosslinked jacket over the metallic shield would have a maximum allowable temperature of 350°C. With a thermoplastic jacket, it would be 200°C.

Values of “M” Based on Shield Temperature (T_2) Above

T_2 Max (°C)	Rated Voltage (kV)	Values of “M” (90°C)			Values of “M” (105°C)		
		Cu	Al	Pb	Cu	Al	Pb
200	5	0.063	0.042	0.012	0.058	0.039	0.011
350	5	0.089	0.059	----	0.085	0.056	----
200	15	0.063	0.042	0.012	0.058	0.039	0.011
350	15	0.089	0.059	----	0.085	0.056	----
200	25	0.063	0.042	0.012	0.060	0.040	0.011
350	25	0.089	0.059	----	0.086	0.057	----
200	35	0.065	0.043	0.012	0.060	0.040	0.011
350	35	0.090	0.060	----	0.086	0.057	----
200	46	0.065	0.043	0.012	0.060	0.040	0.011
350	46	0.090	0.060	----	0.086	0.057	----

To calculate the circular mil area of a shield design, use the following formulas:

Type of Shield or Sheath	Formulas For Calculating "A" (See notes 1 & 2)
1. Wires applied either helically, as a braid or serving; or longitudinally with corrugations.	$nd_S{}^2$
2. Helically applied tape not overlapped.	$1.27nwb$
3. Helically applied flat tape, overlapped (See note 3).	$4bd_m \cdot \sqrt{\frac{100}{2(100-L\ )}}$
4. Corrugated tape, longitudinally applied.	$1.27\left[\pi \cdot (d_{is}+50)+B\right] \cdot b$
5. Tubular Sheath.	$4bd_m$

NOTE 1:
Where:

- ***A = Effective cross-sectional area, shield or sheath***
- ***B = Tape overlap, mils (usually 375)***
- ***b = Thickness of tape, mils***
- ***d_{is} = Diameter over semiconducting insulation shield, mils***
- ***d_m = Mean diameter of shield or sheath, mils***
- ***d_s = Diameter of wires, mils***
- ***w = Width of tape, mils***
- ***n = Number of serving or braid wires, or tapes***
- ***L = Overlap of tape, percent***

NOTE 2:
The effective area of composite shields is the sum of the effective areas of the components. For example, the effective area of a composite shield consisting of a helically applied tape and a wire serving would be the sum of the areas calculated from Formula 2 (or 3) and Formula 1.

NOTE 3:
The effective area of thin, helically applied overlapped tapes depends, also, upon the degree of electrical contact resistance of the overlaps. Formula 3 may be used to calculate the effective cross-sectional area of the shield for new cable. 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 Formula 2 could apply.

OTHER CALCULATIONS

Charging Current

The charging current I of a single conductor insulated power cable can be obtained from the following formula:

$$I = 2 \cdot \pi \cdot f \cdot C \cdot E$$

Where:

I = microamperes per 1000 ft.
f = Frequency, Hz
C = Capacitance, picofarads per ft
E = Voltage, phase-to-ground, kV

Capacitance of Cables

The capacitance of a one conductor shielded cable is given by the following formula:

$$C = \frac{7.354 \cdot (SIC)}{\log \frac{D}{d}}$$

Where:

C = Capacitance, picofarads per ft
SIC = Dielectric constant of the insulation material
D = Diameter over insulation
d = Diameter under insulation

Typical Values of SIC	
Polyvinyl Chloride	3.5 - 8.0
EPR Insulation	2.5 - 4.0
Polyethylene	3.0 - 6.0
Crosslinked Polyethylene	2.1 - 2.3
Impregnated Paper	3.3 - 3.7

Dielectric Loss of Cable Insulation

The dielectric loss of a single conductor cable can be calculated by the following formula:

$$W_d = \frac{0.00276 \cdot E^2 \cdot (SIC) \cdot \tan\delta}{\log\left(\frac{D}{d}\right)}$$

Where:

W_d = Dielectric loss, watts per ft.
E = Phase-to-neutral voltage, kV
SIC = Dielectric constant of the insulation material
tan δ = dissipation factor

