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Subject: Hornsea Project Three (UK) Ltd response to Deadline 6 (Part 8)

Dear Kay, K-J

Please find attached the 8th instalment of documents.

Best regards,
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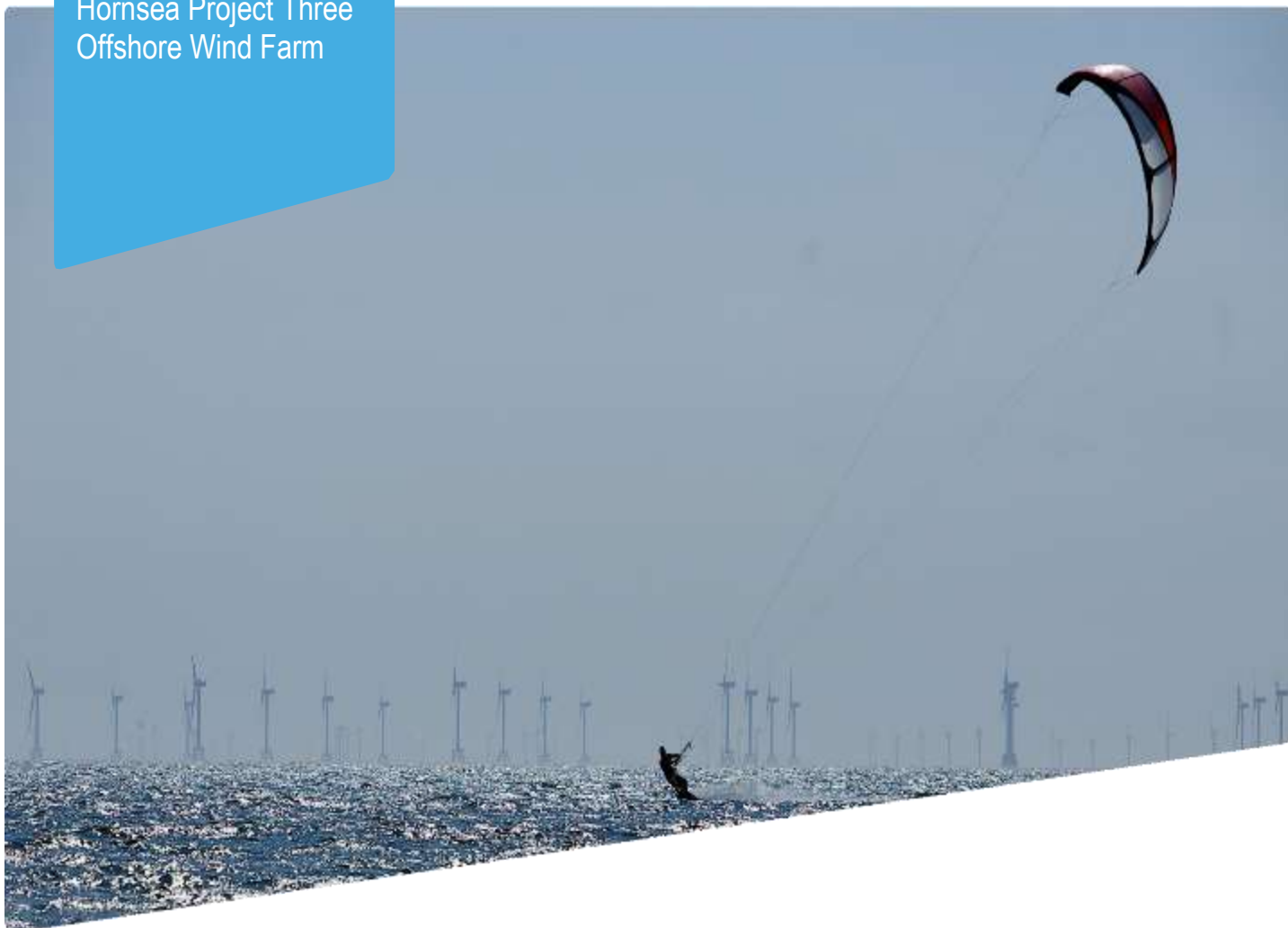
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Appendix 31 to Deadline 6 submission –
CIGRE Report 2009 - Service Experience of HV Underground
and Submarine Cable Systems

