Safety & Survival of Electric Cables

Presented by
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MCMA
MALAYSIAN CABLE MANUFACTURERS ASSOCIATION

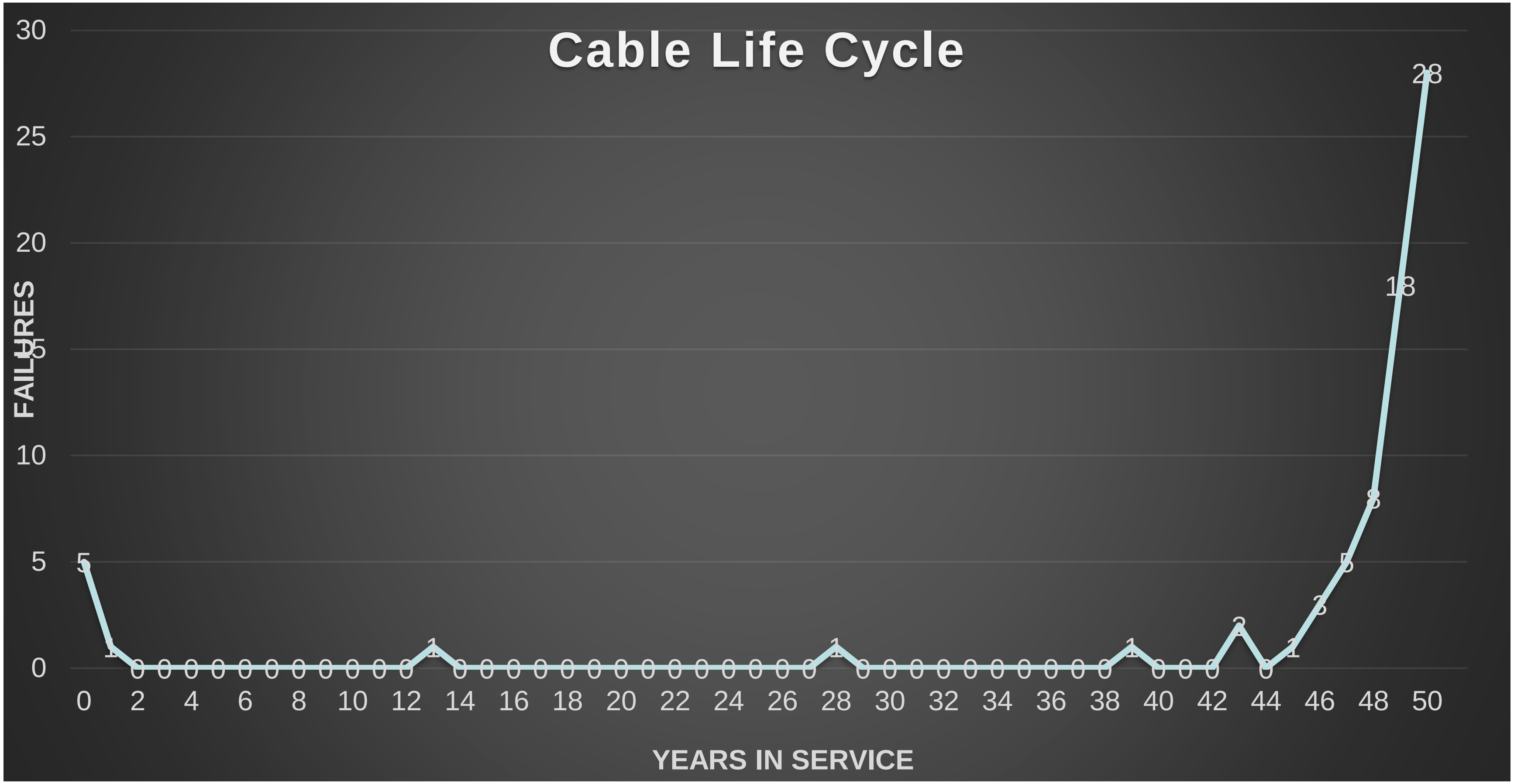
POWER CABLES MALAYSIA SDN BHD
Company No. 21637-X

Design Requirements

- Satisfies **power** needs
- Flexible
- Reliable
- Has LONG life
- Minimal maintenance
- **Economic**

In relation to electric cables, safety..

- Is not a design requirement
- Prescribed by system designer
- Constructed as prescribed
- Appropriately installed by trained/competent installer
- Safely managed by users

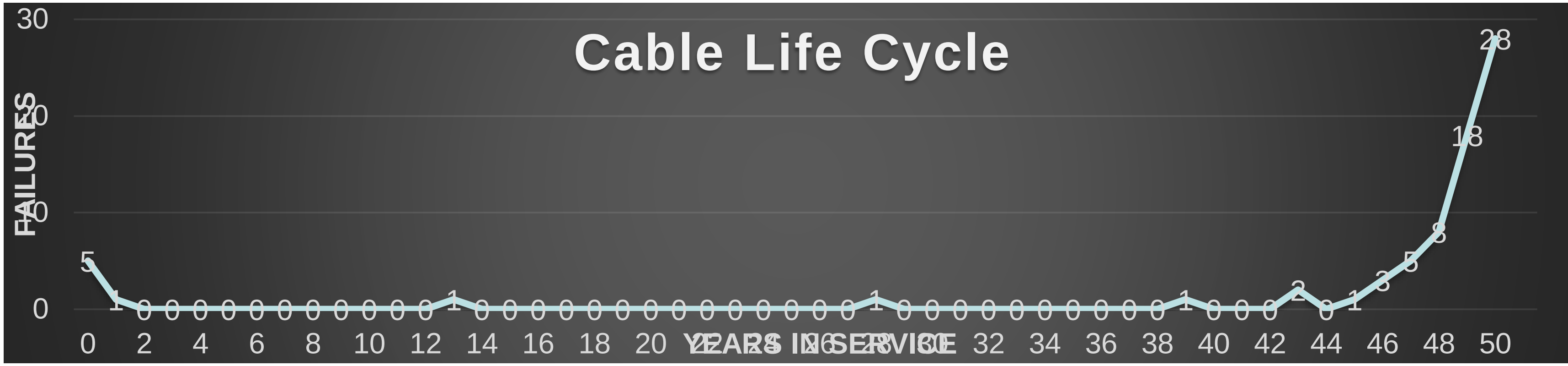


Initiation stage

The golden years

Retirement age

The End



Years	<1	0-35	30-40	>40
Phase	Initiation stage	The Golden years	The Pensioner	The End
Failure freq	Diminishing	Erratic - low	Erratic - high	Increasing, exponentially
Key suspects	installation (workmanship)	physical damage (external)	imperfections (internal)	"unknown" (expired)
Action	repair & make good	cut & joint	replace cable length	replace cable lengths

Cable life is..

The end of useful life

- Upon reaching a state of system instability

OR

- As prescribed by “experts” and/or from experience

Cable life ?

The IEE

Commentary on IEE Wiring Regulations
16th Edition BS 7671 : 2001
published 2002
ISBN 0 85296 237 1

UPDATE issued 15 April 2004

Introduction to amendment to 6.1.3

The recent interest shown in the section on ageing of cables has shown that engineers are interested in this rather non specific aspect of installation design and prompted the provision of a little more information and a specific reference.

6.1.3 Ageing of cables
131-06, 433-01

Estimating the life of a cable can only be approximate because of the obvious difficulties in accumulating data. There is a general understanding that p.v.c. cables with a continuous conductor operating temperature of 70 °C have a life of 20 years. There is also a rough guide that for each 8 °C increase in core conductor continuous operating temperature above 70 °C the life of the cable will be halved. A p.v.c. cable running with an overload such that its core conductor temperature is 78 °C will last for 10 years.

The general equation for ageing is:

$$\mathrm{Log}_e\, t = \frac{A}{T} + A^1$$

where:

t = time in hours
T = absolute temperature K (273 + °C)
A = a constant 15 028 for PVC, 14 500 for EPR and PRC
A^1 = a constant –31.6 for PVC, –27.19 for EPR and PRC

Table 6 provides further guidance.

Life termination is assumed to be on the appearance of cracks on samples of cables wound on their own diameter.

TABLE 6 Life until deterioration against conductor core temperature

Life until deterioration [1]				
Material	PVC		EPR and PRC [5]	
Temperature (°C) [2]	Permanent Rating [3]	Normal Rating [4]	Permanent Rating [3]	Normal Rating [4]
70	23 yrs	69 yrs		
75	12 yrs	37 yrs		
80	7 yrs	20 yrs		
85	4 yrs	11 yrs	69 yrs	
90	2 yrs	6 yrs	39 yrs	
95	14 mths	43 mths	23 yrs	69 yrs
100	8 mths	25 mths	13 yrs	40 yrs
105	5 mths	15 mths	8 yrs	24 yrs
110	3 mths	9 mths	5 yrs	15 yrs
115	2 mths	5 mths	3 yrs	9 yrs
120			23 mths	69 mths
125			14 mths	43 mths
130			9 mths	27 mths
135			6 mths	18 mths
140			4 mths	12 mths
Temperature indices:				
Duration 5000 h	101 °C		133 °C	
Duration 20000 h	89 °C		118 °C	

Notes: 1. The values indicated are only orders of magnitude due to the different types of materials and the great dispersion of the complex ageing phenomena of these materials.
2 The temperature referred to is that of the cable conductor resulting from the ambient temperature and its own temperature rise.
3 Permanent rating – load/temperature maintained 24 hours a day
4 Normal rating – load/temperature maintained 8 hours a day
5 PVC-polyvinyl chloride, EPR-ethylene/propylene rubber, PRC - chemically reticulated polyethylene.

From IEC 943, 1989

Cable loadings are rarely constant, estimates can be made of the combined affects of different loadings by the use of the formulae below:

$$\frac{1}{L} = \frac{1}{24}\left\{\frac{a}{L^1} + \frac{b}{L^2} + \frac{c}{L^3}\right\}$$

where:
L^1, L^2 and L^3 = lives at specific temperature
a, b, c, etc. = hours in day at these temperatures

Bibliography
Chapter 6
IEC 943: Guide for the specification of permissible temperature and temperature rise for parts of electrical equipment, on particular for terminals

Cable Life – Contributing Factors

- Internal – the requirements of specifications & relevant standards, construction, manufacture, tests and transportation of cables to site
- Operational – the manner of handling, installing, jointing & terminating, loading and servicing as per system design
- External – the conditions endured by the cables in service

The quadrants of cable life

Designed as required, installed & operated as intended	*Installed & operated as intended, NOT designed as required*
Designed as required, NOT installed or operated as intended	*NOT designed, NOT installed or operated as intended*

Cable Standards - International

- IEC 60227 Polyvinyl Chloride insulated cables 450/750V
- IEC 60502 Cables with extruded insulation 1-33kV
- IEC 60055 Paper Insulated 1-33kV
- IEC 60840 Tests for cables with extruded insulation >33 - 150kV
- IEC 60811 Common test methods for cable insulation and sheaths
- IEC 60287 Calculation of Current Rating

Malaysian Standards (MS) on Cables

1	MS 2108: 2007	Electric Cable : 6.35/11(12)kV single core XLPE insulated cables – non-armoured	
2	MS 2109: 2007	Electric Cable : 6.35/11(12)kV single core XLPE insulated cables – armoured	
3	MS 2110 :2007	Electric Cable : 19/33(36)kV single core XLPE insulated cables – non-armoured	
4	MS 2111: 2007	Electric Cable : 19/33(36)kV single core XLPE insulated cables –armoured	
5	MS 2113*	Electric Cable : 12.7/22(24)kV single core XLPE insulated cables – non-armoured	
6	MS 2114*	Electric Cable : 12.7/22(24)kV single core XLPE insulated cables – armoured	MV-XLPE
7	MS 2115*	Electric Cable : 6.35/11(12)kV three core XLPE insulated cables – non-armoured	
8	MS 2116*	Electric Cable : 6.35/11(12)kV three core XLPE insulated cables –armoured	
9	MS 2117*	Electric Cable : 12.7/22(24)kV three core XLPE insulated cables –armoured	
10	MS 2118*	Electric Cable : 2.7/22(24)kV three core XLPE insulated cables –armoured	
11	MS 2119*	Electric Cable : 19/33(36)kV three core XLPE insulated cables –armoured	
12	MS 2120*	Electric Cable : 19/33(36)kV three core XLPE insulated cables –armoured	
13	MS 2104:2007	Electric Cable and Wire: 600/1000(Um = 1200) V single core XLPE insulated cable – non-armoured	
14	MS 2105:2007	Electric Cable and Wire: 600/1000(Um = 1200) V single core XLPE insulated cable –armoured	LV-XLPE
15	MS 2106:2007	Electric Cable and Wire: 600/1000(Um = 1200) V multi core XLPE insulated cable –non-armoured	
16	MS 2107: 2007	Electric Cable and Wire: 600/1000(Um = 1200) V multi core XLPE insulated cable –armoured	
17	MS 2100:2006	Electric Cable and Wire: 600/1000(Um = 1200) V single core PVC insulated cable – non-armoured	
18	MS 2101:2006	Electric Cable and Wire: 600/1000(Um = 1200) V single core PVC insulated cable –armoured	LV-PVC
19	MS 2102:2007	Electric Cable and Wire: 600/1000(Um = 1200) V multi core PVC insulated cable –non-armoured	
20	MS 2103: 2007	Electric Cable and Wire: 600/1000(Um = 1200) V multi core PVC insulated cable –armoured	
21	MS 2112-1: 2009	Electric Cable and Wire: Polyvinyl Chloride(PVC) insulated cables of rated voltages up to and including 450/750 V – Part 1 : General requirements	
22	MS 2112-2: 2009	Electric Cable and Wire: Polyvinyl Chloride(PVC) insulated cables of rated voltages up to and including 450/750 V – Part 2 : Test Methods	
23	MS 2112-3: 2009 **	Electric Cable and Wire: Polyvinyl Chloride(PVC) insulated cables of rated voltages up to and including 450/750 V – Part 3 : Non-sheathed cables for fixed wiring	450/750V-PVC
24	MS 2112-4: 2009 **	Electric Cable and Wire: Polyvinyl Chloride(PVC) insulated cables of rated voltages up to and including 450/750 V – Part 4 : Sheathed cables for fixed wiring	
25	MS 2112-5: 2009 **	Electric Cable and Wire: Polyvinyl Chloride(PVC) insulated cables of rated voltages up to and including 450/750 V – Part 5 : Flexible cables	
26	MS 2112-6: 2009 **	Electric Cable and Wire: Polyvinyl Chloride(PVC) insulated cables of rated voltages up to and including 450/750 V – Part 6 : Cables for Lifts and flexible connections	
27	MS 2121*	Telecommunication Cable : Plastic Twin pair,triple and unit types, internal cable	
28	MS 2122*	Telecommunication Cable : Jumper cable	
29	MS 2123*	Telecommunication Cable : Self supporting drop wire	Telecoms
30	MS 2124*	Telecommunication Cable :Fully Filled Unit Twin moisture barrier polyethylene sheathed cable (FF PEUT)	
31	MS 2125*	Telecommunication Cable :Integral Barrier Unit Twin moisture barrier polyethylene sheathed cable (IB PEUT)	
32	MS 2126*	Telecommunication Cable :Polyethylene Insulated 25 Pair Unit Twin moisture barrier polyethylene sheathed cable (FS PEUT)	

Overview of Standards & Quality of Cables

Um (max voltage)	Class	Ref Stds & Specifications		Risk	Control on Quality & Inspection
		Existing/Prev	New		
Above 170kV	EHV	Utility	Utility	Nil	High scrutiny at all levels
37kV - 170kV	HV	IEC/Utility	IEC/Utility	VLow	High sampling rate of test & inspection
3.7kV - 36kV	MV	BS/IEC/Utility	IEC/MS	Low	Adequate control on test & inspection
1.2kV - 3.6kV	LV	BS/IEC/Owner	IEC/MS	Low	Adequate control on test & inspection
Below 1.2kV	**ELV**	**BS/MS**	**MS**	**High**	**Minimum or no control**

SUB-STANDARD CABLES

Cables which are not designed, constructed, test approved, installed or used in accordance to their prescribed standards and/or specifications

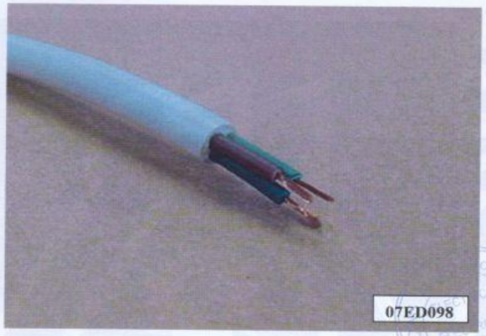
The development of national standards for electric cables takes into account the principles and norms as established internationally, current prevailing conditions and local practices. It is important to understand that these aspects are majorly unbeknown to buyers and users, hence failure to comply on critical aspects may present an undetermined risk on safety.

