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Transmission and Distribution Power Cables

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1.0 Introduction

1.1 General

Electric power systems are designed to deliver electricity from generation sources to end-users safely, reliably, and efficiently. This process is typically divided into three major stages: generation, transmission and distribution. The scope of this course is the latter two; transmission and distribution (T&D). Understanding the distinction between these two stages is essential for engineers, utility operators, and anyone involved in power system planning and operation.

This course will discuss the power cables that may be used in these two types of systems, but first, it is useful to discuss how they differ.

1.2 Transmission Systems

Transmission systems involve the bulk transfer of electrical energy from generating stations to substations located near demand centers. Transmission lines carry electricity over long distances at high voltages, typically ranging from 69 kV up to 765 kV. High voltage is used to reduce energy loss over long distances and improve overall system efficiency.

The transmission system serves as the backbone of the electrical grid. Its primary purpose is to move large quantities of power across regions, ensuring that electricity generated in one area can meet the demand in another. Transmission lines often span hundreds of kilometers, crossing urban areas, rural landscapes, and even difficult terrains.

Transmission systems rely on high-voltage conductors, including aluminum, steel-reinforced aluminum, and specialized high-temperature or low-sag conductors. Overhead lines are most common due to cost efficiency and ease of maintenance, though underground cables are increasingly used in urban areas or environmentally sensitive zones.

1.3 Distribution Systems

Distribution systems deliver electricity from substations to individual customers including residential, commercial, or industrial customers. Distribution systems operate at lower voltages, generally 46 kV and lower, and are designed to provide reliable, safe, and localized access to electricity. While transmission focuses on moving large amounts of power efficiently, distribution focuses on delivering power reliably and safely to end-users.

Distribution systems, conversely, serve as the “last mile” of electricity delivery. They ensure that energy reaches homes, businesses, and industrial facilities at usable voltages. Distribution

networks must balance reliability, safety, and flexibility, often integrating a mix of overhead lines, underground cables, and service connections tailored to local conditions.

Distribution systems typically employ medium-voltage cables, often insulated and can be armored for additional safety. Overhead distribution lines use bare or covered conductors, while underground distribution networks rely on solid dielectric or extruded insulated cables to ensure safety and reliability in close proximity to buildings and infrastructure.

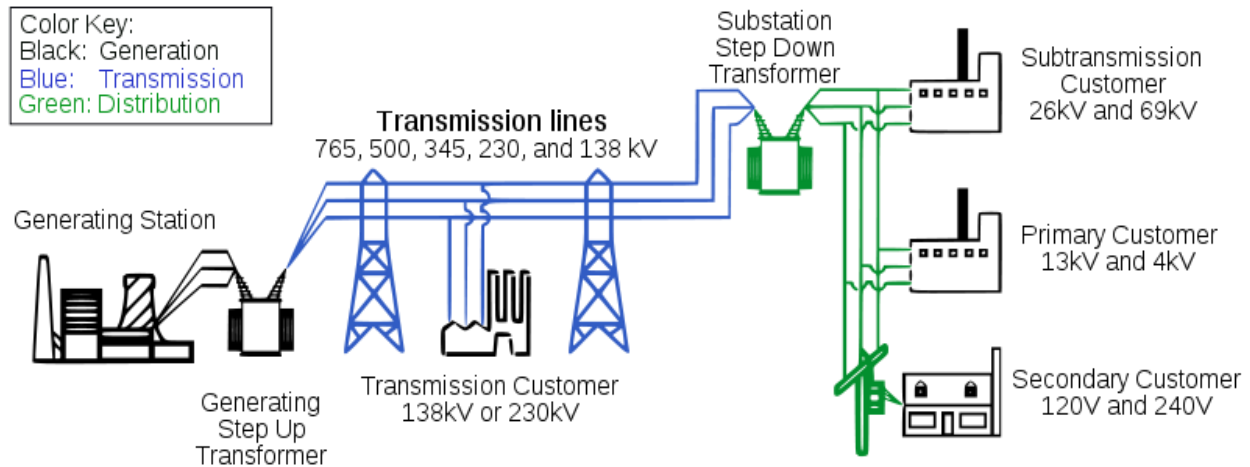


Figure 1 – High-level view of T&D systems

1.4 Transmission & Distribution (T&D) System Operators

Operators of transmission and distribution systems face numerous technical and operational challenges. Transmission System Operators (TSOs) and utilities must plan for long-term network growth while addressing immediate operational needs. Some of the key challenges include:

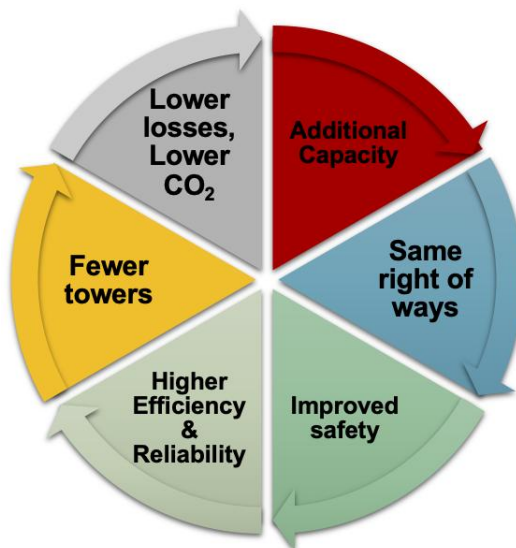


Figure 2 – Needs of System Operators

1. **Meeting Increasing Energy Demand** – Population growth, urbanization, and electrification of transport and industry are driving higher electricity demand. Networks must be expanded or reinforced to accommodate this growth without compromising reliability.
2. **Accelerating Permits and Using Existing Right-of-Ways** – Constructing new lines often requires navigating complex permitting processes and limited land availability. Utilities often seek to maximize existing rights-of-way to minimize costs and environmental impact.
3. **Improving Safety** – Maintaining adequate clearance and reducing conductor sag at peak loads are essential to prevent hazards such as line contact, fires, or equipment damage.
4. **Enhancing Efficiency and Reliability** – Modern networks aim to reduce losses during transmission and improve reliability through robust line design, advanced monitoring, and predictive maintenance.
5. **Cost Reduction** – Installing fewer towers, optimizing conductor selection, and using efficient construction methods help reduce capital and operational costs.
6. **Environmental Considerations** – Minimizing network losses and CO₂ emissions is a growing priority. This includes optimizing the system to reduce energy wastage and adopting sustainable construction practices.

Both systems play complementary roles in the electrical grid. Transmission ensures efficient movement of large-scale power, while distribution guarantees reliable access for consumers. Both systems require careful planning, operation, and maintenance to meet growing demand, maintain safety, and minimize environmental impact.

2.0 The Role of Power Cables in T&D Systems

2.1 Introduction

Power cables play a fundamental role in the reliable operation of transmission and distribution power systems, serving as the medium through which electrical energy is transferred from generating stations to end users. In the transmission stage, power must travel long distances at very high voltages to minimize energy losses. This is most commonly achieved using overhead bare conductors, which are suspended on towers or poles and designed to handle voltages ranging from 69 kV up to 765 kV or higher.

Their construction emphasizes mechanical strength, durability, and the ability to withstand environmental stresses such as wind, ice, and temperature changes. By operating at high voltage and low current, transmission cables maximize efficiency while moving large amounts of power across regions.



Figure 3 – Transmission Tower

As electricity moves into the distribution stage, voltages are stepped down to safer, more practical levels (typically ranging from 5 kV to 46 kV) for delivery to homes, businesses, and industries. At this point, the types of cables used often shift from overhead bare conductors to underground insulated power cables, particularly in urban or environmentally sensitive areas. These cables are commonly extruded types, such as XLPE (cross-linked polyethylene) and EPR (Ethylene Propylene Rubber) insulated cables, designed to provide electrical insulation, mechanical protection, and resistance to moisture and heat. Underground systems improve reliability, reduce exposure to weather-related faults, and enhance aesthetics in populated areas, though they come with higher installation and maintenance costs. Together, overhead conductors in transmission and insulated underground cables in distribution ensure that electricity can be delivered safely, efficiently, and continuously from source to consumer.