Date: 8th February 2019

Document Control			
Document Properties			
Organisation	Ørsted Hornsea Project Three		
Author	CIGRE 2009		
Checked by	n/a		
Approved by	n/a		
Title	Appendix 31 to Deadline 6 submission – CIGRE Report 2009 - Service Experience of HV Underground and Submarine Cable Systems		
PINS Document Number	n/a		
Version History			
Date	Version	Status	Description / Changes
08/02/2019	A	Final	Submitted at Deadline 6 (8 th Feb 2019)

Ørsted

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London, SW1P 1WG

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UPDATE OF SERVICE EXPERIENCE OF HV UNDERGROUND AND SUBMARINE CABLE SYSTEMS

**Working Group
B1.10**

April 2009



WG B1.10

UPDATE OF SERVICE EXPERIENCE

OF

HV UNDERGROUND AND SUBMARINE CABLE SYSTEMS

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ISBN 978-2-85873- 066-7

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Executive Summary

In recent years, significant quantities of land and submarine cables and accessories have been installed and the associated technology and laying techniques have matured and evolved. With the increasing demands on electrical power transmission and distribution systems, significant quantities of cable are currently being installed.

CIGRE WG B1.10 has recently undertaken a survey to collect and analyse data relating to the installed quantities of underground and submarine cable systems rated at 60 kV and above together with the service experience and the performance of existing underground and submarine cable systems. In addition to the performance measures, the data was used to establish trends in cable and accessory technologies.

A 5 year period ending December 2005 has been considered for land cables compared to a 15 year period ending similarly for submarine cables.

More than 33,000 circuit km of underground (land) cables and approximately 7000 circuit km of submarine cable systems were identified as being in service at the end of 2005. It is clear that not all cable systems were captured in the survey and replies were not received for some important geographical areas. Nevertheless it is felt that the data collected is representative and those trends in technology, design and service experience can be quantified.

The previous statistics published some twenty years ago have therefore been updated and some emerging trends identified.

The 33000 circuit km of AC land cable compares with 6195 km in the previous CIGRE survey published in Electra 137 (August 1991) and covering the 5 year period to December 1986. This latest survey shows that SCOF and XLPE insulated cables are the predominant two technologies.

Between the years 2000 and 2005, almost all installed AC cables have been XLPE or SCOF cables with XLPE being the preferred cable type. At voltages below 220 kV, more than 90% of the cable circuit length installed from 2001 to 2005 was of the XLPE type. For voltage levels above 220 kV SCOF cables still account for more than 40% of the cables installed. There is a trend towards using XLPE cables with a radial moisture barrier and adopting pre-moulded accessories. Other trends in extruded cable and accessory designs are discussed.

800 circuit km of DC land cable was reported in the new survey, with significant quantities of extruded insulated cables now installed at voltages up to 150 kV.

During the years 1990 to 2005, extruded cables have become the most widely used DC cable type with all installed DC land cables at voltages below 219 kV being the extruded

type. At voltages of 220 kV and above, SCOF is still the only DC cable type used for land applications.

Information regarding some 855 service failures was collected. Analysis of the data leads to some conclusions regarding failure rates, the most frequent cause of failure and some correlations with cable system age, mode of installation and repair time.

Analysis of the fault data revealed some key points;

A very large number of failures were reported on PILC cables are related to the age of these cable systems. These cable systems have reached the end of their useful life.

Internal failures in AC XLPE cables were greater than in SCOF cables

The low level of faults on DC SCOF cable can all be attributed to one project.

Almost 50% of faults were internal failures and 50% were external faults.

Of the internal faults, 60% of these were in the lower voltage class

77% of faults occurred in cables that were direct buried.

Third party mechanical damage accounts for 34% of all faults.

- The internal failure rates reflect the inherent performance of the cable system
- It is not possible to compare failure rates of cable and accessories due to different scaling factors
- Internal failure rates are greater at the higher voltage levels
- Internal failure rates of SCOF and XLPE cable are in line with previous data
- Internal failure rates of accessories, particularly on XLPE cable are of higher and of greater concern. Focus on quality control during jointing operations must be maintained.
- Repairs on SCOF cables take on average 29 days whilst XLPE cable systems require 20 days.