Myths of Sub-Standard Cables

- **Conductors are smaller due to “technological improvements”**
- **Copper purity is higher**
- **Able to withstand higher temperatures hence more current**
- **The standards have “changed”**
- **“There is no problem, it still works..”**

Anatomy of Sub-Standard Cables

PHOTOGRAPH OF TEST SAMPLE



REPORT NO.: 2007ED121	PAGE : 2 OF 8

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2. All the tests were conducted at SIRIM QAS International Sdn. Bhd. And had been checked in accordance with the following clauses;

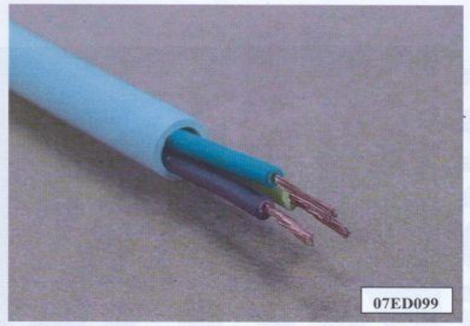
   a) Clause 5.1, 6.2, 7.2, 7.3, 7.4, 19.3 and 22.3 of MS 140: 1987
   b) Clause 7.1, 7.2, 7.3 and 7.4 of MS 69: 1995
   c) Tensile & elongation (before ageing) and resistance to crack of MS 138: 1995
3. The test sample as described in this test report deemed to comply with the requirements of those test conducted except clause 7.2 and 7.4 of MS 69: 1995 and tensile & elongation (before ageing) of MS 138: 1995.

ADDITIONAL INFORMATION:

1. Tested by : Effahaikal Mahmudi Signature : ______ Date: 3/01/08
2. Checked by: Mr.Surian Rasol Signature : ______ Date: 3/1/08
3. Date of test sample(s) received:
   a) 1st submission : 11 October 2007
   b) 2nd submission : -
   c) 3rd submission : -

[redacted] Prepared by: [redacted]

PHOTOGRAPH OF TEST SAMPLE



REPORT NO.: 2007ED122	PAGE : 2 OF 8

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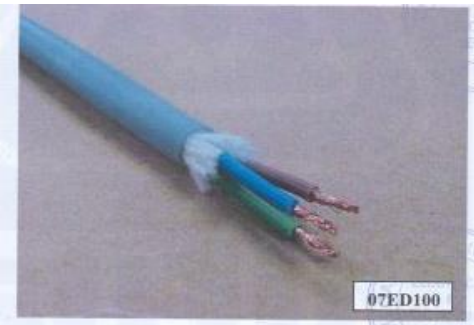

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Sub-Standard Cables - Electrical Properties

Item	***Flexible Cable 40/0.16mm (0.75sqmm) x 3C***				
Reference		STD	07ED100	07ED099	07ED098
Conductor					
- resistance	ohm/km	*26*	*29.8*	*69.3*	*112*
- equiv area	sqmm	*0.731*	*0.638*	*0.274*	*0.170*
Current rating	**amp**	**7.5**	**6.5**	**2.8**	**1.7**
Short cct rating	**amp**	**84.0**	**73.3**	**31.5**	**19.5**
Voltage drop	**mv/A/m**	**63**	**72**	**168**	**271**
Max length (2.5% drop)	**metres**	**14**	**12**	**5**	**3**

Detecting Sub-Standard Cables (DIY)

- Check labels and markings for size, type, manufacturer name/logo and product standard
- Verify physical measurements against manufacturers' data
- Estimate the cross-sectional area of conductor by physical measurement i.e. area x number of wires
- Conduct a conductor d.c. resistance measurement to the Standards

NON-STANDARD CABLES

Cables which are designed and constructed to other standards which may not comply to the prevailing requirements & regulations on test approvals and/or installation conditions

The development of national standards for electric cables takes into account the principles and norms as established internationally, current prevailing conditions and local practices. It is important to understand that these aspects are majorly unbeknown to buyers and users, hence failure to comply on critical aspects may present an undetermined risk on safety.

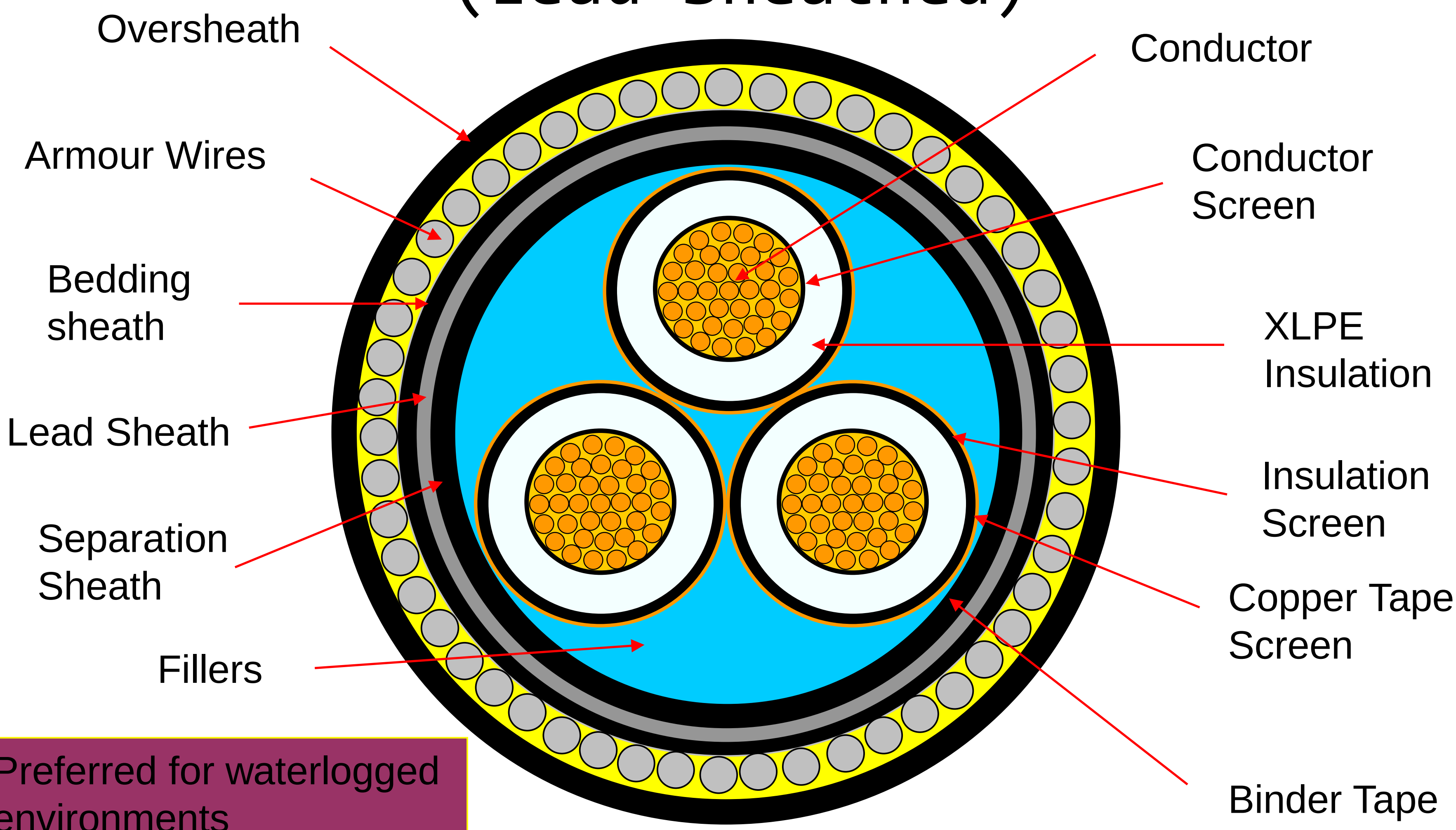
Basic Design Elements

- CONDUCTOR
  - *determines base current ratings*
- INSULATION
  - *determines voltage / stress levels*
- PROTECTION
  - *determines installation conditions*

Empirically..

Cable type	Voltage	Primary	Service life	
			Low	Med
Bare Conductors	All	Reinforced	35	40
	All	Non-reinforced	25	35
Paper insulated, metal sheath	All	Fluid filled	35	50
	All	Solid	30	40
Thermosets (XLPE, EPR)	All	Metal sheathed	30	40
	All	Foil laminated	25	35
	All	Water tight	25	35
	All	Armoured/Ducted	25	35
	All	Non-armoured	15	25
Thermoplastics (PVC, PE, EVA)	>3.3kV	All types	10	20
	0.6/1kV	Armoured/Ducted	25	35
	0.6/1kV	Non-armoured	15	25
	<1kV	Armoured/Ducted	15	25
	<1kV	Non-armoured	10	20
	<1kV	*"Sub-standard"*	<5	--

THREE CORE XLPE CABLE
(Lead Sheathed)



Preferred for waterlogged environments

Conductor Metals

Metals	VR @ 20°C (Ω.mm^2/km)	Density (gm/cm^3)	Mass (kg/km)	1990 (US$/km)	2015 (US$/km)
Silver	16.4	10.5	172.2	29,205	116,044
Copper	17.2	8.89	152.9	255	799
Gold	24.4	19.3	470.9	3,925,590	19,789,913
Aluminium	28.3	2.7	76.4	110	112
Tin	124	7.29	904	4,742	14,122
Lead	214	11.4	2440	754	4,243

- Copper
  - Highly Conductive
  - Good Mechanical Properties
  - Relatively Easy to Process
  - Usually Annealed
- Aluminium
  - 60% conductance of copper at same size
  - Half the weight of copper at the same conductance

Insulation Types

- Common types
  - 70^{o}C PVC (Polyvinyl Chloride)
  - 70^{o}C PE (Polyethylene)
  - 90^{o}C XLPE (Cross linked PE)
  - 90^{o}C Rubber (EPR,EVA)
  - 65^{o}C PILC (Paper insulated)

Mechanical Protection

- Cables need to be mechanically protected against external damage & installed environments
- PRIMARY – by the insulation
- SECONDARY
  - double insulation and/or sheaths
  - armour or reinforcement when exposed to potential damage (direct in ground)
  - barriers to prevent ingression of moisture, oils, solvents etc.

Electrical Protection

- Cables need to be electrically protected against damage to adjacent cables, connecting equipment and for safety of users against electrical hazards

- PRIMARY – by the insulation & sheaths

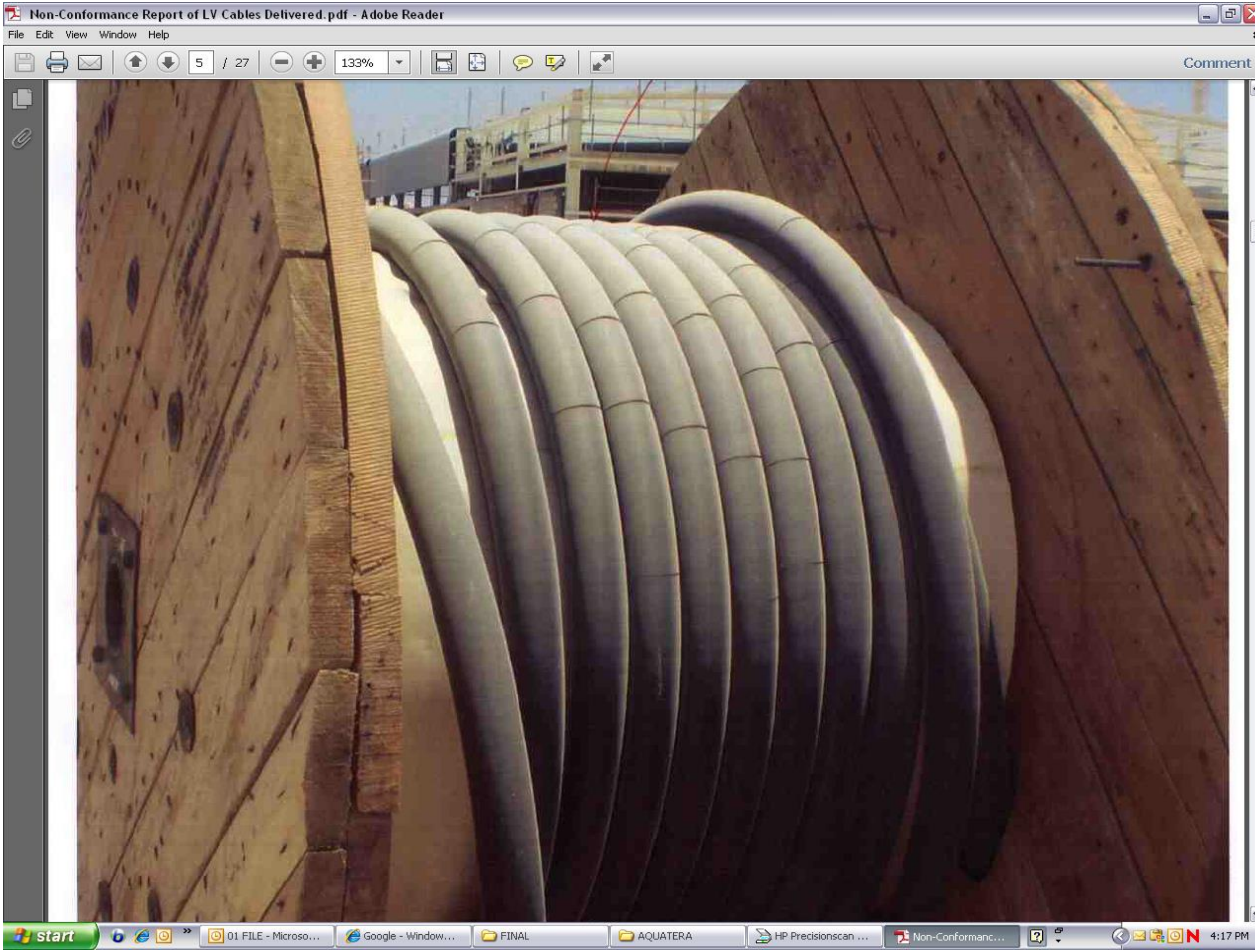
- SECONDARY

  - by conductive layer(s) for the safe transfer of leakage currents, to be appropriately sized to meet system ratings and/or suitable grounding or bonding methods against leakages, transients and lightning