The power cables used in T&D systems can be broken down as follows:

1. Overhead and Underground Transmission Power Cables
2. Overhead and Underground Distribution Power Cables
3. Overhead and Underground Service Entrance Cables
4. High-Temperature Superconducting (HTS) Cables
5. Submarine Power Cables

2.2 Overhead Transmission Power Cables

Overhead transmission lines remain the backbone of power delivery in most countries due to their cost-effectiveness, reliability, and relative ease of installation. The choice of conductor type is critical for ensuring system efficiency, mechanical strength, and resilience against environmental factors. Each conductor type has unique properties that make it suitable for specific applications and voltage levels.



Figure 4 – Bare Overhead Aluminum Conductors

2.2.1 All Aluminum Conductor (AAC / ASC)

All Aluminum Conductors (AAC) or Aluminum Stranded Conductors (ASC), made entirely of 1350 alloy aluminum, offer high electrical conductivity, approximately 61% IACS (International Annealed Copper Standard), making it suitable for short spans where mechanical strength is less critical. Its low density reduces line weight but limits tensile strength, making it unsuitable for long-distance lines or heavy-loading conditions.

2.2.2 All Aluminum Alloy Conductor (AAAC / AASC)

All Aluminum Alloy Conductors (AAAC) or Aluminum Alloy Stranded Conductors (AASC), improve on AAC/ASC by using 6101 aluminum alloys with alloying elements of 0.8% Si and 0.5% Mg that offer higher tensile strength and corrosion resistance, particularly in coastal environments. These conductors are often used in applications where environmental exposure is a concern.



Figure 5 – Bare Overhead Aluminum Conductors

2.2.3 Aluminum Conductor Alloy Reinforced (ACAR)

Aluminum Conductor Alloy Reinforced (ACAR) combines high-strength aluminum alloy cores (6101/6201 alloy) with standard 1350 alloy aluminum wires, offering a balance between conductivity and mechanical strength. This makes ACAR suitable for medium- to long-span transmission lines where line tension is a concern.

2.2.4 Aluminum Conductor Steel Reinforced (ACSR)

Aluminum Conductor Steel Reinforced (ACSR) is the most widely used conductor for long-distance transmission. It consists of an aluminum conductor wrapped around a steel core, providing exceptional strength-to-weight ratio. ACSR supports long spans, high currents, and severe weather conditions, making it the go-to choice for many high-voltage lines.

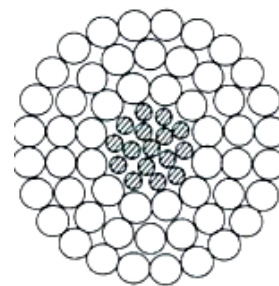


Figure 6 – ACSR cross-section

2.2.5 Covered Line Wire

Covered line wire is a type of conductor used in overhead distribution lines that does not have a specific voltage rating. It includes conductor types such as ASC/AAC, AASC/AAAC, ACSR and Copper. It is protected with covering materials like polyethylene (PE), medium-density polyethylene (MDPE), high-density polyethylene (HDPE), and cross-linked polyethylene (XLPE). See **Figure 7**.

This wire is suited for short-span applications where space is limited, such as along alleys, on poles supporting multiple circuits, or near trees. The covering provides protection against environmental factors, such as moisture, UV exposure, and abrasion, reducing the risk of short circuits and improving safety for nearby personnel and the public. Additionally, the insulation allows for closer spacing of conductors, enhances reliability in congested areas, and minimizes maintenance needs.



Figure 7 – Covered line wire

2.2.6 Specialty Conductors (ACSS/TW, ACCC, Z-Shaped Carbon Core)

Advanced conductors such as ACSS/TW (Aluminum Conductor Steel Supported / Trapezoidal Wire), ACCC (Aluminum Conductor Composite Core), and Z-shaped carbon-core wires allow higher operating temperatures, reduced sag, and increased ampacity. These are particularly useful in areas requiring grid upgrades without the need for additional towers or extensive right-of-way expansion.

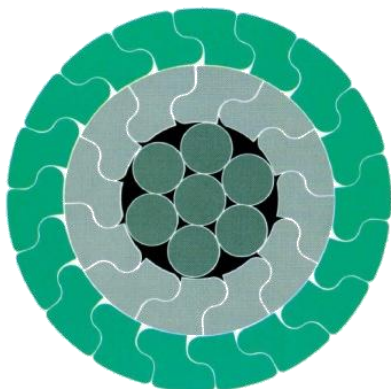


Figure 8 – Conductor with Z-shaped wires



Figure 9 – Conductor with trapezoidal wires

2.2.7 Overhead Conductor Code Words

Each conductor type is identified by industry-standard code words, indicating its composition, construction, and intended application. Understanding these codes is essential for engineers and operators during specification, design, and procurement.

The following tables showcase examples of conductor code words for the various conductor types and sizes recognized in Canada and the US. See **Figures 10 to 18**.



ASC (FLOWERS)



Table 1: Bare 1350 Conductors

CODE WORD	SIZE AWG or cmil	STRANDS	CODE WORD	SIZE AWG or cmil	STRANDS
Passionflower	6	Solid	Amaryllis	636 000	61
Peachbell	6	7	Orchid	636 000	37
Pom Pom	4	Solid	Heuchera	660 000	37
Rose	4	7	Ice Plant	660 000	61
Lily	3	7	Verbena	700 000	37
Begonia	2	Solid	Flag	700 000	61
Iris	2	7	Violet	715 500	37
Pansy	1	7	Nasturtium	715 500	61
Wallflower	1	19	Petunia	750 000	37
Thistle	1/0	Solid	Cattail	750 000	61
Poppy	1/0	7	Arbutus	795 000	37
Geranium	1/0	19	Lilac	795 000	61
Aster	2/0	7	Fuchsia	800 000	37
Buttercup	2/0	19	Heliotrope	800 000	61
Phlox	3/0	7	Anemone	874 500	37
Primrose	3/0	19	Crocus	874 500	61
Oxlip	4/0	7	Cockscomb	900 000	37
Sunflower	4/0	19	Snapdragon	900 000	61
Sneezewort	250 000	7	Magnolia	954 000	37
Valerian	250 000	19	Goldenrod	954 000	61
Dandelion	250 000	37	Hawthorn	1 000 000	37
Daisy	266 800	7	Camellia	1 000 000	61
Laurel	266 800	19	Bluebell	1 033 500	37
Foxglove	266 800	37	Larkspur	1 033 500	61
Peony	300 000	19	Margold	1 113 000	61
Agave	300 000	37	Hawthorn	1 182 500	61
Tulip	336 400	19	Gentian	1 272 000	37
Hollyhock	336 400	37	Narcissus	1 272 000	61



Figure 10 – ASC/AAC (Concentric Round)



ASC
(COMPACT – SMOOTH BODY)
(REPTILES)

Table C2: Alum. Stranded Conductors (ASC)
- Compact Round (Smooth Body),
Concentric Lay Stranding (1350 - H19)

Reference Specification = CSA C49.5



Canadian Code Word	Area AWG or kcmil	Alum. Area mm ²	No. Alum. Strands
Toad	6	13.33	7
Ozark	5	16.77	7
Dragon	4	21.10	7
Lizard	3	26.66	7
Moloch	2	33.63	7
Monitor	1	42.41	7
Newt	1	42.41	19
Tuatara	1/0	53.51	7
Skink	1/0	53.51	19
Alligator	2/0	67.44	7
Gecko	2/0	67.44	19
Crocodile	3/0	85.03	7
Anoli	3/0	85.03	19
Salamander	4/0	107.2	7
Clayman	4/0	107.2	19
Komodo	266.8	135.2	19
Tadpole	300	152.0	19
Basilisk	336.4	170.5	19
Hatteria	397.5	201.4	19
Chockwalla	477.0	241.7	19



