Understanding MV Cables Testing, applications, cable selection & standards

Nov 10, 2020 IEEE Northern Canada Chapter Meeting

Introduction

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Major Project & Engineering Support

- 19 years wire & cable experience, major industrial projects
- BSc. Eng. (University of Alberta)
- Employer – Texcan, Surrey BC – Wire and Cable distributor
- Previous employers – Cable manufacturers – in Application Engineering and Sales roles
  - Southwire
  - Shawflex
  - Alcan Cable
- IEEE activity
  - ESTMP presentations
  - PCIC Vancouver Volunteer 2019
  - Presentations at IEEE Chapter meetings in Calgary, Edmonton, and Fort McMurray
- Regular cable technical newsletters

Agenda

- Medium voltage cables, 5KV to 35KV
  - Among the most complex cables, technically and commercially
  - Focus on industrial / commercial cables
- Applicable CSA Standards
- Available products
  - Differentiating between stocked options and customized made to order options
- Demonstrate construction and purpose of each layer
- Testing

Medium Voltage Cables CSA Standards

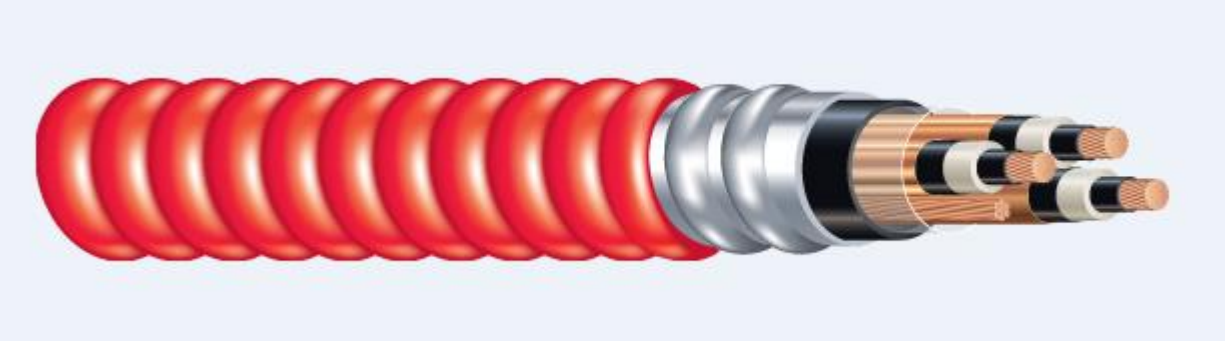
- CSA C68.10 Shielded Power Cable for Commercial and Industrial Applications, 5-46 KV
  - FT4 flame rated for exposed usage required by CE Code 2-130
  - HVTECK, HVTC, CSA MV105
- CSA C68.5 Primary Shielded & Concentric Neutral Cable for Distribution Utilities
  - Not flame rated or only FT1, might not be CSA rated.
  - UD /URD concentric neutral cables
- CSA C22.2 #131 Type Teck 90 Cable
  - Unshielded 5KV Teck90
  - At 5KV you can use either shielded C68.10 or unshielded C22.2 #131
- CSA C22.2 #96 Portable Power Cables
  - SHD-GC mining cables up to 35KV

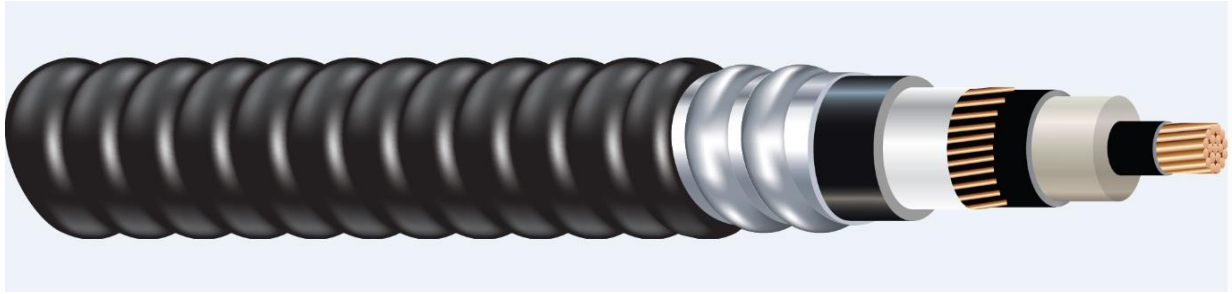
Made to order or commercially available

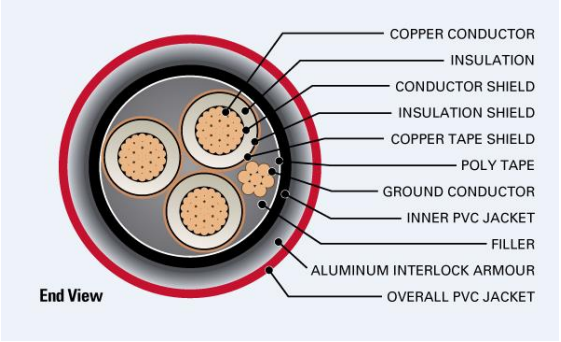
- Limited number of manufacturers making these products.
  - Prysmian / General cable merged
  - Aetna used to make short runs / reduced leadtimes but they went out of business Jan 2017
- Reduced electrical distribution inventory
  - Less stock / available lengths might be a consideration
- Minimum order quantities / leadtime considerations:
  - 1000m for 3 conductor products
  - 3000m for single conductor products
  - 12-20+ week leadtimes
- If you have a smaller project or long lead times don’t work, your best CSA product bets are:
  - 3 conductor HVTECK – TRXLPE insulation / 133% insulation level
  - Single conductor CSA MV105 stocked in the US in large quantities
  - Concentric neutral cables in 15KV and 25KV in select sizes (might need to go up a gauge size or two)

HVTECK

- Built to CSA C68.10 – 5KV to 46KV Shielded
- 3c TRXLPE HVTECK 133% well stocked in 5KV and 15KV
- Single conductor HVTECK, EPR products, or 100% insulation levels are made to order
- Typical lead times for made to order is 12 to 20 weeks, 1000m MOQ for 3c, 3000m for 1c





