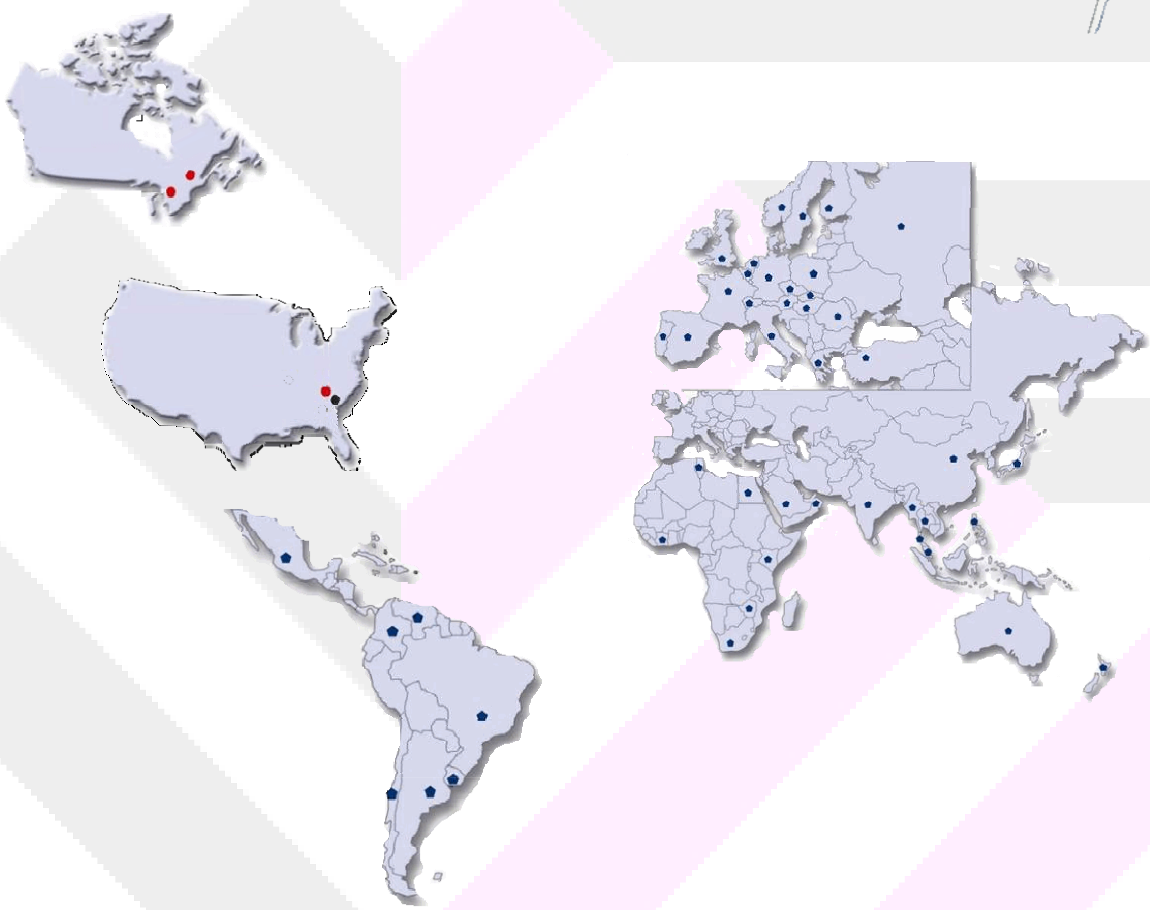
PRYSMIAN'S
Guide to Wind Farm Cables



On July 28, 2005, Pirelli sold the cables portion of their business; however the Pirelli brand name was not included in the transaction. Instead, the name Prysmian was chosen to represent our company. All of the intellectual property for the cables business - including patents, product technologies, and trade names - were included in the sale and are now a part of Prysmian Cables & Systems. The factories, employees and products remained unchanged due to the sale.

Prysmian is an international company that designs and manufactures fiber optic and power cables. Prysmian has more than 50 factories located in over 30 countries worldwide, employing more than 12,000 people. Prysmian has power cable factories , a fiber optic facility and a Research and Development Center located in North America.

Outside of North America, Prysmian provides cabling solutions for applications such as Trains, Marine, Submarine, OPG, Mining and Cranes.