Figure 11 – ASC (Compact Round or “Smooth Body”)



AASC COMPACT
(SMOOTH BODY)
(CANADIAN CITIES)

Table C4: Alum. Alloy Stranded Conductors (AASC)
- Compact Round (Smooth Body),
Concentric Lay Stranding (6101-T81)

Reference Specification = CSA C49.1

Canadian Code Word	Area AWG or kcmil	Alum. Area mm ²	No. Alum. Strands
Halifax	2	38.71	7
Montreal	1/0	61.61	7
Winnipeg	2/0	77.61	7
Toronto	3/0	97.87	7
Vancouver	4/0	123.4	7



AASC
(CONCENTRIC ROUND)
(US CITIES)

Table 5: Bare 6201 Alloy Conductors

CODE WORD	SIZE AWG or cmil	STRANDS	ACSR OF EQUAL DIAMETER	
			AWG or cmil	STRANDING
Abilene	10 230	7	8	6/1
Albion	30 550	7	6	6/1
Athens	38 640	7	5	6/1
Alton	48 690	7	4	6/1
Austin	61 400	7	3	6/1
Ames	77 470	7	2	6/1
Astoria	97 630	7	1	6/1
Albion	123 300	7	1/0	6/1
Annapolis	123 300	19	1/0	6/1
Anaheim	155 400	7	2/0	6/1
Augusta	155 400	19	2/0	6/1
Amherst	195 700	7	3/0	6/1
Aurora	195 700	19	3/0	6/1
Alliance	246 900	7	4/0	6/1
Amarillo	246 900	19	4/0	6/1
Blaine	312 800	19	208 800	26/7
Payetteville	355 100	19	358 400	19/1
Canton	384 600	19	388 400	26/7
Cairo	465 400	19	397 500	26/7
Darien	559 500	19	477 000	26/7
Eight	652 400	19	559 500	26/7
Flint	740 800	37	638 200	26/7
Greerley	927 200	37	795 000	26/7



Figure 12 – AASC (Compact Round) and AASC/AAAC (Concentric Round)

ACSR
(COMPACT – SMOOTH BODY)
(FISH)

Table C8: Alum. Conductors, Steel Reinforced (ACSR)
 - Compact Round (Smooth Body),
 Concentric Lay Stranding

Reference Specification = CSA C49.2

Canadian Code Word	Conductor Type*	Alum. Area AWG	Alum. Area mm ²	Total Area mm ²	Strands AL/ST
Cod	100	8	8.37	8.76	6/1
Minnow	150	8	8.37	11.16	6/1
Sardine	200	8	8.37	12.84	6/1
Ray	100	7	10.55	12.31	6/1
Cisco	150	7	10.55	14.13	6/1
Halibut	200	7	10.55	16.19	6/1
Bass	100	6	13.30	15.51	6/1
Mullet	150	6	13.30	17.74	6/1
Herring	200	6	13.30	20.39	6/1
Tuna	100	5	16.77	19.56	6/1
Darter	150	5	16.77	22.39	6/1
Goldeye	200	5	16.77	25.68	6/1
Pike	100	4	21.15	24.67	6/1
Pollock	150	4	21.15	28.26	6/1
Flounder	200	4	21.15	32.39	6/1
Chub	100	3	26.66	31.10	6/1
Whiting	150	3	26.66	35.54	6/1
Graveling	200	3	26.66	40.84	6/1
Carp	100	2	33.63	39.23	6/1
Haddock	150	2	33.63	44.83	6/1
Pickering	200	2	33.63	51.48	6/1
Shad	100	1	42.41	49.47	6/1
Lamprey	150	1	42.41	56.58	6/1
Sole	100	1/0	53.51	62.43	6/1
Sculpin	150	1/0	53.51	71.35	6/1
Hake	100	2/0	67.44	78.66	6/1
Cusk	100	3/0	85.03	99.19	6/1



ACSR
(CONCENTRIC ROUND)
(BIRDS)

Tat



CODE WORD	AWG or cmil	AL/STEEL	CODE WORD	AWG or cmil	AL/STEEL
Wren	8	6/1	Longspur	397 500	45/7
Warbler	7	6/1	Pintail	416 000	30/7
Turkey	6	6/1	Pelican	477 000	18/1
Thrush	5	6/1	Tallorbird	477 000	20/7
Sparrow	4	6/1	Toucan	477 000	22/7
Swallow	4	7/1	Flicker	477 000	24/7
Swallow	3	6/1	Hawk	477 000	26/7
Sparrow	2	6/1	Hen	477 000	30/7
Sparrow	2	7/1	Kestrel	477 000	42/7
Robin	1	6/1	Jackdaw	477 000	46/7
Raven	1/0	6/1	Heron	500 000	30/7
Quail	2/0	6/1	Nightingale	517 000	20/7
Bob-white	2/0	7/1	Ostrich	556 500	18/1
Pigeon	3/0	6/1	Tody	556 500	20/7
Vulture	4/0	5/1	Sapsucker	556 500	22/7
Penguin	4/0	6/1	Parakeet	556 500	24/7
Sparrow	4/0	18/1	Dove	556 500	26/7
Jaguar	228 200	18/1	Eagle	556 500	30/7
Chil	288 800	6/7	Blackbird	556 500	42/7
Warbling	288 800	18/1	Sunbird	556 500	46/7
Spoonbill	288 800	22/7	Peacock	606 000	24/7
Scalp	288 800	24/7	Squid	606 000	26/7
Timonise	288 800	42/7	Wood Duck	606 000	30/7
Eider	288 800	45/7	Wood Duck	606 000	30/7

Additional Canadian Code Words

CODE WORD	SIZE AWG or cmil	STRANDS AL/STEEL
Abitibi	520 200	18/7
Shelter Bay	504 200	22/7
Chignecto	588 800	22/7
Peace River	623 800	46/7
Grand Rapids	685 400	22/7
Chute des Passes	850 000	45/7
Les Boules	864 900	42/7
Carlton	1 028 700	42/7
Gatineau	1 168 100	46/7
Seaway	1 277 500	42/7
Bersfort	1 354 800	48/7
Bersimis	1 361 000	42/7



Figure 13 – ACSR (Compact Round and Concentric Round)

COVERED ASC
(COMPACT)
(PLANTS/TREES)

Table C11: Covered Aluminum Conductors (ASC*)
 - Compact Stranding

Canadian Code Word	Area AWG or kcmil	Alum. Area mm ²	Nominal Covering mm	No. Alum. Strands
Bay	6	13.33	0.76	7
Hop	4	21.10	0.76	7
Sloe	2	33.63	1.14	7
Alder	1	42.41	1.14	7
Aspen**	1/0	53.51	1.52	7
Thorn	2/0	67.44	1.52	7
Barwood	3/0	85.03	1.52	7
Camwood	3/0	85.03	1.52	18
Dogwood	4/0	107.2	1.52	7
Oakwood	4/0	107.2	1.52	18
Redwood	268.8	135.2	1.52	7
Corkwood	268.8	135.2	1.52	18
Hornbeam	300	152.0	1.52	18
Ironwood	336.4	170.5	1.52	18
Beechwood	397.5	201.4	1.90	18
Buttonwood	477.0	241.7	1.90	18



COVERED ASC
(FRUITS)