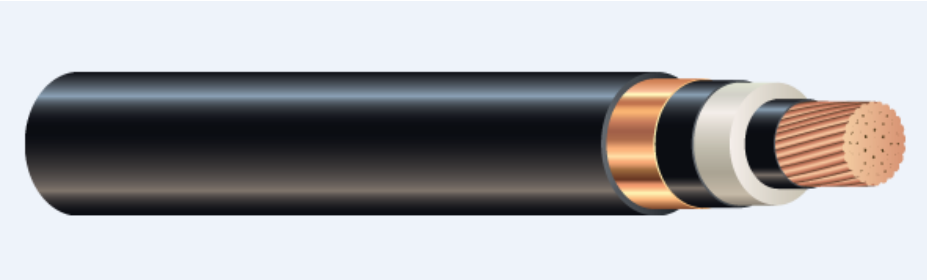


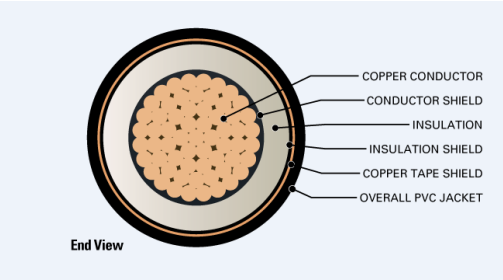
UD / URD Concentric Neutral Cables

- C68.5 Utility Grade Cables, 15KV – 46KV
- Concentric neutral – Full Neutral, 1/3 CN, or reduced neutral
- Either no flame rating or only FT1, suitable for direct burial or conduit applications.
- Typically these are made to order cables or stocked by the Utility. Distribution stocks select gauge sizes.
- Minimum order quantity 3000m for made to order product. 14 – 24 week lead times

CSA MV105

- MV105 is the US standard 5KV to 35KV cable, now CSA / UL dual listed
- It is well stocked in 5KV 133% and 15KV 133% in copper
  - Some sizes stocked in 5KV alum, 15KV alum, 25KV cu, 35KV cu
- Built to CSA C68.10 – FT4, TC (tray rated), direct burial, HL Class 1 Div 2 per CE Code Table 19
- 105C EPR insulation, 5mil 25% overlap copper tape shield, PVC jacket
- A great substitute if you can't find an HVTECK or URD cable you are looking for.
- Note the copper tape shield is a shield only, need to run an additional bond (Table 16)





HVTC

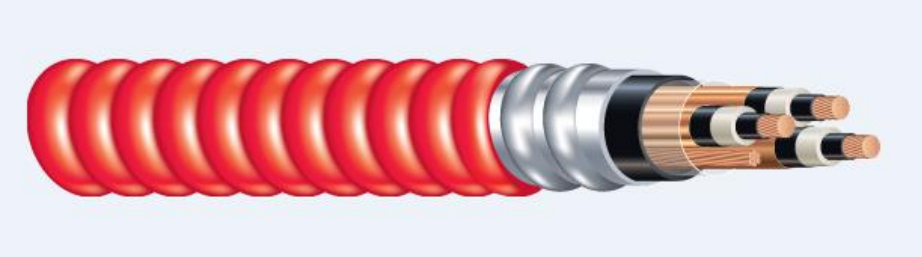
- 3c version of CSA MV105 built to CSA C68.10
- 100% or 133% insulation level, TRXLPE or EPR insulation
- Looks like UD cable except it is FT4 flame rated and can be installed exposed.
- Made to order product 12 to 20 weeks lead time, 1000m MOQ

Mining Cables

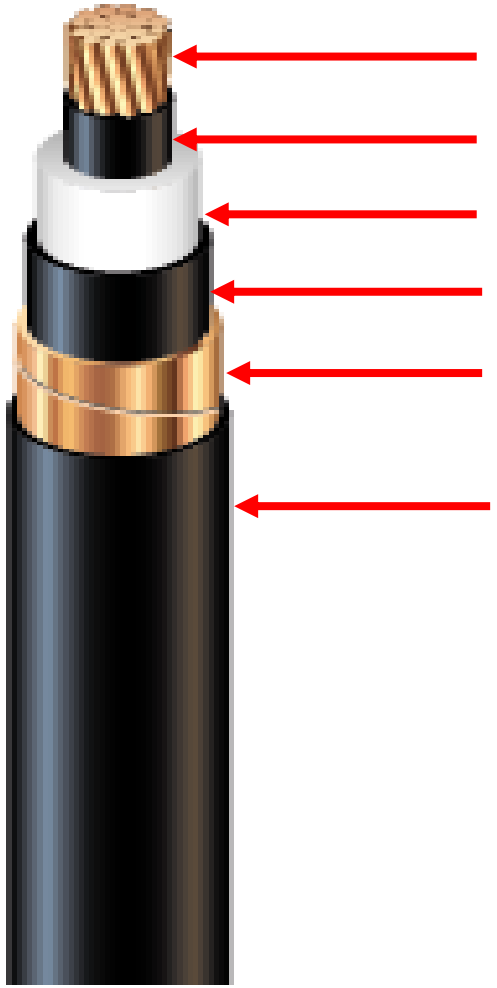
- CSA C22.2 #96 Portable Cords, 600V - 35KV
- For temporary applications and therefore can’t be run on cable tray. They are very rugged and flexible constructions.
- However the new C22.2 #230-17 Tray Cable standard allows SHD-GC cables to be TC-ER marked allowing them to now be installed on cable trays.
- 5KV and up are typically made to order but the minimum order quantities can be as low as 300m.