In North America, Prysmian focuses on the production and supply of power cables, accessories and fiber optic cables. Prysmian is one of the main power cable providers in North America, supplying millions of feet annually to the Utility and the Contractor & Industrial markets (inclusive of the Wind Farm market).

Prysmian specializes in the supply of 35 kV, aluminum, 100% TRXLPE insulated, concentric neutral, polyethylene jacketed cables used throughout the wind farm collection grid.

Prysmian's wind farm collection cables include conductors sized from 1/0 AWG to 1500 kcm as well as customized neutral designs for specific fault current conditions. Conductor sizes larger than 1500 kcm can also be designed and provided.

Single conductor cable with unfilled or filled strand, true-triple extruded insulation system consisting of a thermosetting semi-conducting conductor shield, high dielectric strength VOLTALENE™ TRXLPE insulation, thermosetting semi-conducting insulation shield, bare copper concentric neutral wires, water swellable agents, black encapsulating or sleeved linear low-density polyethylene (LLDPE) jackets.

Class A or B Compressed concentric strand - aluminum alloy 1350 per ASTM. Water-blocked stranded conductors with STRANDSEAL® are optional and recommended. Copper conductors for higher ampacity ratings are also available.

Extruded thermosetting semi-conducting conductor shield which is free stripping from the conductor and bonded to the insulation.

Natural high dielectric VOLTALENE™ TRXLPE insulation, exhibiting an optimum balance of mechanical and electrical properties, assuring resistance to treeing and high reliability. EPR insulation is available

Extruded thermosetting semi-conducting insulation shield with controlled adhesion to the insulation providing the required balance between electrical integrity and ease of stripping.

Solid bare copper wires, helically applied and uniformly spaced. Water-blocking agents are recommended and can be applied over the insulation shield, around the neutral wires and beneath the jacket to resist longitudinal water migration.

Black insulating sunlight resistant linear low-density polyethylene encapsulating the neutral wires with three extruded red stripes and NESC lightning bolt symbol. Sleeved jackets are also available.

OPTIONS

- UL Rating
- Plexed Cables
- 105°C EPR
- Strandseal® Filled Conductors

INSTALLATIONS

- Direct Buried
- Underground Duct
- Wet Locations
- Dry Locations

QUALITY

- 15 psi Water-blocking*
- ISO 9000**
- True-Triple Extrusion

OPERATING CONDITIONS

- 90°C Continuous
- 130°C Emergency***
- 250°C Short-Circuit

* with Prysmian Doubleseal™ design
** Prysmian is ISO 9000 certified in our North American Facilities
*** not to exceed 1500 hours over the life of the cable, per ICEA