Maximum Voltage Stress Across Insulation

$$V = \frac{2 \cdot E_g}{D_{cs} \cdot \ln\left(\frac{D_i}{D_{cs}}\right)}$$

Where:

V = Maximum voltage stress, kV
E_g = Phase-to-neutral voltage, kV
D_{CS} = Diameter over conductor shield
D_i = Diameter over insulation

Dissipation Factors for Insulation Materials (tan δ)	
Impregnated Paper……….…..	0.002 - 0.0025
EPR Insulation……………….	0.002 - 0.0800
Crosslinked Polyethylene…..	0.0001 - 0.0003

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Support Grip Length or Maximum Riser Length for Given Support Grip

The following formula may be used to determine either:

1) Minimum support grip lengths for a given riser section length, or
2) Maximum riser section length for a given support grip working length.

$$SL = \frac{1.8 \cdot (\pi \cdot D \cdot GL)}{W_C}$$

Where:

SL = Riser Section Length, in feet
D = Diameter over cable jacket, in.
GL = Working length of grip, in.
W_C= Cable weight, pounds per ft

Prysmian recommends that a recognized manufacturer supply the correct grip(s) on an individual application basis, utilizing the formula shown above. Prysmian does suggest using grips, which will provide "balanced" support for the cable (i.e. a "Double Eye" grip vs. a "Single Eye" type).

NOTE: Grips are not suitable for all vertical riser installation and the above is offered as a general guide only. If you have any questions of the suitability of a grip and/or cable construction for a vertical application, please consult the cable manufacturer.