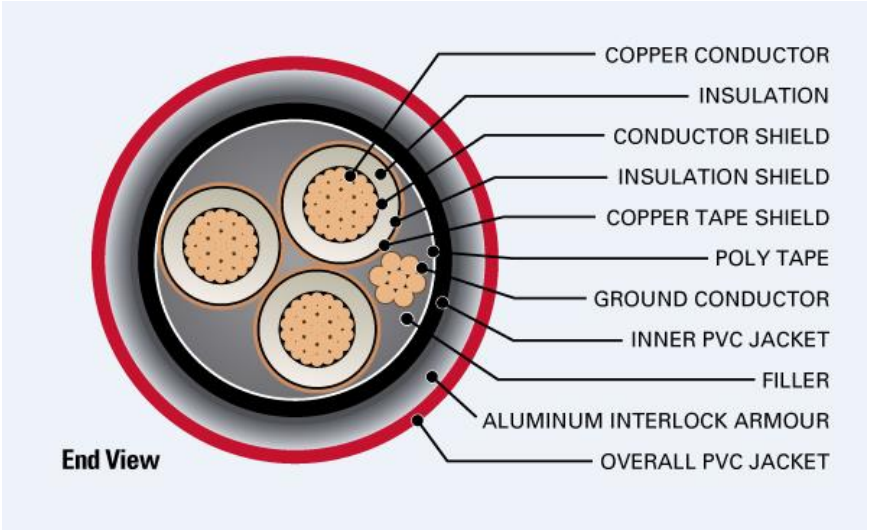
5KV Shielded vs Unshielded

- Built to 2 different CSA Standards – C68.10 and C22.2 #131
- In Canada most 5KV historically has been 3c unshielded Teck90
- In the US the NEC requires 5KV cables to be shielded
- Shield drains any leakage currently safely to ground
- Shielded cables can be properly acceptance / maintenance tested
  - Can do a proper DC Hi Pot or VLF test on a shielded cable, not on unshielded.
- Shield distributes electrical stresses evenly around the conductor extending insulation life
- Only 5KV shielded can now be called 100% or 133% insulation level



MV Power Cable Construction





Conductor Stranding

Class B stranding most common

Higher class high strand conductors for high flexibility

Stranding Constructions

- Concentric Round (Bare Conductors)
- Compressed (3% reduction)
- Compact (10% reduction)

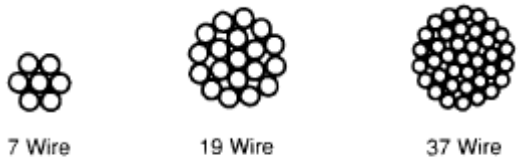
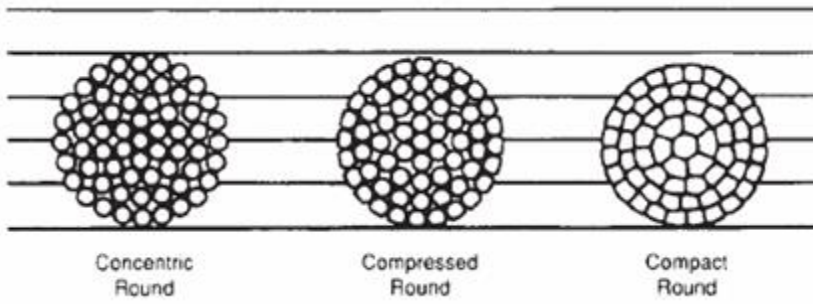


Figure 2-2
Concentric Stranding Constructions



Copper vs. Aluminum Conductors

Copper is the industrial standard but there are places for aluminum.

Typically go up 2 gauge sizes for equal ampacity alum

Alum is 1/2 the weight and more flexible

Aluminum conductors are generally used by Utilities

Less expensive.

Stable pricing.

Reliable

Spec dual rated ALCU lugs

Insulation

A material that has a high resistance to the flow of current to prevent leakage from the conductor to ground.

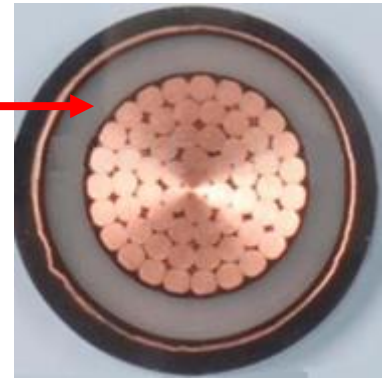
2 Types of insulation in MV cables

- TRXLPE – tree retardant cross-linked polyethylene
- EPR – ethylene propylene rubber

Two Types of Thermoset MV Insulations

TRXLPE (Cross-Linked Polyethylene)

- Excellent electrical properties
- Temperature rating **90C**
- Physically tough insulation
- Stiff
- Slightly lower di-electric losses
- Most common Cdn industrial MV insulation



EPR (Ethylene Propylene Rubber)

- Excellent electrical properties
- Flexible; easier to work with
- Great low temp performance
- Higher temperature rating **105C**
- Tree retardant
- US standard not well stocked in Canada

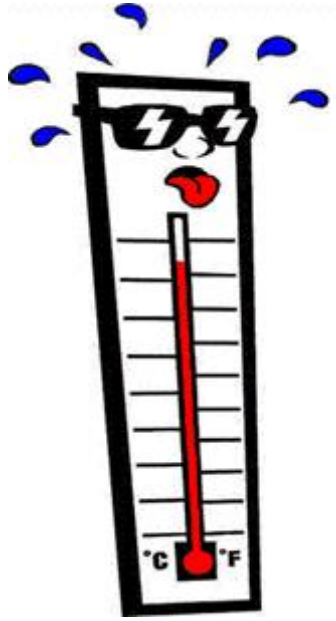
Operating Temperatures

EPR

Thermoset Material
- 105C Continuous
- 140C Emergency
- 250C Short Circuit

TRXLP or XLP

Thermoset Material
- 90C Continuous
- 130C Emergency
- 250C Short Circuit



MIL Thickness – Power Cable Insulations CSA C68.10

Table 8
Conductor sizes, insulation thicknesses, and test voltages
(See Clauses 6.2, 6.4.1, 6.4.3, 14.2.3.1, and F.1.2 and Table 51.)