CANADIAN STANDARDS ASSOCIATION

PHYSICALS

35kV, 100% TRXLPE, AL

CONDUCTOR		INSULATION[2]		CONCENTRIC NEUTRAL[3]			JACKET[4]	WEIGHT[4] (lbs/1000 ft)
AL Size	Nom. Dia.[1] (in.)	Min. Dia. (in.)	Max. Dia. (in.)	Size	No. of Wires	Size of Wires	Nom. Dia. (in.)	
1/0 AWG	0.364	1.045	1.145	Full	16	14	1.41	914
1/0 AWG	0.364	1.045	1.145	2/3	11	14	1.41	841
1/0 AWG	0.364	1.045	1.145	1/2	8	14	1.41	812
1/0 AWG	0.364	1.045	1.145	1/3	6	14	1.41	802
2/0 AWG	0.408	1.090	1.190	Full	20	14	1.45	982
2/0 AWG	0.408	1.090	1.190	2/3	14	14	1.45	912
2/0 AWG	0.408	1.090	1.190	1/2	10	14	1.45	865
2/0 AWG	0.408	1.090	1.190	1/3	7	14	1.45	852
3/0 AWG	0.458	1.140	1.240	Full	16	12	1.56	1190
3/0 AWG	0.458	1.140	1.240	2/3	17	14	1.50	1044
3/0 AWG	0.458	1.140	1.240	1/2	13	14	1.50	951
3/0 AWG	0.458	1.140	1.240	1/3	9	14	1.50	944
4/0 AWG	0.515	1.195	1.295	Full	20	12	1.60	1330
4/0 AWG	0.515	1.195	1.295	2/3	21	14	1.58	1171
4/0 AWG	0.515	1.195	1.295	1/2	16	14	1.58	1126
4/0 AWG	0.515	1.195	1.295	1/3	11	14	1.58	1074
4/0 AWG	0.515	1.195	1.295	1/6	6	14	1.58	1020
250 kcm	0.561	1.250	1.350	1/3	13	14	1.62	1160
250 kcm	0.561	1.250	1.350	1/6	10	16	1.60	1069
250 kcm	0.561	1.250	1.350	1/12	6	16	1.60	1033
350 kcm	0.664	1.355	1.455	1/3	18	14	1.77	1484
350 kcm	0.664	1.355	1.455	1/6	9	14	1.77	1372
350 kcm	0.664	1.355	1.455	1/12	7	16	1.74	1256
500 kcm	0.794	1.480	1.580	1/3	16	12	1.95	1854
500 kcm	0.794	1.480	1.580	1/6	13	14	1.92	1669
500 kcm	0.794	1.480	1.580	1/12	10	16	1.89	1629
750 kcm	0.974	1.670	1.770	1/3	24	12	2.16	2486
750 kcm	0.974	1.670	1.770	1/6	19	14	2.14	2185
750 kcm	0.974	1.670	1.770	1/12	10	14	2.14	2076
1000 kcm	1.124	1.815	1.920	1/3	20	10	2.36	3077
1000 kcm	1.124	1.815	1.920	1/6	16	12	2.32	2697
1000 kcm	1.124	1.815	1.920	1/12	13	14	2.27	2455
1250 kcm	1.251	2.045	2.155	1/3	20	9	2.61	3755
1250 kcm	1.251	2.045	2.155	1/6	20	12	2.54	3225
1250 kcm	1.251	2.045	2.155	1/12	16	14	2.49	2984
1500 kcm	1.370	2.120	2.225	1/6	24	12	2.62	3544
1500 kcm	1.370	2.120	2.225	1/12	19	14	2.58	3251

1 - Diameters are based on ASTM Class B Compressed diameters
2 - Minimum and maximum insulation diameters are based on ICEA S-94-649 (and will meet AEIC CS8-07). Diameters for 1250 kcm and 1500 kcm include the use of a semi-conducting tape over the strand.
3 - Neutral wire designs are subject to change based on manufacturing logistics, but will remain equivalent to the conductivity requirements.
4 - Weights and dimensions are subject to manufacturing tolerances and in some cases may be calculated estimates.