Protection from Pest Attack

Method		Features
Mixing termite repellent in surrounding earth		Environmental problem
Coating oversheath with termite repellent		Difficult to apply Health problem
Mixing termite repellent into cable sheaths	Aldrin & Dieldrin	Effective but use is however banned in many countries
	Copper naphthanate, Cypermethrin	Alternative to Aldrin & Dieldrin, reasonably effective
Polyethylene Sheath		Slows down attack
Common metal sheaths		Slows down attack
Tape armour		Good protection from large insects and rodents
Nylon Sheath		Resistant to termites, but difficult to manufacture

Property	PVC	Polyethylene	LSOH
Tensile (N/sqmm)	15	25	10
Elongation	150%	300%	100%
Density	1.3 - 1.5	0.91 - 0.96	1.4 - 1.6
Physical	Soft and flexible	Hard and rigid	Semi-hard and rigid
Abrasion Resistance	Poor	Excellent	Acceptable
Hot indentation	Acceptable	Excellent	Good
Impact Resistance (thick slab)	Good	Poor	Poor
Stress cracking	Resistant	Variable (dependent on molecular weight i.e. density)	Variable (dependent on base compound and mix)
Moisture	Absorbs moisture with prolonged contact	Negligible absorption	Absorbs and retains moisture within a short time
Vapour permeability	Reasonably permeable	Resistant	Permeable
High temp. performance	Increased ageing at higher temps.	Improved thermal & ageing performance	Generally stable
Low temp. performance	Brittle at sub zero	Stable at sub zero	Generally stable
Resistance to chemicals	Good	Excellent	Poor
Fire Performance	Flame retardant, emits toxic fumes & smoke	Low OI, burns without toxic fumes	Flame retardant, low smoke & no toxic fumes
Processability	Readily extrudable	Extrudable	Extrudable with special tools
Compound	Compounded with additives and fillers	Homogeneous	Highly filled base compound with additives and fillers
InstallationConditions :			
Direct in Ground - Dry	Excellent	Excellent	Good
Direct in Ground - Wet	Good (short term only)	Excellent	Not Recommended
Exposure to UV light	Resistant	Good (require UV resistant additives)	Variable (dependent on base compound and mix)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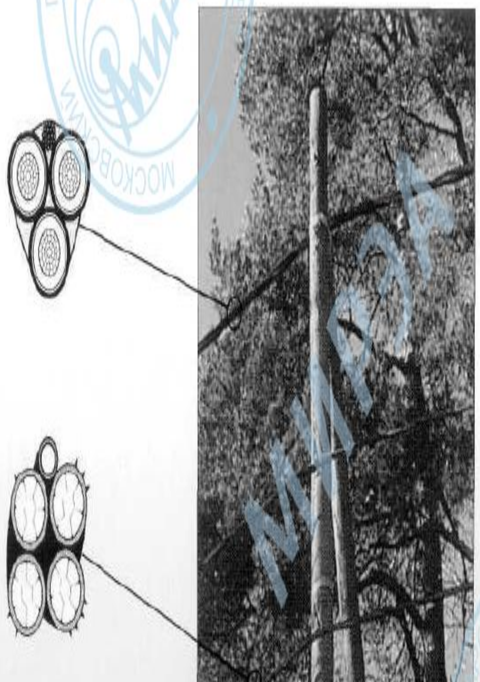
Cable and conductor systems

NK Cables Ltd. has a long history and outstanding experience in the cable business. NK Cables Ltd. was formerly known as Nokia Cables Ltd. and its history spans over 85 years of neverending development of products and services, from small industrial enterprise established in 1912 to today's high-tech cable manufacturer. Since 1996 the company has been a part of NKF Group which is an international group of companies, supplying globally cable products and services for power and telecommunications networks and other applications.

NK Cables Ltd. got it's new name in 1997. The company has three production plants in Finland and three abroad.

NK Cables manufactures Aerial Bundled Cable systems (ABC-systems) for low and medium voltage distribution networks and medium and high voltage (up to 154 kV) plastic covered conductor systems:

- AMKA low voltage and SAXKA medium voltage ABC-cables
- XLPE-covered conductors for medium (SAX) and high voltages (LMF SAX)



SAXKA (11 -36 kV) cables have phase conductors insulated with cross-linked polyethylene (XLPE) twisted round a messenger wire which supports the cable. With SAXKA-cables, medium voltage power can be transmitted safely and reliably through areas where clearances are restricted.

The AMKA-system (1kV) is ideal for modernizing and extending low voltage distribution systems. It is safer and more reliable than bare conductors, and overall it is also cheaper because installation and maintenance costs are remarkably reduced.

Power Cables Malaysia

CONFIDENTIAL

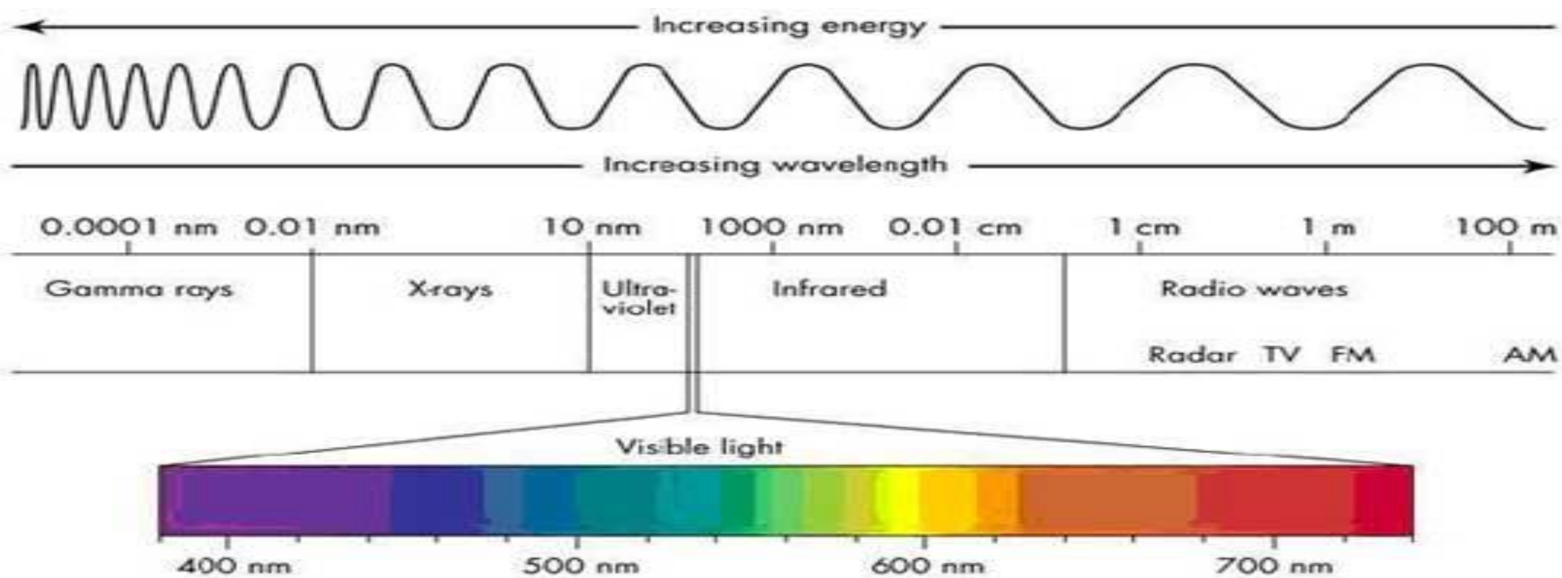
REPORT NO.	CCF97/008/LAD-R02
TITLE	Failure mechanism on 33kV aerial cables in service for Tenaga Nasional Berhad
SUMMARY	This report is a discussion on aspects of design contribution towards formulating a suitable failure mechanism as reported in Report No. CCF97/008/LAD-R01. Experiences from abroad are included in understanding proposals for new designs.
AUTHOR	Lokman A. Dahlan (QA & Technical Manager)
AUTHORISED BY	Jamel Yusof (General Manager - Manufacturing)
DATE OF ISSUE	22nd July 1998
CIRCULATION	AWS, JY, MST, CLC, LAD IR Rahimuddin Jabatan Kejuruteraan (Perkhidmatan Pengguna) Tenaga Nasional Berhad.

LLOYD'S REGISTER QUALITY COMPANY ISO9002

PROFESSIONAL ENGINEER ELECTRICAL IR. TAN CHOW HEANG 8299 MALAYSIA

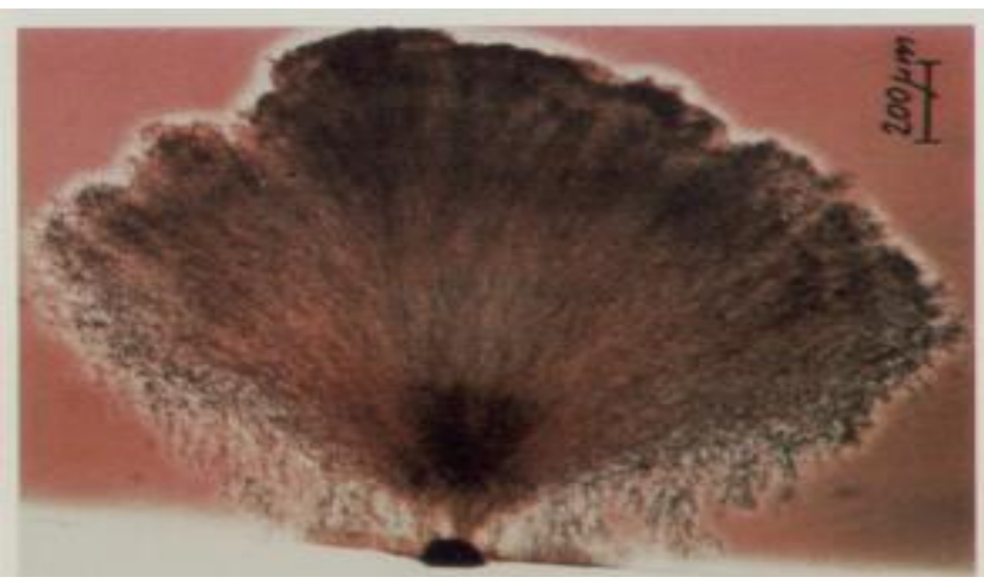
UV Degradation by Colours

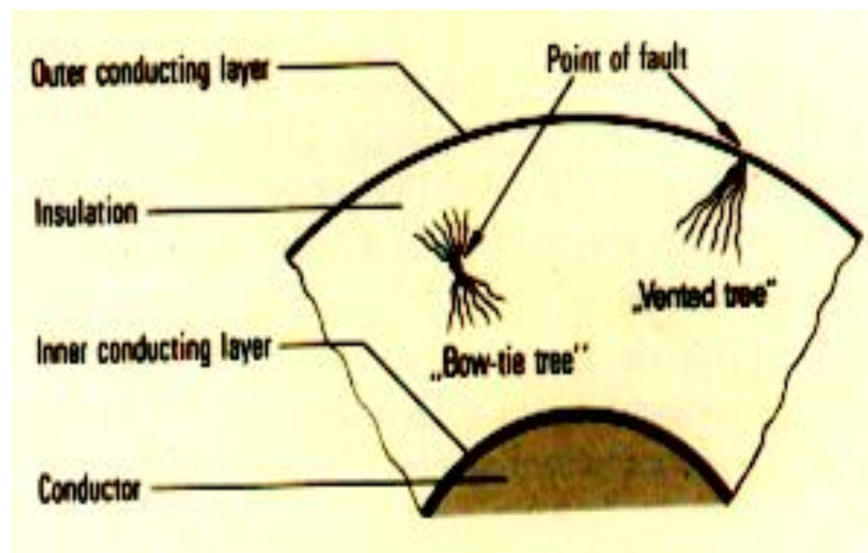
- Exposure to ultraviolet (UV) radiation may cause the significant degradation of many materials. **UV radiation causes photooxidative degradation which results in breaking of the polymer chains, produces free radical and reduces the molecular weight, causing deterioration of mechanical properties and leading to useless materials, after an unpredictable time.**
- The Star-Spangled Banner is a case in point. Both the dyes and the wool of our country's most famous flag have been seriously light-degraded over time. And as expected, the red dye is more faded than the blue. "**The red dyes are more susceptible to fading because they look red and thus absorb blue, and blue is the higher-energy light**," notes David Erhardt of the Smithsonian Center for Materials Research and Education, who assisted the flag's conservation project.