Rated circuit voltage, phase-to-phase,V‡	Conductor size§, AWG or kcmil, mm²	Insulation thickness*, mm (mils)						AC test voltage†, kV		
		100% insulation level		133% insulation level		173% insulation level				
		Mini-mum	Maximum	Minimum	Maxi-mum	Minimum	Maximum	100% insulation level	133% insulation level	173% insulation level
2 001–5 000	8–1000**	2.16 (85)	3.05 (120)	2.79 (110)	3.68 (145)	3.43 (135)	4.32 (170)	18	23	28
	1001–3000	3.43 (135)	4.32 (170)	3.43 (135)	4.32 (170)	3.43 (135)	4.32 (170)	28	28	28
5 001–8 000	6–1000	2.79 (110)	3.68 (145)	3.43 (135)	4.32 (170)	4.19 (165)	5.21 (205)	23	28	35
	1001–3000	4.19 (155)	5.21 (205)	4.19 (165)	5.21 (205)	5.33 (210)	6.35 (250)	35	35	44
8 001–15 000	2–1000	4.19 (155)	5.21 (205)	5.33 (210)	6.35 (250)	6.22 (245)	7.37 (290)	35	44	52
	1001–3000	5.33 (210)	6.35 (250)	5.33 (210)	6.35 (250)	6.22 (245)	7.37 (290)	44	44	52
15 001–25 000	1–3000	6.22 (245)	7.37 (290)	7.75 (305)	8.89 (350)	10.2 (400)	11.4 (450)	52	64	84
25 001–28 000	1–3000	6.73 (265)	7.87 (310)	8.38 (330)	9.53 (375)	10.8 (425)	12.6 (495)	56	69	89
28 001–35 000	1/0–3000	8.38 (330)	9.53 (375)	10.2 (400)	11.7 (460)	14.0 (550)	16.0 (630)	69	84	116
35 001–46 000	4/0–3000	10.8 (425)	12.6 (495)	14.0 (550)	16.0 (630)	††	††	89	116	150

* The cable insulation level to be used in a particular installation shall be selected on the basis of the applicable phase-to-phase voltage and in accordance with the following:
a) 100% level — Cables 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 1 min. While 100% level cables are applicable to the majority of cable installations on grounded systems, they also may be used on other systems for which the application of cable is acceptable, provided that the clearing requirements specified in this Table are met in completely de-energizing the faulting section.
b) 133% level — Formerly designated for ungrounded systems, 133% level cables may be applied where the clearing time requirements of the 100% level category cannot be met, but there is adequate assurance that the faulted section will be de-energized in a time not exceeding 1 h. 133% level cables may also be used when additional insulation strength over the 100% level category is desirable.
c) 173% level — Cables should be applied on systems where the time required to de-energize a grounded section is indefinite. 173% level cables are also recommended for resonant grounded systems and for when additional insulation strength over the 133% level category is desirable.

† All ac voltages are rms values.

‡ The actual operating voltage shall not exceed the rated circuit voltage by more than
a) 5% during continuous operation; or
b) 10% during emergency operation lasting not more than 15 min.

(Continued)

Voltages are:
RMS Phase to Phase

Voltage can not exceed
5% continuous operation
10% emergency operation

Insulation Levels “Thickness”

100%IL: (Grounded Neutral)

- Cable in this category are used on electrical systems with relay protection such that *ground faults (cable failure) will be cleared within 1-minute*. A normal insulation thickness can be used for these cables because no exposure to over- voltages occurs during the failure.

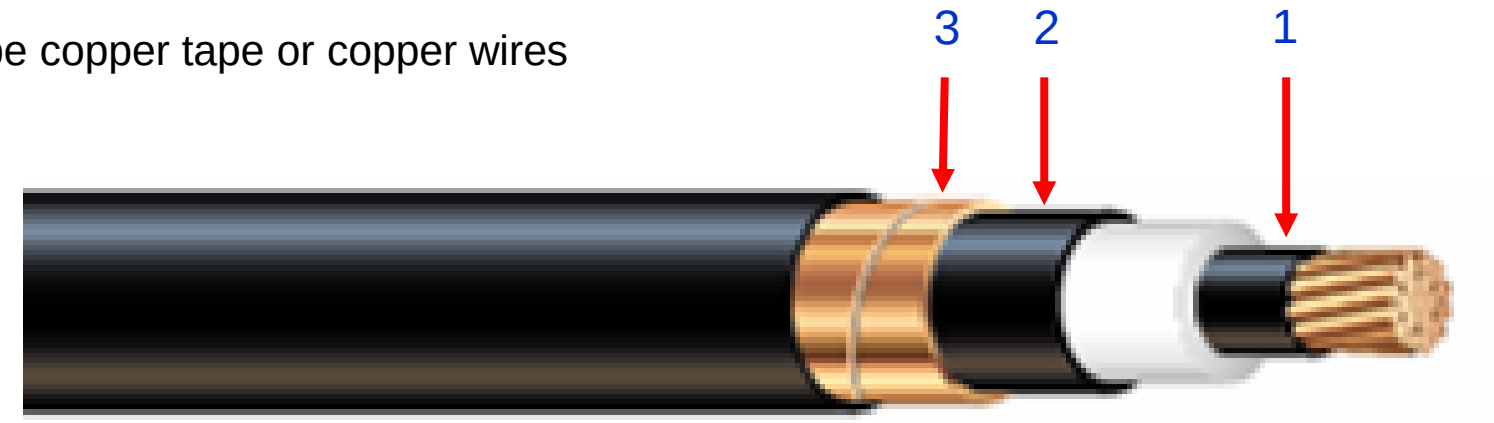
133%IL: (Ungrounded Neutral)

- Cables in this category are used on electrical systems where a *ground fault (cable failure) cannot be cleared in 1-minute but the faulted cables will be de-energized within 1 hour*.
- When one phase fails, the two remaining phases continue to operate but with a higher than normal voltage applied across the insulation. A greater insulation thickness is required on some cables to withstand this higher voltage.

Shielding

There are two semi conductive shields in a medium voltage cable working with a metallic shield designed to even out the voltage stress throughout the entire cable.