ELECTRICALS

35kV, 100% TRXLPE, AL

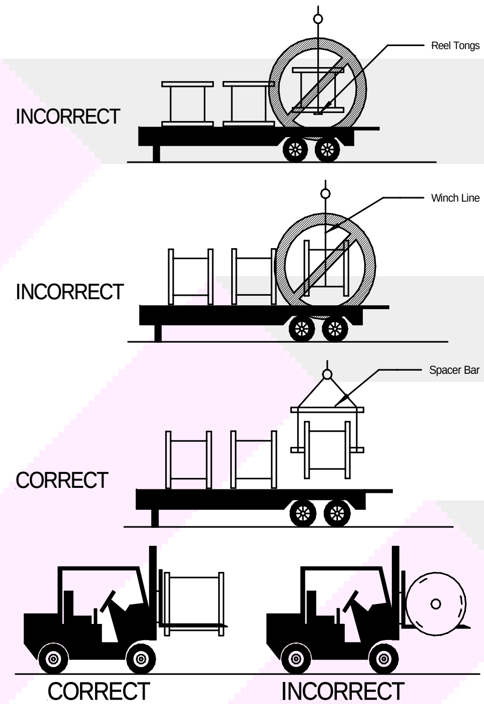
AL Size	Neutral Size	Capaci-tance µF/1000′	TREFOIL			FLAT SPACED @ 7.5 INCHES			FLAT SPACED—TOUCHING		
			Pos/Neg Seq[1] Impedance (µΩ/ft)	Zero Seq[1] Impedance (µΩ/ft)	Ampacity[1] Trefoil (amps)	Pos/Neg Seq[2] Impedance (µΩ/ft)	Zero Seq[2] Impedance (µΩ/ft)	Ampacity[2] Flat(amps)	Pos/Neg Seq[3] Impedance(µΩ/ft)	Zero Seq[3] Impedance (µΩ/ft)	Ampacity[3] Flat (amps)
1/0 AWG	Full	0.0391	213 +j52	408 + j33	221	230 + j91	405 + j34	242	214 + j58	407 + j34	228
1/0 AWG	2/3	0.0391	212 + j52	497 + j34	221	225 + j94	493 + j34	244	214 + j58	469 + j34	228
1/0 AWG	1/2	0.0391	212 + j52	605 + j34	221	222 + j95	598 + j34	245	213 + j58	603 + j34	228
1/0 AWG	1/3	0.0391	212 + j52	736 + j34	221	219 + j96	727 + j34	246	213 + j59	733 + j34	228
2/0 AWG	Full	0.0419	169 + j50	325 + j32	251	189 + j85	323 + j32	273	171 + j55	325 + j32	259
2/0 AWG	2/3	0.0419	169 + j50	393 + j33	251	184 + j90	390 + j32	276	170 + j56	392 + j32	259
2/0 AWG	1/2	0.0419	168 + j50	483 + j32	252	180 + j92	478 + j32	278	169 + j56	482 + j32	259
2/0 AWG	1/3	0.0419	168 + j50	618 + j32	252	176 + j93	611 + j32	279	169 + j56	616 + j32	260
3/0 AWG	Full	0.0451	135 + j49	259 + j30	286	156 + j79	257 + j30	307	138 + j54	258 + j30	294
3/0 AWG	2/3	0.0451	134 + j48	318 + j30	287	151 + j85	316 + j30	311	136 + j55	318 + j30	295
3/0 AWG	1/2	0.0451	133 + j49	376 + j30	287	147 + j88	373 + j30	314	135 + j55	375 + j30	296
3/0 AWG	1/3	0.0451	133 + j49	484 + j30	287	143 + j90	479 + j30	317	134 + j56	483 + j30	297
4/0 AWG	Full	0.0486	109 + j47	207 + j29	324	132 + j73	206 + j29	343	112 + j52	207+ j29	332
4/0 AWG	2/3	0.0486	107 + j47	257 + j28	326	127 + j80	255 + j28	349	110 + j53	256 + j28	335
4/0 AWG	1/2	0.0486	107 + j47	304 + j28	326	123 + j84	302 + j28	352	109 + j53	303 + j28	336
4/0 AWG	1/3	0.0486	106 + j47	394 + j28	327	118 + j86	391 + j28	357	108 + j54	393 + 28	337
4/0 AWG	1/6	0.0486	106 + j47	635 + j28	327	112 + j88	627 + j28	362	107 + j54	632 + j28	338
250 kcm	1/3	0.0519	90 + j45	334 + j27	359	103 + j83	331 + j27	388	92 + j51	330+ j27	369
250 kcm	1/6	0.0519	90 + j45	611+ j27	360	96 + j86	604 + j27	397	90 + j52	609 + j27	371
250 kcm	1/12	0.0519	89 + j45	958 + j27	360	93 + j87	946 + j27	401	90 + j52	955 + j27	372
350 kcm	1/3	0.0583	66 + j43	241 + j25	432	81 + j77	240 + j25	454	68 + j49	241 + j25	442
350 kcm	1/6	0.0583	65 + j43	438 + j25	434	73 + j81	434 + j25	470	66 + j50	437 + j25	446
350 kcm	1/12	0.0583	64 + j43	812 + j25	435	68 + j83	80 3 + j25	479	65 + j50	810 + j25	448
500 kcm	1/3	0.0662	48 + j41	173 + j23	521	66 + j69	173 + j23	522	40 +j45	173 + j23	528
500 kcm	1/6	0.0662	46 + j41	292 + j23	527	57 + j76	291 + j23	551	47 + j45	292 + j23	537
500 kcm	1/12	0.0662	46 + j41	571 + j22	531	51 + j78	557 + j22	575	46 + j46	570 +j22	543
750 kcm	1/3	0.0775	34 + j39	116 + j21	639	54 + j59	117 + j21	598	36 + j39	116 + j21	641
750 kcm	1/6	0.0775	32 + j39	200 + j21	654	46 + j69	200 + j21	645	33 + j40	200 + j21	658
750 kcm	1/12	0.0775	31 + j39	352 + j21	661	36 + j73	351 + j21	686	32 + j41	352 + j21	668
1000 kcm	1/3	0.0865	28 + j37	88 + j20	726	47 + j51	88 + j20	650	29 + j35	88 + j20	727
1000 kcm	1/6	0.0865	26 + j37	153 + j19	752	41 + j63	153 + j19	700	27 + j37	153 + j19	752
1000 kcm	1/12	0.0865	24 + j37	272 + j19	768	33 + j68	272 + j19	767	25 + j37	272 + j19	769
1250 kcm	1/3	0.0946	25 + j35	70 + j19	790	43 + j44	70 + j19	695	25 + j32	70 + j19	794
1250 kcm	1/6	0.0946	22 + j36	123 + j18	832	38 +j58	123 +j18	738	23 + j34	123 + j18	827
1250 kcm	1/12	0.0946	20 + j36	222 + j18	857	30 +j65	222+ j18	821	21 +j35	222 + j18	851
1500 kcm	1/6	0.1017	20 + j35	103 + j17	893	36 + j54	103 + j17	765	20 + j32	104 + j17	883
1500 kcm	1/12	0.1017	18 + j35	187 + j17	928	29 + j62	188 + j17	856	19 +j33	188 + j17	914