Water Treeing

- Formation of “tree-like” structures in polyolefins such as PE and XLPE.
- Reduces the breakdown strength of insulation resulting in “electrical trees”
- Degrades with time, electrical stress, frequency and water pressure
- “Bow ties” within insulation due to voids and contaminants
- “Vented trees” from screen interface protrusions and imperfections





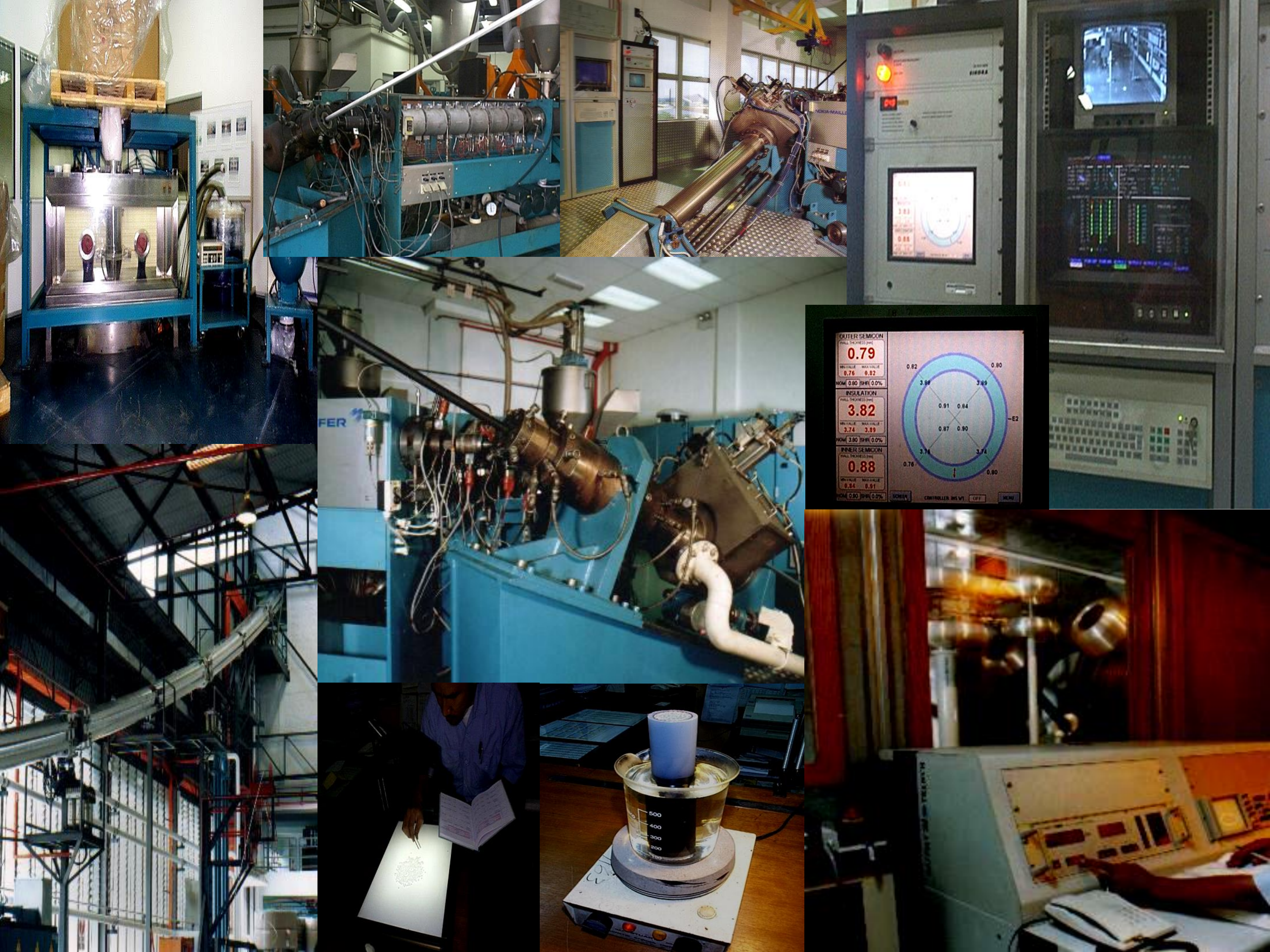
Moisture Barrier for HV XLPE Cables

A radial moisture barrier is required to prevent the initial ingress of moisture into the cable

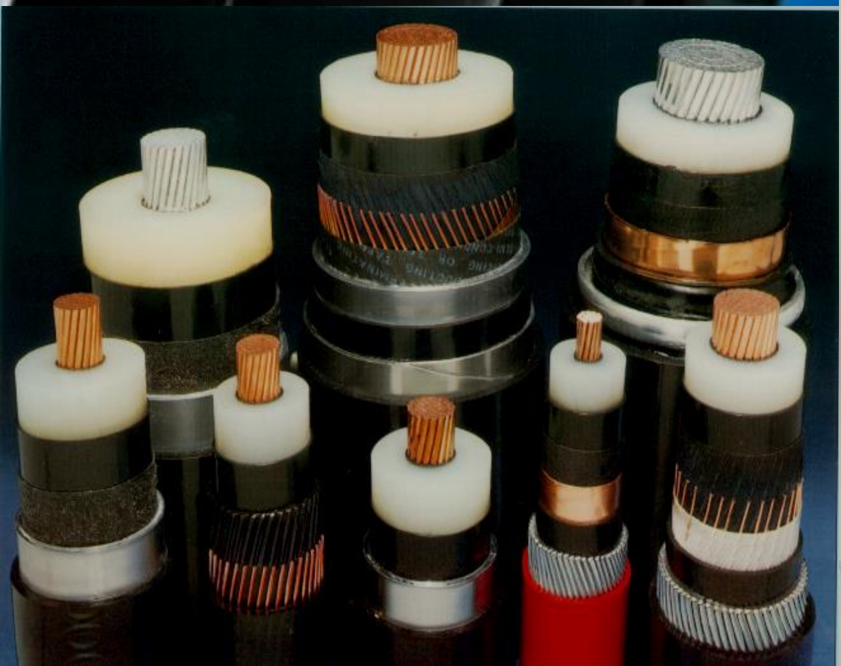
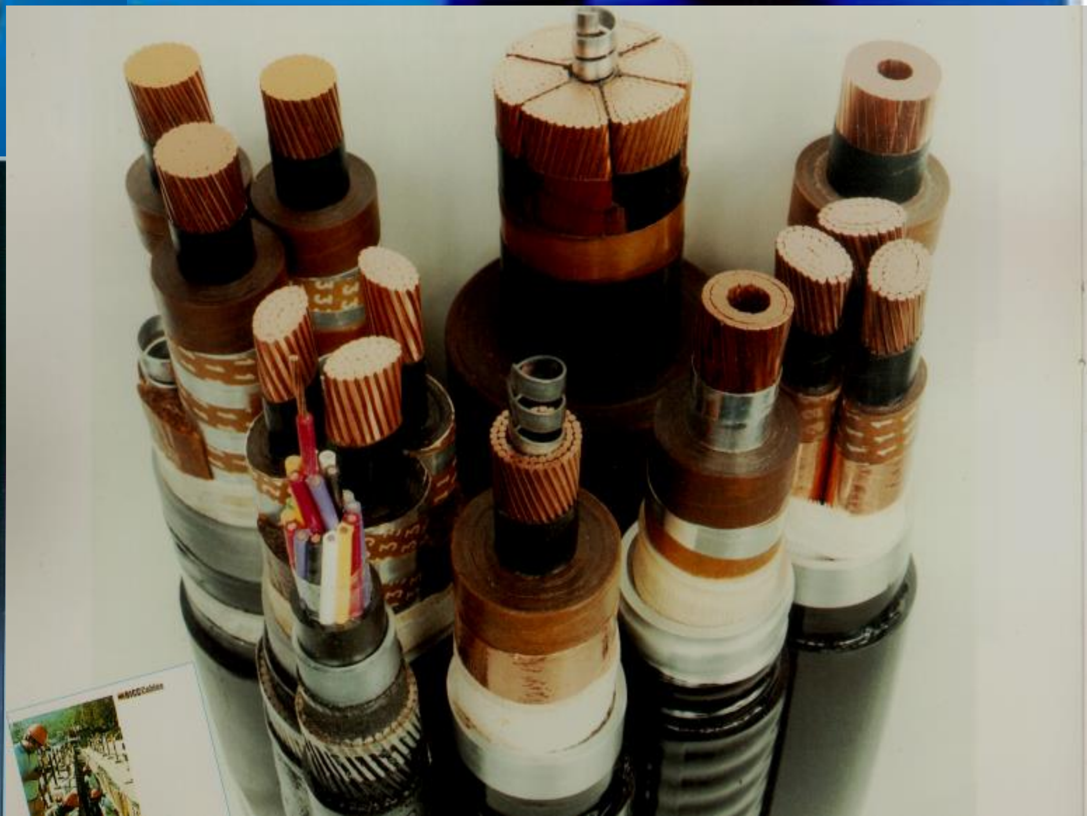
- Extruded Lead Sheath (preferred)
- Extruded Aluminium Sheath
- Metallic Foil Laminate (most economical but least effective)

In the event of damage to the radial moisture barrier longitudinal water blocking is essential

- Using tapes and yarns loaded with swellable material or “solid” compounds
- Strategically positioned underneath and between extruded layers, within metal screens, armour or conductor


OUTER SEMICON
0.79
INSULATION
3.82
INNER SEMICON
0.88



IEC 60287 Part 1-1: Current rating equations (100 % load factor) and calculation of losses - General

1.4.1.1 AC cables

The permissible current rating of an a.c. cable can be derived from the expression for the temperature rise above ambient temperature:

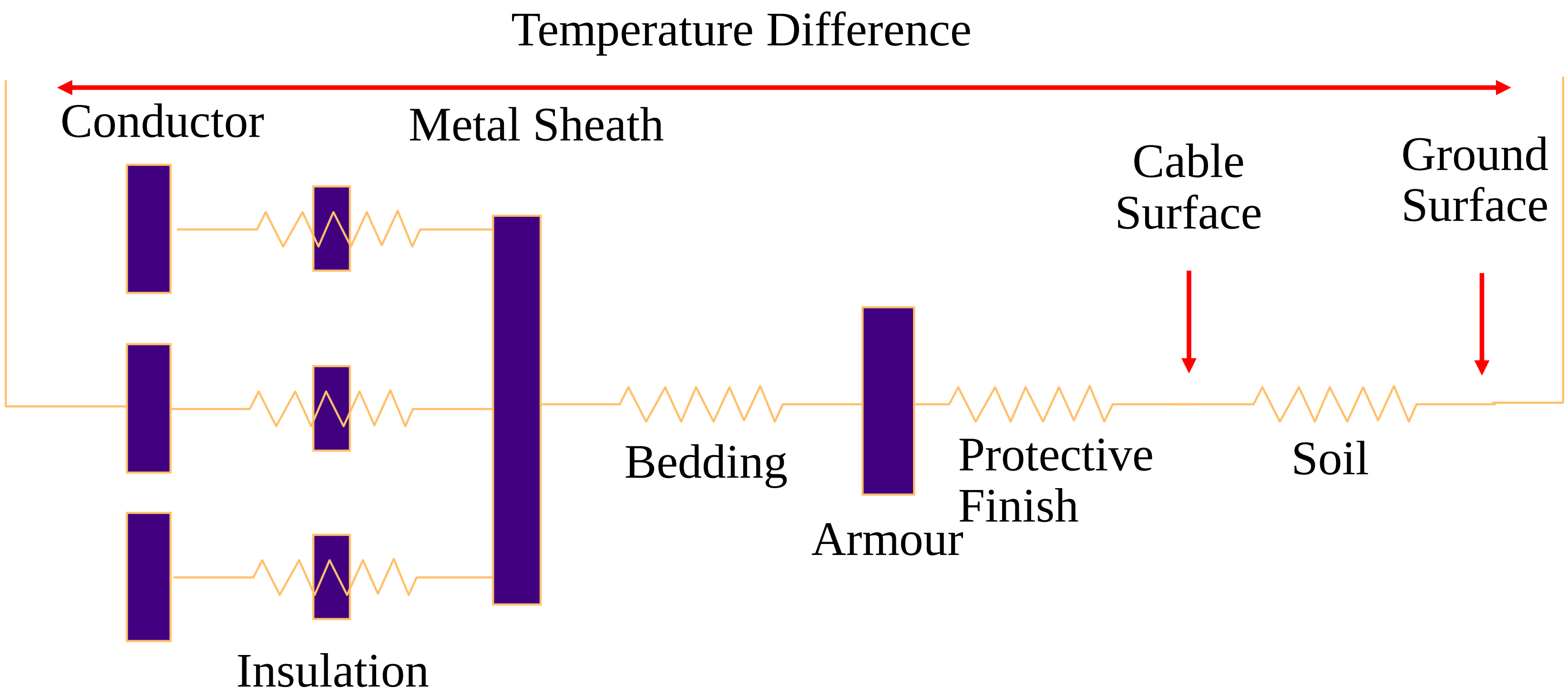
$$\Delta\theta = (I^2 R + \tfrac{1}{2} W_d)\, T_1 + [I^2 R\,(1 + \lambda_1) + W_d]\, n\, T_2 + [I^2 R\,(1 + \lambda_1 + \lambda_2) + W_d]\, n\,(T_3 + T_4)$$

where

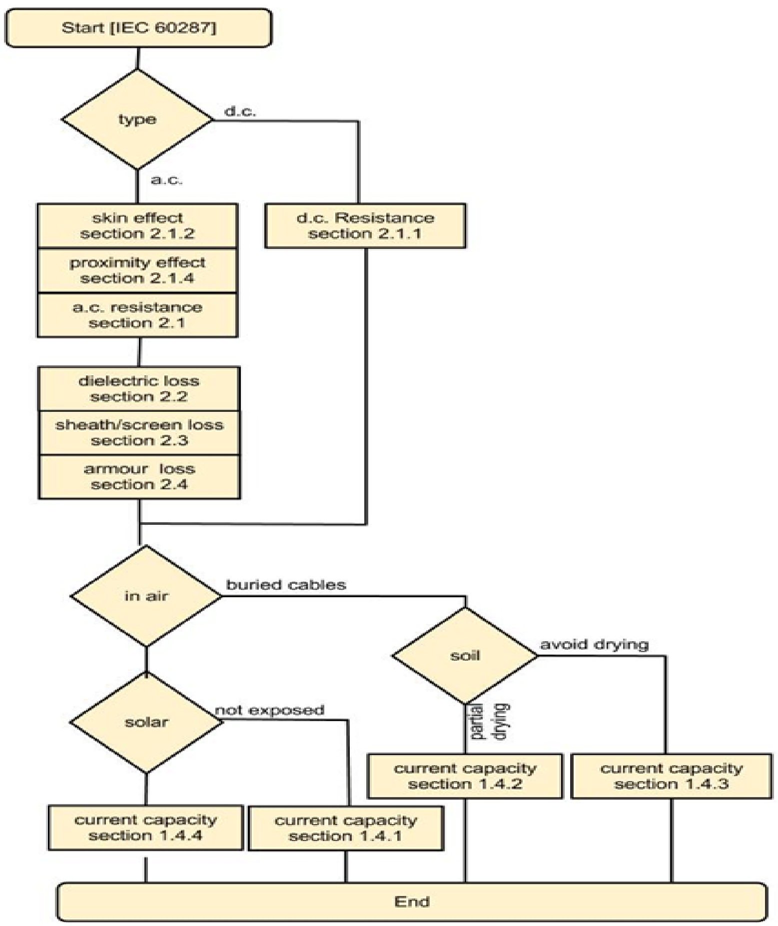
- I is the current flowing in one conductor (A);
- $\Delta\theta$ is the conductor temperature rise above the ambient temperature (K);

  NOTE The ambient temperature is the temperature of the surrounding medium under normal conditions, at a situation in which cables are installed, or are to be installed, including the effect of any local source of heat, but not the increase of temperature in the immediate neighbourhood of the cables due to heat arising therefrom.
- R is the alternating current resistance per unit length of the conductor at maximum operating temperature (Ω/m);
- W_d is the dielectric loss per unit length for the insulation surrounding the conductor (W/m);
- T_1 is the thermal resistance per unit length between one conductor and the sheath (K.m/W);
- T_2 is the thermal resistance per unit length of the bedding between sheath and armour (K.m/W);
- T_3 is the thermal resistance per unit length of the external serving of the cable (K.m/W);
- T_4 is the thermal resistance per unit length between the cable surface and the surrounding medium, as derived from 2.2 of Part 2 (K.m/W);
- n is the number of load-carrying conductors in the cable (conductors of equal size and carrying the same load);
- λ_1 is the ratio of losses in the metal sheath to total losses in all conductors in that cable;
- λ_2 is the ratio of losses in the armouring to total losses in all conductors in that cable.

