POLYCAB

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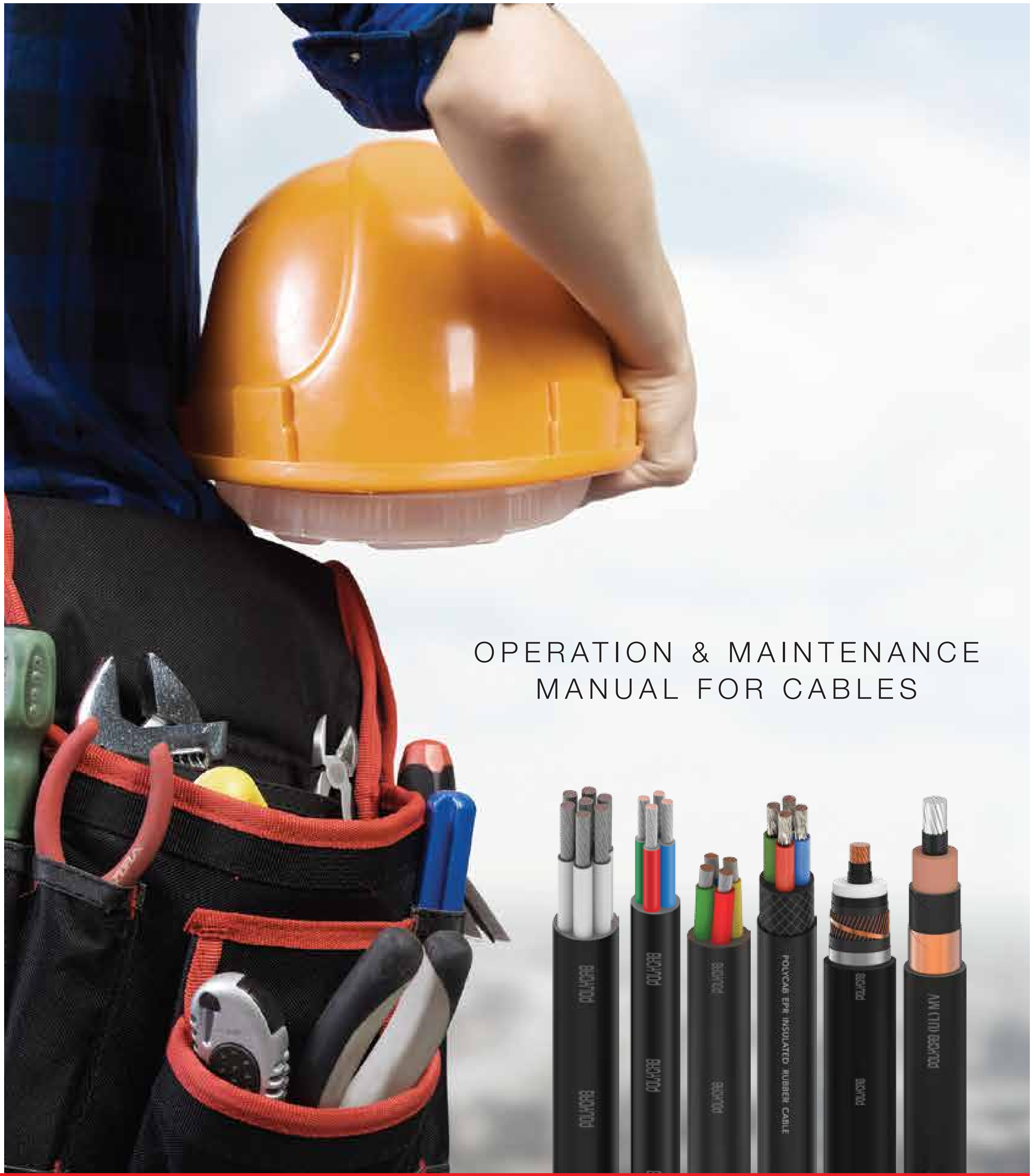

OPERATION & MAINTENANCE MANUAL FOR CABLES

Issue No: 01
Revision No : 00

Issue Date : 9th October 2021
Revision Date :

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POLYCAB

POLYCAB'S HISTORY

In 1964, Late Thakurdas Jaisinghani had established 'Sind Electric Stores', which dealt in various electrical products including fans, lighting, switches, and wires. Subsequently, the family business was managed from 1968 by Girdhari T. Jaisinghani, Inder T. Jaisinghani, Ajay T. Jaisinghani and Ramesh T. Jaisinghani being sons of Late Thakurdas Jaisinghani. The family founded a partnership firm in the name of 'Thakur Industries' under the Indian Partnership Act, 1932.

Subsequently, the partners of 'Thakur Industries' entered into a lease agreement with MIDC in 1975 in respect of a parcel of land at Andheri, Mumbai for the purposes of setting up a factory for manufacturing cables and wires which was in operation until 1984.

In 1983, 'Polycab Industries', a partnership firm founded by Girdhari T. Jaisinghani, Inder T. Jaisinghani, Ajay T. Jaisinghani and Ramesh T. Jaisinghani, was registered as a small-scale industrial unit by the Directorate of Industries, Government of Gujarat in respect of a factory located at Halol for manufacturing/processing activity of 'PVC insulated wires and cables, copper and aluminium and bare copper wire.

In 1996, the Company was incorporated as 'Polycab Wires Private Limited' at Mumbai as a private limited company under the Companies Act, 1956.

In 1998, 'Polycab Industries' was subsequently converted into a private limited company as 'Polycab Industries Private Limited' under the Companies Act, 1956. Polycab Industries Private Limited was subsequently amalgamated with the Company in 2011.

In 2000, the Company became a deemed public limited company under Section 43A(1) of the Companies Act, 1956, and the word 'private' was struck off from the name of the Company with effect from June 30, 2000.

Thereafter, the Company was converted into a private limited company under section 43A(2A) of the Companies Act, 1956, and the word 'private' was added in the name of the Company with effect from June 15, 2001.

Later, the Company was converted into a public limited company, the word 'private' was struck off from the name of the Company and consequently, a fresh certificate of incorporation dated August 29, 2018 was issued by the Registrar of Companies, National Capital Territory of Delhi and Haryana ("ROC"), recording the change of the Company's name to "Polycab India Limited (Formerly Known as Polycab Wires Limited)".

ABOUT POLYCAB

Polycab is engaged in the business of manufacturing and selling wires and cables and fast-moving electrical goods 'FMEG' under the 'POLYCAB' brand. Apart from wires and cables, we manufacture and sell FMEG products such as electric fans, LED lighting and luminaires, switches and switchgear, solar products and conduits & accessories.

Our promoters collectively have more than four decades of experience among them. Our Company was incorporated as 'Polycab Wires Private Limited' on January 10, 1996 at Mumbai as a private limited company under the Companies Act, 1956.

We manufacture and sell a diverse range of wires and cables and our key products in the wires and cables segment are power cables, control cables, instrumentation cables, solar cables, building wires, flexible cables, flexible/single multi core cables, communication cables and others including welding cables, submersible flat and round cables, rubber cables, overhead conductors, railway signaling cables, specialty cables and green wires. In 2009, we diversified into the engineering, procurement and construction 'EPC' business, which includes the design, engineering, supply, execution and commissioning of power distribution and rural electrification projects. In 2014, we diversified into the FMEG segment and our key FMEG products are switches and switchgear and conduits & accessories.

Our Telecom Division is engaged in manufacturing OFCs, FRP/ARP Rods, IGFR Yarns and a whole range of end-to-end passive networking solutions and providing EPC-services to transform people's lives, in terms of digital infrastructure and accessibility.

SCOPE OF MANUAL

The scope of this manual is to provide in depth view of Technical information on Operation & Maintenance of Low voltage, High voltage & Extra High Voltage cables up to & including 220 kV Voltage grade.

TECHNICAL INFORMATION

DEFINATIONS

NOMINAL VALUE: Value by which a quantity is designated, and which is often used in tables.

MEDIAN VALUE: When several test results have been obtained & ordered in an increasing or decreasing succession, the median value is the middle value if number of available values is odd, & the mean of two middle values if the number is even.

APPROXIMATE VALUE: Value, which is neither guaranteed nor checked, it is used, for example for the calculation of other dimensional values.

ROUTINE TESTS: Tests made by manufacturer on each manufactured length of cables to check that each length meets the specified requirements.

SAMPLE / ACCEPTANCE TESTS: Tests made by manufacturer on samples of complete cable or components taken from complete cable, by random selection in the presence of purchaser or his representatives so as to verify that the finished products meet the specified requirements.

TYPE TESTS: Test made before supplying, on a general commercial basis, a type of cable covered by the standard, in order to demonstrate satisfactory performance characteristics to meet the intended application. (Note: these tests are of such a nature that, after they have been made, they need not to be repeated, unless changes are made in the cable materials or design or manufacturing process which might change the performance characteristics)

PREQUALIFICATION TESTS (applicable only for EHV Cables)**:** Test made before supplying, on a general commercial basis, a type of cable system covered by the standard, in order to demonstrate satisfactory long-term performance of the complete cable system.

EXTENSION OF PREQUALIFICATION TESTS: Test made before supplying, on a general commercial basis, a type of cable system covered by the standard, in order to demonstrate satisfactory long-term performance of the complete cable system taking into account an already prequalification cable system.

ELECTRICAL TESTS AFTER INSTALLATION: Test made to demonstrate the integrity of the cable and its accessories as installed.

CABLE SYSTEM: Cables with installed accessories.

NOMINAL ELECTRICAL STRESS: Electrical stress calculation at Uo using nominal dimensions.

Uo: The rated RMS power frequency voltage between each conductor & screen or sheath for which cables and accessories are designed.

U: The rated RMS power frequency voltage between any two conductors for which cables and accessories are designed.

Um: The maximum RMS power frequency voltage between any two conductors for which cables and accessories are designed. It is the highest voltage that can be sustained under normal operating conditions at any time and in any point in a system.

CABLE ELECTRICAL PARAMETERS

1. **Resistance**

The Values of DC Resistance are dependent on the temperature and it is calculated by the following Formula:

$R_\theta = R_{20}$ (1 + α (θ – 20)) **Ω/km**

Where,

R_θ = The conductor DC Resistance at θ ° C Ω/km

R20= The Conductor DC Resistance at 20 ° C Ω/km

θ = Operating Temperature ° C

α = Temperature Coefficient 1/ ° C

= 0.00393 for copper

= 0.00403 for Aluminum

Generally, the DC Resistance is based on IEC 60228 and to calculate the AC resistance of the conductor at the operating temperature the following.

$R_{AC} = R_\theta$ (1 + Y_S + Y_P) **Ω/km**

Where,

Y_S = Skin Effect Factor

Y_P = Proximity effect factor

2 **INDUCTANCE**

L = K + 0.2 In (2S /d) **mh/km**

Where,

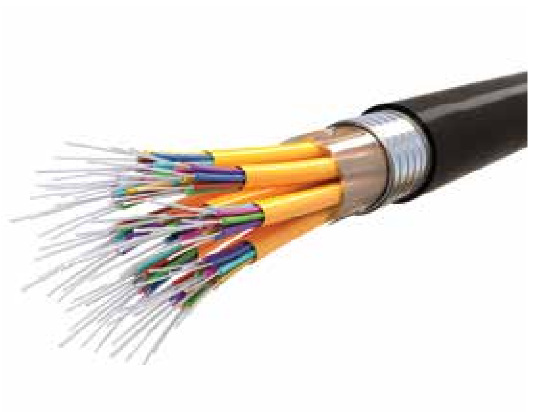
L : The Inductance mh/km

K : Constant depend on number of wires

d : Conductor diameter mm

S : Axial Spacing between Conductors

No. of wires in Conductor	K
7	0.0642
19	0.0554
37	0.0528
61	0.0514
Above 61	0.0500



3. **REACTANCE**

$X = 2\pi fL \times 10^{-3}$ **Ω / km**

Where,

X = The cable reactance Ω / km

L = The Inductance mh/km

f = Frequency Hz

To calculate the cable impedance, we should follow the bellow equation:

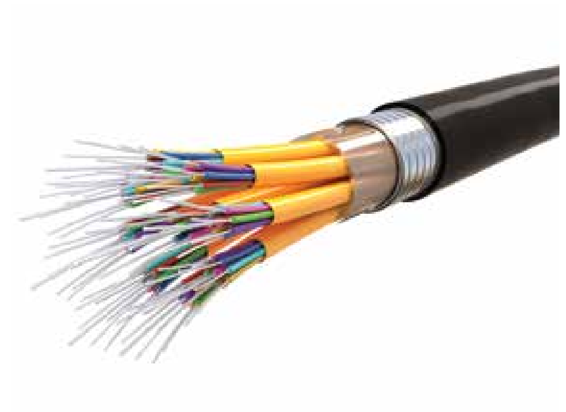
IMPEDANCE

Z = √(X2 + R2AC) **Ω / km**

Where,

R = A.C Resistance at operating temperature Ω / km

X = Reactance



4. **CAPCITANCE**

C = εr / (18 In (D/d)) **μF/km**

Where,

C : Capacitance μF/km

εr : Relative permittivity of insulation material (FOR XLPE : 2.3)