In the case of AC land cables, there has been a very noticeable change from the conventional pressurized laminar cable to the extruded, predominantly XLPE insulated design. This change started at the lower voltage level but now extends also to EHV transmission voltages. Cable designs are tending to include a radial moisture barrier to reduce the risk of water ingress. Joint designs are currently either of the pre-moulded design or site made with a trend towards pre-moulded. Emphasis on good jointing practices must be maintained.

In the case of submarine cables 7000 circuit km of AC and DC cable was reported. The use of extruded cables for AC links at higher voltage levels up to 170 kV can be observed. SCOF cables continue to be used for higher voltage AC applications. This trend is likely to continue and will extend to higher voltages as technology and confidence with joints matures. In the case of DC, higher transmission voltages than in the case of land cables have been used to date and the well proven MIND technology continues to dominate. However at lower voltages since the late 1990's, extruded insulated cables are being widely used for HVDC VSC (voltage source conversion) applications.

Installation is an extremely important element in submarine cable systems. The importance of cost effective cable protection from external Damage is well understood. More focus on surveys and routing to find more suitable routes to both facilitate protection of the cables by burial and to ensure a more controlled installation has certainly led to a reduction in external damage.

49 faults were reported which has enabled an analysis to be carried out on failure rates, the most frequent cause of failure, age, mode of installation and repair times.

The conclusions of the analysis of the information collected on submarine cable systems include

- 55% of faults were on AC cable systems and 45% on DC cable.
- 7 cases (14%) are reported to have an unknown cause of failure.
- 16 faults (33%) are reported to have been caused by “other” reasons. This is rather higher than expected. Further analysis of these incidents is reported
- 86% of failures were on cable rather than accessories.
- There was insufficient data to quantify a fault rate for accessories.
- 51% of failures were on SCOF cables, with 84% of these being on AC systems.
- Over 50% of faults occurred on unprotected cables. Buried cables are well protected against fishing gear, but can still be damaged by anchors penetrating deep into the seabed.
- 30% of faults occurred at water depths up to 10m and 52% at depths between 11 and 50m.
- The average reported repair time of submarine cables is approx. 60 days.
- The failure rate reported is lower than reported previously, probably due to improved methods for surveying and finding optimal routing and enhanced methods for cable laying and protection

Significant changes have been made over the last two decades in terms of the introduction of new materials and technologies.

The use of extruded insulation has been adopted for DC land cable applications at up to 150 kV and its use is expected to increase in future years.

In the case of submarine cables, the conventional MIND cable remains the predominant design for DC transmission whilst for AC applications XLPE insulation is becoming more widely used up to 150 kV and is likely to be employed also at higher voltages in future years. Much emphasis has been placed on installation and protection, including burial of submarine cables in recent years In order to reduce the risk of damage.

Currently the demand for land and submarine cable systems is very high. Changes are being introduced in testing protocols in order to reduce costly testing programs and encourage innovation whilst retaining quality and reliability standards.

In the light of these changes, it is important to monitor service performance and ensure that the decisions to introduce such changes are being taken on the basis of proven and satisfactory service performance.

1. BACKGROUND

The first survey to establish service experience statistics for land cable systems during the 5 year period from 1977 to 1981 was not published. The second survey was based on the experience gained from 1982 to 1986 and the result was published in August 1991 (Electra 137). The last service experience on accessories for HV cables with extruded insulation gained up to the end of 1992 was presented in Technical Brochure 177 in 2001.

Submarine cable systems Reliability Experience was first published in 1986 in Session Paper 21-12 by WG 21-06 entitled "Methods to prevent mechanical damage to submarine cables covering the period 1950 to 1980". A second survey covering the period 1980-1990 was published in 1991 at the CIGRE Symposium in Montreal Paper 2-07 "Reliability of Underground and Submarine HV Cables".

Since then, significant quantities of cables and accessories have been installed and the associated technology and laying techniques have matured and evolved.

The voltage range to be considered will be limited to transmission voltage levels of 60 kV and above, AC and DC transmission and both land and submarine cables are included in the study.