- Conductor shield[1] on the inside of the insulation.
- Insulation shield[2] on the outside of the insulation.
- Metallic shield[3] over the insulation shield.
  - Can be copper tape or copper wires



Non-Shielded Cable

E Field

M Field

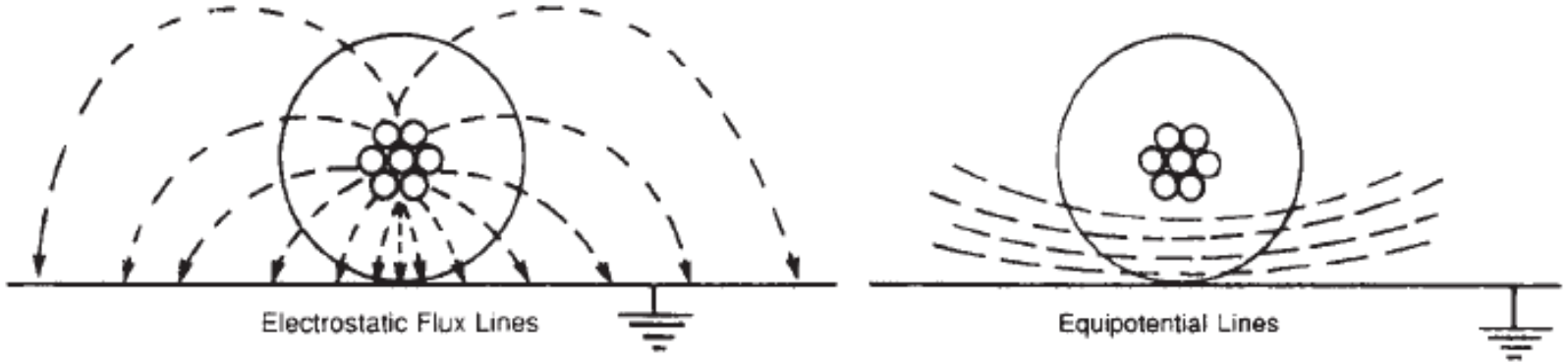


Figure 1-2
Dielectric Field of Low-Voltage Nonshielded Cable In Contact with Electrical Ground

Electric/Magnetic fields exist outside the cable and are not equally distributed

Shielded Cable

E Field

M Field

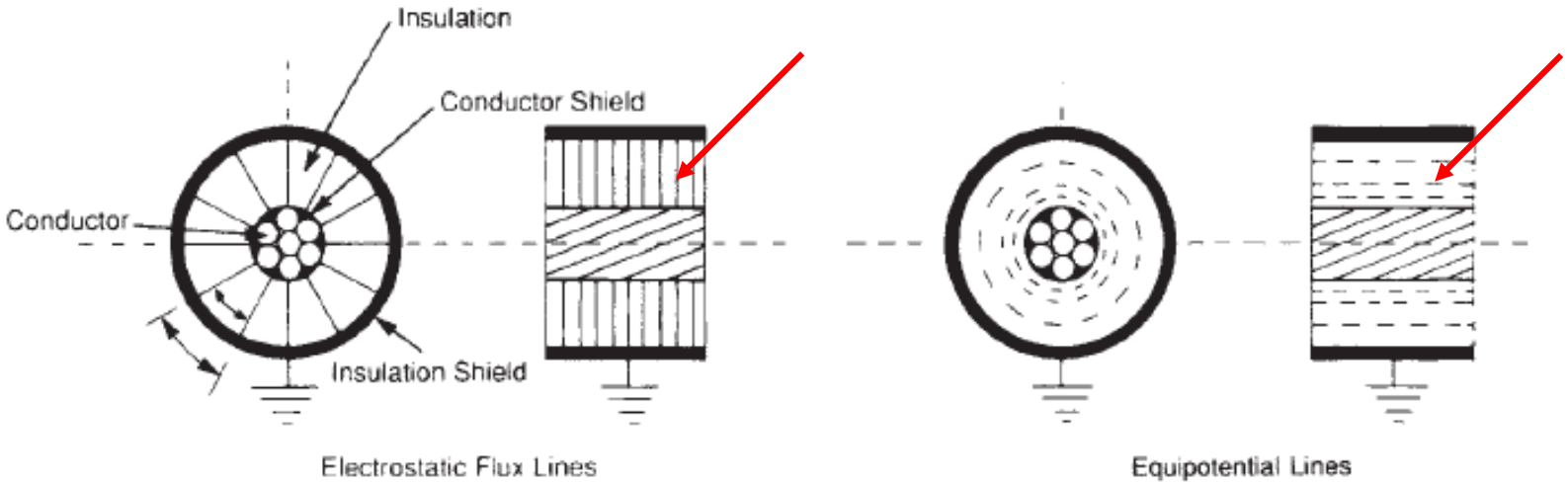


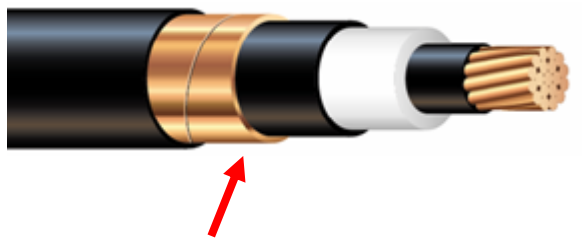
Figure 1-4
Dielectric Field of Shielded Power Cable

Electric/Magnetic fields contained within the cable and equally distributed

Metallic Shield Components

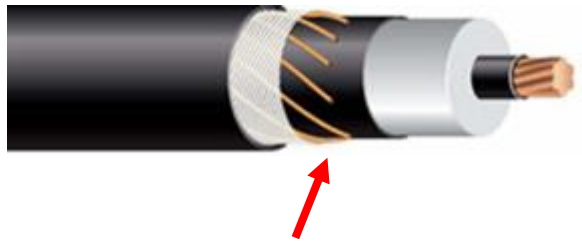
Copper tape

- Takes all leakage current back to ground
- Various overlaps & intercalcated options
- 100% coverage or gapped
- Can not be used as a bonding conductor
- Need to run a separate bonding conductor