D : Diameter over Insulation mm

d : Diameter under insulation mm

5. **CHARGING CURRENT**

$I_c = 2\pi fCU_0 \times 10^{-6}$ **A/ km**

Where,

C : Capacitance μF/km

f : Frequency Hz

U_0 : Rated Phase Voltage V

6. **DIELECTRIC LOSSES**

$W_d = 2\pi fCU^2_0$ Tan σ x 10^{-6} **Watt/km/ph**

Where,

C : Capacitance μF/km

f : Frequency Hz

U_0 : Rated Phase Voltage V

Tan σ : Dielectric Power Factor (0.003 FOR XLPE)

7. SHORT CIRCUIT CURRENT

$I_{SC}@t = I_{SC}@1\ Sec/\sqrt{t}$ **kA**

Where,

$I_{SC}@t$: Short Circuit current for t Seconds kA

$I_{SC}@1$: Short Circuit current for 1 Second kA

t : Duration Sec

8. ELECTRIC STRESS

$E = 2U_0 / (X \ln (D_{INS} / D_{ISC}))$ **kV/mm**

Where,

E : Electric Stress kV/mm

U_0 : Rated phase Voltage V

D_{INS} : Diameter after insulation mm

D_{ISC} : Diameter after inner semi- conductor mm

X : When substitute the X in the above equation by DISC this will give the electric stress at conductor Screen which is the highest stress When substitute the X in the above equation by DINS this will give the electric stress at insulation Screen

9. VOLTAGE DROP

For 3 Core Cables : **$\sqrt{3} \times Z$** **V/A/Mtr**

For 1 Core Cables : **$2 \times Z$**

Where Z = Impedance

10. VOLTAGE INDUCED IN SHEATH

ES = IXm

$Xm = 2\pi fM \times 10^{-3}$ **Ω / km**

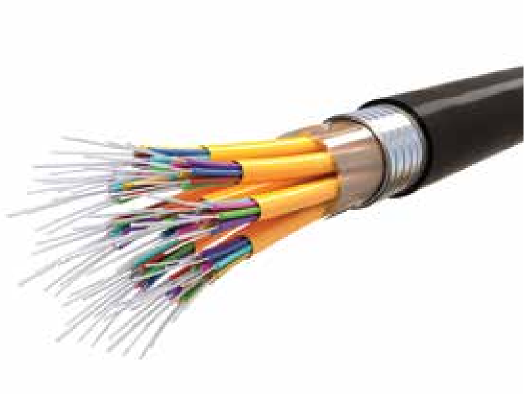
$M = 0.2 \log_e (2S/dm)$ **mH/km**

Where,

I: conductor current (A)

S: Distance between Cable Centers,

dm: Mean Diameter of Sheath



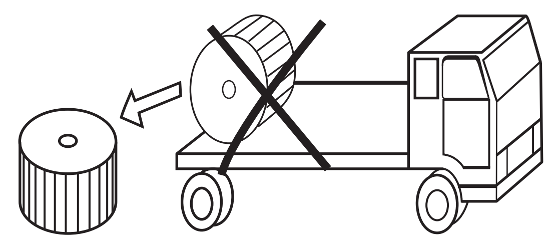
HANDLING, PACKING, TRANSPORTATION & STORAGE

Cables are generally received wound on wooden drums or in steel drums, both the ends of the cable being easily accessible for inspection and testing. However, short lengths may be transported without drums.

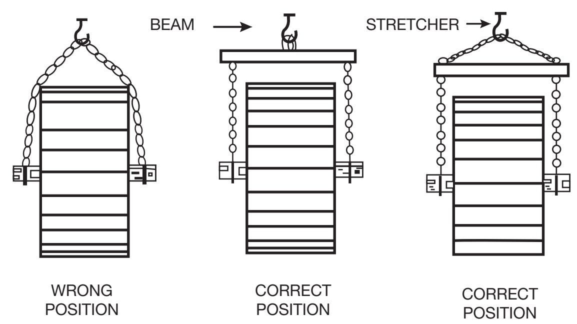
In case of PVC, plastic end caps should be used & in case of XLPE cables Heat shrinkable end caps should be used.

The cable drums or coils must not be dropped or thrown from railway wagons or from trucks/trailers during unloading operations. A ramp or crane may be used for unloading cable drums. If neither of these is available, a temporary ramp with inclination I:3 to 1:4 approximately should be constructed.

DO NOT LET FALL / RELEASE CABLE DRUMS FROM TRUCKS

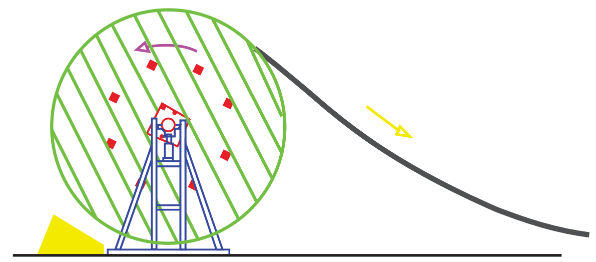


LIFTING CABLE DRUMS USING CRANE



The cable drum should then be rolled over the ramp by means of ropes and winches. Additionally, a sand bed at the foot of the ramp may be made to break the rolling of cable drum.

The arrows painted on the flange of the drum indicate the direction in which the drum should be rolled on ground & not for pulling cable from drum. The cable will unwind and become loose if the drum is rolled in the opposite direction.



When for any reason, it is necessary to rewind a cable on to another drum, the barrel of the drum should have a diameter not less than that of the original drum.

Cable drums should only be transported with suitable vehicles and must be fixed, so that they cannot shift during transportation. The same applies in case cables are transported in a container.

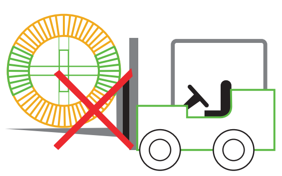
Each drum is identified by a unique drum number with barcode. In case a cable or part of it is rewound onto another drum, it is recommended to note the original drum number, otherwise backtracking is impossible. Drums must be labelled to allow easy and quick identification of the cable: - identification labels showing cable type, length, code no., etc. - other markings.

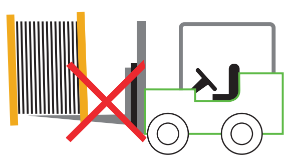
Cable drums shall be stored safely at a place which should have concrete or firm surface. Place with sharp particles, stones should be avoided which will damage the cables. Cables should be out of harm's way both physical as well as environmental hazards. Periodic visual inspection to be done to check cable conditions at frequent intervals. Improper storage conditions can easily cause damage to cable drums or cables themselves.

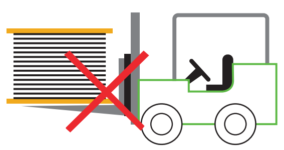
Wooden drums can be stored in the open for a period of maximum 24 months subjects to the type of wood used in drum. However, it is always advisable to store wooden drums in closed shed.

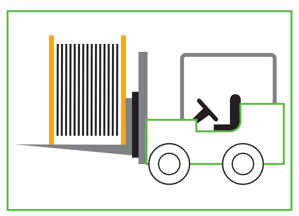
Rate of deterioration and ageing is dependent on the environment conditions & seasons.

If cable drums are required to be stores for periods longer than 2 years, it is recommended that they are stored in an enclosed area sheltered from the environment. If considered necessary, the cable could be rewound on to steel cable drums (if not already supplied).









Cables are supplied with end caps sealing to prevent ingress of moisture or water. Cable drums should be handled such that damage to the cable sheath or to sealing caps does not occur as this would subsequently permit the ingress of moisture.

If the cable is used progressively (partial length is cut off and used) the exposed end must be immediately sealed with a new end cap. Heat shrinkable end caps are recommended for this purpose.

Cable ends should be fixed to drum to avoid getting loose during transport, handling or storage. Cable ends shall be sealed with caps against ingress of water.

If a forklift is used for handling and/or shifting of Cable drums, then fork shall approach drum from flange side.

The fork shall be positioned such that the cable drum is lifted with both the flanges of cable drum.

IMPORTANT NOTE:

Cables with colored outer sheaths should not be stored in direct sunlight to prevent fading of the color. Cables should be protected against direct sunlight with suitable protection package such as black plastic sheeting, laggings etc…

GUIDELINES FOR CABLE LAYING & INSTALLATIONS

SELECTION OF ROUTE

- Selection of route should be decided keeping in view the immediate & ultimate use of the cable.
- For transporting cable drums to site, it is necessary to check road conditions. Special attention to be paid to the load bearing capacity of the bridges and culverts and other obstructions which fall enroute.
- If possible, cable to be laid along the footpath. Plans for future building projects should be considered.
- Cable route should be, as far as possible, away from parallel running gas, water pipes and telephone/communication cables.
- Suitable location for joints & terminations to be selected.

RECOMMENDED MINIMUM BENDING RADIUS FOR FIXED INSTALLATIONS:

a) **Up to 1.1 kV grade cable:**
Single core - 15D
Multi core - 12D

b) **Above 1.1 kV to 11 kV grade cable:**
Single core - 15D
Multi core - 15D

c) **Above 11 kV to 33 kV grade cable**
Single core - 20D
Multi core - 15D

d) **Above 33 kV to 220 kV Grade Cable**
for cables with plain aluminium sheaths:
36 (d + D) + 5 % for single core cables

for cables with lead, lead-alloy, corrugated metal sheaths or with longitudinally applied metal tapes or foils (overlapped or welded) bonded to the over sheath: **25 (d + D) + 5 %** for single-core cables

for other cables: **20 (d + D) + 5** % for single-core cables

Where, D = is the nominal overall diameter of the cable, in mm
d = is the nominal diameter of the conductor, in mm

At joints & terminations bending radius for the individual cores should be above 12 times the diameter over the insulation.

MAXIMUM PERMISSIBLE TENSILE STRENGTH FOR CABLES:

a) For cables pulled with stocking:

Armoured Cables P = $9D^2$
Unarmoured Cables P = $5D^2$
Where, D = overall diameter of cable, in millimeters

b) For cables pulled by pulling eye:

If the cables are pulled by gripping the conductor directly with pulling eye, the maximum permissible tensile stress depends on the material of the conductor and on their cross section as given below:
For Aluminium conductors: 30 N/mm^2 (Approx. 3 kg/mm^2)
For Copper conductors : 50 N/mm^2 (Approx. 5 kg/mm^2)

METHOD OF CABLE LAYINGS AND INSTALLATION

Widely used methods of cable laying & installation are:

- Laying cables direct in ground,
- Drawing cables in ducts,
- Laying cables on racks in air,
- Laying cables on racks inside a cable tunnel,

The choice of any of above system is totally depend on the installation conditions, laying cost, maintenance & repair, desired ease in replacement or adding new cable.

LAYING DIRECT IN GROUND

Method involves digging a trench in the ground and laying cable(s) on a bedding of 75 mm soil or sand at bottom of trench and covering it with additional riddled soil or sand of 75 mm & protecting it by means of tiles, bricks or slabs.

RECOMMENDED DEPTH OF LAYING FOR CABLES:

- The actual depth of laying is, however decided depending on the underground obstacles.
- The deeper laying causes reduction in current carrying capacity.
- As general rule, the desired depth of cable for underground laying is as under.

LV Power & Control Cables = 0.75 m

HV Power Cables up to 11 kV = 0.90 m

HV Power Cables from 22 kV up to 33 kV = 1.05 m

EHV Power Cables = 1.20 m

Cables at road crossings = 1.00 m

Cables at Railway level crossings = 1.00 m

CLEARANCES

The desired minimum clearances are as follows: -

Clearances are not required for Power Cable to power cable. However, larges the clearance, better would be current carrying capacity.

Power Cable to Control Cables = 0.2 m

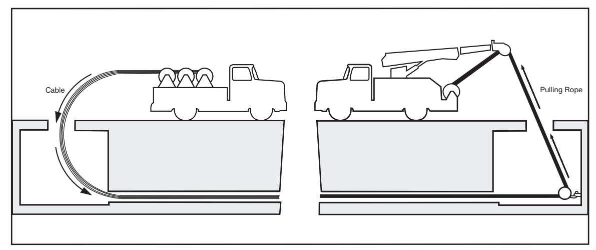
Power cable to communication cable = 0.3 m

Power Cable to Gas / Water main = 0.3 m

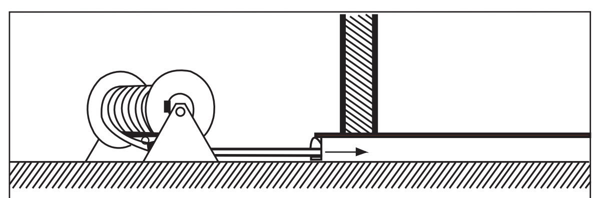
Inductive influence on control cable on account of nearby power cables to be checked.