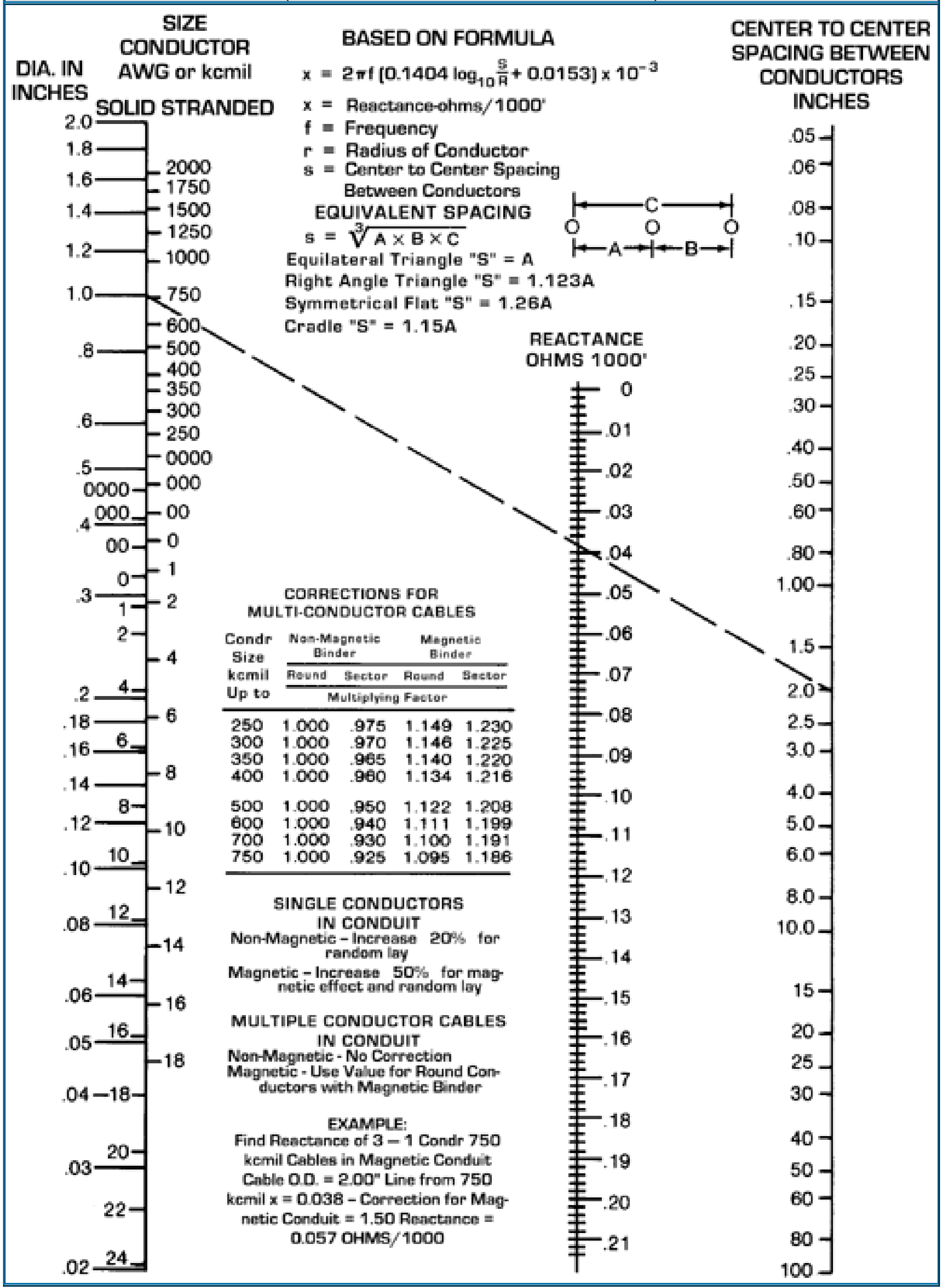
Inductive Reactance to Neutral

The following is a nomogram used to determine the inductive reactance of solid or stranded (concentric) conductors at 60 Hz. It accommodates various spacing of the conductors and other unique parameters as indicated within the nomogram itself.

Special consideration should be given to cables when installed in magnetic ducts. Installing a single cable in a magnetic duct results in HIGH reactance and a de-rated ampacity. If magnetic ducts must be used, it is recommended that all three cables be placed in a single duct. While resulting in slightly higher reactances than three cables in a non-magnetic duct, it is optimal relative to the alternative of a single cable in a magnetic duct.

Nomogram for Determining Conductor Reactance at 60 Hz

(Series Inductive Reactance to Neutral)



BASED ON FORMULA

$x = 2\pi f\,(0.1404 \log_{10}\frac{S}{R} + 0.0153) \times 10^{-3}$

x = Reactance-ohms/1000'
f = Frequency
r = Radius of Conductor
s = Center to Center Spacing Between Conductors

EQUIVALENT SPACING

$s = \sqrt[3]{A \times B \times C}$

Equilateral Triangle "S" = A
Right Angle Triangle "S" = 1.123A
Symmetrical Flat "S" = 1.26A
Cradle "S" = 1.15A

CORRECTIONS FOR MULTI-CONDUCTOR CABLES

Condr Size kcmil Up to	Non-Magnetic Binder: Round	Non-Magnetic Binder: Sector	Magnetic Binder: Round	Magnetic Binder: Sector
	Multiplying Factor			
250	1.000	.975	1.149	1.230
300	1.000	.970	1.146	1.225
350	1.000	.965	1.140	1.220
400	1.000	.960	1.134	1.216
500	1.000	.950	1.122	1.208
600	1.000	.940	1.111	1.199
700	1.000	.930	1.100	1.191
750	1.000	.925	1.095	1.186

SINGLE CONDUCTORS IN CONDUIT

Non-Magnetic – Increase 20% for random lay
Magnetic – Increase 50% for magnetic effect and random lay

MULTIPLE CONDUCTOR CABLES IN CONDUIT

Non-Magnetic - No Correction
Magnetic - Use Value for Round Conductors with Magnetic Binder

EXAMPLE:
Find Reactance of 3 — 1 Condr 750 kcmil Cables in Magnetic Conduit Cable O.D. = 2.00" Line from 750 kcmil x = 0.038 – Correction for Magnetic Conduit = 1.50 Reactance = 0.057 OHMS/1000