Circuit Analogy – Heat Transfer



Current Rating Calculations



Current Rating Calculations

CUSTOMER	PRYSMIAN POWER CABLES &SYSTEMS AUSTRALIA PTY LTD
PROJECT/REF.	WOTONGA PROJECT
MANUFACTURER	POWER CABLES MALAYSIA SDN BHD
DOCUMENT NO.	PCM–CR–2011/259–1
DOC. TITLE	CURRENT RATING CALCULATIONS FOR XL1/0400C66.CPQV

Issued by : ZAIREEN	Date : 4–Jul–2011	Revision No. 0	Sheet No. 1 of 1

Cables laid direct in Ground, in PE Ducts, in Air (shaded) and in buried Trough.

Phase to earth voltage	38000	V	DC resistance at 20°C	47.0	μohm/m
Phase to phase voltage	66000	V	Ins. thm. resistivity	3.5	K.m/W
Power frequency	50	Hz	Non–metallic sheath TR	3.50	K.m/W
Ins. rel. permittivity	2.5	—	Soil thm. resistivity	1.2	K.m.W
Tangent delta	.001	—	Duct thm. resistivity	3.50	K.m/W
Duct "u" constant	1.87	—	Diameter over conductor	22.8	mm
Duct "v" constant	.31	—	Diameter over core	50.9	mm
Duct "y" constant	.00	—	Metal cov. mean diam.	54.0	mm
Air "z" trefoil,flat	.96,1.31	—	Overall diameter	64.9	mm
Air "e" trefoil,flat	1.25,2.00	—	Duct internal diameter	100	mm
Air "g" trefoil,flat	.20, .20	—	Duct external diameter	110	mm
Trough temp.rise trefoil	14.7	°C	Depth in ground, ducts	1200,1200	mm
Trough temp.rise flat	16.7	°C	Trough depth, width	1000, 500	mm
Capacitance	221.0	pF/m	Cross–bond sections	100/100/100	m/m/m

Lay configuration	—	Trefoil	Trefoil	Trefoil	Trefoil	Flat	Flat	Flat	Flat
Sheath bonding	—	Special	Special	Special	Special	Special	Special	Special	Special
Cable laying condition	—	Ground	Ducts	Air	Trough	Ground	Ducts	Air	Trough
Phase axial spacing	mm	65	110	65	65	130	220	130	130
Ambient lay temperature	°C	25.0	25.0	30.0	30.0	25.0	25.0	30.0	30.0
Max. conductor temperature	°C	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Skin effect	—	.0225	.0225	.0225	.0225	.0225	.0225	.0225	.0225
Proximity effect	—	.0113	.0039	.0113	.0113	.0028	.0010	.0028	.0028
AC resistance at max. temp.	μohm/m	62.0	61.5	62.0	62.0	61.4	61.3	61.4	61.4
Metallic covering resistance	μohm/m	215.1	215.3	207.4	211.5	214.3	214.7	204.1	209.7
Metallic covering loss factor	—	.0406	.0154	.0421	.0413	.0207	.0098	.0097	.0095
Therm. resistance – Insulation	K.m/W	.4480	.4480	.4480	.4480	.4480	.4480	.4480	.4480
Therm. resistance – Oversheath	K.m/W	.1020	.1020	.0638	.0638	.0638	.0638	.0638	.0638
Therm. resist. cable to ducts	K.m/W	–	.3790	–	–	–	.3808	–	–
Therm. resist. of ducts	K.m/W	–	.0531	–	–	–	.0531	–	–
Therm. resist. outside ducts	K.m/W	–	1.8025	–	–	–	1.6354	–	–
Therm. resistance – External	K.m/W	2.1048	2.2345	.6930	.7387	1.9367	2.0692	.4933	.5303
External surface temperature	°C	76.9	77.3	65.0	71.8	76.9	77.3	59.6	68.8
Conductor loss per phase	W/m	23.7	23.0	48.5	35.3	26.3	25.0	59.4	41.3
Dielectric loss per phase	W/m	.10	.10	.10	.10	.10	.10	.10	.10
Metallic cov. loss per phase	W/m	.96	.35	2.04	1.46	.54	.24	.58	.39
Calculated ratings	Amps	618	612	885	755	654	639	983	820
Equivalent capacity	mva	70.68	69.97	101.16	86.28	74.75	73.02	112.38	93.76
Cct nos : centre spacing	no:mm	1:	1:	1:	1:—	1:	1:	1:	1:—
Tier nos : depth spacing	no:mm	1:—	1:—	1:—	1:—	1:—	1:—	1:—	1:—

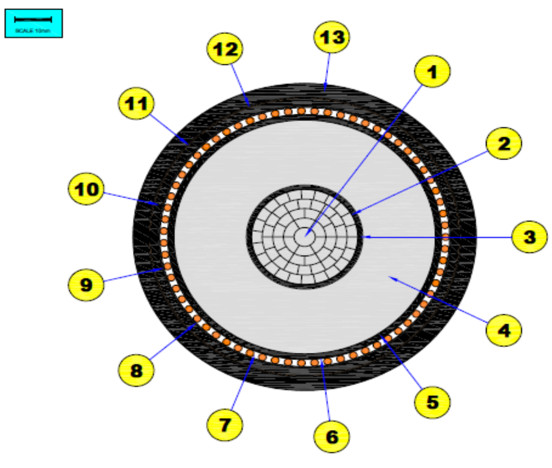
Cable Current Rating Considerations

- Cable laying conditions
- Ambient & operating temperatures
- Lay configuration
- Bonding system
- External heat sources (including nearby cables)

Case Study:
630sqmm Alum XLPE 132kV Cable

Description

Single Core 630 sqmm Aluminium Conductor, XLPE Insulated, Copper Wire Screened, Laminated Aluminium Taped, Tin Bronze Taped, MD Polyethylene Sheathed, 132 kV(Um=145 kV) Cable to IEC 60840, 2011 Specifications.



ITEM	DESCRIPTION	THICKNESS (MM)	NOMINAL DIA. (MM)
1	Aluminium Conductor <water-blocked>	-	29.9
2	Semi-Cond. Swellable Tape	0.3	30.2
3	Conductor Screen	1.2	32.8
4	XLPE Insulation	20.0	73.6
5	Insulation Screen	1.3	76.6
6	Semi-Cond. Swellable Tape	0.5	77.1
7	Copper Wire Screen	67x2.19	81.5
8	Semi-Cond. Swellable Tape	0.3	82.0
9	Laminated Alum Tape	0.2	82.4
10	PE Bedding	2.0	87.2
11	Tin Bronze Tape	0.1	87.6
12	Polyester Tape Binder	0.2	88.0
13	MDPE Oversheath <c/w graphite>	4.0	96.6

Cablecode	XL1/0630A132.CLMZMG		
Customer	SARAWAK ENERGY BERHAD		
Project	132KV		
Dwg Ref	2013/580-3	Revision	A
Issued by	LOKMAN	Date	30.12.13

POWER CABLES MALAYSIA SDN BHD

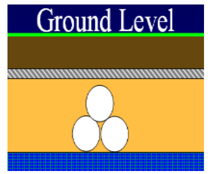
Thermal Conditions

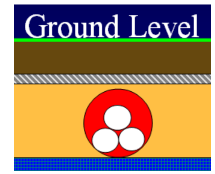
- Laid direct in ground
- Ground temperature 25ºC
- Depth of laying 1000 mm
- Soil TR 1.2 Km/W

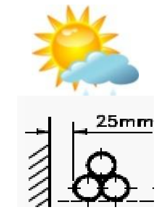
System Configuration

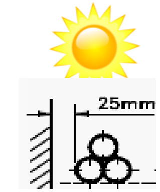
- Single circuit
- In trefoil formation
- Specially bonded without transposition

Manner of Cable Laying









Lay configuration	--	*Trefoil*	Trefoil	Trefoil	Trefoil	Trefoil
Sheath bonding	--	*Special*	Special	Special	Special	Special
Cable laying condition	--	*Ground*	Ducts	Ducts	Air	Air
Phase axial spacing	mm	*96*	160	96	96	96
Ambient lay temperature	**°C**	***25***	***25***	***25***	***25***	***25***
Depth of Laying	**mm**	***1000***	***1000***	***1000***	**---**	**---**
Soil thermal resistivity	**K.m/W**	***1.2***	***1.2***	***1.2***	**---**	**---**
Max. conductor temperature	°C	*90*	90	90	90	90
Skin effect	--	*0.0223*	0.0223	0.0223	0.0223	0.0223
Proximity effect	--	*0.0088*	0.0031	0.0088	0.0088	0.0088
AC resistance at max. temp.	μohm/m	*62*	61.7	62	62	62
Metallic covering loss factor	--	*0.0013*	0.0027	0.0013	0.0014	0.0013
Therm. resistance – Insulation	K.m/W	*0.5323*	0.5323	0.5323	0.5323	0.5323
Therm. resistance – Oversheath	K.m/W	*0.0918*	0.0918	0.0918	0.0574	0.0574
Therm. resist. cable to ducts	K.m/W	–	0.2807	0.1415	–	–
Therm. resist. of ducts	K.m/W	–	0.036	0.0189	–	–
Therm. resist. outside ducts	K.m/W	–	1.4833	1.7779	–	–
Therm. resistance – External	**K.m/W**	***1.7779***	***1.8000***	***1.9382***	***0.5097***	***0.4774***
External surface temperature	°C	*73.1*	73.3	74.2	55.2	64.2
Conductor loss per phase	W/m	*27*	26.8	25.3	59.1	43.8
Dielectric loss per phase	W/m	*0.31*	0.31	0.31	0.31	0.31
Metallic cov. loss per phase	W/m	*0.04*	0.07	0.03	0.08	0.06
Calculated ratings	**Amps**	***660***	***659***	***639***	***976***	***840***
Equivalent capacity	mva	*150.97*	150.61	146.16	223.18	192.08

Temperature "Rise"

$$I = \left[\frac{\Delta\theta - W_d \left[0,5\ T_1 + n\ (T_2 + T_3 + T_4)\right]}{RT_1 + nR\ (1+\lambda_1)\ T_2 + nR\ (1+\lambda_1+\lambda_2)\ (T_3 + T_4)} \right]^{0,5}$$

Δϑ is the conductor temperature rise above the ambient temperature (K);

NOTE The ambient temperature is the temperature of the surrounding medium under normal conditions, at a situation in which cables are installed, or are to be installed, including the effect of any local source of heat, but not the increase of temperature in the immediate neighbourhood of the cables due to heat arising therefrom.

		STD	
Lay configuration	--	Trefoil	Trefoil
Sheath bonding	--	Special	Special
Cable laying condition	--	Ground	Ground
Phase axial spacing	mm	96	96
Ambient lay temperature	**°C**	**25**	**35**
Depth of Laying	**mm**	**1000**	**1000**
Soil thermal resistivity	**K.m/W**	**1.2**	**1.2**
Max. conductor temperature	°C	90	90
Skin effect	--	0.0223	0.0223
Proximity effect	--	0.0088	0.0088
AC resistance at max. temp.	µohm/m	62	62
Metallic covering loss factor	--	0.0013	0.0013
Therm. resistance – Insulation	K.m/W	0.5323	0.5323
Therm. resistance – Oversheath	K.m/W	0.0918	0.0918
Therm. resist. cable to ducts	K.m/W	–	–
Therm. resist. of ducts	K.m/W	–	–
Therm. resist. outside ducts	K.m/W	–	–
Therm. resistance – External	**K.m/W**	**1.7779**	**1.7779**
External surface temperature	°C	73.1	75.7
Conductor loss per phase	W/m	27	22.9
Dielectric loss per phase	W/m	0.31	0.31
Metallic cov. loss per phase	W/m	0.04	0.03
Calculated ratings	**Amps**	**660**	**607**
Equivalent capacity	mva	150.97	138.87

Insulation	*Maximum Conductor Temperature (°C)*
PVC	*70*
Polyethylene	*70*
Butyl Rubber	*85*
EPR	*90*
XLPE	*90*
Natural Rubber	*60*
Impregnated Paper	*65 - 80*

oC	amos	*"factor"*
15	709	1.074
20	685	1.038
25	660	1.000
30	634	0.961
35	607	0.920

Thermal Resistances : T_1, T_2, T_3, T_4

$$I = \left[\frac{\Delta\theta - W_d \left[0{,}5\ T_1 + n\ (T_2 + T_3 + T_4)\right]}{RT_1 + nR\ (1+\lambda_1)\ T_2 + nR\ (1+\lambda_1+\lambda_2)\ (T_3+T_4)} \right]^{0{,}5}$$

T_1 is the thermal resistance per unit length between one conductor and the sheath (K.m/W);

T_2 is the thermal resistance per unit length of the bedding between sheath and armour (K.m/W);

T_3 is the thermal resistance per unit length of the external serving of the cable (K.m/W);

T_4 is the thermal resistance per unit length between the cable surface and the surrounding medium, as derived from 2.2 of Part 2 (K.m/W);

2.2.2 *Single isolated buried cable*

$$T_4 = \frac{1}{2\pi}\ \rho_T \ln\left(u + \sqrt{u^2 - 1}\right)$$

where

ρ_T is the thermal resistivity of the soil (K.m/W)

$u = \frac{2L}{D_e}$

L is the distance from the surface of the ground to the cable axis (mm)

D_e is the external diameter of the cable (mm)

for corrugated sheaths $D_e = D_{oc} + 2\ t_3$

Cable Laying

- In Air – on racks, bridges, along walls, suspended on poles (aerial)
- Laid in open/closed troughs, tunnels, in conduits (exposed)
- Laid Direct in ground as-is or in pipes/ducts
- Underwater, submarine or river crossing

Cables laid direct in Ground, in PE Ducts, in Air (shaded) and in buried Trough.