Other calculations and engineering services are available—fees may apply.

1 - Ampacities and impedances based on cables operating in a 3-phase installation with one cable per phase, in a trefoil configuration, earth rho of 90°C·cm/W, earth ambient of 20°C, neutral wires grounded at both ends, 75% load factor, conductor temperature of 90°C, and 36” depth of burial.
2 - Ampacities and impedances based on cables operating in a 3-phase installation with one cable per phase, flat spaced at 7.5” center-to-center spacing, earth rho of 90°C·cm/W, earth ambient of 20°C, neutral wires grounded at both ends, 75% load factor, conductor temperature of 90°C, and 36” depth of burial.
3 - Ampacities and impedances based on cables operating in a 3-phase installation with one cable per phase, flat spaced and touching, earth rho of 90°C·cm/W, earth ambient of 20°C, neutral wires grounded at both ends, 75% load factor, conductor temperature of 90°C, and 36” depth of burial.

Installation Guidelines

Cable Handling



Upon receiving cable, reel wrap (if applicable) should be inspected for damage. Damaged reel wrap is a key indicator that further cable inspection should be made prior receiving the cable into inventory. Information on reel tags should be verified to insure the correct cable is being received into inventory.

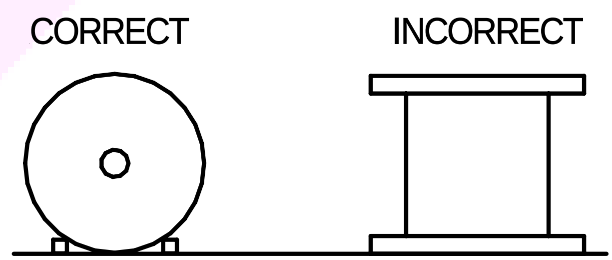
Cable reels should always be handled in a manner that minimizes opportunities for cable damage to occur.

Forklift blades, winch lines or other devices should never come in direct contact with the cable on the reel. Handling should be done only by the reel itself.

Cable Storage

It is recommended that cable be stored on the manufacturer's reels on a dry level surface to prevent deterioration of the reels and possible ingress of moisture into the cables. Reels should be protected from other objects, vehicles, etc. coming in contact with the cable on the reel. Cable ends should remain sealed via manufacturer supplied end caps. If these end caps are removed, equivalent, weatherproof end caps should be replaced on the cable ends.

Reel flanges should remain perpendicular to the ground throughout the handling and installation processes. Cable reels should be chocked to prevent the reels from moving unintentionally; this prevents "reel to reel" damage.



Installation Guidelines

Most cables can be safely handled if not subjected to temperatures lower than -10°C (14°F) in the twenty-four (24) hour period preceding the pulling and bending of the cable. If temperatures are expected to fall below this value during the 24 hours preceding installation, provisions should be made to move the cable to a warm storage area or provide localized shelter and heating. The cable should be exposed to a temperature of 15°C (60°F) for 24 hours prior to installation to ensure complete warm-up of the cable.