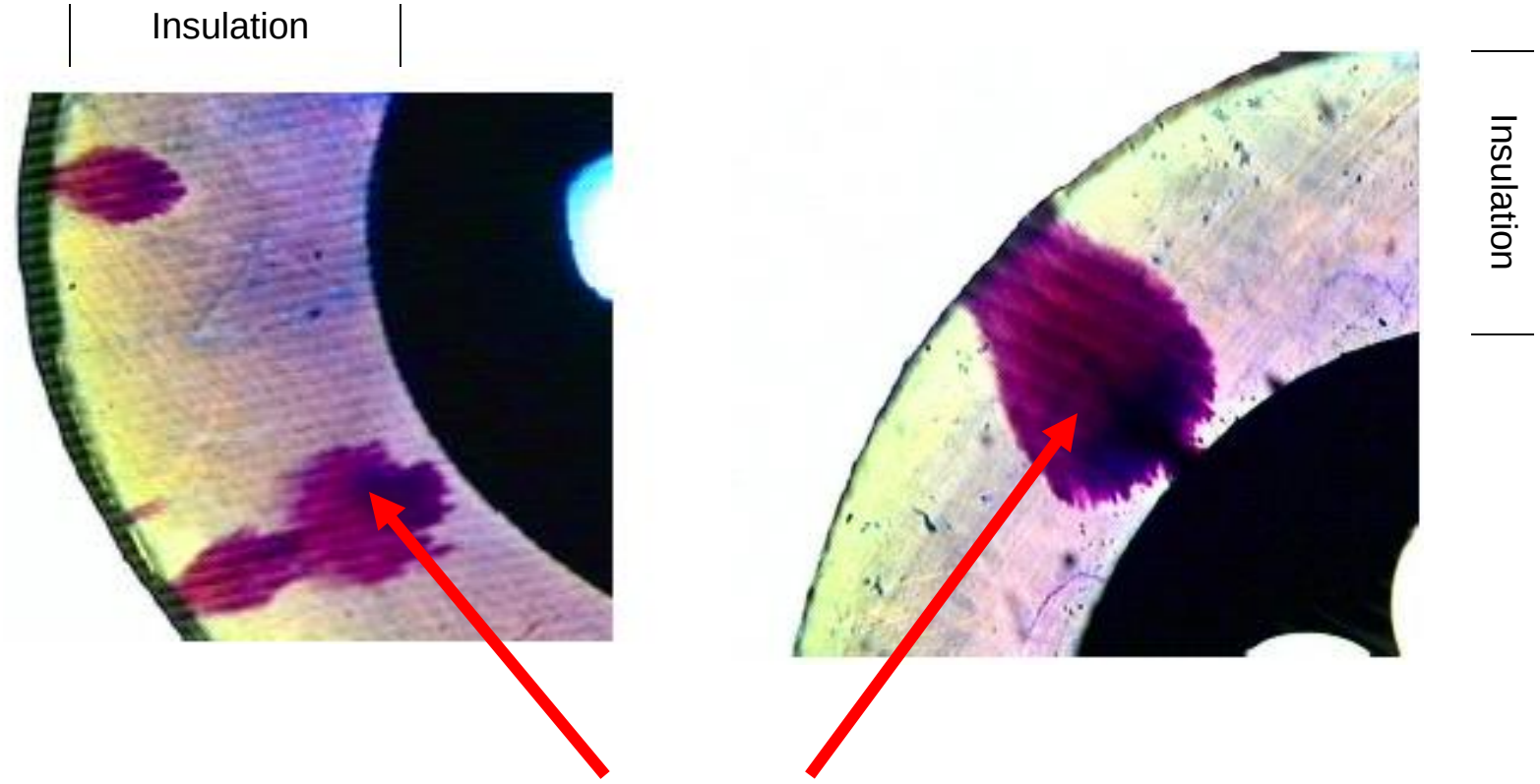


Concentric neutrals

- Large copper wires (traditionally used by Utilities)
- 3 purposes: metallic component of insulation shield, fault current, and conductor for the neutral return current
- Can also have the copper wires sized only for shielding like a copper tape



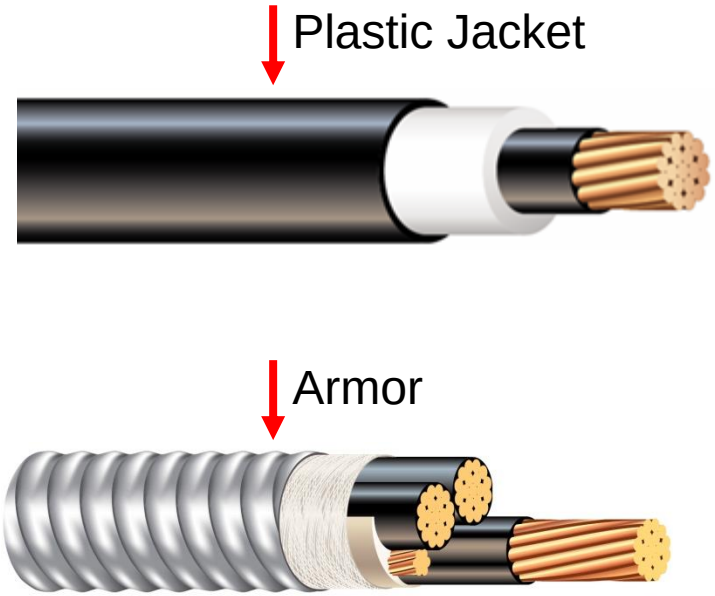
Water Trees



Jackets and Armour (or “Sheaths”)

The jacket and/or armor are the parts of the cable which supply all other *properties other than electrical properties*.