2. TERMS OF REFERENCE

To update the service experience to the end of 2005, using a format comparable to earlier publications. Published information is to include:

- Land and submarine cables
- Type of current (AC, DC)
- Technology (the main designs of cables in use)
- Mode of installation (Land Cables: direct burial, tunnels, troughs, duct banks and Submarine Cables: protected or unprotected)
- Internal and external faults
- Number of faults per year

The voltage range was limited to 60 kV and higher according to the transmission levels of the various countries.

3. QUESTIONNAIRE AND DATA REQUIRED

The earlier work identified the factors to be considered in carrying out the surveys.

For this new work, an electronic questionnaire with interactive windows, guidance notes and validation features was prepared to facilitate the work of responders and reduce the risk of errors. Two documents were prepared for Utilities, one dealing with land cable systems and a second with submarine cable systems. In order to be able to collect more information, a third questionnaire was also prepared for submarine cable systems suppliers.

The data required included the lengths of underground and submarine cable that had been installed in recent years and the faults that have occurred over these periods.

The land cable questionnaire dealt with the five year period from the beginning of 2001 to the end of 2005, whilst the submarine questionnaire looked at a longer period from 1990 to the end of 2005.

Responders were invited to provide identification and contact details.

The survey was designed to collect the quantities of cables in service at the end of December 2005 and in the case of land cables, the annual quantities of cables and Accessories installed during the reporting period. In addition, it collected data on faults.

Information useful to other CIGRE working groups working in the areas of cable life and third party external cable damage was also requested. Further details of the data requested and definitions of terms are given in appendices 1 and 2.

4. CONFIDENTIALITY

Responders were assured that the information contained in the responses would remain confidential to CIGRE and the precise individual responder (Utility or Country) details will not be disclosed.

Only global statistics will be published, similar to those previously published.

5. CRITERIA FOR REPORTING FAILURES

DEFINITION OF A FAILURE

A failure is defined as “Any occurrence on a cable system which requires the circuit to be de-energised.”

Failures during commissioning or re-commissioning tests are excluded.

CLASSIFICATION OF FAILURES

Two categories of failure are defined follows;

1. Instantaneous failure leading to automatic disconnection
2. Occurrence requiring subsequent unplanned outage

Note

Further information including definitions of the cable systems considered can be found in the Appendices.

6. COLLECTED DATA AND COMPARISONS WITH PREVIOUS SURVEYS

Land Cables

The response to the land cable questionnaire covered 73 Utilities from 24 different countries. Replies were not received from some important cable users including Australia, New Zealand, China, India, Malaysia, Mexico, Russia, Hong Kong, Thailand, Africa and the Middle East. In some countries not all the Utilities within that country provided data.

A full list of participating countries is given in the Appendix 3.

In some cases not all the information requested in the questionnaire was provided, for example, the number of accessories were not available in 5 replies (8%) and there were no faults reported in 19 replies (29%).

Comparing the quantity of cable identified in the replies received (appendix 1) to other surveys (refs 6, 7, 8), it is felt that the data collected is representative and worthy of analysis and reporting. Extensive checking and validation of the data was carried out.

The table below shows the quantities of cables reported in recent surveys compared to this actual WG B1-10 land cable survey and old Electra 137 survey. There is a large difference in the data which results from the diversity in the scope of the surveys and in the questions posed. The EHV World wide survey dealt only with extruded cable systems. The questions posed in the WG B1-07 and the EU surveys were very straight forward and simple to answer. The WG B1-10 questions were rather extensive and as a consequence the replies were fewer.

CIRCUIT KM OF CABLES FROM OTHER SURVEYS					
<i>Name / year of survey</i>	<i>CIGRE B1-10 / 2008</i>	<i>Electra 137 / 1991</i>	<i>Worldwide EHV / 2006</i>	<i>CIGRE B1-07 / 2007</i>	<i>EU Commision / 2003</i>
<i>Voltage Range (kV)</i>					
<i>60-109</i>	18000	3646	0	24859	0
<i>110-219</i>	9500	717	0	22406	16000
<i>220-314</i>	4500	1591	2000	5555	1720
<i>315-500</i>	1000	239	200	1586	120
<i>>500</i>	0	2	0	0	0
<i>TOTAL</i>	33000	6195	2200	54406	17840

Submarine Cables

The WG B1-10 questionnaire was rather extensive taking time to collect the information and as a consequence it appears that utilities were unable or reluctant to complete the questionnaire.