Cable Installation

Maximum Pulling Tensions for Stranded Aluminum Conductors Using Pulling Eyes (pounds)

Conductor Size	1/C Single	3-1/C Parallel	3-1/C Triplex
1/0 AWG	844	1688	2532
2/0 AWG	1064	2128	3192
3/0 AWG	1342	2684	4026
4/0 AWG	1692	3384	5076
250 kcm	2000	4000	6000
350 kcm	2800	5600	8400
500 kcm	4000	8000	12000
750 kcm	6000	12000	18000
1000 kcm	8000	16000	24000
1250 kcm	10000	20000	-
1500 kcm	12000	24000	-

Maximum Tension for Stranded Aluminum Conductors Using Pulling Grips

Maximum pulling tensions utilizing a pulling grip, for TRXLPE insulated cables, with concentric neutral wire shielding and an overall jacket have a maximum of limit of 10,000 pounds for a single conductor cable, and a maximum limit of 5000 pounds for multiple cables. The above tensions for the multiple cables assume three cables in one grip (per AEIC CG5-2005). If using a pulling grip, the maximum value CANNOT exceed the corresponding value for pulling the cable using a pulling eye; the lesser of theses two values must be used as the limit.

Cables must be handled with care during installation. This practice will maintain the integrity of the cable and help ensure increased reliability and long cable life. Three major mechanical stresses must be observed during cable installation: Maximum Pulling Tensions, Maximum Sidewall Bearing Pressures and Minimum Bending Radii.

The table (left) provides maximum pulling tension limits for the most commonly installed medium voltage power cables for either installing with pulling eyes of using pulling grips. Other manufacturers may recognize lower tension limits based on their designs than are recognized by Prysmian.

Minimum Bending Radii

Care must be exercised when handling cables, especially when bending cables for the purposes of training them for connections as well as pulling them around bends while under tension. These are two very different limitations for the cable. Bending for the purposes of training the cable for connections is considered a static condition, while bending the cables

Installation Guidelines

Minimum Bending Radius (Static Conditions)

The minimum values for the radii to which such cables may be bent for permanent training can be determined by the following formula:

MBR = OD x M

Where:

MBR = Minimum radius of bend (in.)
OD = Outside diameter of cable (in.)
M = Diameter multiplier [for concentric neutral cables = 8]

Note: Most wind farm cables are concentric neutral type cables.

Minimum Bending Radius (Dynamic Conditions)

The minimum values for the radii to which such cables may be bent while being pulled under tension can be determined by the below formula. This value will greatly depend on the tension the cable is experiencing as it exits the bend in question. For instance, the greater the exiting tension, the greater the minimum-bending radius required for the cable.

MBR = (Te ÷ SWBP) X 12 (inches)

Where:

MBR = Minimum radius of bend (in.)
Te = Tension as cable exits the bend (pounds•force)
SWBP= Maximum allowable Sidewall Bearing Pressure (pounds•force per radial-foot)

Sidewall Bearing Pressure

To preclude damage to the cable from the dynamic radial pressure which develops when a cable is pulled around a bend under tension, this pressure must be kept as low as possible, and should not exceed the 2000 lbs per radial-foot for jacketed concentric neutral cables.

Installation Guidelines

Sidewall Bearing Pressure (cont.)

$P_{SW} = T_e \div B_r$

Where:

P_{sw}	=	**Sidewall Bearing Pressure (pounds per radial-foot)**
T_e	=	**Pulling Tension as cable exits the bend (pounds•force)***
B_r	=	**Bend radius (feet)**

NOTE: The maximum pulling tension of the cable must be observed.

Cable Issues

It is important that the above noted limitations of maximum pulling tensions, minimum bending radii, and sidewall bearing pressure be adhered to during cable handling and installation. Cables exposed to excessive mechanical forces may be damaged, but possibly not to an extent that is determinable by historical testing methods. Exceeding maximum pulling tensions can easily damage the cable; see below photos of cable that experienced excessive pulling tensions.

Photo1

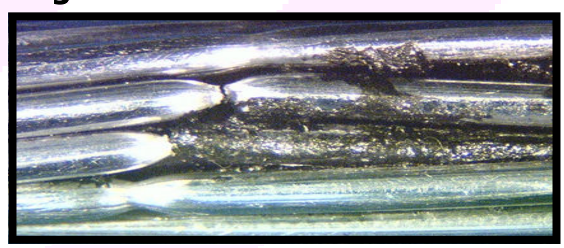


Photo 2

Photo 1 clearly shows damage that is evident by visual inspection. Photo 2 shows damage that is not visible via external inspection.