Table 9: Covered 1350 Conductors

CODE WORD	SIZE AWG or cmil	STRANDS	COVERING THICKNESS IN.
POLYETHYLENE COVERED			
Prune	10	Solid	.030
Cumquat	8	Solid	.030
Apple	6	Solid	.030
Plum	6	7	.030
Pear	4	Solid	.030
Apricot	4	7	.030
Cherry	2	Solid	.045
Peach	2	7	.045
Nectarine	1	7	.045
Quince	1/0	7	.060
Haw**	1/0	19	.060
Orange	2/0	7	.060
Ironwood**	2/0	19	.060
Fig*	3/0	7	.060
Lemon	3/0	19	.060
Olive	4/0	7	.060
Pomegranate	4/0	19	.060



Figure 14 – Covered ASC (Compact Round) and Covered ASC/AAC (Concentric Round)



COVERED AASC (TREES)



Table 11: Covered 6201 Alloy Conductors



CODE WORD	SIZE AWG or cmil 1350 EQ.	ACTUAL cmil area	STRANDS	COVERING THICKNESS IN.
POLYETHYLENE COVERED				
Birch	6	33 580	Solid	.030
Maple	6	30 590	7	.030
Poplar*	4	48 690	Solid	.030
Hornbeam**	6	48 690	7	.030
Elm*	2	77 470	Solid	.045
Linden	2	77 470	7	.045
Corktree	1	97 630	7	.045
Oilnut	1/0	123 300	7	.060
Cockspur	1/0	123 300	19	.060
Waterash	2/0	155 400	7	.060
Coconut	2/0	155 400	19	.060
Shellbark	3/0	195 700	7	.060
Rattan	3/0	195 700	19	.060
Planetree	4/0	246 900	7	.060
Mangrove	4/0	246 900	19	.060



Figure 15 – Covered AASC/AAAC (Concentric Round)

COVERED ACSR (COMPACT) (WOOD)



COVERED ACSR (PLANTS)



Table C14: Covered Aluminum Conductor, Steel Reinforced (ACSR), - Compact Stranding

Canadian Code Word	Area AWG or kcmil	Alum. Area mm ²	Nominal Covering mm inches	Type
Acadia	8	8.4	0.76 .030	100
Banyan	8	8.4	0.76 .030	150
Gum	6	13.30	0.76 .030	100
Solah	6	13.30	0.76 .030	150
Teak	4	21.15	0.76 .030	100
Ebony	2	33.63	1.14 .045	100
Liana	1	42.41	1.14 .045	100
Bamboo	1/0	53.51	1.52 .045	100
Corypha	2/0	67.44	1.52 .045	100
Mahogany	3/0	85.03	1.52 .045	100
Eucalyptus	4/0	107.2	1.52 .045	100



Table 12: Covered ACSR (Aluminum Conductor, Steel Reinforced)

CODE WORD	SIZE AWG or cmil	STRANDS AL/STEEL	COVERING THICKNESS IN.
POLYETHYLENE COVERED			
Walnut	6	6/1	.030
Acorn	5	6/1	.030
Butternut	4	6/1	.030
Hickory	4	7/1	.030
Hazelnut	3	6/1	.045
Pignut	2	6/1	.045
Beech	2	7/1	.045
Chestnut	1	6/1	.045
Almond*	1/0	6/1	.060
Pecan	2/0	6/1	.060



Figure 16 – Covered ACSR (Compact Round) and Covered ACSR (Concentric Round)

**DUPLEX NS WITH
ACSR NEUTRAL
(STARS)**

**DUPLEX NS WITH
ACSR NEUTRAL
(DOG BREEDS)**

**Table C17: Duplex
Neutral-Supported Secondary and Service Drop Cable Type NS-1
Alum. Conductor, Steel Reinforced (ACSR) Neutral - Full**

Canadian Code Word	Phase Conductor			Neutral	
	Size AWG or cmil	Strands	Insulation Thickness mm inches	Size AWG	Strands Alum.
Regulus	8	1	1.14 .030	8	6/1
Pollux	8	7	1.14 .030	8	6/1
Algol	6	1	1.14 .030	6	6/1
Arcturus	6	7	1.14 .030	6	6/1
Castor	4	7	1.14 .030	4	6/1
Deneb	2	7	1.14 .030	2	6/1
Vega	1/0	19	1.52 .045	1/0	6/1

**Table 19: Duplex
Neutral-Supported Secondary and Service Drop Cable
ACSR NEUTRAL**

CODE WORD	PHASE CONDUCTOR			NEUTRAL	
	SIZE AWG	STRANDS	INSULATION THICKNESS IN.	SIZE AWG	STRANDS AL/STEEL
POLYETHYLENE INSULATED					
Setter	6	Solid	.045	6	6/1
Shepherd	6	7	.045	6	6/1
Retriever	6	7	.060	6	6/1
Eskimo	4	Solid	.045	4	6/1
Terrier	4	7	.045	4	6/1
Yorkshire	4	7	.060	4	6/1
Chow	2	7	.045	2	6/1
Labrador	1	19	.060	1	6/1
Bloodhound	1/0	7	.060	1/0	6/1
Bull	1/0	19	.060	1/0	6/1

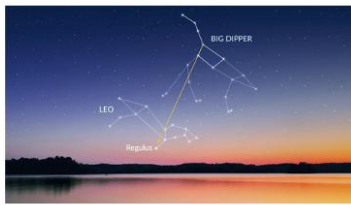


Figure 17 – Duplex NS with ACSR

**TRIPLEX NS WITH
ACSR NEUTRAL
(GEMSTONES)**

**TRIPLEX NS WITH
ACSR NEUTRAL
(SHELLFISH)**

**Table C19: Triplex
Neutral-Supported Secondary and Service Drop Cable Type NS-1
Alum. Conductor, Steel Reinforced (ACSR) Neutral - Full**

Canadian Code Word	Phase Conductor			Neutral	
	Size AWG or cmil	Strands	Insulation Thickness mm inches	Size AWG	Strands AL/ST
Jade (Topez)	6	1	1.14 .030	6	6/1
Opal	5	7	1.14 .030	5	6/1
Ruby (Carpet)	4	7	1.14 .030	4	6/1
Sard	3	7	1.14 .030	3	6/1
Topaz (Jade)	2	7	1.14 .030	2	6/1
Garnet	1	19	1.52 .045	1	6/1
Jasper	1/0	19	1.52 .045	1/0	6/1
Diamond	2/0	19	1.52 .045	2/0	6/1
Emerald	3/0	19	1.52 .045	3/0	6/1
Sapphire (Zircon)	4/0	19	1.52 .045	4/0	6/1

**Table 30: Triplex
Neutral-Supported Secondary and Service Drop Cable
ACSR NEUTRAL**

CODE WORD	PHASE CONDUCTOR			NEUTRAL	
	SIZE AWG or cmil	STRANDS	INSULATION THICKNESS IN.	SIZE AWG or cmil	STRANDS
POLYETHYLENE INSULATED					
Paludina	6	Solid	.045	6	6/1
Voluta	6	7	.045	6	6/1
Bolma	6	7	.060	6	6/1
Scallop	4	Solid	.045	6	6/1
Strombus	4	7	.045	6	6/1
Carnea	4	7	.060	6	6/1
Whelk	4	Solid	.045	4	6/1
Weakfish	4	Solid	.045	4	7/1
Penwinkle	4	7	.045	4	6/1
Calma	4	7	.060	4	6/1
Cockle	2	7	.045	4	6/1
Gebia	2	7	.060	4	6/1
Conch	2	7	.045	2	6/1
Uca	2	7	.060	2	6/1
Ovula	1	7	.060	3	6/1



Figure 18 – Triplex NS with ACSR

2.2.8 Environmental and Mechanical Considerations

Conductors must withstand environmental stresses, including wind, ice, temperature variations, and corrosion. Mechanical factors such as sag, tension, and vibration are critical to line safety and performance. Proper conductor selection balances electrical efficiency, mechanical resilience, and long-term operational cost.