The response from the submarine cable questionnaire resulted in 32 replies being received from 16 countries. In some cases not all the information requested in the questionnaire was provided, for example, the number of accessories were not available in 2 replies (6%) and there were no faults reported in 14 replies (45%). Some utilities that did not report faults were contacted and confirmed that they had no failures during the reporting period.

In order to obtain additional data, a supplementary questionnaire was prepared and sent to the main suppliers of submarine cable systems. A very positive response was obtained and following some validation of the data with various bodies, it is believed that the data is representative and sound. It is felt that the information received for the period in question (1990 to 2005) is reasonably complete.

Long submarine cables may have a number of factory made joints prior to armouring of the long delivery length. It is believed that most utilities do not have such information easily available. Consequently, it is probable that the number of joints has been underreported. Similarly, there could be some underreporting of terminations, transition joints and ancillary equipment at the submarine cable – land interface.

The fault analysis is based on information provided for the fifteen year period 1990 to 2005.

Failure Rates

Failure rates were estimated for the various cable circuit kilometer or failed components separately by the formula:

$$\text{Failure rate} = \frac{\sum_{i=1}^5 N_i}{\sum_{i=1}^5 A_i} \times 100$$

No. of failure / 100 ct. km yr
or
No. of failure / 100 comp. yr

Where: N_i = Number of failures of the component considered during the i - th year of the period concerned

A_i = Quantity of the component in service at the end of the i - th year (ct. km or No.)

Caution should be used when interpreting failure rates, particularly in cases when the size of the data population is small. The failure rate for components has been adopted from the previous publications and is expressed as the no. of faults per 100 units.

Failure rates are mean failures rates and it is not appropriate to use them to calculate MTBF (mean time between failures) and availability of circuits.

7. ANALYSIS AND RESULTS – LAND CABLES

List of tables and graphs for land cable systems

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Table 1 Quantities of AC land cables in service at the end of 2005

CABLE TYPE	SHEATH/BARRIER TYPE	VOLTAGE RANGE kV			
		60 to 109	110 to 219	220 to 314	315 to 500
SCOF	N/A	3300	4116	2342	724
HPOF	N/A	121	474	579	24
GC	N/A	68	592		
PILC	N/A	522			
EPR	Extruded or welded metallic barrier	11	137	1	
	No radial moisture barrier		16		
PE	Extruded or welded metallic barrier	497	60	397	1
	No radial moisture barrier	125	7		
	Laminated barrier	9			
XLPE	Extruded or welded metallic barrier	3161	2609	1114	229
	No radial moisture barrier	4480	415	1	
	Laminated barrier	5683	1057	23	21
Total installed AC circuit length to the end of 2005 (km)		32917	17978	9483	4457
% (Polymeric cables)		61	78	45	34
% (Paper cables)		39	22	55	66

A total of 32917 circuit km was reported. This quantity compares to 6195 km in the last CIGRE survey.

The following comparative information can be obtained from this table:

- 84 % of cables are in the voltage range below 220 kV
- There were no cables reported above 500kV
- 57 % of all cables are XLPE insulated
- 32 % of all cables are SCOF insulated. No differentiation was made between paper and PPL insulated cables
- SCOF and XLPE insulated cables account for 89% of all reported cables and are the predominant two technologies
- In the voltage range 60 to 219 kV, 63 % of cables are XLPE and 27% are SCOF
- At 220 kV and above, 25 % of cables are XLPE whereas 43% are SCOF (XLPE being a relatively new technology)
- Among XLPE cables, metallic or laminated water barriers are used in 74% of all cable designs. Below 220 kV this figure is 72% and above 220 kV it is 100 %.
- Laminated barrier cable designs account for 36 % of all designs (39 % below 220 kV and 3 % above 220 kV).
- Of the "other cable types", HPOF accounts for 4% of installed cable and 11% of cable at 220 kV and above

Table 2 Quantities of AC land accessories and components in service at the end of 2005