Ground temperature	25.0	°C	DC resistance at 20°C	125.0	µohm/m
Ambient air temp.	30.0	°C	Ins. thm. resistivity	3.5	K.m/W
In Trough temp. rise	11.2	°C	Non–metallic sheath TR	3.50	K.m/W
Phase to earth voltage	6350	V	Soil thm. resistivity	1.2	K.m/W
Phase to phase voltage	11000	V	Duct thm. resistivity	3.50	K.m/W
Power frequency	50	Hz	Ductbank/Backfill TR	1.20, 1.20	K.m/W
Ins. rel. permittivity	2.5	—	Diameter over conductor	18.2	mm
Tangent delta	.004	—	Diameter over core	27.6	mm
Duct "u" constant	1.87	—	Metal cov. mean diam.	28.0	mm
Duct "v" constant	.31	—	Overall diameter	73.9	mm
Duct "y" constant	.00	—	Duct internal diameter	125	mm
Air "z" constant	.21	—	Duct external diameter	135	mm
Air "e" constant	3.94	—	Depth in ground, ducts	800, 800	mm
Air "g" constant	.60	—	Trough depth, width	1000, 500	mm
Ductbank dimensions		mm			

Cable laying condition	—	Ground	Ducts	Air	Trough
Ambient lay temperature	°C	25.0	25.0	30.0	30.0
Max. conductor temperature	°C	90.0	90.0	90.0	90.0
Skin effect	—	.0032	.0032	.0032	.0032
Proximity effect	—	.0058	.0058	.0058	.0058
AC resistance at max. temp.	µohm/m	161.7	161.7	161.7	161.7
Metallic covering resistance	µohm/m	2011.3	2021.8	1986.3	2001.6
Metallic covering loss factor	—	.0061	.0060	.0061	.0061
Therm. resistance – Insulation	K.m/W	.3238	.3238	.3238	.3238
Therm. resistance – Oversheath	K.m/W	.1027	.1027	.1027	.1027
Therm. resist. cable to ducts	K.m/W	-	.3341	-	-
Therm. resist. of ducts	K.m/W	-	.0429	-	-
Therm. resist. outside ducts	K.m/W	-	.6043	-	-
Therm. resistance – External	K.m/W	.7196	.9812	.3521	.3692
External surface temperature	°C	75.3	78.5	67.6	72.3
Conductor loss per phase	W/m	23.2	18.1	35.4	27.9
Dielectric loss per phase	W/m	.02	.02	.02	.02
Metallic cov. loss per phase	W/m	.14	.11	.22	.17
Calculated ratings	Amps	378	334	468	415
Equivalent capacity	mva	7.21	6.37	8.91	7.91
Cct nos : centre spacing	no:mm	1:	1:	1:	1:—
Tier nos : depth spacing	no:mm	1:—	1:—	1:—	1:—

Cable laying condition	—	Ground	Ducts	Air	Trough
Ambient lay temperature	°C	25.0	25.0	30.0	30.0
Max. conductor temperature	°C	139.0	173.0	90.0	108.0
Skin effect	—	.0024	.0020	.0032	.0029
Proximity effect	—	.0044	.0037	.0058	.0052
AC resistance at max. temp.	µohm/m	186.5	203.2	161.7	170.7
Metallic covering resistance	µohm/m	2289.1	2494.0	1986.3	2096.3
Metallic covering loss factor	—	.0046	.0039	.0061	.0055
Therm. resistance – Insulation	K.m/W	.3238	.3238	.3238	.3238
Therm. resistance – Oversheath	K.m/W	.1027	.1027	.1027	.1027
Therm. resist. cable to ducts	K.m/W	-	.2451	-	-
Therm. resist. of ducts	K.m/W	-	.0429	-	-
Therm. resist. outside ducts	K.m/W	-	.6043	-	-
Therm. resistance – External	K.m/W	.7196	.8922	.3521	.3483
External surface temperature	°C	****	****	67.6	84.3
Conductor loss per phase	W/m	40.9	44.6	35.4	37.4
Dielectric loss per phase	W/m	.02	.02	.02	.02
Metallic cov. loss per phase	W/m	.19	.17	.22	.21
Calculated ratings	Amps	468	468	468	468
Equivalent capacity	mva	8.92	8.92	8.91	8.92
Cct nos : centre spacing	no:mm	1:	1:	1:	1:—
Tier nos : depth spacing	no:mm	1:—	1:—	1:—	1:—

Bending Radii

	No of Cores	With Former	Without Former	Laid Direct	Laid in Ducts
33kV Armoured	1		15D	20D	
	3		12D	15D	
33kV Unarmoured	1		12D	15D	
	3		10D	12D	
66 - 132kV	1	15D	20D	30D	35D

D = Cable Diameter

T_4 : Depth of Laying

		STD	
Lay configuration	--	*Trefoil*	*Trefoil*
Sheath bonding	--	*Special*	*Special*
Cable laying condition	--	*Ground*	*Ground*
Phase axial spacing	mm	*96*	*96*
Ambient lay temperature	**°C**	***25***	***25***
Depth of Laying	**mm**	***1000***	***500***
Soil thermal resistivity	**K.m/W**	***1.2***	***1.2***
Max. conductor temperature	°C	*90*	*90*
Skin effect	--	*0.0223*	*0.0223*
Proximity effect	--	*0.0088*	*0.0088*
AC resistance at max. temp.	µohm/m	*62*	*62*
Metallic covering loss factor	--	*0.0013*	*0.0013*
Therm. resistance – Insulation	K.m/W	*0.5323*	*0.5323*
Therm. resistance – Oversheath	K.m/W	*0.0918*	*0.0918*
Therm. resist. cable to ducts	K.m/W	–	–
Therm. resist. of ducts	K.m/W	–	–
Therm. resist. outside ducts	K.m/W	–	–
Therm. resistance – External	**K.m/W**	***1.7779***	***1.3807***
External surface temperature	°C	*73.1*	*69.8*
Conductor loss per phase	W/m	*27*	*32.4*
Dielectric loss per phase	W/m	*0.31*	*0.31*
Metallic cov. loss per phase	W/m	*0.04*	*0.04*
Calculated ratings	**Amps**	***660***	***723***
Equivalent capacity	mva	*150.97*	*165.25*

mm depth	amps	*"factor"*
500	723	1.095
750	684	1.036
1000	660	1.000
1250	643	0.974
1500	631	0.956

T_4 : Soil thermal resistivity

		STD	
Lay configuration	--	*Trefoil*	*Trefoil*
Sheath bonding	--	*Special*	*Special*
Cable laying condition	--	*Ground*	*Ground*
Phase axial spacing	mm	*96*	*96*
Ambient lay temperature	**°C**	***25***	***25***
Depth of Laying	**mm**	***1000***	***1000***
Soil thermal resistivity	**K.m/W**	***1.2***	***0.9***
Max. conductor temperature	°C	*90*	*90*
Skin effect	--	*0.0223*	*0.0223*
Proximity effect	--	*0.0088*	*0.0088*
AC resistance at max. temp.	µohm/m	*62*	*62*
Metallic covering loss factor	--	*0.0013*	*0.0013*
Therm. resistance − Insulation	K.m/W	*0.5323*	*0.5323*
Therm. resistance − Oversheath	K.m/W	*0.0918*	*0.0918*
Therm. resist. cable to ducts	K.m/W	–	–
Therm. resist. of ducts	K.m/W	–	–
Therm. resist. outside ducts	K.m/W	–	–
Therm. resistance − External	**K.m/W**	***1.7779***	***1.3334***
External surface temperature	°C	*73.1*	*69.3*
Conductor loss per phase	W/m	*27*	33.2
Dielectric loss per phase	W/m	*0.31*	*0.31*
Metallic cov. loss per phase	W/m	*0.04*	*0.04*
Calculated ratings	**Amps**	***660***	***731***
Equivalent capacity	mva	*150.97*	*167.23*

soil Km/w	amps	*"factor"*
0.9	731	1.108
1.0	705	1.068
1.1	682	1.033
1.2	660	1.000
1.5	607	0.920
2.0	540	0.818

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3.2.2 *Thermal resistivity of soil*

Thermal resistivity (K.m/W)	Soil conditions	Weather conditions
0,7	Very moist	Continuously moist
1,0	Moist	Regular rainfall
2,0	Dry	Seldom rains
3,0	Very dry	Little or no rain

4 Values relating to the operating conditions in various countries

4.1 *Australia*

1) *Standard conditions*

Soil thermal resistivity	1,2 K.m/W
Soil ambient temperature	25 °C summer
	18 °C winter

2) *Depth of laying*

Measured from the ground surface to the centre of the cable, or to the centre of a trefoil group.

L.V. cables	500 mm under footways
	750 mm under roadways
11 kV cables	800 mm under footways
	800 mm under roadways
33 kV cables and higher voltages	1 000 mm under footways
	1 000 mm under roadways

3) *Air ambient temperature*

Maximum value	40 °C summer
	30 °C winter

Combined effects of temperature rise, depth of laying and soil Tr

		STD				
Lay configuration	--	*Trefoil*	*Trefoil*	*Trefoil*	*Trefoil*	*Trefoil*
Sheath bonding	--	*Special*	*Special*	*Special*	*Special*	*Special*
Cable laying condition	--	*Ground*	*Ground*	*Ground*	*Ground*	*Ground*
Phase axial spacing	mm	*96*	*96*	*96*	*96*	*96*
Ambient lay temperature	**°C**	***25***	***35***	***25***	***25***	***35***
Depth of Laying	**mm**	***1000***	***1000***	***500***	***1000***	***500***
Soil thermal resistivity	**K.m/W**	***1.2***	***1.2***	***1.2***	***0.9***	***0.9***
Max. conductor temperature	°C	*90*	*90*	*90*	*90*	*90*
Skin effect	--	*0.0223*	*0.0223*	*0.0223*	*0.0223*	*0.0223*
Proximity effect	--	*0.0088*	*0.0088*	*0.0088*	*0.0088*	*0.0088*
AC resistance at max. temp.	µohm/m	*62*	*62*	*62*	*62*	*62*
Metallic covering loss factor	--	*0.0013*	*0.0013*	*0.0013*	*0.0013*	*0.0013*
Therm. resistance - Insulation	K.m/W	*0.5323*	*0.5323*	*0.5323*	*0.5323*	*0.5323*
Therm. resistance - Oversheath	K.m/W	*0.0918*	*0.0918*	*0.0918*	*0.0918*	*0.0918*
Therm. resist. cable to ducts	K.m/W	-	-	-	-	-
Therm. resist. of ducts	K.m/W	-	-	-	-	-
Therm. resist. outside ducts	K.m/W	-	-	-	-	-
Therm. resistance - External	**K.m/W**	***1.7779***	***1.7779***	***1.3807***	***1.3334***	***1.0355***
External surface temperature	°C	*73.1*	*75.7*	*69.8*	*69.3*	*69.3*
Conductor loss per phase	W/m	*27*	*22.9*	*32.4*	*33.2*	*33.1*
Dielectric loss per phase	W/m	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*
Metallic cov. loss per phase	W/m	*0.04*	*0.03*	*0.04*	*0.04*	*0.04*
Calculated ratings	**Amps**	***660***	***607***	***723***	***731***	***731***
Equivalent capacity	mva	*150.97*	*138.87*	*165.25*	*167.23*	*167.07*

oC	amos	*"factor"*
15	709	1.074
20	685	1.038
25	660	1.000
30	634	0.961
35	607	***0.920***

mm depth	amps	*"factor"*
500	*723*	***1.095***
750	684	1.036
1000	660	1.000
1250	643	0.974
1500	631	0.956

soil Km/w	amps	*"factor"*
0.9	731	***1.108***
1.0	705	1.068
1.1	682	1.033
1.2	660	1.000
1.5	607	0.920
2.0	540	0.818

660A x 0.920 x 1.095 x 1.108 = 737A

Consideration of external heat sources

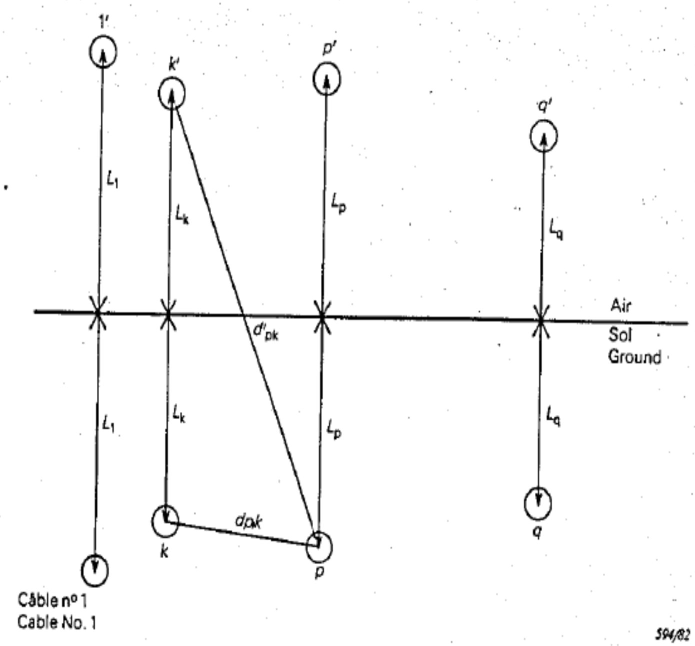


Figure 1 – Diagramme montrant un groupe de câbles *q* et leur symétrique par rapport à la surface du sol

Diagram showing a group of *q* cables and their reflection in the ground-air surface

2.2.3.1 *Unequally loaded cables*

The method suggested for groups of unequally loaded dissimilar cables is to calculate the temperature rise at the surface of the cable under consideration caused by the other cables of the group, and to subtract this rise from the value of $\Delta\theta$ used in the equation for the rated current in 1.4 of part 1. An estimate of the power dissipated per unit length of each cable must be made beforehand, and this can be subsequently amended as a result of the calculation where this becomes necessary.