2.3 Underground Transmission Power Cables

Underground transmission systems provide an alternative to overhead lines where space is limited, aesthetics is a concern, or environmental restrictions apply. Underground cables are common in urban centers, industrial complexes, and environmentally sensitive areas.

2.3.1 Solid Dielectric (XLPE) Cables

Solid Dielectric (XLPE) cables are a widely used type of high-voltage power cable that employ cross-linked polyethylene (XLPE) insulation to provide excellent electrical and thermal performance. Unlike fluid-filled designs, XLPE cables use solid, thermoset polymer insulation that is lightweight, chemically stable, and highly resistant to electrical stress. This insulation allows the cables to operate at high voltages and elevated temperatures with minimal dielectric losses, making them suitable for both underground and submarine transmission, as well as utility and industrial applications. XLPE cables are mechanically robust and resistant to moisture, corrosion, and environmental degradation, simplifying installation and reducing long-term maintenance needs. Their compact design, high current-carrying capacity, and reliability under demanding conditions have made XLPE cables a preferred choice for modern high-voltage transmission systems globally. See **Figure 19 and 20**.

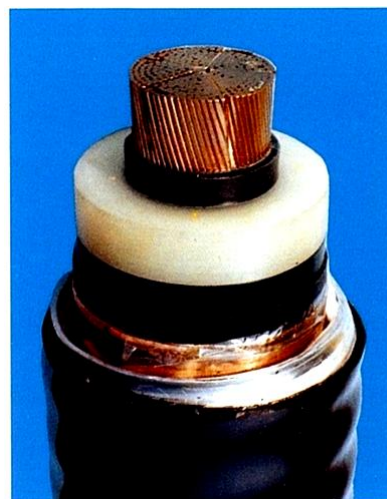


Figure 19 – Solid Dielectric (XLPE) Cable

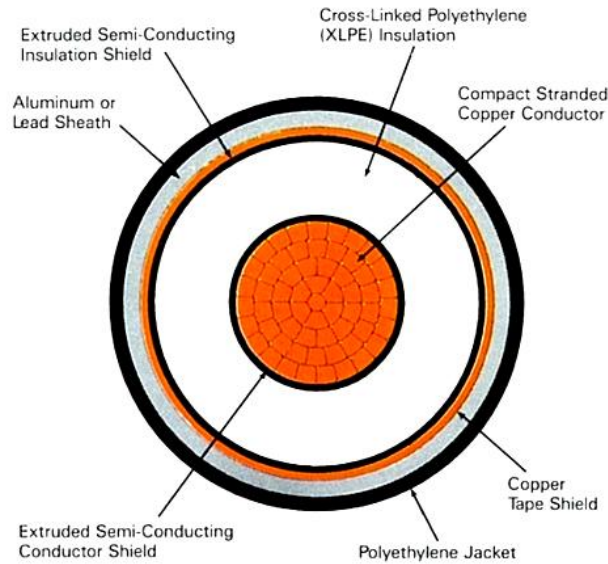


Figure 20 – Solid Dielectric (XLPE) Cable Cross-Section

2.3.2 Self-Contained Liquid-Filled (SCLF) Cables

Self-Contained Liquid-Filled (SCLF) cables are a type of high-voltage power cable designed for long-distance underground or submarine transmission. They consist of a conductor surrounded by a pressurized fluid-filled insulation system, typically using mineral oil or synthetic dielectric fluid, which provides excellent electrical insulation and helps dissipate heat generated during operation. The “self-contained” aspect refers to the integrated metallic sheath or lead covering that contains the fluid under pressure, eliminating the need for external piping or pressurization equipment along the route. This design allows SCLF cables to operate reliably at high voltages and large current capacities, making them suitable for utility transmission networks, interconnections, and underwater installations. Their robust construction protects against moisture ingress, mechanical stress, and thermal expansion, ensuring long-term durability and consistent performance even in challenging environmental conditions. See **Figures 21, 22 and 23**.



Figure 21 – SCLF Cable

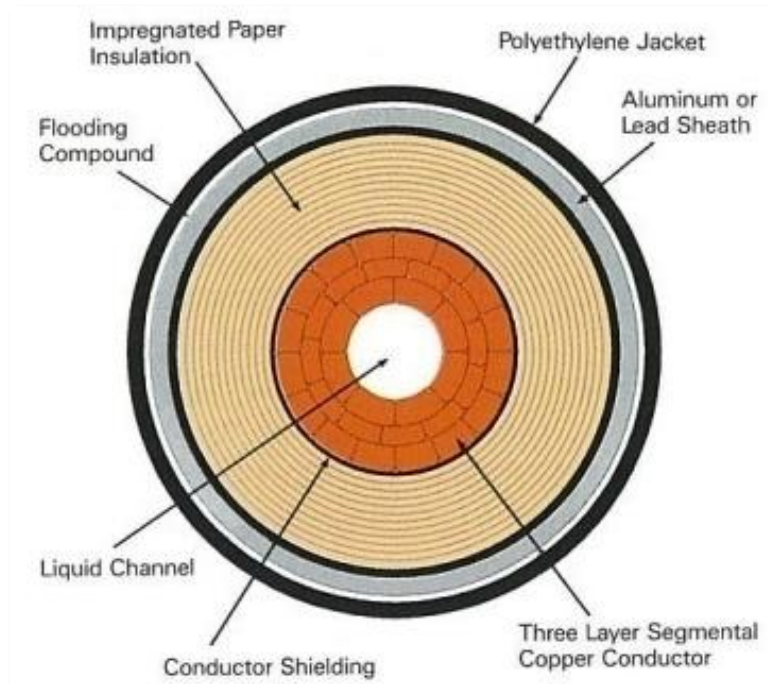


Figure 22 – SCLF Cable With Liquid Channel Core Cross-Section

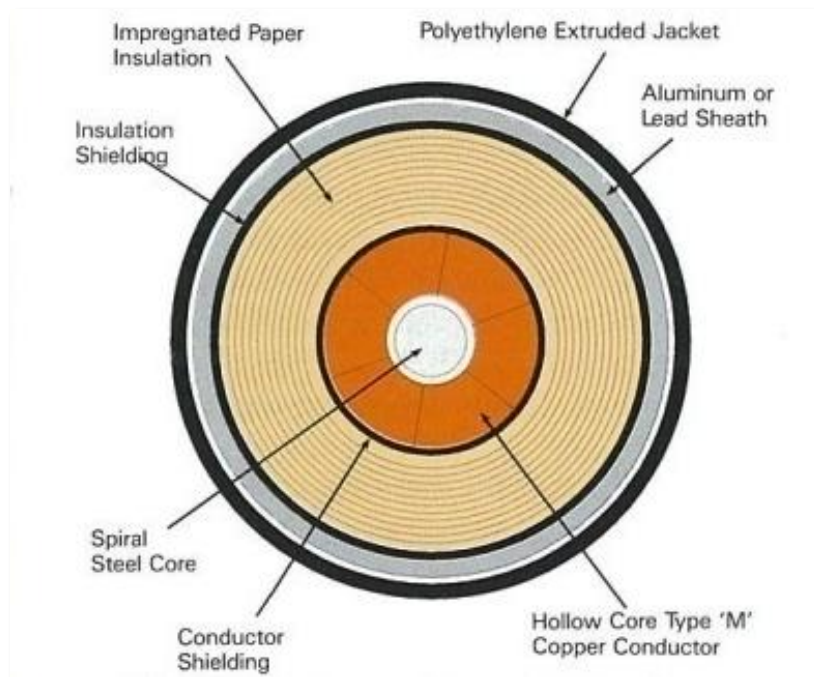


Figure 23 – SCLF Cable With Spiral Steel Core Cross-Section

2.3.3 High-Pressure Liquid-Filled Pipe-Type (HPLF) Cables

High-Pressure Liquid-Filled (HPLF) Pipe-Type cables are a specialized form of high-voltage power cable designed for large-scale, long-distance transmission, including underground and submarine applications. Unlike self-contained designs, HPLF cables are installed within rigid metallic pipes that are continuously pressurized with insulating fluid, typically mineral oil or synthetic dielectric oil. This high-pressure system ensures excellent electrical insulation, efficient heat dissipation, and mechanical stability, allowing the cables to carry very high currents over long distances with minimal losses. HPLF cable systems are highly reliable, as the pressurized pipe protects against moisture ingress, thermal expansion, and mechanical stresses, while also allowing for relatively straightforward maintenance and leak detection. Their capacity to handle extremely high voltages and currents makes them ideal for utility transmission corridors, interconnections between grids, and critical power infrastructure projects. See **Figures 24 and 25**.