AC ACCESSORIES		VOLTAGE RANGE kV			
CABLE TYPE	COMPONENT TYPE	60 to 109	110 to 219	220 to 314	315 to 500
Extruded cables (EPR, PE or XLPE)	Premoulded Straight joint	12180	4815	1876	336
	Site Made Straight joint	110231	17480	2386	394
	Transition joint	1026	310	7	
	Outdoor Termination - Fluid filled - Porcelain	39556	6670	1434	59
	Outdoor Termination - Fluid filled - Composite insulator	493	2126	49	12
	Outdoor Termination - Dry - Porcelain	511	1443		
	Outdoor Termination - Dry - Composite insulator	1109	244	17	36
	GIS or Transformer Termination - Fluid filled	2225	1997	2254	193
	GIS or Transformer Termination - Dry	15604	5167	625	12
SCOF Cables	Straight joint	20761	25744	10909	2936
	Stop joint	526	2423	929	442
	Transition joint	12	190	13	
	Outdoor Termination Porcelain	7230	5203	3367	775
	Outdoor Termination Composite Insulator	9	12		
	GIS or Transformer Termination - Fluid filled	1189	1997	2809	1023
HPOF Cables	Straight joint	500	859	904	19
	Stop joint	29	27	8	8
	Trifurcating Straight joint	6	39	36	2
	Trifurcating Stop joint			8	
	Outdoor Termination Porcelain	64	732	214	30
	GIS or Transformer Termination - Fluid filled	3	35	109	
PILC	Straight joint	3096			
	Outdoor Termination Porcelain	1014			
	GIS or Transformer Termination - Fluid filled	126			
GC Cables	Straight joint	282	912		
	Outdoor Termination Porcelain	94	286		
	GIS or Transformer Termination	10	89		
	Transltion joint	0	41		
Total number of installed AC accessories to the end of 2005	330958	217886	78841	27954	6277

Over 330,000 accessories were reported.

The following information can be obtained from this table:

- 90 % of all accessories are in the voltage range below 220 kV
- 70 % of all accessories are of extruded type whereas 30 % are of paper type
- 67 % of all accessories are joints whereas 33% are terminations
- Transition joints are listed under both SCOF and XLPE; only 1600 are in service (0.7%)
- About 8% of the installed outdoor terminations for XLPE cables are of the composite type.

Table 3 Quantities of DC land cables in service at the end of 2005

DC CABLES		VOLTAGE RANGE kV			
		60 to 109	110 to 219	220 to 314	315 to 500
SCOF, paper			134	20	158
Polymeric Extruded, laminated barrier		265	181		
Total installed DC circuit length to the end of 2005 (km)	758	265	315	20	158
% (Polymeric cables)	59	100	57	0	0
% (Paper cables)	41	0	43	100	100

A total of 758 circuit km of DC land cable was reported.

- Polymeric cables account for 59 % of this total. 100 % of these cables are operated below 220kV.
- SCOF cables account for 41 % of this total. Among these, 43 % are used below 220 kV and 57 % above 220 kV.
- Only SCOF cables are reported above 220 kV

Table 4 Quantities of DC land accessories and components in service at the end of 2005

DC ACCESSORIES		VOLTAGE RANGE kV			
CABLE TYPE	COMPONENT TYPE	60 to 109	110 to 219	220 to 314	315 to 500
Extruded cables	Premoulded Straight joint	385	400		
	Site Made Straight joint				
	Outdoor Termination - Fluid filled - Porcelain				8
	Outdoor Termination - Fluid filled - Composite insulator				
	Outdoor Termination - Dry - Porcelain				
	Outdoor Termination - Dry - Composite insulator	150	60		
SCOF cables	Straight joint		687	8	146
	Stop joint				20
	Outdoor Termination Porcelain		2056	26	3
	Outdoor Termination Composite Insulator				
Total number of installed DC accessories to the end of 2005	3949	535	3203	34	177