Cable preparation for termination and splicing plays an equally important role in maintaining the life expectancy of the power cable. Insulation shield cutback should be smooth and even. Poor cutbacks such as the one in the red oval to the right, are indicative of poor technique, will result in areas of high stress and a cable that will likely fail prematurely. It is unlikely that typical DC Hi-Pot testing will find such workmanship errors.

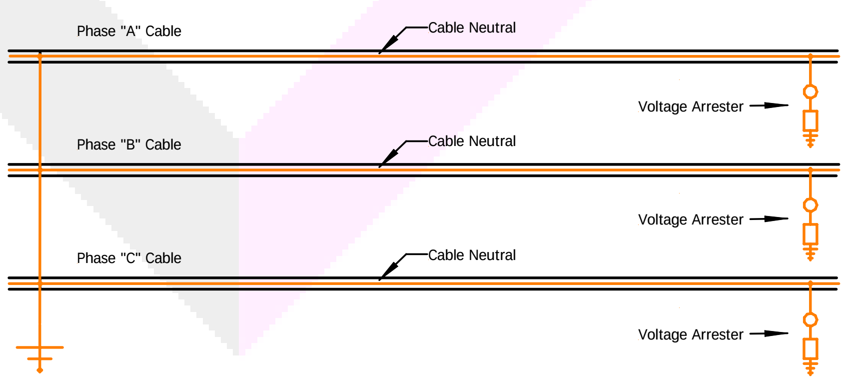
Installation Guidelines

Cuts into the insulation are often the result of cutting through the insulation shield during its removal process. Deep cuts into the insulation can be the culprit for partial discharge and ultimate cable failure. This type of cut not only creates the possibility for partial discharge, but can also result in creating a tracking path from the insulation shield towards the conductor. This happens as the blade from the removal tool pushes the semi-conducting material from the insulation shield into the insulation. The red arrow in the above photograph highlights insulation shield that has been pushed into the insulation during cable preparation.

Grounding Options

Another area that should be focused on is the grounding of the concentric neutrals. There are several different options for grounding which include single point grounding, multi-point grounding and even cross-bonding.

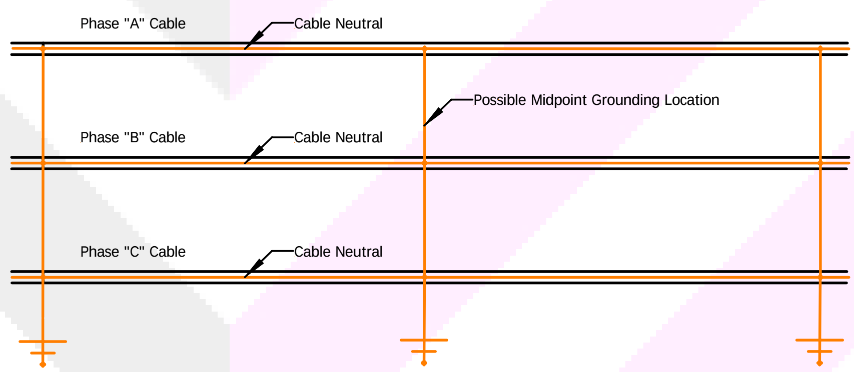
With *single point grounding* neutrals are solidly grounded on one end and grounded through a voltage limiting device at the other end or left open circuited. The advantage of this grounding method is an increase in cable ampacity. This method eliminates the circulating currents induced into the neutral wires, removing a heat source and allowing more current to flow in the conductor. The concern associated with single point grounding is the induced voltage at the end that is grounded through the voltage limiter. The amount of voltage depends on the amount of current, the cable length, the spacing between the cables and the mean radius of the neutral wires.