DRAWING THE CABLES IN DUCTS

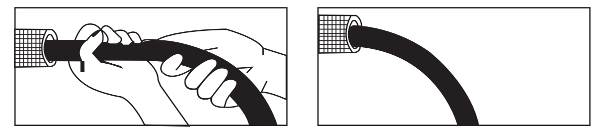
- At the feed-in, the curvature of cable feed is in the same continuous arc with no reverse bends. At the pull-out, the pulling rope exits the duct directly to a pulling sheave.



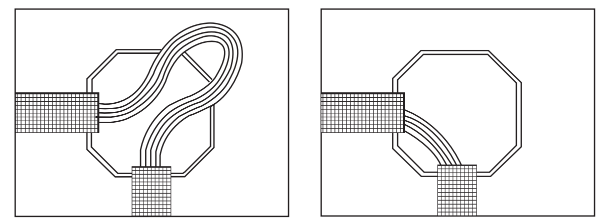
- The Cable is fed from the cable reel directly into the conduit at floor level. The cable is fed from bottom of the reel so that its curvature is continuous with no reverse bends.


Cable Feed into Conduit at Floor Level

- While fixing the cables in ducts, pulling eyes may be used. Pulling is carried out with manual by means of winches or other mechanical means when the cable to be pulled is very long.
- To eliminate sharp bend & crossovers, always have a person feed the cable(s) straight into conduit by hand or, for larger cables, over a large diameter sheave.


Proper Improper

- Do not pull cable directly across short, sharp angles. After pulling completely out of one side of the enclosure, feed the cable into the other side of the enclosure & pull that segment.


Proper Improper

LAYING CABLES ON RACKS IN AIR

Inside buildings, industrial plants, generating stations, sub stations cables are generally installed on racks fixed to the walls. The necessary size of the racks & associated structure must be worked out taking into consideration the cable grouping & permissible bending radius.

The space provided for cable racks must be sufficient. The vertical distance between two racks should be minimum 0.3 m, width of racks should not exceed 0.75 m & clearance between the first cable & wall should be 25mm

The cables are directly laid on the trays. Each tray should contain only one layer of cables. Multiple layers of cables will reduce current carrying capacity to a very great extent.

LAYING CABLES ON RACKS INSIDE A TUNNEL

The System is same as laying cables on racks in air. Heat generated in the cables are dissipated only through the walls of the tunnel. There will be increase in the temperature of the cables installed in the tunnel & accordingly proper derating factor to be applied to the current carrying capacity.

Proper barriers to be provided to isolate various sections of long tunnels to contain flooding & fire.

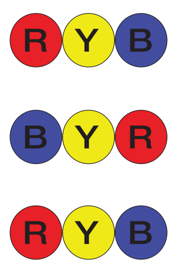
LAYING AND INSTALLATION

- After removal of planks/battens, cable to be examined for external damage. To protect cable from damage, cable should not be pulled across hard & sharp objects.
- The cable should always be pulled off the top of the drum. In doing so, the drum should be placed in such a way that the painted arrow points to the opposite direction of the pulling.
- Braking arrangements to be provided to a sudden stop further rolling and consequent buckling of cable is avoided.
- At temperature below 3 ºC, the cables should be warmed before laying out, otherwise would damage the insulation & protective covering (outer sheath) of cable. Warming of cables can be achieved by keeping them for 24 hours in place where temperature of 10 ºC or more is available.
- The leading end of the cable stocking to be placed over for pulling. Alternatively, pulling eye is also can be fixed.

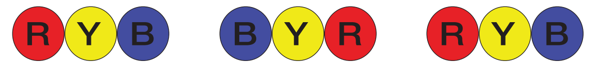
SPECIAL NOTES FOR SINGLE CORE CABLES

- The spacing between cables to be equal to diameter of cable.
- When the cables are arranged in a duct or on a rack in this way, each one should be secured either to be base or to the others by non-magnetic, non-corrosive clamps every 0.5 metres to 0.8 metres.
- Cables can also be lain in trefoil arrangement in duct or on rack which improves current distribution and reduces sheath losses. non-magnetic, non-corrosive clamps to be provided at every 0.5 metres to 0.8 metres.
- Single core cables should not be installed individually in protective steel ducts; instead, all three should be laid together on one single duct.
- If several single core cables are laid, these should be arranged as follows to ensure balanced current distribution:

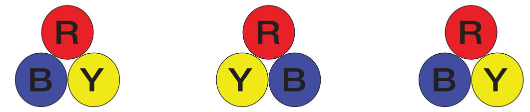
Flat Vertical



Flat Horizontal



Trefoil Horizontal



LAYING OF CABLES

PAYING OUT FROM TRAILER/TRUCK

- Cables may be paid out directly from a drum mounted on trailer/truck if there are no obstacles in a trench.
- Cable drum to be rotated by Hand.

LAYING BY HAND

- Cable drum is mounted on jack, drum is jacked high enough to fit in breaking plank. Drum should never be kept on flat on its flange & cable taken away from the same. This leads to bird caging.
- Cable rollers to be placed every 3 to 4 metres in cable trench. At least 3 solid plates for guiding the cable around the bend should be used maintaining minimum bending radius.
- The cable drum is mounted on jack & is kept at proper position in such a way that the cable is pulled out from the top of the drum when turned against the direction of arrow marked "ROLL THIS WAY"

CABLE LAYING IN LOW TEMPERATURE

- If the external temperature is bellow -5 ºC, you should postpone cable pulling. If installation of cable necessary. it is imperative to store them, before unreeling, in warmed room above + 10ºC for at least 24 hours. Unreeling has to be done within 2 hours using a slow & steady speed (around 20 metres/ minutes) without any jerk.

PULLING BY WINCHES

- If winch (Manually operated or motor driven) is available, it should preferably be used for pulling armoured cables which have a factory-made pulling eye.
- The pulling rope should be secured to the eye.
- The duct should be cleaned before pulling the cable through it.

Scan to watch Cable laying video

PRE-COMMISSIONING TESTS (TESTS AFTER INSTALLATION)

- Tests after installation are carried out when the installation of the cables and accessories has been completed.
- To check the healthiness of the cable system, following test are carried out:

a) Insulation Resistance test by megger

- All new cables should be tested for insulation resistance before jointing.
- After satisfactory results are obtained cable jointing & termination work should commence.

PROCEDURE FOR MEGGER TEST AT SITE

LT XLPE / LT PVC Cables

- Remove the planks at the place Indicated as “cable end” To take out running end of cable.
- Remove 300 mm outer sheath, Armor, Inner sheath from both ends of Cable.
- Remove 100 mm Insulation (XLPE/PVC) & expose conductor.
- Connect Voltage lead of megger to Conductor & earth lead of megger to balance all cores & armor & apply 1000 Volts DC to conductor. Note megger Value after one minute.
- Repeat this procedure for all cores.

HT XLPE Cables

- Remove 300 mm outer sheath, Armor, Inner sheath, fillers & copper tape from both ends of Cable.
- Remove 200 mm outer semi-conducting layer (Black layer below copper tape) of all cores.
- Semi-conducing layer can be removed by applying heat or by use of glass or by semi-con stripper tool.
- Connect Voltage lead of megger to Conductor & earth lead of megger to balance cores, copper tape & armor.
- Apply suitable Volts to conductor. Note megger Value after one minute.
- Repeat this procedure for all cores.

Megger available in 500 Volt, 1000 Volt, 2000 Volts, 5000 Volts & 10000 Volts. Select suitable type of megger according to voltage grade of Cable.

Note:

1. Never keep ends of cable in open condition. Always cables / samples to be kept in with proper end caps. If moisture ingress inside the cable, it will damage, armor, copper tape & cable leads to failure.
2. Proper lugs to be used for best results. Un-proper lugs will lead to heating of the cables at termination. Always use DOWELL’s lugs for proper results. Sector shaped lugs to be used for sector shaped cables.

The voltage rating of the insulation resistance tester for cables of different voltage grades should be chosen from following table.

VOLTAGE GRADE OF CABLE (kV)	VOLTAGES RATING OF IR TESTER (kV)
0.65/1.1	0.5
1.9/3.3	1.0
3.8/6.6	1.0
6.35/11	1.0
12.7/22	2.5
19/33	2.5

b) Capacitance Measurement

- The capacitance shall be measured between conductor and metal screen/sheath at ambient temperature, and the temperature shall be recorded with the test data.
- The measured value of the capacitance shall be corrected to a 1 km length and shall not exceed the declared nominal value by more than 8 %.

c) DC Voltage test of the outer sheath

(This test is applicable only on the cable having conductive layer over outer sheath.)

- DC Voltage shall be applied between each metal sheath or metal screen and the ground. For the test to be effective, it is necessary that the ground makes good contact with the entire outer surface of the outer sheath. A conductive layer on the outer sheath can assist in this respect.
- The DC Voltage of 4 kV per millimeter of specified thickness of extruded outer sheath, maximum 10 kV, for the period of 1 minute.

e) High Voltage test:

AC Testing (for MV cable):

By agreement between the purchaser and the contractor, an AC voltage test in accordance with item i), ii) or iii) as below may be carried out-

i. Test for 15 minutes with phase-to-phase voltage U, at a frequency between 20 Hz to 300 Hz applied between the conductor and the metal screen/sheath.

ii. Test for 24 hours with the normal rated voltage Uo of the system applied between the conductor and the metal screen/sheath.

iii. Test for 15 minutes with the RMS rated voltage value of 3 Uo at a frequency of 0.1 Hz applied between the conductor and the metal screen/sheath.

Note:

1) The cable cores must be discharged on completion of D.C. high voltage test & Cable should be kept earthed until it is put into service.

DC Testing (For MV & LV cables):

i. For MV cables, as an alternative to the A.C. test, a D.C. test voltage equal to 4 Uo may be applied for 15 minutes in case of IEC.

ii. For MV cables, as an alternative to the A.C. test, a D.C. test voltage as per following table to be applied in case of Indian Standard (BIS) for 15 minutes.

Rated Voltage	Test Voltages (kV)		Time (Minutes)
	Conductor & metallic sheath/Screen/Armour	Conductor to Conductor (for unscreened cables)	
0.65/1.1	3.0	3.0	5
1.9/3.3	5.0	9.0	5
3.3/3.3	9.0	9.0	5
3.8/6.6	10.5	18.0	5
6.6/6.6	18.0	18.0	5
6.35/11	18.0	30.0	5
11/11	30.0	30.0	5
12.7/22	37.5	--	5
19/33	60.0	--	5

iii. For LV cables, a D.C test voltage equal to 4 Uo applied for 15 minutes.

Note:-

1) A DC test may endanger the insulation system under test. Where possible an a.c. test as described above should be used.

2) The cable cores must be discharged on completion of DC high voltage test & Cable should be kept earthed until it is put into service.

ELECTRICAL TESTS AFTER INSTALLATION – EHV CABLES

DC VOLTAGE TEST ON OUTERSHEATH

- DC voltage equal to 4 kV per mm thickness of extruded outer sheath shall be applied with maximum 10 kV DC between graphite coating/ conductive layer & metallic sheath for a period of 1 minute.
- No breakdown of Outer sheath shall occur during the test

AC VOLTAGE TEST ON INSULATION

- AC voltage as given in table 4 of IEC 60840 / IEC 62067 or 1,7 U0 with frequency between 20 HZ to 300 HZ to be applied between conductor & screen for a period of 1 Hour. No breakdown of Insulation shall occur during the test.

Cable Voltage Grade (kV)	Test Voltage (kV)	Test Duration (minutes)
26/45	44.20	60
36/66	61.20	60
38/66	64.60	60
64/110	108.80	60
76/132	129.20	60
87/150	147.90	60
127/220	215.90	60

Alternatively Voltage of U0 kV to be applied between conductor & screen for a period of 24 Hour. No breakdown of Insulation shall occur during the test.

Cable Voltage Grade (kV)	Test Voltage (kV)	Test Duration (Hours)
26/45	26.00	24
36/66	36.00	24
38/66	38.00	24
64/110	64.00	24
76/132	76.00	24
87/150	87.00	24
127/220	127.00	24

FIELD TESTING OF SCREENED POWER CABLES USING VLF (LESS THAN 1 HZ)

A significant investment with respect to electric power system is underground cables. A high degree of reliability & reasonable life expectancy of cable systems is necessary. To get optimum performance, standards and guidelines have been developed which address the specific testing requirements for new and service aged extruded and laminated dielectric cable insulations.

Ideally, field withstand testing of cable systems would be done using same power frequency as would normally applied to cable under operating conditions, but at higher test voltage. However, because of the inherent capacitance of long runs medium/high voltage shielded cable, the excessive charging current is beyond the limits of normally available power sources and test equipment found in the field, except costly ac resonant test systems.

High voltage DC testing would eliminate the charging current issue associated with AC tests but would not subject the cable system to the voltage stress distribution that it is exposed to under normal operating conditions. Furthermore, there are significant negative issues affecting the integrity of aged XLPE cable after it is exposed to high voltage DC tests and then placed back into service. In addition, DC is not effective in detecting many forms of gross defects that may be present in a cable system that will otherwise be detected by VLF or at operating frequency.