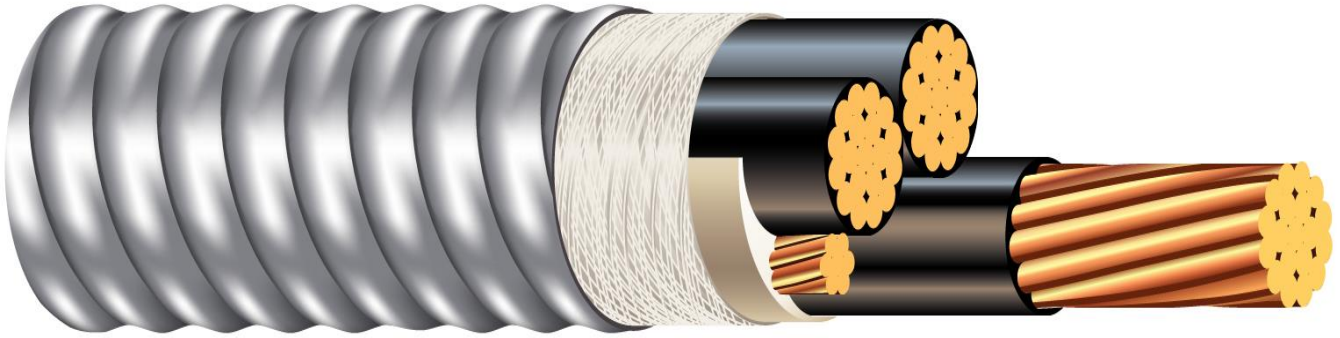
- Fire Retardancy 
- Chemical resistance 
- Water-Impervious 
- Toughness 
- Physical protection 



Armour (If Required)

Types of Armor

AIA (Aluminum Interlocked Armor)
GSIA (Galvanized Steel Interlocked Armor)
CCA (Continuous Corrugated Armor)



Provides physical and mechanical protection for the cable

Interlocked Armour vs. Continuously Corrugated Armour

Interlocked Armor

Interlocked armor is produced by taking a flat metal tape, preforming it into an approximated “S” shape, and then helically wrapping it around a cable core so that the formed edges lock together.

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CSA Teck90

Continuous Corrugated Armor

Continuously corrugated armored cable is formed by a flat metal sheet that is longitudinally folded around the cable core, seam welded and then corrugated.

=

CSA RA90

CEC Code Requirements – Flame Ratings

CE Code 2-130 Electrical wiring and cables installed in buildings shall meet the flame spread requirements of the National Building Code of Canada. (see Appendix B and G)

Appendix B clarifies:

- FT1 for combustible buildings
- FT4 for noncombustible buildings
- FT6 for plenums

Most Widely Used Jacket Materials

PE (Polyethylene)
- -High Water Resistance
- -Excellent Physical Properties
- -Flammable
- -UD/URD Cables

PVC (Polyvinyl Chloride)
- -Good Chemical Resistance
- -Flame Retardant
- -Inexpensive
- -Teck90 / HVTECK Cables

CPE (Chlorinated Polyethylene)
- -Thermoset or Thermoplastic
- -Tough and chemical resistant
- -Flame Retardant
- -Mining Cables

TPU (Thermoplastic Polyurethane)
-Excellent water submersion
-Very tough, stiff in low temperatures
-Mining Cables

Low Smoke Non Halogen
-Reduced Smoke Hazards
-Improved Flame Retardancy
-Lower coefficient of friction
-Pricey in Canada – tunnel / transit applications

Plastic Pellets

Factory Acceptance Test -CTR

CABLE DESCRIPTION: 1/C 500 KCMIL CU 115 EPR CPE JKT 5KV133% 8KV100% CT

HV Test Tag No		104182	102538	102540	102541	102542	
Section No. Test		44	68	69	70	71	
Master Length		2,900	3,200	3,050	3,034	3,100	
Certification Lot		118044	118068	118069	118070	118071	
Shipout Reel No.		110058	110059	110060	110061	110062	
Shipout Length (FEET)		2,100	2,100	2,100	1,900	1,900	
	SPECIFICATION						
CONDUCTOR							
MIN Diameter (INCH)	0.774	0.776	0.776	0.776	0.776	0.776	
CONDUCTOR SHIELD							
MIN Thickness (INCH)	0.016	0.023	0.023	0.023	0.023	0.023	
INSULATION							
MIN Diameter (INCH)	1.035	1.050	1.050	1.050	1.050	1.050	
MIN Thickness (INCH)	0.110	0.117	0.117	0.117	0.117	0.117	
INSULATION SHIELD							
MIN Diameter (INCH)	1.085	1.150	1.140	1.140	1.140	1.140	
MIN Thickness (INCH)	0.032	0.036	0.036	0.036	0.036	0.036	
METALLIC SHIELD							
MIN Thickness (INCH)	1.104	1.140	1.140	1.140	1.140	1.140	
NOM Tape Overlap	22.5%	25%	25%	25%	25%	25%	
JACKET							
NOM Diameter (INCH)	1.244	1.400	1.370	1.365	1.380	1.340	
MIN Thickness (INCH)	0.070	0.082	0.082	0.082	0.082	0.082	
ELECTRICAL TESTING							
AC Withstand Time (Minutes)	5	5	5	5	5	5	
AC Withstand Voltage (kV)	23	23	23	23	23	23	
MAX Partial Discharge (pC)	5	2	1	1	1	1	
MIN Insulation Resistance (Meg Ohms/1000ft)	3450	19395	20064	20398	19023	19437	
MAX Conductor Resistance (Ohms/1000ft)	0.0220	0.0216	0.0216	0.0216	0.0216	0.0216	

SPECIFICATIONS ICEA S-93-639
NEMA PUB. NO. WC-74
UL STANDARD 1072

Testing Overview

- Start with a Continuity and Megger Test (insulation resistance)
  - Refer to NETA 100.1 for test information

- DC Hipot test equipment is widely available, inexpensive, and easy to use
  - Refer to IEEE 400.1 for test information
- DC testing might not be effective in detecting certain types of insulation defects
- IEEE 400 doesn‘t recommend DC Hipot tests for aged /underground extruded cables.

- VLF withstand testing is much more common now and recommended for field testing of aged or underground cables
  - Refer to IEEE 400.2 for test information
  - Can also do a Tan Delta test giving you information you can trend over time.

DC Installation – Hi Pot Testing

- DC installation testing is accomplished by employing high voltage, low current dc power to the cable. Installation testing is important in that it provides assurance that no damage has occurred during installation or in handling after leaving the factory. If the cable is installed by a contractor, the test can serve as an acceptance test and assure the owner that the cable has not been damaged and should perform satisfactorily.