Figure 24 – HPLF Pipe-Type Cable

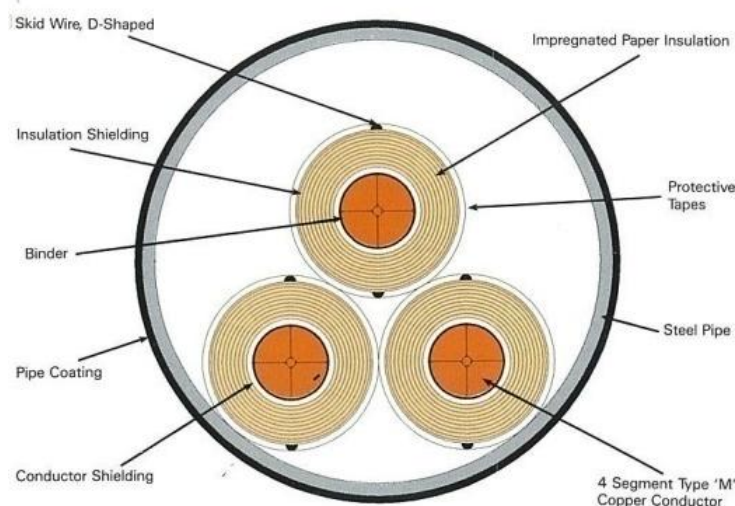


Figure 25 – HPLF Pipe-Type Cable Cross-Section

2.4 Overhead Distribution Power Cables

Overhead conductors for use in distribution systems are similar to those used in transmission systems.

2.5 Underground Distribution Power Cables

In many modern power networks, underground medium-voltage (MV) cables are essential to meet reliability, safety, and operational requirements. Unlike overhead conductors, buried cables are shielded from weather-related disruptions such as storms, ice, and lightning, ensuring more consistent power delivery and reducing costly outages. They are also crucial in densely populated or high-risk areas, where overhead lines would be unsafe or physically impractical. By eliminating the risk of accidental contact and minimizing interference from trees, animals, or human activity, underground MV cables provide a safer, more secure, and reliable solution. The growing demands of modern infrastructure, combined with the need for resilient and dependable power distribution, make underground MV cables a necessary component of today's electrical networks. The two main types of medium voltage shielded cables are discussed below.



Figure 26 – MV Underground Cables

2.5.1 Medium Voltage Concentric Neutral Cables

Medium Voltage Concentric Neutral (MV CN) cables are a type of power cable commonly used in primary distribution networks to deliver electricity at voltages typically ranging from 5 kV to 46 kV. These cables typically consist of a single conductor surrounded by a concentric layer of neutral wires serve multiple purposes: they carry unbalanced current, provide a reliable return path, and allow for grounding and fault current protection. The neutral wires are often made of bare copper or tinned copper and are helically wound around the medium voltage core, ensuring consistent electrical performance.

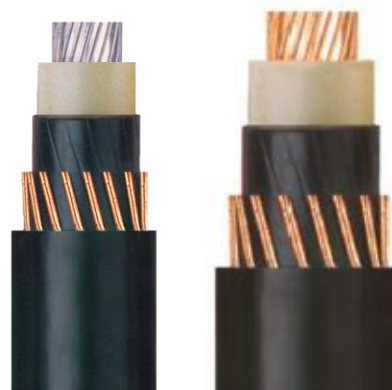


Figure 27 – MV CN Cables

Medium voltage concentric neutral cables are widely used in urban and suburban settings where overhead lines are impractical, or underground installation is preferred, offering reliable and safe power delivery in both commercial and industrial applications.

The construction of concentric neutral cables typically includes a three-layer insulation system (TR-XLPE or EPR), concentric neutral wires, and an optional overall PVC/PE/XLPE jacket. See **Figure 27**.

These cables are designed to handle fault currents, system imbalances, and transient loads while maintaining thermal stability. Their concentric neutral arrangement simplifies grounding and fault protection compared to separate neutral conductors, reducing installation complexity and improving system reliability.

Standards and specifications play a critical role in ensuring the safety, performance, and interchangeability of medium voltage concentric neutral cables. These cables are typically designed and manufactured to CSA C68.5, ICEA S-94-649 and ICEA S-113-684 which include requirements for conductor sizes, insulation types, voltage ratings, and testing methods.

2.5.2 Medium Voltage Shielded Power Cables

Although MV CN cables are considered shielded, there is a subset of cables for use in commercial and industrial applications and commonly referred to as **Medium Voltage Shielded Power Cables (MV SP)**.

MV SP cables are commonly used in industrial power distribution systems to ensure safe and reliable electricity delivery at voltages typically ranging from 5 kV to 46 kV.

The construction typically includes the main conductor, a three-layer insulation system (TR-XLPE or EPR), a metallic shield consisting of either (1) a helically applied copper tape, (2) a longitudinally applied copper tape (LACT), or (3) a wire shield, along with an overall PVC/PE/XLPE jacket. See **Figure 28**.



Figure 28 – MV SP Cables

The shield serves multiple purposes: it controls the electric field around the conductor, reduces electrical stress on the insulation, provides a low-impedance path for fault and ground currents, and minimizes electromagnetic interference (EMI). The shield is often bonded at intervals to ensure continuous electrical continuity, essential for fault current conduction and proper grounding. These cables are widely used in motor circuits, heavy machinery, and industrial power distribution networks, where robust fault protection, thermal stability, and electrical reliability are critical.

These cables are typically designed and manufactured to CSA C68.10, ICEA S-97-682, and UL 1072 which define construction, insulation, shielding, and performance requirements to ensure compliance with electrical safety and operational standards.

Compliance with CSA, ICEA, and UL 1072 ensures that these types of medium voltage shielded cables perform reliably, safely manage fault currents, and maintain long-term electrical integrity.

2.6 Underground, Above-Ground, and Overhead Service Entrance Cables

Service entrance cables provide the critical link between utility infrastructure and the customer. Key cable types include:

1. **USEI75, USEI90, USEB90** – Underground service entrance cables
2. **USE/USE-2** – Underground service entrance cables
3. **Type SE (Styles SER/SEU)** – Above-ground service entrance cables
4. **Neutral-supported cables** – Overhead service entrance cables

Installation considerations include conductor size, insulation type, voltage rating, and environmental protection. Proper installation ensures long-term reliability, safety, and minimal maintenance.

2.6.1 USEI75, USEI90 and USEB90

These cable types are recognized in Canada.

USEI75 is an underground service/secondary cable used in Canada. It operates at up to 600 V, uses aluminum conductors, has Linear Low Density Polyethylene (LLDPE) insulation and a PVC jacket over each conductor. This cable is rated for 75 °C conductor temperature. It is intended for underground or in-duct or direct burial installations.



Similarly, **USEI90** is an underground service entrance cable, also 600 V, with aluminum conductors, but uses cross-linked polyethylene (XLPE) insulation plus PVC jacket. It is rated for 90 °C conductor temperature and also suitable for underground/duct/burial application.

Figure 29 – USEI75/USEI90

USEB90 is also an underground service entrance cable designed for direct burial. It typically features two aluminum conductors with durable XLPE insulation surrounded by a copper concentric neutral, and an overall PVC jacket to withstand moisture, sunlight, and mechanical stresses. This cable is primarily used in Western Canada providing a reliable connection from the utility supply to a building's main electrical panel.