When required to perform field testing on long lengths of medium/high voltage cable with AC source, an alternative to applying power frequency is very low frequency (VLF 0.01 Hz to 1 Hz). The charging current at a very low frequency of 0.1 Hz is only 1/500 or 1/600 of that of 50 Hz or 60 Hz respectively so that significantly smaller and more portable VLF power sources have the capability to test cable systems of relatively longer lengths.

DIAGNOSTIC TESTING

BACKGROUND

Diagnostic tests are performed to assess the health of a cable system, and thereby determine the likelihood that an aged cable system will or will not experience failures in the near future. Usually such testing is part of an overall cable system asset management program or a means of minimizing failures or highly critical or problematic circuits.

These diagnostic tests are usually undertaken either when it is some significant way into the cable system life (25-40 years) or as a response after more frequent incidents than usual. This is why diagnostic tests differ from commissioning tests in that with Diagnostic tests there is seldom good maintenance/performance history upon which to determine the appropriate test or judge current results. Furthermore, it should be clear that in these circumstances the criteria applied in the factory electrical tests cannot be applied tests.

As the cable system ages, the dielectric strength of various components tends to weaken. Since the aging mechanism depends on factors that involve the cable characteristics, accessory characteristics, and operating conditions, different power cable systems will age in different ways. Furthermore, the aging process is statistical in nature, thus there can be substantial variations in how the mechanisms develop and evolve over time with respect to cable length and accessories. This leads to significant differences between power cable systems operating under the same conditions and exposed to similar environments.

Moreover, the power cable system properties measured through the diagnostic testing will also show statistical features. This means that when utility engineers try to estimate the statistical time of failure for a given cable segment, the data should be interpreted correctly, e.g. with a sufficient number of data points to provide a reasonable assessment of trends and predictions.

Cable system diagnostic technologies usually fall into one of two categories. The first category involves techniques to assess the global or "bulk" condition of a cable system. The second category involves techniques to assess localized defects within the cable system. Again, various techniques are used to accomplish this goal, including a withstand test to "blow out" the weak location or the measurement of localized electrical discharges within the system.

Cable system diagnostic testing should be considered a process (either continuous or scheduled), not a single event. Ideally, the circuit performance should be studied and then matched to the appropriate technology of the diagnostic to the specific components in the circuit as well as any known circuit conditions. (e.g. failure history, cause of failures). In many applications, it is best to begin with an easy-to-apply technology, which provides general information that can then be used to select a more focused technology.

In many cases, it is desirable to apply diagnostic technologies periodically over the life of the cable circuit to establish, over time, how a circuit is performing. It is useful to recognize the four basic elements of an effective diagnostic program:

1. Selection
2. Action
3. Generation
4. Evaluation

Setting realistic expectations is one of the most important considerations when using cable diagnostic testing technologies. Diagnostic test results are meaningful and useful, but not precise and perfect. When diagnostic test results indicate that no immediate actions is required, the failure rate over the next three to five years for circuits with that designations may be quite low, but not zero. Conversely, when diagnostic test results indicate that a circuit requires action, it does not necessarily experience failures with a three-to-five-year time horizon. Rather, the action required simply means that there is a notable higher risk (3 to 10 times) of failure in service than a circuit categorized as not needing immediate attention.

There is no question that when applied properly, diagnostic testing can provide information to help lower cable system failure rates. And the improved reliability using diagnostics can be more strategically achieved than would occur without diagnostic testing. In this respect, cable diagnostic testing is much like a medical examination in which the resulting information induces a patient to take corrective action that extends their life. However, the information is rarely able to predict the patient's exact life expectancy. Carrying that analogy one step further, applying a technique that looks for a symptom that is not present in the patient will provide no useful information for that patient.

In principle diagnostic tests can be undertaken online or offline. Online is potentially attract in that there is no change in the cable system characteristics (current still flows) and fewer outages are required. However, the concerns of connecting sensors whilst operating and the poorer sensitivity to detect detection mean that offline diagnostics are preferred. The enhanced ability to detect defects with short exposures to elevated voltages and switching schemes that avoid customer outages outweigh concerns changing characteristics and slightly increased risk of damage.

Recent work has highlighted several general findings that follow:

1. The interpretation of diagnostic data is probabilistic-not deterministic, i.e. diagnostic results indicate what is most likely to happen to a circuit; they do not predict precise outcomes for the circuit.

2. There is no one "right" approach to cable system diagnostic testing-each situation may be different, even within a single utility or area.

3. Multiple diagnostics may be needed to obtain sufficient information to understand the condition of the cable circuit under study.

4. Diagnostic test users have to accept that there are finite (non-zero) risks of failure associated with any diagnostic test, including those described as "online" diagnostics.

5. The benefits from diagnostic testing (knowledge/improved reliability) are not instantaneous; they take time to develop. Thus, it is important to stick with a program while continually evaluating the outcomes.

6. "Trending" and "Knowledge Building" are important benefits from diagnostics. However, it is difficult to garner these benefits if the test program parameters (voltages/times/decision criteria) change. It is important to be consistent with testing protocols.

7. Diagnostic testing does not in itself deliver the improvements in reliability; the actions taken based on the diagnostic indications yield increased reliability. Recall testing identifies the problems it does not fix them.

8. Most utilities do not currently undertake underground cable diagnostic testing.

9. The most widely utilized voltage source for diagnostic testing in the field of is offline very low frequency (VLF)

10. The most widely utilized voltage sources for commissioning testing in the field are offline AC resonant (MV, HV & EHV) and very low frequency (MV and HV)

DIAGNOSTIC TECHNIQUE

The basic cable system diagnostic testing technologies used to assess the condition of health of the cable circuit appear below are discussed in a little more detail in this section.

a) Mainstream techniques (routinely deployed at utilities today)

As mentioned in following table, diagnostic Techniques typically deployed at utilities:

X Means applicable for bellow Table Test

Mainstream Techniques	Typical Use		Type	
	MV	HV/EHV	Global	Local
Time Domain Reflectometry (TDR)	X	X	X	X
Tan delta at very low frequencies (VLF)	X		X	
Simple withstand tests at elevated very low frequencies (VLF)	X			X
Simple Withstand tests at elevated resonant ac		X		X
Monitored withstand tests at elevated very low frequencies (VLF) with simultaneous monitoring of tan delta	X		X	X
Monitored withstand tests at elevated very low frequencies (VLF) with simultaneous monitoring of PD	X		X	X
Monitored withstand tests at elevated resonant AC with simultaneous monitoring of PD		X	X	X
Partial Discharge (PD) at elevated Resonant ac Voltages		X		X
Partial Discharge (PD) at elevated damped ac (DAC) Voltages	X			X
Infra-Red Thermography	X	X		X

b) Niche techniques (not routinely deployed but where equipment may be/has been commercially available)

i) Combined Diagnostic tests at Very Low frequencies (VLF) using sequential PD and Tan delta.

ii) Dielectric spectroscopy

iii) DC Leakage current

iv) Polarization Index and Depolarization current

v) Recovery voltage

Although not used to diagnose the health of the cable system asses there are a group of related techniques that are often used in combination with diagnostics to "locate" issues/failures.

These techniques enable appropriate repairs to be made and the cable asset to be either returned to service or to be re diagnosed to identify less critical defects. The techniques that may in suitable conditions, provide local information are:

i) Partial Discharge

ii) Time Domain Reflectometry

iii) Acoustic emission/ Thumping

Different diagnostic testing technologies assess different cable system characteristics. In many cases, using more than one technology can help establish a reasonably complete picture of the cable system condition. This is a particularly complex problem for hybrid cable circuits that contain more than one type of cable insulation and/or one or more types of cable joints or cable terminations. Whether a cable circuit is simple or complex, diagnostic tests must be employed carefully to assure meaningful results.

The main characteristics of the major diagnostic techniques are provided below:

TIME DOMAIN REFLECTOMETRY (TDR)

This test (right) should be utilized on all but the most complicated/ long circuits to obtain at a minimum the length of the cable system. It also provides useful information on the number of joints in a cable circuit and qualitative information on the condition of the metallic neutral which is important for the operation of many diagnostics.

If a TDR was taken after installation and is available, it can be compared with the current trace to establish a major change that may have occurred.

Some of the challenges are identified below; connecting cables add spurious effects and the choice of pulse impacts usefulness: slow pulses provide more range at the expense of resolution; fast pulses give good resolution at a limited range.

<u>ADVANTAGES</u>

- Testing is easy to employ, equipment is small and inexpensive.
- Periodic testing provides historical data that increases the value of future tests by observing changes over time (trends)
- Locate areas of the cable system with impedance related problems.

<u>DISADVANTAGES</u>

- Skilled operators are required for testing and post analysis.
- Successful location depends on having the correct velocity of propagation.
- Metric for condition of metallic neutral is unreliable/ for indication only.

VLF TAN DELTA

The test protocols are well defined and exist in a n approved industry standard. Assessment tools are available for interpreting the data into "No Action Required", "Further Study", and "Action Required" classes for all insulation types: See below table for PE bases insulations (PE, HMWPE, XLPE & WTRXLPE)

Typical table used for Diagnostic assessment for standard voltage test points of $0.5U_0$, $1U_0$, $1.5\ U_0$ (EPR's covered in different tables)

Conditional Assessment (E-3)	No Action required	Further Study advised	Action required
Assessment of PE Based Insulations (i.e. PE, XLPE, WTRXLPE)			
Stability for TDU0	<0.1	0.1 to 1.0	>1.0
	& or		
Tip Up	<6.7	6.7 to 94.0	>94.0
$(TD_{1.5\,U0} – TD_{0.5U0})$	& or		
Tip Up Tip Up $\{(TD_{1.5\,U0} – TD_{U0})$- (TD U0 – TD 0.5U0)}	<2.0	2.0 to 50.0	>50.0
Mean TD at U_0	& or		
	<6.0	6.0 to 70.0	>70.0

A health index can be determined to assist in trending using a combination of the test features from the previous table.

<u>ADVANTAGES</u>

- Test results provided as simple numerical values can easily and quickly be compared to other measurements or reference values.
- Provides on overall condition assessment (Cables, terminations, and joints)
- Measurements can be compared.
- There is minimal influence from external electric fields/noise.
- Periodic testing provides numerical data for comparison with future measurements to establish trends.
- Simple numeric results enable a quick risk assessment prior to testing at higher voltage level.
- Data may be reanalyzed and reinterpreted if needed as better criteria emerge.
- There is a low risk of failure on test.

<u>DISADVANTAGES</u>

- Cannot locate discrete defects.
- Cable system must be taken out of service for testing.
- By itself is not an effective test for commissioning newly installed cable systems

SIMPLE WITHSTAND

This is the most straightforward diagnostic test to interpret and perform.

The test protocols are well defined and exist in an approved industry standard.

Voltages and times must be carefully chosen. Increasing voltage to reduce the t4est time does not yield the same performance. In fact, it can cause problems that would not have been seen in normal operation.

In the MV arena the simple withstand is the most common voltage source to simple withstand tests uses a very low frequency (VLF) waveform of 0.1 Hz. A typical unit providing the most common sinusoidal wave is shown to the right.

In some cases, AC resonant test equipment operating near power frequencies is used in a diagnostic mode for aged circuits. However, this is in frequent.

Damped AC tests have not been shown to be effective in a withstand mode, though they show great promise as a PD source.

IEEE 400.2 recommends a tests time of 30 minutes for most diagnostic tests. This generally results in 2.7 % of the aged cable system population experiencing a dielectric puncture. When testing critical infrastructure, a test time to 60 minutes is recommended.

ADVANTAGES

- Easy to employ.
- Clear recommendations for test voltages and times in IEEE Std. 400.2-2013
- Results for the simple withstand test are unambiguous- pass/ not pass Can be used to test any circuit type: extruded, paper insulated, or hybrid.

DISADVANTAGES

- Cable must be taken out of service for testing.
- An inexperienced test operator can cause damaged by applying a voltage that is either too high or for too long.

MONITORED WITHSTAND

The test protocols are well defined and exist in an approved industry standard. Most of the commercially available equipment can perform a monitored withstand.

Usually, VLF Tan σ is combined with VLF withstand. However, PD has been used on critical infrastructure projects. Trending is more difficult with PD.

ADVANTAGES

- Provides additional information over the simple “Pass” or “Not Pass” obtained from a simple withstand test.
- Allows for information trending during a single test.
- Provides real time feedback so that the test may be adapted (test time increased or decreased) to fit utility objectives. Monitored withstand can require considerably less total test time when compared to a simple withstand approach (40 % to 60 % efficiency improvement)

DISADVANTAGES

- Adds complexity (Interpretation, set up, and data recording) to simple withstand test.
- Skill and fast decision-making required of personnel.

PARTIAL DISCHARGE

There is limited agreement within the industry on the condition assessment if PD is present. There is only agreement that having PD on a cable system is “not desirable” and it is important to know where it is located. No industry standard is available for interpreting PD measurements in the field.

The architecture of the cables system installed in the field means that field data cannot be quantitatively related to any tests that might be conducted in the factory on the separate components.