PRYSMIAN

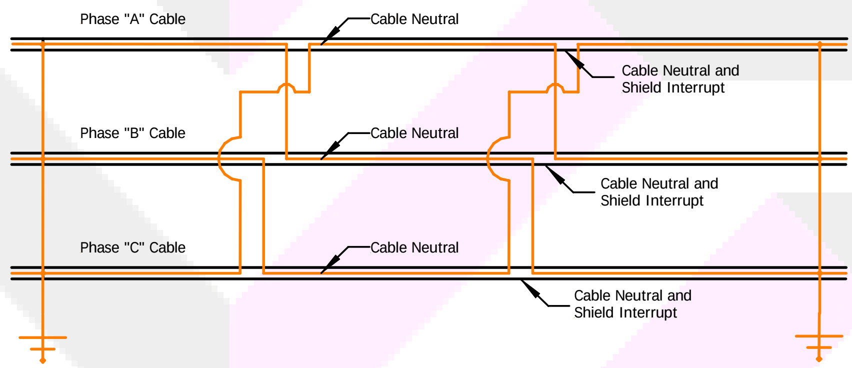
Installation Guidelines

Multi-point grounding **consists of grounding the neutral wires at both ends of the cable installation or in some cases at intervals throughout the installation length. Most commonly, if the cable is grounded in intermittent points along the cable installation, it is at intervals of 1300 feet (400m) as noted in the National Electric Code. This grounding method eliminates the safety concern of the induced voltage as noted in the single point grounding method. However, it will result in induced currents into the neutral wires thereby adding an additional heat source to the cable installation and thus lowering the cable ampacity rating. See following diagram for Multi-point grounding.**

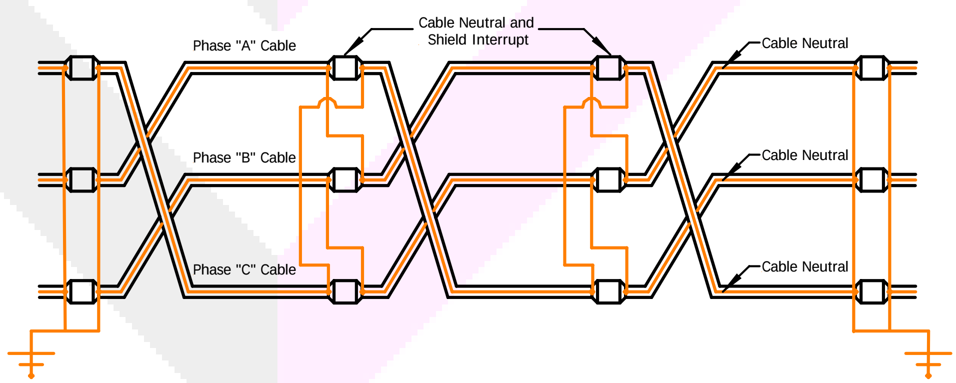


The third method of grounding cable neutrals is *cross-bonding*. While very common in high voltage transmission cable installations, cross-bonding is the least common method of grounding cables in a medium voltage, wind farm environment. Cross-bonding consists of dividing the cable run, or portions of the cable run, into three equal lengths and interrupting the insulation shield and metallic shield continuity at each length. Cross-bonding the neutrals eliminates the induced circulating currents in the neutral wires thereby increasing the ampacity rating of the cable. This is achieved via the interruption of the insulation shield and neutrals wires and the unique connection of these shields and neutrals. This is evidenced in the following diagram where it is assumed the cables are maintained in a triangular configuration.

Installation Guidelines



Of course with the cables in a triangular configuration, they are subject to proximity heating from the adjacent cables, limiting the ampacity rating. To counter the effects of proximity heating the cables can be horizontally spaced apart. With the extruded and metallic shields interrupted, other than eddy currents, there are no induced currents in the metallic shield. However, with the cables spaced horizontally it is necessary to physically *transpose* the cables. This configuration gives the dual benefit of reducing both the heat generated from circulating currents flowing in the neutrals and proximity heating generated from adjacent operating phases. This helps provide the maximum ampacity for the circuit while minimizing concerns for any standing voltages. See the diagram below for more details.



Installation Guidelines

It should be understood that cross-bonding is an expensive practice, requiring specialized splices and should be performed by linemen that are experienced in the process. As the cable is to be isolated from ground, it is imperative that an insulating jacket be utilized. Below are pictures from a wind farm that employed cross-bonding on cables with a semi-conducting jacket. The use of semi-conducting jackets in conjunction with cross-bonding resulted in multiple cable failures across the wind farm grid.

Evidence of pitting in the semi-conducting jacket due to the potential differences between the jacket and the earth.

Subsequent failure of the cable, after pitting became severe enough to compromise the jacket and the insulation system.

In conclusion great care and consideration should be given to the operating conditions of the cable, how the cable is handled, installed, prepared and grounded. Using good practices in these areas will help ensure a cable that provides a long life and a high level of reliability for the wind farm operator and owner.

For additional information, please see Prysmian's website or call Prysmian.

www.prysmianusa.com - 1.800.845.8507 - www.prysmiancanada.com