Figure 30 – USEB90

2.6.2 USE/USE-2

These cable types are recognized in the US.

USE cables are used for underground service entrance installations. They are rated 75°C, 600V, and approved for direct burial.

USE-2 cables are used for underground service entrance installations. They are rated 90°C, 600V, and approved for direct burial.



Figure 31 – USE/USE-2

2.6.3 Type SE (Styles SER/SEU)

This cable type is recognized in the US.

Type SE cables are service entrance cables are used *above ground*, for bringing power from supply to meter or panel. **Style SER** are round cables that typically come with two, three or four aluminum conductors, a bare aluminum ground conductor and an overall gray PVC jacket. **Style SEU** cables have two phase conductors surrounded by a concentric neutral and a gray PVC outer jacket.



Figure 32 – Type SE, Style SER



Figure 33 – Type SE, Style SEU

2.6.4 Neutral Supported Cables

Neutral supported cables are used in overhead power distribution systems where a separate neutral conductor provides mechanical support for the phase conductors.

These cables combine the functions of carrying current and providing structural stability, allowing the system to span between poles without requiring additional support hardware. They are typically used for overhead service entrances and may come with an optional PVC jacket over each individual conductor to give it an additional flame rating.

In Canada, these cables are designated as **Type NS75 or NS90** depending on the insulation material used (LLDPE vs XLPE, respectively).



Figure 34 – Neutral-supported cables

2.7 High Temperature Superconducting Cables

High-Temperature Superconducting (HTS) cables represent a significant advancement in power transmission technology, offering capabilities far beyond those of conventional conductors.



Figure 35 – HTS Installation

Superconducting cables work by using materials that can carry electricity with zero electrical resistance when cooled below a certain temperature, known as their critical temperature, T_C . See **Figure 36**. This property is called superconductivity, and it allows electric current to flow without any energy loss as heat — a major advantage over traditional copper or aluminum cables, which always experience some resistance.

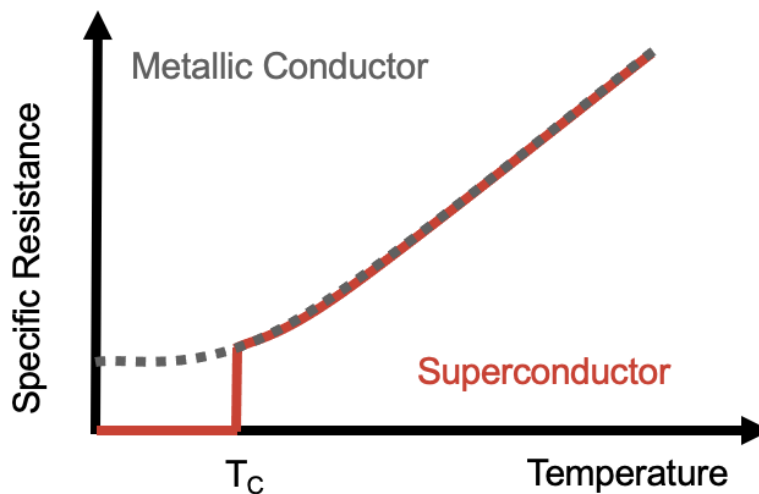


Figure 36 – How HTS works

In a typical High-Temperature Superconducting (HTS) cable, the conductor is made of special ceramic-based materials arranged as thin tapes or layers. These materials are placed inside a cryogenic system that uses a coolant, usually liquid nitrogen, to keep them at very low temperatures (around -196°C or higher, depending on the material). Once cooled below their critical temperature, the superconducting materials allow large amounts of current to pass through with no resistance, enabling the cable to transmit far more power than a conventional conductor of the same size. See **Figure 37**.



Figure 37 – HTS cable

To further improve performance, HTS cables are often designed with multiple layers, including a superconducting shield that cancels out external magnetic fields, preventing electromagnetic interference. Because they generate virtually no heat, these cables do not require special thermal backfill or spacing, and they can be installed at any depth without environmental impact.

In essence, superconducting cables work by combining advanced materials science with cryogenic engineering to create a highly efficient, compact, and powerful way to transport electricity — especially useful in urban areas, high-demand transmission corridors, and grid bottlenecks.

2.7.1 Advantages

One of their most notable advantages is their exceptionally high power transmission capacity. Because HTS cables can carry much higher current densities than traditional copper or aluminum conductors, they are able to transmit significantly more power at the same voltage level. This allows utilities to upgrade transmission capacity within existing infrastructure without the need for larger cables or higher voltages. The result is an extremely high power density that enables large amounts of electricity to be transported through a cable system with a minimal physical footprint, making HTS cables ideal for use in densely populated urban areas or locations where space is limited.

Another key benefit of HTS technology is its very low electrical impedance. This property enables HTS cables to naturally take on additional load from parallel, overloaded transmission paths within the grid. By redistributing power more efficiently, HTS cables can enhance grid stability and

reliability, helping to alleviate congestion and reduce stress on existing infrastructure without the need for extensive network modifications.

A unique feature of superconducting cables is the presence of a superconducting magnetic screen around the conductor. This screen effectively eliminates the external magnetic field that would typically be generated by high-current power lines. As a result, HTS cables do not interfere electromagnetically with other parallel cables or nearby equipment, enabling closer installation of multiple systems and improved utilization of underground or tunnel space.

From an environmental and installation perspective, HTS cables offer several additional advantages. Because they operate at cryogenic temperatures and generate virtually no resistive heating, there is no thermal impact on the surrounding environment. This eliminates common concerns such as soil drying, the need for thermal backfill materials, or constraints on laying depth due to heat dissipation. Furthermore, the absence of heat-related restrictions means there are no bottlenecks at cable crossings, simplifying installation and expanding design flexibility in these installations.

2.7.2 Challenges

Despite their many advantages, HTS cables face several significant challenges that limit their widespread use. One of the main obstacles is the need for cryogenic cooling systems to keep the cables at extremely low temperatures, which adds complexity, maintenance requirements, and potential reliability risks — a failure in cooling can cause the cable to lose its superconducting state (quench).

Additionally, the high cost of superconducting materials, manufacturing processes, and specialized installation infrastructure makes HTS projects much more expensive than conventional cable systems, restricting their use to high-value or space-constrained applications.

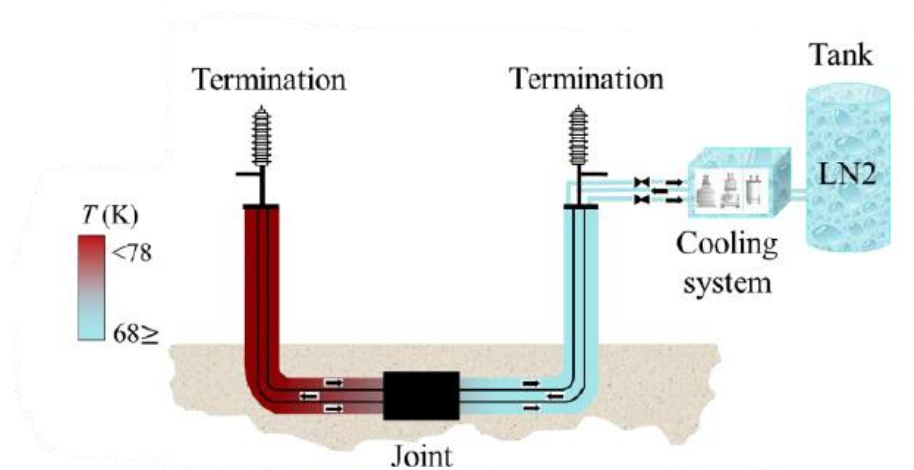


Figure 38 – HTS cable system set-up

Other challenges include the complexity of installation and maintenance, limited manufacturing capacity, and the need for new grid integration strategies due to the cables' unique electrical properties. Mechanical fragility and the potential for quenching also require advanced monitoring and protection systems. While ongoing research is addressing many of these issues, HTS cables are currently best suited for niche, high-performance applications, with broader adoption expected as costs fall and technology matures.