This is the most difficult diagnostic to employ in the field as issues surrounding test setup and execution are diverse and complex. Thus, it is usually only deployed at the time of commissioning on circuits requiring the highest reliability.

Although equipment exists to make measurements in the field. Generally, the technique remains too complicated for most utilities to conducts and interpret on their own.

In a few cases, online PD measurements have been conducted. However external noise the difficulty of discriminating significant changes in condition continue to make this a challenging technique.

Although qualitative in nature, and thus less preferred for trending, acoustic PD methods have made useful contributions to vault/ manhole entry tests and the localization of PD initially detected by electrical methods.

METALLIC SHIELD RESISTANCE

Resistance measurements is a technique that is commonly used in the field to assess the condition of the neutrals and to provide a quantitative rating.

Although most thought of as an unjacketed cable issue, corroded neutrals do occur on jacketed cable systems. The most common location is where the jacket is breaked, and corrosion becomes concentrated.

The importance of metallic shield assessments is that the cable may be thought of as having a conductor system, a dielectric system, and a neutral system. A functioning cable needs all three of these systems to function. Thus, when making a diagnostic assessment of a cable the life expectancy of the dielectric system must be of the same order as the neutral system. An example of the probabilistic life curve for neutrals in unjacketed cables is shown above- half of all unjacketed cables will have lost more than 50% of their neutrals by age 40.

If the neutral system is seriously degraded (between 50% and 75% lost) then the cable will most likely need to be replaced.

ADVANTAGES

- Specifically designed for metallic shield assessment
- Testing is easy to employ.
- Numeric easy to understand results.
- Easy to deploy no expert operator required.

DISADVANTAGES

- Requires temporary neutral isolation at far end.
- Long lengths are challenging because of long lead length and potential voltage drop issues as well as the uncertainty of the cable conductor resistance if using the cable conductor as the return path.

SHIELD REFLECTOMETRY ASSESSMENT (TDR)

Many of the diagnostics (TDR, PD, Tan σ) all require that the metallic shield be in a good condition. If it is not, then these diagnostics will give spurious results. This test (provides useful qualitative information on the condition of the metallic neutral.

If a trace was taken after installation and is available, it can be compared with the current trace to establish any major changes that have occurred. Thus, ageing rates and remnant lifetimes can be estimated.

ADVANTAGES

- Testing is easy to employ.
- Test equipment is small and inexpensive.
- Information of location of corrosion or break may available
- Complete breaks in the entire metallic shield cab be clearly identified.

DISADVANTAGES

- Not designed for metallic shield assessment
- Skilled operators are required for testing and post analysis.
- “Blind spots” due to the ringing effect occurring near the pulse injection end.
- Generally, only detects very significant localized corrosion.
- No quantitative metric

INFRARED THERMOGRAPHY

With the widespread availability of IR cameras, utilities are undertaking many more surveys than in the past. Clearly, a cable system presents many challenges to this diagnostic as the operator must have a sufficient access to the location/ component of interest to capture a suitably detailed image. This has meant that this technique has found most use in terminations and joints within manholes/vaults.

Optimal operation of the camera requires, at least, a sufficiently large image of the area of interest (too much background degrades performance) and the selection of the appropriate emissivity for the devices/ local (termination lugs will differ from a joint body and a joint body will differ from one covered in detritus from a recently pumped vault).

Most studies have found that temperature alone does not provide sufficient information for a diagnosis. The most robust approach is to use the temperature difference between like components at a location as well as the absolute temperature.

Experiential studies have shown that most users will operate a three-level system of:

1) No Action required
2) Action Required
3) Further Study

When considering joints and terminations temperatures of 650°C to 750°C or temperature differences of 100°C to 250°C to 750°C are seen as reasonable indicators for action being required.

Along with acoustic PD detection, simple (Semi quantitative) infra-red “Hot spot” scans are often used within vault entry protocols, where poorly performing joints are a major concern.

It is likely that a formal thermography certification is required to perform robust IR diagnostics.

MANITENANCE OF CABLE INSTALLATIONS

Maintenance of cable installation includes inspection, routine checking of current loading, maintenance, and care of all cables & end terminations.

INSPECTION

Wherever cables or joints are accessible periodical inspection should be made so that any repair can be made before any interruption to services. Frequency of inspection should be decided by own experience. Heavily loaded lines will require more attention than less important lines.

Cables laid direct in ground are not accessible for routine inspection. However, all digging operations can be inspected. Exposed cables should be examined thoroughly for damages if any.

CHECKING OF CURRENT LOADING

Loads are conveniently to be checked by “Clip-on” type portable ammeters. Distributor load should be checked at intervals not exceeding 3 months.

MAINTENANCE OF CABLES

MAINTENANCE is required: -

- To avoid failures
- To avoid environmental damage
- To avoid more expensive maintenance later
- To extend the life of the equipment
- To avoid risk
- To repair failed cables / components of accessories.

TYPE OF MAINTENANCE

1. CONDITION BASED MAINTENANCE OR PREDICTIVE MAINTENANCE

Performance of condition assessment on a cable or accessory, followed by adequate action to avoid failure in service.

Plan based on measuring the condition of equipment to assess whether it will fail subsequently, and then take appropriate action to avoid the consequences of failure.

2. TIME BASED MAINTENANCE OR PREVENTIVE MAINTENANCE

Perform an action at predetermined intervals to avoid a failure in service condition.

3. CORRECTIVE MAINTENANCE

To repair a fault on a cable or cable accessory after the failure has occurred.

ELECTRICAL TESTS

- Insulation Resistance
- Capacitance measurement:
- Tan delta (Loss angle measurement)
- Metallic sheath resistance measurement
- Partial Discharge Test: Sensitivity of measurement (Background noise)

PROBABILITIES OF FAILURES

1. Damage by third party
2. Damage due to brittleness of outer sheath.
3. Ingress of water in the insulation.
4. External mechanical stress, thermal stress, improper clamping /mounting
5. Improper preparation of joints & terminations
6. Movement of cable due to thermal cycling
7. Improper laying of cables, cable damage while Probability of Failures in cable Laying
8. Water ingress into link boxes

MAIN DEFECTS IN CABLE SYSTEM

Bad peeling of semi-conducting

Poor cable preparation (should be smooth)

Internal PD in the cable and its accessories

Surface PD on cable terminations

Corroded Shield

Broken Jacket

CONDITION MONITORING

Goal of condition monitoring/ preventative maintenance is to get a non-destructive health assessment of the cable which will enable to:

- Identify local defects.
- Identify the level of insulation degradation.

This all prevent outages, extend the life of cables, increase reliability & reduces cost.

REMOVAL OF MOISTURE FROM POWER CABLES

Normally, Cable ends are sealed until the cable is installed to prevent moisture from entering the cable. When open cable ends are submerged or exposed, water can migrate inside the cable. If water remains in a medium-voltage cable, it can accelerate insulation deterioration and lead to premature failure.

You can remove water from wet cable by Purging the cable with dry nitrogen gas under pressure. Any wire or cable product that does not contain fillers and is suitable for wet locations, can be purged under engineering supervision.

If you do have to purge a length of wire or cable, always test it before you energize it. At a minimum, conduct an insulation resistance Test with a megaohm-meter.

Note: - The purging procedures described here assume the water in the wire or cable does not contain unusually high concentrations of oils or chemicals, such as may be found in floodwaters. If you suspect that water inside a cable carries unusual contaminates. Consult the manufacturer before deciding to continue using the wire or cable.

If you are not certain about the source of water in cable. Water samples from the cable. The work site, and the manufacturer can be annualized for mineral content, comparing mineral contents can, many times, identify the source of the water.

Problems with ingress of moisture into cables

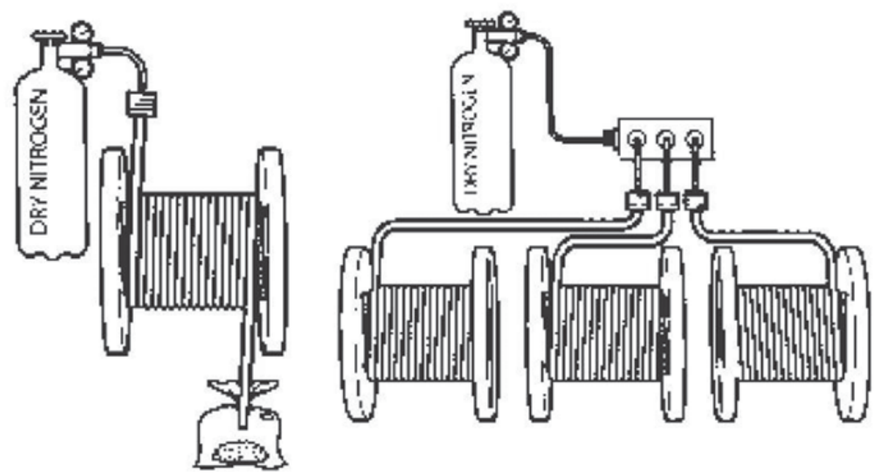
- Water treeing in the primary insulation in a cable with ingress of moisture
- Electrical treeing of the primary insulation causing failure.
- Shortened life expectance of the high voltage cable.

Results after Nitrogen purging

- Vast improvement in IR tests
- Flat lining on Tan Delta tests on the insulation.

General Purging Process

The Purging setup is shown in figure. To purge several cables at once, connect them to the gas supply with a manifold, as shown in figure. If only one end of the cable contains water, apply purging gas to the dry end. If the whole cable is wet, apply purging gs to the higher end.



Always purge the cable shield separately from the insulated strands. If you try to do them at the same times, the gas will flow only through the path offering the least resistance. Before purging installed cables, remove cable terminations and splices. Do not try to purge across or though splices.

PURGING CABLE CONDUCTORS

1. Select an end cap that fits over the cable core.
2. Cut a hole in the end cap for the valve stem and install the valve stem.
3. At the dry (or higher) cable end, apply two layers of half lapped high voltage insulating tape as a sealing cushion for the end cap.
4. Install the end cap on the cable using the radiator hose clamp.
5. Connect the low-pressure side of the nitrogen regulator to the end cap with the gas hose.
6. Turn on the nitrogen and adjust the regulator to 15 psi.
7. If water is not running or dripping out the open cable end, sprinkle a tablespoon of color indicating desiccant into a plastic bag and tape or camp the bag to the open cable end.
8. Check to make sure the bag is filling with nitrogen. If it is, make a small vent hole by clipping off one corner of the bag.
9. After a few hours, check the desiccant to see if it has changed from the blue to off white or pink. This indicates moisture coming out of the cable. If the desiccant has changed colour, replace it with fresh desiccant and continue purging. (you can also check for moisture by holding a piece of tissue or blotter paper next to the vent hole for a few minutes. If the paper gets damp, moisture is still coming out of the cables.)
10. Change the desiccant every few hours until it stops changing colour. When you have gone several hours with no sign of moisture, you can assume the cable is dry. Depending on how much moisture is in the cable, purging may take up to eight hours occasionally even longer. One cylinder of nitrogen should be enough for at least one cable run.

You can also drive water vapour from conductor strands by lightly loading the cable with low voltage and low current. This process does not dry out the shield assembly. The cable terminations must have an open strand design or terminations must be removed to let the water vapour escape.

PURGING CABLE SHIELD

You can purge cable shield systems by following the conductor purging process with the following exceptions.

- block the conductor strands so no gas can pass through them, and
- place and caps over the jacket rather than the cable core. Apply gas pressure and check for moisture as before. Do not exceed 15 PSI maximum.

CABLE ON REELS

You will have to unleash the cable ends to connect the purging set-up to cables on reels. If you find water in only one end of a reel of cable, position the reel so the wet end is in its lowest possible elevation. If you see moisture at both ends of the cable, position the inside end of the cable as low as possible and purge from the outer end of the cable.

CABLE FAULT: BASIC CONDITIONS, CAUSES, TYPES & METHOD TO FIND FAULTS

WHY DO CABLES FAIL?

Power cables can fail for several reasons, the most common causes being external interference or damage, overheating, moisture ingress, poor accessory installation, cable or accessory defects, all of which will result in electrical failure or breakdown of the primary insulation.

Identifying the real cause of a failure can be a difficult task as one form of damage may lead to another, and the root cause may not be plainly evident.

Mechanical Damage

Mechanical damage is usually attributed to activities during or after installation, when the cable is most exposed to the possible damage, however experience shows that damage during transport, and handling & sometimes during manufacturing also is also possible.

Testing of each cable length by the manufacturer of cable and care during manufacture results in a product without defect that can be expected to perform for the entire design cable life. Such confidence can only be assured by close adherence to proven design concepts, quality procedures during manufacture, and strict quality control criteria during the testing phase.

Analysis of cable failures due to mechanical damage shows that damage that occurred during installation is often the direct cause of failure in service.