Recommended dc Test Voltages for Shielded Power Cable Systems From 5 - 35KV

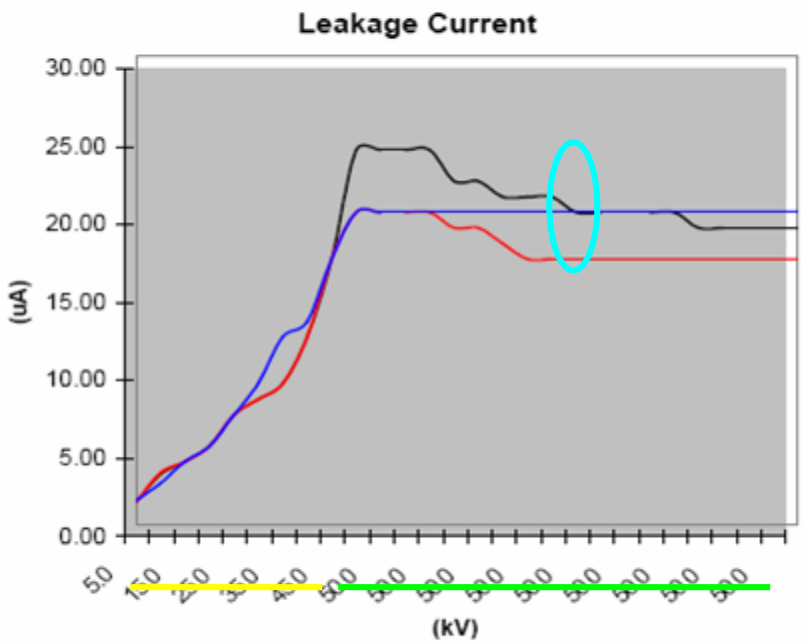
System Voltage KV Phase to Phase	Accceptance Test Voltage (KV dc, Cond-gnd)	Maintenance Test Voltage (KV dc, Cond-gnd)
5	28	23
8	36	29
15	56	46
25	75	61
28	85	68
35	100	75

Acceptance test voltage duration is normally 15 minutes. Maintenance test voltage duration is normally not less than 5 minutes or more than 15 minutes

High Potential Test Report

LEAKAGE CURRENT (uA)					
Time	kV	A	B	C	N
DC Voltage Buildup	5.0	1.40	1.40	1.50	
	10.0	3.20	3.30	2.60	
	15.0	4.00	4.00	4.00	
	20.0	5.00	5.00	5.00	
	25.0	7.00	7.00	7.00	
	30.0	8.00	8.00	9.00	
	35.0	9.00	9.00	12.00	
	40.0	12.00	12.00	13.00	
	45.0	17.00	17.00	17.00	
	50.0	24.00	20.00	20.00	
15 sec	50.0	24.00	20.00	20.00	
30 sec	50.0	24.00	20.00	20.00	
45 sec	50.0	24.00	20.00	20.00	
1 min	50.0	22.00	19.00	20.00	
2 min	50.0	22.00	19.00	20.00	
3 min	50.0	21.00	18.00	20.00	
4 min	50.0	21.00	17.00	20.00	
5 min	50.0	21.00	17.00	20.00	
6 min	50.0	20.00	17.00	20.00	
7 min	50.0	20.00	17.00	20.00	
8 min	50.0	20.00	17.00	20.00	
9 min	50.0	20.00	17.00	20.00	
10 min	50.0	20.00	17.00	20.00	
11 min	50.0	19.00	17.00	20.00	
12 min	50.0	19.00	17.00	20.00	
13 min	50.0	19.00	17.00	20.00	
14 min	50.0	19.00	17.00	20.00	
15 min	50.0	19.00	17.00	20.00	

INSULATION RESISTANCE (MEGOHMS)		
	PRE	POST
A-GND	MΩ	MΩ
B-GND	MΩ	MΩ
C-GND	MΩ	MΩ
NEU-GND	MΩ	MΩ



COMMENTS AND REMARKS:

IEEE 400.2 VLF Testing

also recommended to retest with VLF-TD, VLF-DTD, VLF-TDTS, or VLF-PD after repair to assess the workmanship of the repair. Monitoring cannot be used to reduce the testing time for retests as the cable system has already been shown to be potentially weak by the prior failure.

Table 3—VLF withstand test voltages for sinusoidal and cosine-rectangular waveforms (see Note 1)

Waveform	Cable system rating (phase to phase) [kV]	Installation (phase to ground)		Acceptance (phase to ground)		Maintenance[2] (phase to ground) (see Note 2)	
		[kV rms]	[kV peak]	[kV rms]	[kV peak]	[kV rms]	[kV peak]
Sinusoidal	5	9	13	10	14	7	10
	8	11	16	13	18	10	14
	15	19	27	21	30	16	22
	20	24 (Note 3)	34 (Note 3)	26	37	20	28
	25	29 (Note 3)	41 (Note 3)	32	45	24 (Note 3)	34 (Note 3)
	28	32	45	36 (Note 3)	51 (Note 3)	27	38
	30	34	48	38	54	29 (Note 3)	41 (Note 3)
	35	39	55	44	62	33	47
	46	51	72	57	81	43	61
	69	75	106	84	119	63	89
Cosine-Rectangular	5	13	13	14	14	10	10
	8	16	16	18	18	14	14
	15	27	27	30	30	22	22
	20	34	34	37	37	28	28
	25	41	41	45	45	34	34
	28	45	45	51	51	38	38
	30	48	48	54	54	41	41
	35	55	55	62	62	47	47
	46	72	72	81	81	61	61
	69	106	106	119	119	89	89

What to do when you see an anomaly?

- If a cable does not pass the test it may still be good.
- Dirty cable end and high humidity can have significant effects on tests
  - Ensure the cable ends are clean and dry and retest
- Ensure the cable isolated from other components
  - The issue could be with the terminations or other equipment
- Ensure the cable length is within the test sets limitations

Contact Info

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