2.8. Submarine Power Cables

2.8.1 General

Submarine power cables are specialized electrical cables designed to transmit electricity across bodies of water, such as seas, rivers, and lakes, forming critical links between power grids, offshore energy sources, and coastal infrastructure. They play a vital role in modern power systems by enabling the transfer of electricity from offshore wind farms, remote islands, or intercontinental grids directly to onshore networks with minimal energy loss. Built to operate reliably in harsh underwater environments, submarine cables are engineered with robust insulation, water-resistant layers, and protective armoring to withstand high pressures, mechanical stress, and marine conditions over long distances. As the demand for renewable energy and cross-border electricity exchange continues to grow, submarine power cables have become an essential technology for expanding grid connectivity, enhancing energy security, and supporting the global transition to a more sustainable power system.



Figure 39 – Submarine cable

2.8.2 Cable Types

Submarine power cables come in several different types, each designed for specific voltage levels, applications, and installation environments. The main categories are based on voltage type (AC or DC), insulation technology, and application purpose. The following subsections breakdown some of the most common types.

2.8.2.1 High-Voltage AC (HVAC) Submarine Cables

Purpose: Used for relatively short to medium distances (typically up to ~80–100 km) such as connecting offshore wind farms to onshore grids or linking islands close to the mainland.

Construction: Usually consist of copper or aluminum conductors with XLPE insulation (up to 420 kV), steel armoring, and water-blocking layers.

Advantages: Mature technology, easier to integrate with existing AC grids, and generally lower cost than HVDC.

Limitations: Capacitive losses increase with length, making them less efficient for long-distance transmission.

2.8.2.2 High-Voltage DC (HVDC) Submarine Cables

Purpose: Preferred for long-distance power transmission (often over 100 km) or for interconnecting asynchronous grids (e.g., between different countries or continents).

Construction: Can use mass-impregnated (MI) paper insulation (up to 600 kV) or modern extruded XLPE insulation (up to 400 kV), along with metallic sheaths and robust armoring.

Advantages: Very low losses over long distances, higher transmission capacity, and ideal for bulk power transfer.

Limitations: Requires expensive converter stations at both ends to convert between AC and DC.

2.8.2.3 Medium-Voltage Submarine Cables (6 – 66 kV)

Purpose: Used for shorter distances and lower power requirements, such as connecting offshore oil and gas platforms, small islands, or subsea equipment to shore.

Construction: Similar to high-voltage cables but with smaller conductor sizes and insulation thickness.

Advantages: Cost-effective for localized power distribution and industrial applications.

Limitations: Not suitable for long-distance or large-capacity transmission.

2.8.2.4 Dynamic Submarine Cables

Purpose: Designed for floating offshore wind farms and other moving or flexible installations.

Construction: Include flexible insulation, reinforced armoring, and bend-resistant structures.

Advantages: Enable the deployment of floating renewable energy infrastructure.

Limitations: More complex and expensive to design and manufacture.

2.8.2.5 Inter-Array and Export Cables

In offshore wind farms, submarine cables are often further categorized by their function.

Inter-Array Cables: Medium-voltage AC cables that connect individual turbines within a wind farm.

Export Cables: High-voltage AC or DC cables that transport the collected power from the offshore substation to the onshore grid connection point.

2.8.3 Turnkey Project Considerations

When planning a turnkey submarine cable project — meaning the contractor delivers the complete system from design to commissioning — there are several critical considerations across technical, logistical, environmental, and regulatory areas. These factors ensure the project is delivered safely, efficiently, on time, and within budget.



Figure 40 – Submarine cable installation (land operations)

2.8.3.1 Project Planning and Route Engineering

Careful route selection and seabed surveying are essential early steps. This includes detailed geophysical and geotechnical studies to understand seabed conditions, avoid obstacles (e.g., rock outcrops, shipwrecks, pipelines), and identify optimal burial depths. Proper route engineering helps minimize installation risks, reduce future maintenance needs, and extend cable lifespan. Planning must also account for landfall locations, shore crossings, and integration with onshore substations.

2.8.3.2 System Design and Technical Specifications

The cable's design — including voltage level (AC or DC), conductor size, insulation type, armoring, and protection layers — must match the project's power capacity, distance, and operating environment. Additional considerations include thermal performance, electromagnetic compatibility, and mechanical strength to handle underwater pressures and dynamic forces. Selecting suitable jointing and termination systems is also critical for reliability and ease of maintenance.

2.8.3.3 Environmental and Permitting Requirements

Environmental impact assessments (EIAs) and regulatory approvals are often complex and time-consuming parts of a turnkey project. Developers must evaluate potential impacts on marine ecosystems, fishing areas, shipping routes, and coastal habitats, and implement mitigation strategies such as controlled burial depth or route adjustments. Compliance with local, national, and international regulations is mandatory, and stakeholder engagement (e.g., fisheries, marine authorities, environmental agencies) is often required.

2.8.3.4 Installation Engineering and Logistics

Installation planning must consider vessel selection, cable laying techniques, burial methods, and weather windows. Specialized cable-laying ships, remotely operated vehicles (ROVs), and trenching or ploughing equipment are often needed. Accurate tension control and real-time monitoring are crucial to prevent mechanical damage during deployment. Logistics coordination — including cable manufacturing schedules, storage, transport, and offshore operations also must be considered.



Figure 41 – Submarine cable installation

2.8.3.5 Risk Management and Contingency Planning

Submarine cable projects involve significant risks, including weather delays, seabed challenges, mechanical failures, or installation accidents. A robust risk assessment and contingency plan should address potential delays, backup vessels or equipment, emergency repair strategies, and insurance coverage. Early involvement of experienced contractors and thorough pre-installation testing can help reduce project risk.

2.8.3.6 Testing, Commissioning, and Handover

Comprehensive factory acceptance tests (FAT), site acceptance tests (SAT), and post-installation tests are essential to verify performance and reliability before energizing the system. Final commissioning includes electrical testing, thermal load verification, and system integration checks. Documentation, training for operations teams, and a detailed maintenance plan should also be provided as part of the turnkey delivery.

2.8.4 Other Challenges

Submarine cable installation is a complex and high-stakes process, and several technical, environmental, logistical, and regulatory challenges must be carefully managed to ensure a successful project. One of the main challenges is route selection and seabed conditions — cables must be laid along paths free of obstacles like rocky outcrops, shipwrecks, or existing infrastructure, and variable seabed geology can make burial difficult or risky. Unexpected seabed conditions, such as hard soil or shifting sediments, can delay installation or require specialized equipment. In addition, weather and marine conditions (like high waves, strong currents, or storms) can significantly impact vessel operations and limit installation windows, causing costly delays.

Another major challenge is mechanical stress and cable protection during laying and burial. Cables must be handled with precise tension control to avoid bending, twisting, or overstressing, which could lead to long-term damage or failure. Ensuring adequate burial depth and protection is also critical to prevent damage from anchors, fishing activities, or seabed movement. Environmental and permitting issues add another layer of complexity, as projects must navigate strict regulations and conduct impact assessments to protect marine ecosystems, coastal habitats, and navigation routes.

Logistical difficulties — including transporting and storing long, heavy cable sections, coordinating specialized vessels, and timing operations — further increase project complexity. Finally, unexpected faults, jointing challenges, or repair difficulties after installation can be costly and time-consuming, given the remote and underwater location of the cable. Together, these factors make submarine cable installation a technically demanding and resource-intensive process that requires careful planning, advanced engineering, and precise execution.

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