Severe mechanical damage (such as dig-ins) during service will result in immediate failure of the insulation and disruption of the supply of electricity. However, if the damage is not so severe as to cause such an instant reaction, it may go unnoticed and eventually lead to failure by one of the other main causes. For example, a civil contractor installing water pipes near a cable circuit slightly damages the cable sheath and does not repair the damage. In time, moisture from the surrounding soil eventually corrodes the metallic sheath, permeates into the insulating layers and eventually causes electrical breakdown. Unfortunately, the energy released at the time of eventual failure will often burn away the evidence of the real cause.

There are also several other opportunities for mechanical damage to occur over the life of the cable, including insect and rodent attack, vibration, soil erosion, and corrosion.

Therefore, having a cable with the best possible protection and good installation procedures is some of the best assurance for a reliable cable asset in service. Continued cable life is assisted by the monitoring and period checking of the cable and accessories.

Ageing and Overheating

Ageing and overheating is a direct result of incorrect system design, inappropriate installation, or abuse of the cable by overloading.

Overheating of cables accelerates the ageing process and can lead to cable or core movement (due to thermal expansion) that was never designed or catered for in the system arrangement. If such movement is concentrated at one-point (as is often the case, for example, at the accessory) damage and/or failure at that point (the accessory) will certainly result.

The XLPE insulated cables also suffer problems when overheated, initially seen as deformation of the insulation layer, but eventually resulting in a breakdown of the polymer chains, baking, and carbonizing of the insulation. With the insulation at any one of these stages of deterioration, any additional stresses imposed by voltage peaks, impulses, and spikes will initiate the breakdown of the entire thickness of insulation.

Deterioration of the primary insulation is the most severe type of ageing damage, but the most common ageing damage occurs to the outer parts of the cable, as they are in contact with the external environment.

For the polymeric sheathing materials, such factors as UV radiation and chemical reactions, are the most significant, while for the metallic layers, corrosion and electrolytic action are a danger. The breakdown of the external cable protection then leads to damaging effects onto the primary insulation and cable eventual failure.

In many cases it is not the cable that initiates the failure, but the accessory, by allowing the ingress of water at an aged or poorly installed interface or at a broken interface due to movement.

Improper Application/Design:

If cable selected is not appropriate for the application, it is more likely to fail in service. For example, a cable which is not robust enough for the environment, either mechanically tough enough to wear and abrasion or chemically resistant to the ambient conditions, is more likely to fail than one whose construction is suitable for the installation environment.

Degradation of the cable sheath:

There are several reasons why the sheathing material may degrade, including excessive heat or cold, chemicals weather conditions, and abrasion of the sheath. All of these factors can ultimately cause electrical failure as the insulated cores are no longer protected by the sheathing as originally designed.

Moisture in the insulation:

Moisture ingression can cause significant problems including short circuit and corrosion of the copper conductors.

Rodent attack:

Rodents frequently attack the outer layers of cables. This damage can be extensive, significantly reducing the sheathing or insulation properties of the cable, another likely source of electrical fires.

UV exposure:

UV exposure can have a significant influence on electrical cable insulation and sheathing. Cables likely to be exposed to UV light should either be designed with UV resistant materials with a suitable carbon black content or protected from exposure with a protective covering such as installing inside cable conduit not in direct sunlight. UV exposure frequently causes cracking of the insulation and therefore potential short circuit failures.

Electrical Deterioration

Partial discharge is, as the name suggests, a "partial" discharge (or breakdown) within the insulation medium. It is generally initiated from a small defect or contaminant within the insulation or a void. These defects increase the electrical stress at that point to a level where discharge is possible even within solid materials.

Manufacturers of XLPE cables take great care during manufacture to ensure no sites for partial discharge activity exist, and during routine testing, all cables are energized well beyond their working voltage whilst PD levels are monitored. It is therefore unlikely for new cables to exhibit such problems for many years of service.

In the field however, these cables must be fitted with accessories suitable for jointing or termination, and unless the design and workmanship in fitting of these accessories is effective for the electrical stress levels involved, partial discharge can occur at the interface between cable and accessory.

XLPE can also suffer from the phenomenon of water treeing, where under the influence of electrical stress and moisture, "trees", which are microscopic void channels can occur and propagate slowly through the insulation, causing increasing levels of electrical stress and leading to eventual electrical breakdown.

It is consequently extremely important that highly stressed XLPE insulations (such as in EHV cables) have an effective moisture barrier provided for their entire lifetime.

Prevention of overheating and ageing, prior to installation

It is normal to monitor the current flowing in the cable and the limits passed on a circuit are based on the assumed maximum current that can be allowed to flow. However, at a more basic level, it is really the temperature of the cable that is being limited by the restrictions on the electric current. This correlation and relationship of current to temperature is critical.

Traditionally, the current rating of cables is based on thermal equations established many years ago and published as IEC documents, such as the IEC 60287 and IEC 60853 series. Whilst these have proven reliable, they are generally accepted as conservative and underestimating of the cable temperature. As mentioned earlier, there are pressures on the electricity supply industry to become more efficient, and this has focused attention on the thermal design and installation conditions (backfill) of new high and medium voltage insulated cable systems, to ensure the accurate rating of the cable with minimum investment outlay.

Soil Thermal Resistivity

The importance of correct backfill properties has been appreciated almost since the first underground cables were installed, but the selection of appropriate materials to use as trench backfill was more dependent on local availability and experience in the selection of a "good" material. As an example, many installers considered sand to be a reasonably uniform material, so that it was also considered perfectly satisfactory just to add appropriate levels of cement or fly ash, as mentioned in cable handbooks, to achieve suitable stable, backfill materials.

Nowadays, we understand the importance of achieving a low value of thermal resistivity together with a reliable compaction density, just as we now place greater importance on the assessment of the thermal properties of the native surrounding soils.

Soil thermal resistivity can now be readily and accurately measured in the field or in the laboratory using commercially available test equipment.

Installation of prototype sensors in the field, which continually monitor soil temperature and thermal resistivity are also yielding surprising details about the variations of thermal resistivity with moisture content of the soil. The conclusion we draw from all of this additional knowledge is that there is no "standard" installation condition, and that the environmental conditions over the length of even the shortest circuit may vary widely.

Ultimately then, as a cable will always fail at the weakest (or most overstressed) point, we need to be able to interrogate the entire length of cable to establish its condition and ability to continue to function.

Causes of Electrical Deterioration

A perfectly manufactured insulation would tolerate expected operating conditions indefinitely, provided external factors did not affect that insulation adversely.

Partial discharges at accessory interfaces will degrade the insulation of the power cable. As mentioned earlier in this document, the paper insulated cable has the capability to accept some discharge, whereas the XLPE insulation suffers from such discharges so that break down may occur quite rapidly.

Water treeing, the phenomenon of water penetration into the XLPE under voltage stress, resembling a growing tree, tends to develop into a site for an electrical tree and eventual partial discharge, and hence eventually leads to electrical failure of the insulation. Partial discharge testing of all cables as part of final testing after manufacture has been in place for more than 25 years. The detection and monitoring of partial discharges in service, under field conditions, is now becoming ever more important.

Partial Discharge

It is now possible to measure changes in partial discharge on a complete circuit and from the data, extract information, and obtain an indication of the location of such discharges. It should be recognized that actually being able to measure PD outside of a special screened room environment without a special PD free voltage source is a major technological achievement. A comprehensive study of all the various methods is given in a CIGRE WG 21-16 report.

PD at Supply Voltage

In the first case, it is recommended that PD can be measured on a complete cable circuit at the normal operating voltage using directional coupling, so that it is possible to locate whether the discharge is coming from an accessory or from some other location. Very low values of Partial Discharge in HV and EHV accessories can also be monitored directly, although not at this stage economically on a real time basis. But it can be done at regular intervals during the life of the circuit. In most cases this monitoring is used in a manner like a DTS. That is, as a trend analysis, either by comparing the results taken at regular intervals, or on a continuous basis. Because the partial discharge is being measured at normal working voltage the signals (if any) are very small. Hence it may be argued that the by the time a discharge is of such a magnitude as to be observed or detected, the cable or accessory will be on the verge of failure, and hence there is little if any time in which to respond. To compensate for this some systems are developing very sophisticated trend change/recognition software.

PD at Test Voltages

In the second case, because PD can usually only be detected at voltages above normal service voltage, the PD test is carried out by testing at regular intervals with specialized PD detection equipment at a voltage above the normal supply voltage. In this case it is claimed that any minor defect will be detected before failure in service so that appropriate maintenance can be affected before system failure.

Cable routes are influenced by various ambient parameters. A cable route can consist of multiple diverse cable parts of diverse designs and types. Depending on the voltage level, the required load capacity and available fitting and installation technology, cables are used with plastic insulation or mass-impregnated paper insulation. In practice, cable faults must be located at all voltage levels - from low voltage, medium voltage to high voltage. Regardless of the cable type – besides external influence, e.g. damage caused during earth works or earth displacements – the most frequent fault causes include: ageing, service life, over voltage, thermal overload, corrosion, incorrect cable laying, installation defects and damage from transport and storage. It is beneficial for daily use if the equipment for cable fault location is designed for medium- and high-voltage ranges but it can be applied just as well for low voltage.

FAULT LOCATION TECHNIQUES

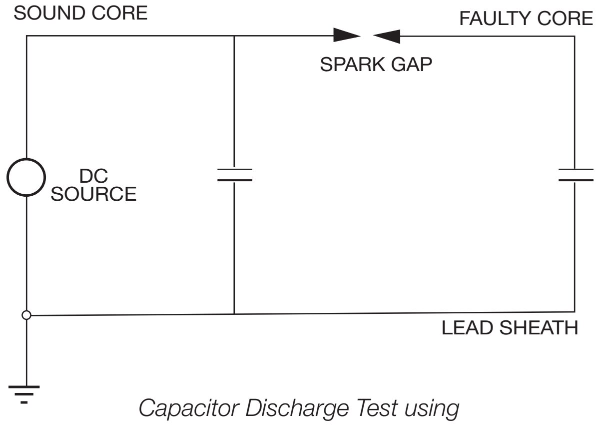
Finding the type of a **fault in underground cables** using a megger should not be a difficult task. But finding the exact **location of the cable fault** needs special techniques. Two of the popular techniques are the Murray and Varley loop tests for locating faults in underground cables. This article explains about few other popular **techniques for locating faults in underground cables** - viz. (i) Cable thumping, (ii) TDR, (iii) High voltage radar methods.

Following are techniques widely used to locate fault.

1. Direct loop test
2. Varley loop test
3. Murray loop tests
4. DC charge and discharge test
5. Radar test
6. Capacitor discharge test (Cable thumping)
7. Acoustic cable tracing and fault locator

CABLE THUMPING (CAPACITOR DISCHARGE TEST)

A **cable thumper** is basically a portable high voltage surge generator. It is used to inject a high voltage DC surge (about 25 kV) into the faulty cable. If you supply a sufficiently high voltage to the faulty cable, the open-circuit fault will break down creating a high-current arc. This high current arc makes a characteristic thumping sound at the exact location of the fault.



Capacitor Discharge Test using Healthy Core as Capacitor

To find the **location of cable fault using the thumping method**, a thumper is set to thump repeatedly and then walking along the cable route to hear the thumping sound. The higher the dc voltage applied; the louder will be the resulting thump. This method is useful for relatively shorter cables. For longer cables, the thumping method becomes impracticable (imagine walking along a cable that runs several kilometres to hear the thump).

Advantages and Disadvantages of Cable Thumping

A major **advantage of cable thumping** is that it can locate open circuit faults very accurately. Also, this method is easy to apply as well as easy to learn.

Though the thumping method provides very accurate fault location, it has its own drawbacks. Applying this method for longer cables is extremely time-consuming. It may take hours or even days to walk along the cable to locate the fault. Moreover, during that time, the cable is exposed to high voltage surges. So, while the existing fault is located, the high voltage surges may weaken the insulation of the cable. If you are proficient in cable thumping, you can limit the damage to the cable insulation by reducing the power sent through the cable to the minimum required to conduct the test. While moderate thumping may not cause noticeable damage, frequent thumping may degrade the cable insulation to an unacceptable condition. Also, this technique cannot find faults that do not arc-over (i.e. short circuit faults).

TIME DOMAIN REFLECTOMETER (TDR) (ACCOUTIC CABLE TRACING)

A **Time Domain Reflectometer (TDR)** sends a short-duration low energy signal (of about 50 V) at a high repetition rate into the cable. This signal reflects back from the point of change in impedance in th e cabl e (such as a fault). TDR works on the similar principle as that of a RADAR. A TDR measures the time taken by the signal to reflects back from the point of change in impedance (or the point of fault). The reflections are traced on a graphical display with amplitude on y-axis and the elapsed time on x-axis. The elapsed time is directly related to the distance to the fault location. If the injected signal encounters an open circuit (high impedance), it results in high amplitude upward deflection on the trace. While in case of a short-circuit fault, the trace will show a high amplitude negative deflection.

Advantages and Disadvantages Of TDR

As a TDR sends a low energy signal into the cable, it causes no degradation of the cable insulation. This is a major **advantage of using TDR** to find the location of a fault in an underground cable. A TDR works well for open-circuit faults as well as conductor to conductor shorts.