Thus, the temperature rise $\Delta\theta_p$ above ambient at the surface of the p^{th} cable, whose rating is being determined, caused by the power dissipated by the other $(q - 1)$ cables in the group, is given by:

$$\Delta\theta_p = \Delta\theta_{1p} + \Delta\theta_{2p} + \ldots \Delta\theta_{kp} + \ldots \Delta\theta_{qp}$$

(the term $\Delta\theta_{pp}$ is excluded from the summation)

where

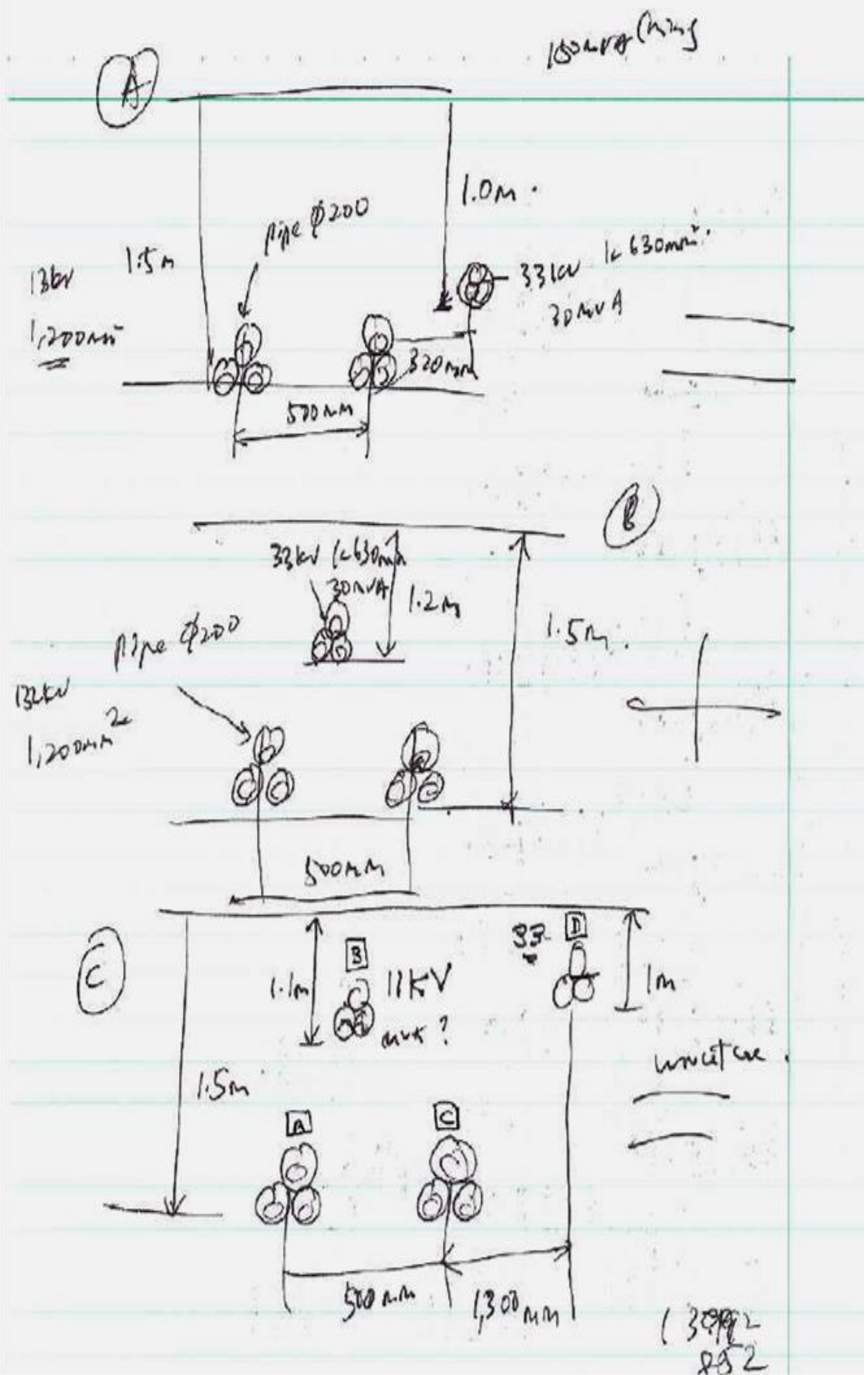
$\Delta\theta_{kp}$ is the temperature rise at the surface of the cable produced by the power W_k watt per unit length dissipated in cable k:

$$\Delta\theta_{kp} = \frac{1}{2\pi} \rho_T W_k \ln\left(\frac{d'_{pk}}{d_{pk}}\right)$$

The distances d_{pk} and d'_{pk} are measured from the centre of the p^{th} cable to the centre of cable k, and to the centre of the reflection of cable k in the ground-air surface respectively (see figure 1).

The value of $\Delta\theta$ in the equation for the rated current in 1.4 of part 1 is then reduced by the amount $\Delta\theta_p$ and the rating of the p^{th} cable is determined using a value T_4 corresponding to an isolated cable at position p.

This calculation is performed for all cables in the group and is repeated where necessary to avoid the possibility of overheating any cable.



Case C

		A	B	C	D
		132kV 1200 Cu	11kV 3c240 Al	132kV 1200 Cu	33kV 630 Al
Uo		76000	6350	76000	19000
TanD		0.001	0.004	0.001	0.004
MVA		150.1	5.0	150.1	30.1
Amps		**656.5**	**263.1**	**656.5**	**525.8**
Cond temp oC		**48.6**	**69.2**	**48.6**	**67.9**
Cond AC ohm/km		0.0178	0.1514	0.0178	0.0576
Capacitance mF/km		0.2389	0.4552	0.2389	0.3041
Sheath Loss factor		0.0082	0.0068	0.0082	0.0032
Conductor	W/m/ph	7.6739	10.4794	7.6739	15.9254
Dielectric	W/m/ph	0.4335	0.0231	0.4335	0.1380
Sheath	W/m/ph	0.0628	0.0716	0.0628	0.0516
TOTAL	**W/m/ckt**	**24.510**	**31.722**	**24.510**	**48.345**

	Soil resistivity Km/W		1.2	1.2	1.2	1.2
	Depth to center mm		1500	1100	1500	1000
	vert	horiz	0	250	500	1800
A	1500	0	1.0000	5.5374	6.0828	1.6490
B	1100	250	5.5374	1.0000	5.5374	1.6804
C	1500	500	6.0828	5.5374	1.0000	2.0231
D	1000	1800	1.6490	1.6804	2.0231	1.0000
A	Delta temp		0.0000	8.0119	8.4516	2.3414
B	Delta temp		10.3694	0.0000	10.3694	3.1447
C	Delta temp		8.4516	8.0119	0.0000	3.2984
D	Delta temp		4.6182	4.7925	6.5058	0.0000
	TOTAL		**23.44**	**20.82**	**25.33**	**8.78**

FINAL Cond temp oC	**72.0**	**90.0**	**73.9**	**76.7**

T_1 : Inductive losses

1.4.1.2 *DC cables up to 5 kV*

The permissible current rating of a d.c. cable is obtained from the following simplification of the a.c. formula:

$$I = \left[\frac{\Delta\theta}{R' T_1 + nR' T_2 + nR' (T_3 + T_4)} \right]^{0,5}$$

$$I = \left[\frac{\Delta\theta - W_d \left[0,5\ T_1 + n\ (T_2 + T_3 + T_4)\right]}{RT_1 + nR\ (1 + \lambda_1)\ T_2 + nR\ (1 + \lambda_1 + \lambda_2)\ (T_3 + T_4)} \right]^{0,5}$$

W_d is the dielectric loss per unit length for the insulation surrounding the conductor (W/m);

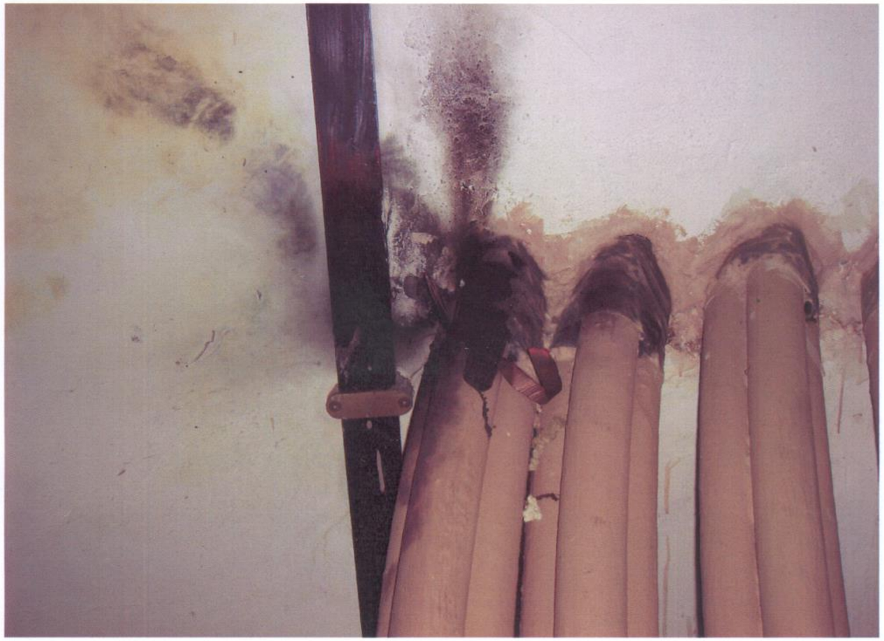
λ_1 is the ratio of losses in the metal sheath to total losses in all conductors in that cable;

λ_2 is the ratio of losses in the armouring to total losses in all conductors in that cable.

2.3 Loss factor for sheath and screen (applicable to power frequency a.c. cables only)
The power loss in the sheath or screen ($\lambda 1$) consists of losses caused by circulating currents ($\lambda 1'$) and eddy currents ($\lambda 1''$), thus: $\lambda 1 = \lambda 1' + \lambda 1''$

For single-core cables with sheaths bonded at both ends of an electrical section, only the loss due to circulating currents in the sheaths need be considered (see 2.3.1, 2.3.2 and 2.3.3). An electrical section is defined as a portion of the route between points at which the sheaths or screens of all cables are solidly bonded.

For a cross-bonded installation, it is considered unrealistic to assume that minor sections are electrically identical and that the loss due to circulating currents in the sheaths is negligible. Recommendations are made in 2.3.6 for augmenting the losses in the sheaths to take account of this electrical unbalance.



3.0 Discussions

The events leading to the fault is suggested as follows;

- Cuts were made on the cable by a sharp edge tool which were not deep enough to have caused an immediate failure
- With the copper wire screen of the cable partially exposed, an electrical connection would have developed over time between the screen and the nearest grounding earth
- The concrete wall and a metal bar in close proximity of the exposed screen provides the nearest point of ground return
- In solid bonding, a potential would be created for circulating currents to flow away from the grounded end to this near point.
- Over an undetermined period, the flow of current would have deteriorated further with a possible increase due to moisture ingression from the concrete wall, eventually leading to the occurrence of fault at the weakest point of damage.

4.0 Conclusion

From the investigation and aforementioned discussions, the conclusions are as follows;

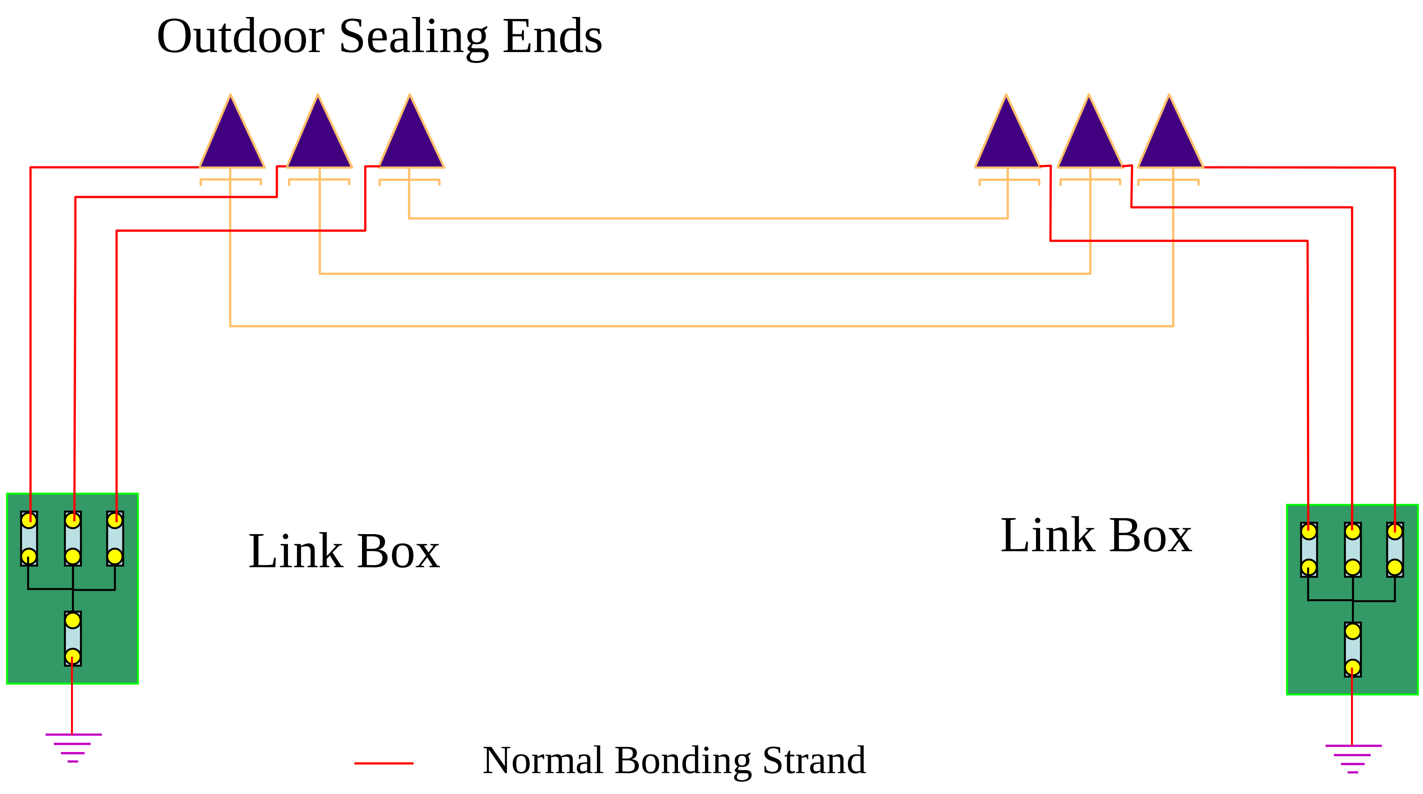
- **The cable fault occurred over a period of time upon initiation of deep cuts exposing the wire screen to the elements of deterioration, leading to eventual failure**
- **Manufacturing defect can be ruled out due to its extensive nature and the unlikelihood that the observation of such damage can be missed during installation works**