A weakness of TDR is that it cannot pinpoint the exact location of faults. It gives an approximate distance to the location of fault. Sometimes, this information alone is sufficient and other times it only serves to allow more precise thumping. When the TDR sends a test pulse, reflections that may occur during the time of outgoing test pulse may be obscured from the user. This can happen with the faults at near end and called as blind spots. Also, a TDR cannot see high resistance (generally above 200 Ohms) ground fault. If there is surrounding electrical noise, it may interfere with the TDR signal.

HIGH VOLTAGE RADAR METHODS

As the low-voltage TDR is unable to identify high resistance ground faults, its effectiveness in **finding underground cable faults** is limited. To overcome this limitation of TDR, following are some popular high voltage radar methods. (i) Arc reflection method, (ii) surge pulse reflection method and (iii) voltage decay reflection method.

ARC REFLECTION METHOD

The arc reflection method uses a TDR with a filter and thumper. The thumper (or surge generator) is used to create an arc across the shunt fault which creates a momentary short-circuit so that the TDR can show a downward deflection effectively. The arc reflection filter protects the TDR from high voltage surge generated by the thumper and routes the low-voltage signal down the cable.

SURGE REFLECTION METHOD

This method uses a current coupler, a thumper and a storage oscilloscope (analyser). This method is used for long run cables and on faults that are difficult to arc over which do not show up using arc reflection method. In this method, a thumper is directly connected to the cable without a filter which can limit both the voltage and current applied to the fault. The thumper injects a high voltage pulse into the cable creating an arc at the fault, which subsequently causes a reflection of energy back to the thumper. The reflection repeats back and forth between the fault and the thumper till its energy gets depleted. The current coupler senses the surge reflections which are then captured and displayed by the storage oscilloscope.

VOLTAGE DECAY REFLECTION METHOD

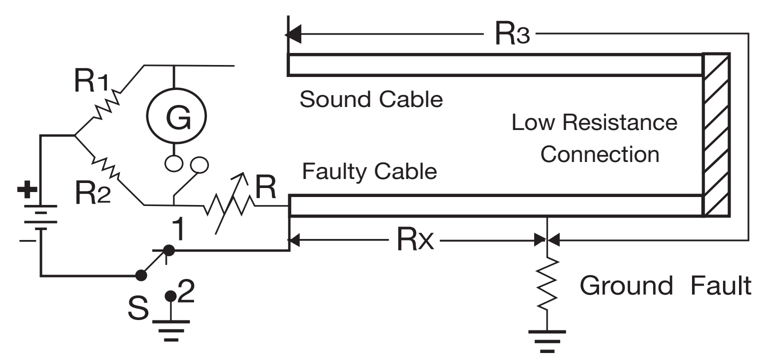
This method uses a voltage coupler, a dielectric test set (high-voltage dc test set or proof tester) and a storage oscilloscope (analyzer). This method is used for transmission class cables when the generation of arc at the fault requires breakdown voltage greater than that a typical thumper or surge generator can provide. Here, the voltage coupler senses the reflections produced by the flashover of DC voltage at the fault and the analyzer captures and displays them.

DIRECT LOOP TEST

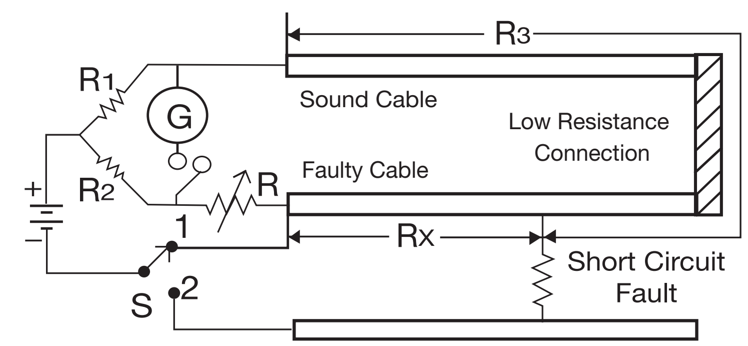
This test is a modification of the Murray loop test where instead of the slide wire being connected across the sound core and faulty core at the same and a CTS or a VIR cable is made to run along the surface exactly above the route of the cable and connected to the two ends of the faulty core to form a slide wire. The battery terminal is connected to a long piece of wire at the other end of which a knife edge is provided to make contact with the CTS or VIR cable placed above ground as described before. The point where the balance is obtained is thus the exact point where the fault exists.

VARLEY LOOP TEST

This test provides for the measurement of the total loop resistance instead of obtaining it from the known lengths of cable and their resistance per unit length. The connections are shown in Figure for both the ground and short-circuit test respectively. In this test the ratio arms R1 and R2 are fixed, balance being obtained by adjustment of a variable resistance R, placed in series with the section of the loop having a smaller resistance. When the balance is obtained with the throw-over switch in the battery circuit on contact S, then, in either of the above tests, the magnitude of the resistance Rx may be obtained from the setting of R for balance, together with the values of R1 and R2 and of the resistance R3 + Rx (that is the total resistance of the loop).



Cicuit connection of Varley loop test for ground fault



Cicuit connection of Varley loop test for short circuit fault

MURRAY LOOP TEST

This test is used to find the fault location in an underground cable by making one Wheatstone Bridge in it and by comparing the resistance we shall find out the fault location. But we should use the known length of the cables in this experiment.

The variable resistors R1 and R2 are forming the ratio arms. Balance of the bridge is achieved by adjusting the variable resistors. G is the galvanometer to indicate the balance. [R3 + RX] is the total loop resistance formed by the sound cable and the faulty cable.

The necessary connection of the **Murray loop test** is shown in figure 1 and 2. The figure 1 shows that the circuit connection for finding the fault location when the ground fault occurs and the figure 2 shows that the circuit connections for finding the fault location when the short circuit fault occurs.

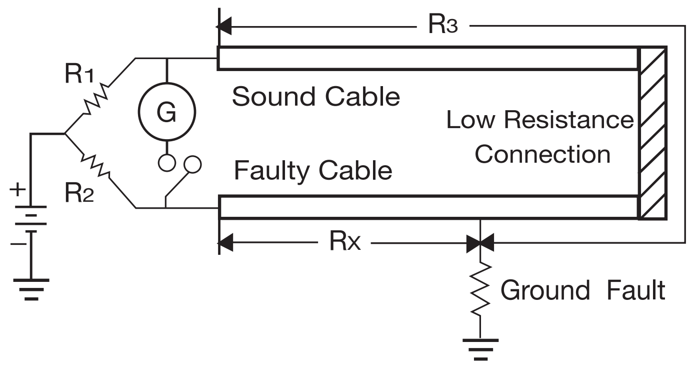


Fig. 1 - Cicuit connection of Murray loop test for ground fault

In this test, the faulty cable is connected with sound cable by a low resistance wire, because that resistance should not affect the total resistance of the cable and it should be able to circulate the loop current to the bridge circuits without loss.

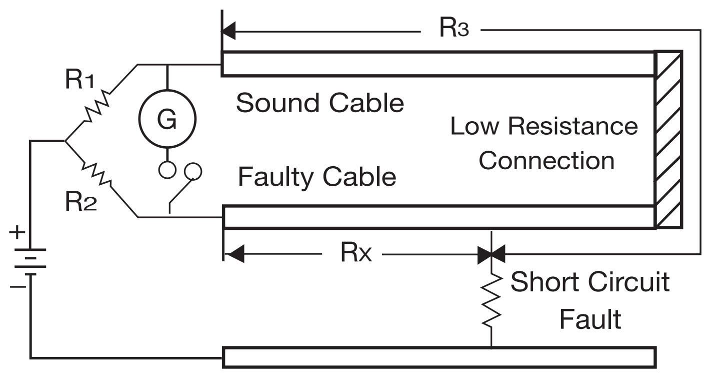


Fig. 2 - Cicuit connection of Murray loop test for short circuit fault

BIRD CAGING

Bird caging is a defect caused due to twist of cable due to improper unreeling. It results outer sheath cracks or cuts or armor swelling. The technique of pulling cables from drum plays important role in this case.

While removing cable from drum, always put drum on Jacks & pull the cable. If drum is kept on flange & removed the cable, then there will be 100% chances of Bird caging.

Improper handling can cause damage to the cable which may weaken the cable components, and cause failure in due course. Care must be taken to select a suitable position for the cable drum jacks to ensure that the drum may be raised and rotate with full safety. The jacks therefore be placed on a firm support of thick boards.

Care should be taken to exert a steady pull avoiding any jerks. Twisting or kinking of cable is very dangerous as this may cause damage to small sizes of conductors, insulation & sheath. Shifting and knife edging of the armoring and damage to the serving etc. Care should be taken to avoid short bends and consequent straining of conductors.

Proper handling of Cables is very important for safety as well long life of the installations. Mishandling of Cables is the main cause of cable failures. This can be prevented by winding the cables by loading drums on jacks & pulling cables in the proper direction with stocking or pulling eye. For longer lengths or higher weight/ diameter of cables can be pulled with pulling eyes whereas smaller length of light weight cables cab ne pulled by manually or by mechanical means.

Please refer video on Bird Caging attached separately.

Scan to watch
Bird caging video



TRANSIT DAMAGE

- Transit Damage is a common problem which occurs during unloading /shifting of cable drums or during transshipment by transporter. It is normally not possible during loading at factory as drums are packed with wooden planks and handled using overhead cranes/forklifts.
- During a mechanical damage on cable, there are possibilities of:
  - Tearing of Outer Sheath
  - Bending of armour wires/ strips
  - Damage of insulation
- When a mechanical damage is observed visual inspection is to be done to assess the condition.
- If armour found intact the cable can be considered for using after validating the insulation resistance as normal. The insulation resistance can be compared by carrying out the megger test.
- If insulation resistance is found not satisfactory, there is no way other than cutting the cable. After cutting both the pieces are to be again megger tested. Pieces with good megger values can be taken for jointing and charging.
- If any damage to the outer sheath is observed should be repaired before backfilling is commenced

REPAIRS TO OUTER SHEATH

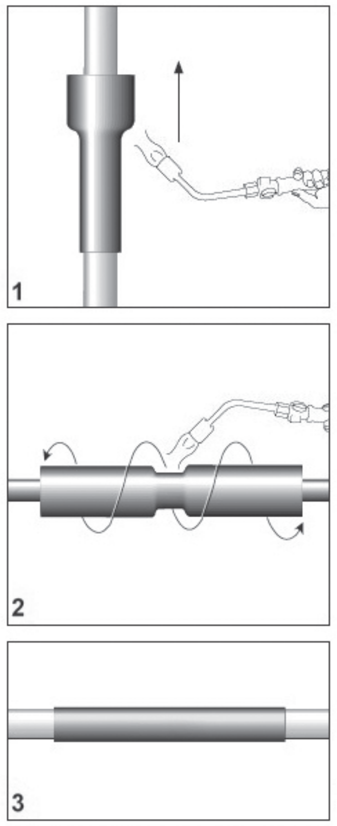
During cable drum unpacking, rewinding, or laying damage to outer sheath may accidentally occurs. If the cable underneath appears to be in good condition, repairs to localized damage at site may be carried out as suggested in the following alternative methods. The objective is that there is no possibility of moisture ingress through damage to armour or other parts of the cable when it is in its final installation position.

a) The local area of damage to be cleaned with a suitable solvent. A patch is then applied to fill the area using approved grade of special putty e. g. BICASEAL. This is followed by an overlapped layer of 50 mm wide PIB self-amalgamating tape with 50 % overlap.

b) Clean the local area with a suitable solvent. Apply heat shrinkable sleeve with required size. Apply heat over the sleeve till it shrinks properly over the outer sheath.

c) Detailed procedure for **Heat shrinkable tube** is as given below: -

- Heat shrinkable sleeves in tubing is supplied in an expanded form. When heated above 125°C they attempt to shrink back to their original dimensions, conforming to the objects they cover. Use a propane (preferred) or butane gas torch.
- Adjust the torch to obtain a soft blue flame with a yellow tip. Pencil-like blue flames should be avoided. Keep the torch aimed in the shrink direction to preheat the material. Keep the flame moving continuously to avoid scorching the material. Tubing should be cut smoothly with a sharp knife leaving no jagged edges. Clean and degrease cable and parts that will come into contact with the tubing. It is recommended to use a forced circulation hot air oven.



1. **Vertical installation:** Place tubing over the relevant area. Start shrinking at the lower end working towards the top.
2. **Horizontal installation:** Place tubing over the relevant area. Start shrinking in the center working towards the ends
3. Properly installed tubing should be smooth and conform to the inner components. On coated tubing adhesive should be visible at both ends.

4. **Installation completed.** Allow to cool before applying mechanical strain.

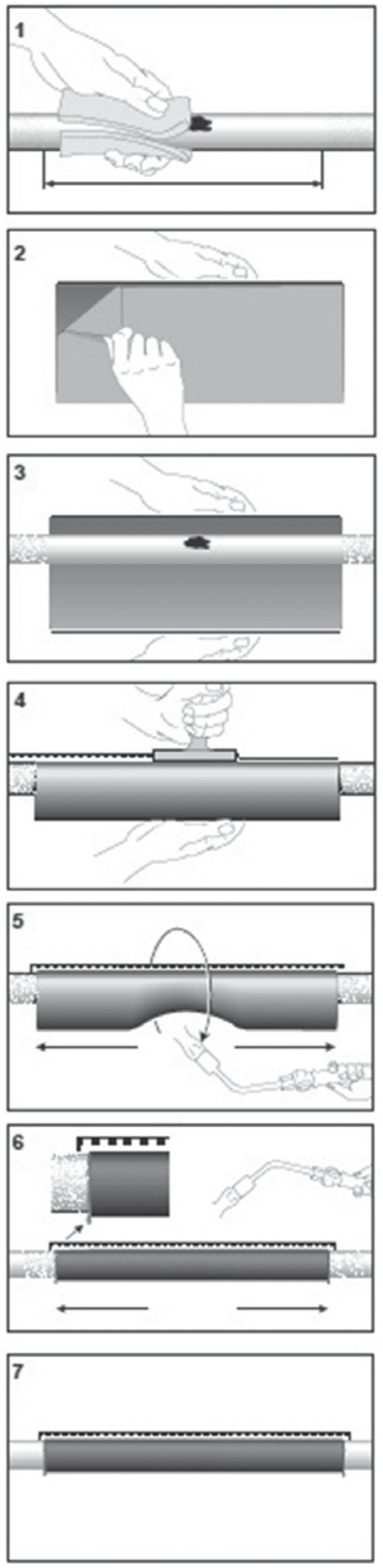
d) Detailed procedure for **Wrap around Heat shrinkable sleeve** is as given below: -

- Carefully remove the cable jacket in the area where the cable is damaged. Control the cable construction beneath the over sheath for tracks of further damage. If there is no damage, replace the over sheath. If there is a damage an appropriate repair must be carried out.
- The wrap-around should extend for at least 50 mm at each end beyond the area to be protected.

1. Clean, degrease (use degreasing solvent) and abrade the over sheath, where it comes into contact with the wraparound.
2. Remove the foil from the adhesive side of the wraparound.
3. Position the wrap around centrally around the area of damage.
4. Slide the steel channel(s) on the rail and if more than one channel is required, fit the clip over the channel ends where they come together.
5. Start shrinking in the center opposite the channel working round towards the ends.
6. Continue heating the channel area until adhesive flows out on both ends of the channel.
7. **Installation completed.** Allow the wraparound to cool before applying any mechanical strain.

Special Note :

Please remove graphite coating/ semi-conducting layer over outhersheath before applying heat shrinkable sleeve. After repairing, graphite coating/ semi-conducting layer to be applied over heat shrinkable sleeve to get continuity.



SPECIAL PRECAUTIONS FOR HANDLING/ INSTALLATION OF LSZH CABLES

Cables like LSF/LSZH sheath needs to be handled with care during installation. While special additives are used in formulation of LSF compound to give the typical flame-retardant characteristics of Zero halogen polymers some mechanical properties deteriorate. The following basic precautions are necessary.

LSZH/LSF sheaths do not have the same mechanical strength as other sheathing materials, particularly at higher temperatures. It is therefore strongly recommended that LSZH sheathed cables be used mainly indoors, and only where cables have been specified to have low smoke & toxic gas emission property.

- Cables should not be exposed to sunlight for considerable period before installation. i.e. the temperature of cable sheath should be below 40°C.
- Preferably installation is done during morning hours when the ambient temperature is low.
- AS LSZH sheaths have lower tear strength property when compared to PVC & PE sheaths, special care must be taken during installation to avoid any damage. Even a small cut on cable sheath could result in the sheath splitting.
- Wire/ Rope should not be used directly on the cable sheath for pulling.
- The cables must not come into contact with hot surfaces.
- When pulled on cable trays/or any uneven surface, special attention is required to welding or unusually rough terrains.
- Minimum bending radius not to be compromised while laying.
- Rollers and bends should not have any sharpness which may damage sheath.
- Rubber Cushion of at least 3 mm to be provided between outer sheath & clamps as clamping device may damage outer sheath.

SOLAR CABLES

Cable termination DC Solar Cable

Once both the ends of the cable are positioned at the termination ends, one proceeds to splice the cable at both the ends. Cut cable ends are spliced to uncover the conductor from the insulation and sheathing. Care should be taken to ensure that strands of the conductor are not cut or damaged and hence a proper splicer tool is recommended during the operation.

Only high-quality connectors made by Dowell's or other similar reputed brands should be used. Both ends of the cut cables are to be crimped to the terminals of the Dowell's connectors and secured fit in the connectors. One end of the cable is attached to the cable connector fixed to the Solar Panel junction box, while the other end of the cable gets connected to either the cable extension connector or to Dowell's connector end of the Inverter. Make sure that the connectors are screwed tight and do not open when pulled. This completes the cable laying and termination task.

This is followed by installation of the balance system and commissioning of the system.

Bending Radius DC Solar Cable

A. Solar Cable (without Nylon sheathing as separator) does not exceed:

i) 8 times the diameter of the cable for 2.5 sq. mm to 6 sq. mm

ii) 10 times the diameter of the cable for 10 sq. mm to 16 sq.mm

iii) 12 to 15 times the diameter of the cable for 25 sq. mm and above

B. Solar Cable (with Nylon sheathing as separator) does not exceed:

i) 12 times the diameter of the cable for 2.5 sq. mm to 6 sq. mm

ii) 15 times the diameter of the cable for 10 sq. mm to 16 sq. mm

iii) 18 to 25 times the diameter of the cable for 25 sq. mm and above

Method of crimping Twin Twisted DC Solar Cable with SC-WBT

Use a stripping tool to cut 5-10mm off the HDPE, Nylon Jacket and Water Blocking Tape (WBT) to create separation between the lugs. Use an auto retractable knife to split the insulation. Ensure that the knife doesn't cut through or score the XLPE insulation during the process. Points where HDPE, Nylon & SC-water blocking tapes are cut should be sealed/covered with heat shrinkable tape to protect moisture from entering the cable. Ensure that there is no physical contact between lugs & semi-conducting water blocking tape. Crimping is to be done with suitable crimping tool & minimum 3 crimping should be done for better results. Proper size & type (Circular or Sector shaped as per the construction of the conductor) of lugs to be used. Loose crimping or oversize lugs will have heating effect on termination which will result in cable failure.

Recommended IR value before commissioning for DC Solar Cable

(only applicable for AS/NZS cable)

According to AS/NZS 5033 Table D2, minimum Insulation Resistance for Cables should be 1M ohm. Hence Cables should be considered suitable if IR values obtained is more than 1 M ohm.

Cable pulling tension calculations:

Please refer to Annexure J of IEEE Std. 525 2007

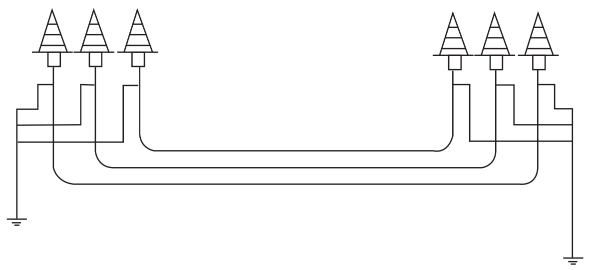
EARTHING METHOIDS, INDUCED VOLTAGE

High voltage cables have a metallic sheath, along which a voltage is induced as a function of the operating current. To handle this induced voltage, both cable ends have to be bonded sufficiently to the earthing system. The following table gives an overview of the possible methods and their characteristics:

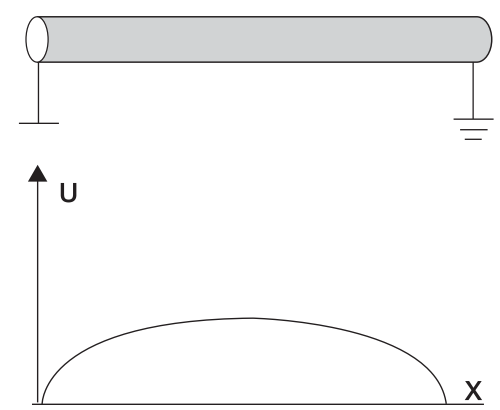
Earthing method	Standing voltage at cable ends	Sheath voltage limiters required	Typical application
Both-end bonding	No	No	Substations, short connections, hardly applied for HV cables, rather for MV and LV cables
Single-end bonding	Yes	Yes	Usually only for circuit lengths up to 1 km
Cross-bonding	Only at cross- bonding points	Yes	Long distance connections where joints are required

BOTH END BONDINGS: -

In this type of bonding, both sides of cable sheath will be connected to earth. With this method no induced voltage occurs at cable ends, which makes it most secure regarding safety aspects. But on the other hand, circulating current will flow in the sheath as the loop between the two earthing points is closed through the ground. And these circulating currents are proportional to conductor current and therefor reduced cable ampacity significantly making it most disadvantageous method regarding economic aspects. So this type of bonding is hardly applied for HV Cables due to high losses but it is the most common bonding type for MV & LV Cables.



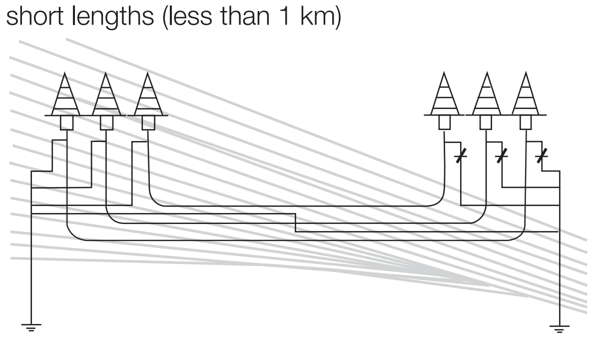
Both end bond connection method



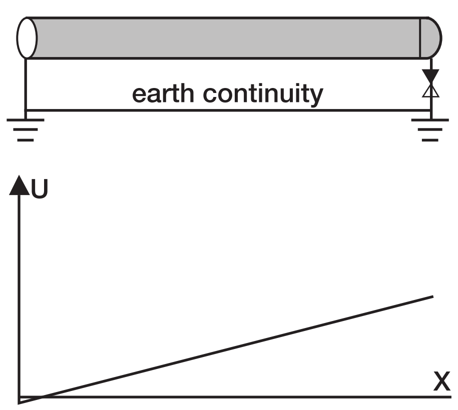
Induced voltage distribution at both-end bonding

SINGLE ENDED BONDINGS: -

In this type of bonding one side of cable sheath will be connected to earth, so that at the other end "open end" the induced voltage will appear. Which will be induced linearly along the cable length and it will increase as the length increases. So, for safety requirements the open end of the sheath has to be protected with surge arrestors (sheath voltage limiter). Also, to avoid potential lifting in case of failure the both ends of cable sheath have to be connected additionally with an earth continuity conductor. This type is much better than both end bonding system as when using single point bonding the losses approximately equal to zero but due to induced voltage on the free end this type is usually used for short lengths (less than 1 km)



The single end bond connection method



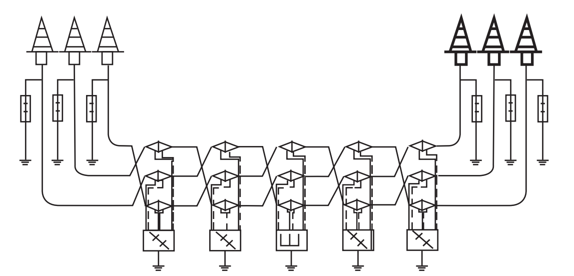
Induced voltage distribution against the cable length

CROSS BONDINGS

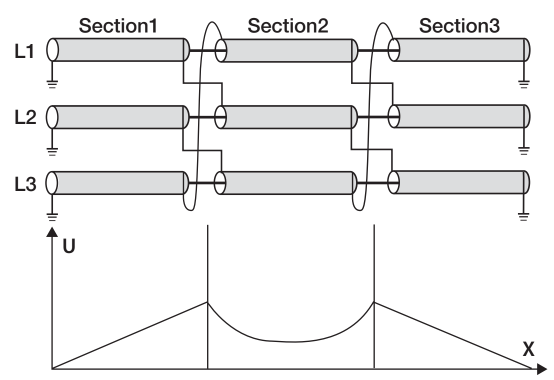
This earthing method shall be applied for longer route lengths where joints are required due to the limited cable delivery length. A cross-bonding system consists of three equal sections with cyclic sheath crossing after each section. The termination points shall be solidly bonded to Earth. In ideal cross bonding systems, the three section lengths are equal, so that no residual voltage occurs and thus no sheath current flows.

Very long lengths can consist of several cross-bonding system in a row, so it is recommended to maintain solid bonding of the system end s in order to prevent travelling surges in case of fault. Also, in cross bonding systems the conductors can be transposed, and this solution is suited for very long cable length or parallel circuits.

This type of bonding is the most common used type for HV Cables.



Cross bonding connection method



The induced voltage Distribution against cable length

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