End of Report

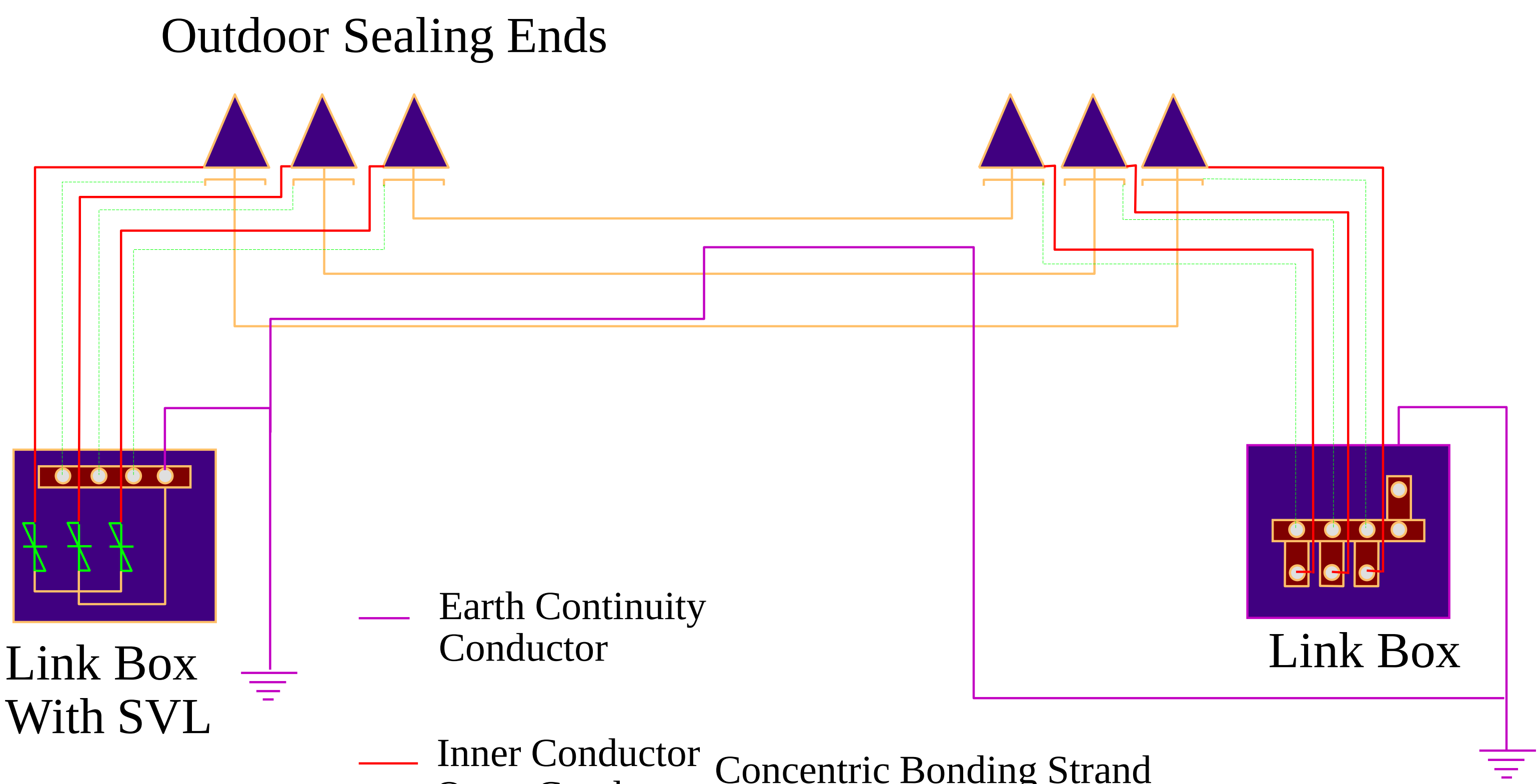
Earthing and Bonding

- Solid Bonding
- Special Bonding
  - Single End Point
  - Mid Point
  - Cross Bonding

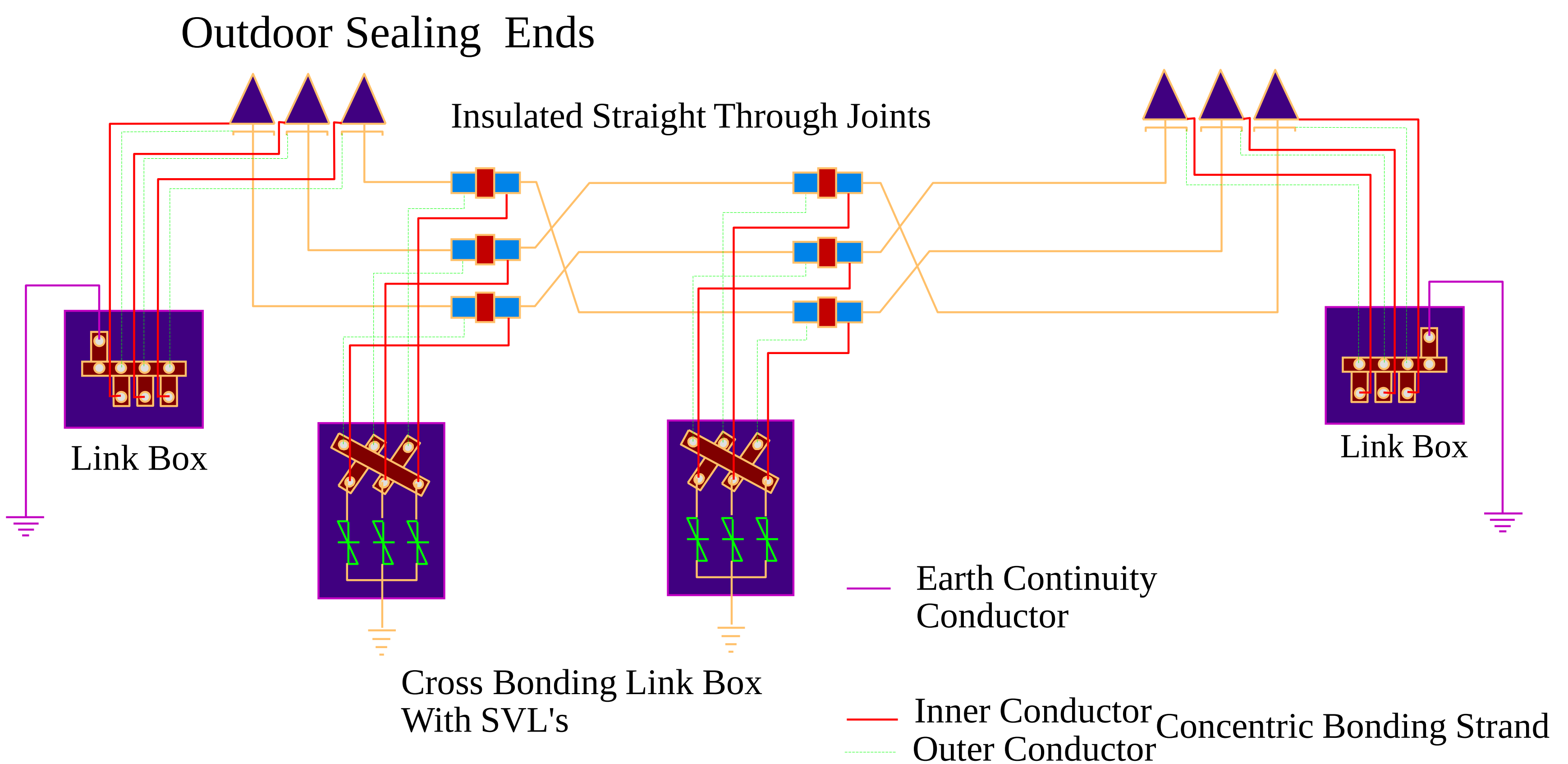
Solid Bonding



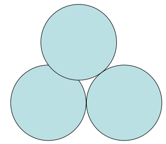
Single End Point Bonding

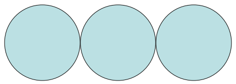


Cross Bonding System



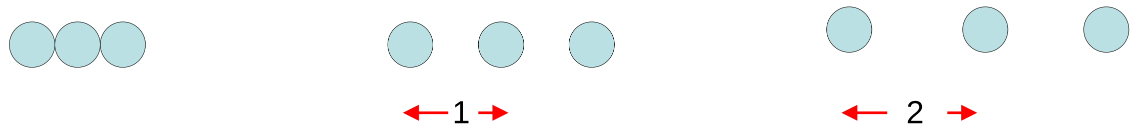
Lay configuration : Trefoil & Flat at Solid & Special bondings



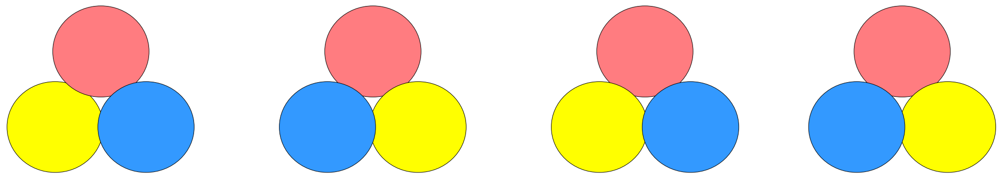


Lay configuration	**--**	***Trefoil***	***Trefoil***	***Flat***	***Flat***
Sheath bonding	**--**	***Special***	***Solid***	***Special***	***Solid***
Cable laying condition	--	*Ground*	*Ground*	*Ground*	*Ground*
Touching or Spaced		***Touching***	***Touching***	***Touching***	***Touching***
Phase axial spacing	mm	***96***	**96**	**96**	**96**
Ambient lay temperature	**°C**	***25***	***25***	***25***	***25***
Depth of Laying	**mm**	***1000***	***1000***	***1000***	***1000***
Soil thermal resistivity	**K.m/W**	***1.2***	***1.2***	***1.2***	***1.2***
Max. conductor temperature	°C	*90*	90	90	90
Skin effect	--	*0.0223*	0.0223	0.0223	0.0223
Proximity effect	--	*0.0088*	0.0088	0.0088	0.0088
AC resistance at max. temp.	μohm/m	*62*	62	62	62
Metallic covering loss factor	**--**	***0.0013***	***0.405***	***0.0008***	***0.2358***
Therm. resistance – Insulation	K.m/W	*0.5323*	0.5323	0.5323	0.5323
Therm. resistance – Oversheath	K.m/W	*0.0918*	0.0918	0.0574	0.0574
Therm. resist. cable to ducts	K.m/W	–	–	–	–
Therm. resist. of ducts	K.m/W	–	–	–	–
Therm. resist. outside ducts	K.m/W	–	–	–	–
Therm. resistance – External	**K.m/W**	***1.7779***	***1.7779***	***1.7126***	***1.7126***
External surface temperature	°C	*73.1*	76.4	73.4	75.6
Conductor loss per phase	W/m	*27*	20.6	28.2	23.9
Dielectric loss per phase	W/m	*0.31*	0.31	0.31	0.31
Metallic cov. loss per phase	W/m	*0.04*	8.33	0.02	5.64
Calculated ratings	**Amps**	***660***	***576***	***675***	***621***
Equivalent capacity	mva	*150.97*	131.7	154.23	141.95

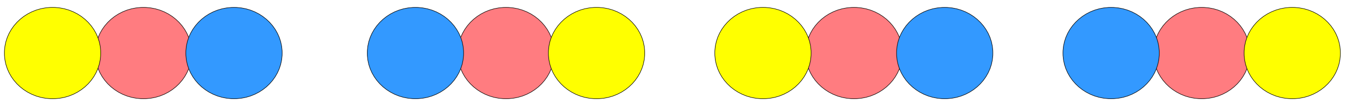
Lay configuration : Flat, Solid & Specially bonded, Touching & Spaced



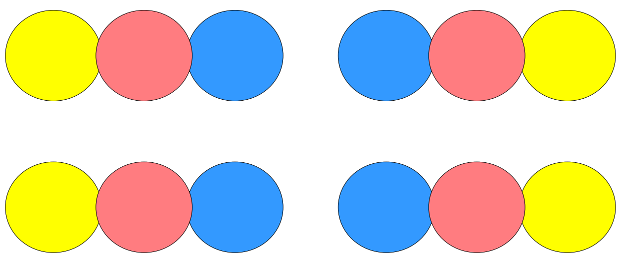
Lay configuration	--	Flat	Flat	Flat	Flat	Flat	Flat
Sheath bonding	--	Special	Special	Special	Solid	Solid	Solid
Cable laying condition	--	Ground	Ground	Ground	Ground	Ground	Ground
Touching or Spaced		Touching	Spaced	Spaced	Touching	Spaced	Spaced
Phase axial spacing	mm	96	191	287	96	191	287
Ambient lay temperature	°C	25	25	25	25	25	25
Depth of Laying	mm	1000	1000	1000	1000	1000	1000
Soil thermal resistivity	K.m/W	1.2	1.2	1.2	1.2	1.2	1.2
Max. conductor temperature	°C	90	90	90	90	90	90
Skin effect	--	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223
Proximity effect	--	0.0088	0.0022	0.001	0.0088	0.0022	0.001
AC resistance at max. temp.	µohm/m	62	61.6	61.5	62	61.6	61.5
Metallic covering loss factor	--	0.0008	0.0025	0.0035	0.2358	0.7849	1.0951
Therm. resistance – Insulation	K.m/W	0.5323	0.5323	0.5323	0.5323	0.5323	0.5323
Therm. resistance – Oversheath	K.m/W	0.0574	0.0574	0.0574	0.0574	0.0574	0.0574
Therm. resist. cable to ducts	K.m/W	–	–	–	–	–	–
Therm. resist. of ducts	K.m/W	–	–	–	–	–	–
Therm. resist. outside ducts	K.m/W	–	–	–	–	–	–
Therm. resistance – External	K.m/W	1.7126	1.6109	1.4582	1.7126	1.6109	1.4582
External surface temperature	°C	73.4	72.6	71.3	75.6	78.2	78.6
Conductor loss per phase	W/m	28.2	29.5	31.7	23.9	18.5	17.5
Dielectric loss per phase	W/m	0.31	0.31	0.31	0.31	0.31	0.31
Metallic cov. loss per phase	W/m	0.02	0.07	0.11	5.64	14.53	19.2
Calculated ratings	Amps	675	692	717	621	548	534
Equivalent capacity	mva	154.23	158.16	163.99	141.95	125.35	122.04



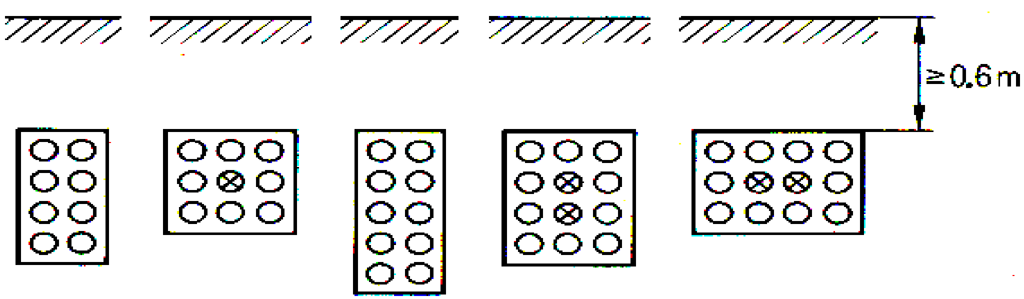
√ ***Single layer in Trefoil***



√ ***Single layer Flat formation***



√ ***Two Tiers in Flat formation***



Electric Cables to be laid on the periphery of duct banks (not recommended for long spans)

⊗ unsuitable for power cables

For a safe and long service life, electric cables are herein prescribed to be..

- Designed to the correct standards, with consideration of its expected rating and environment in service
- Installed in the correct manner as per recommended guidelines
- Maintained (where applicable) and operated within its limits and condition of service
- "Prophesized" for end of life

Thank you !