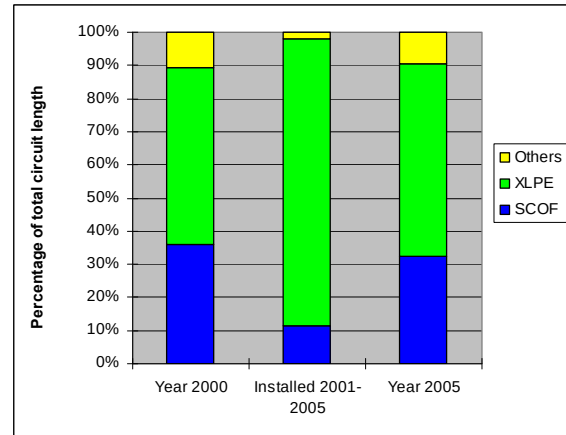
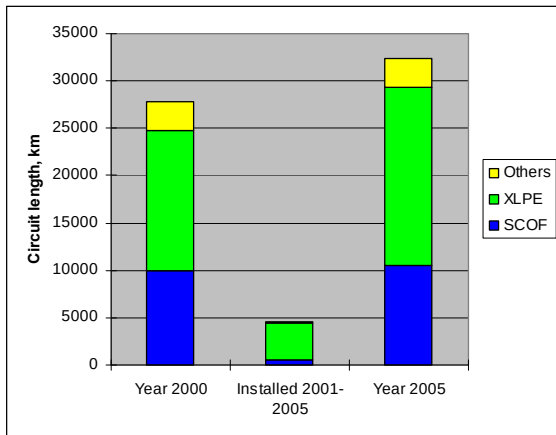
Almost 4000 DC land accessories were in service at the end of 2005.

- 75% of all DC land accessories reported is installed on SCOF. Among these 93 % are below 220kV.
- 25% of all DC land accessories are installed on extruded insulated cable below 220kV.

Figure 5 AC land cables installed between 2000 and 2005

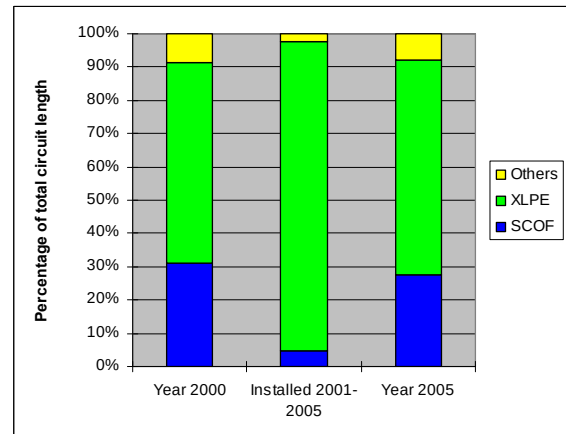
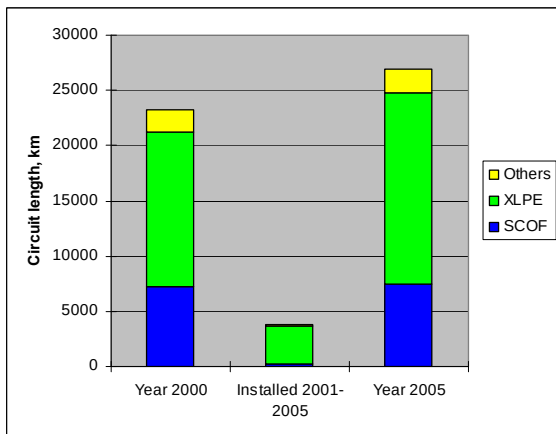
Voltage range

All voltages



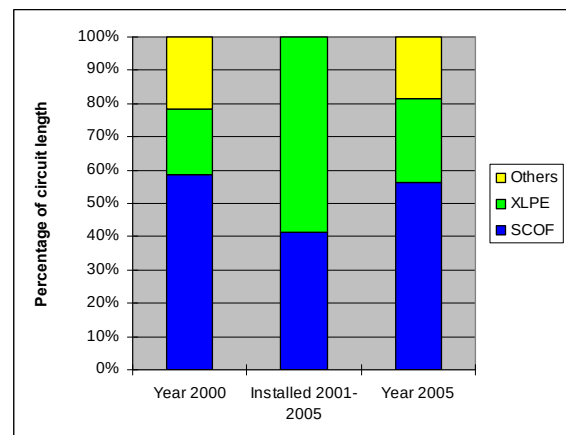
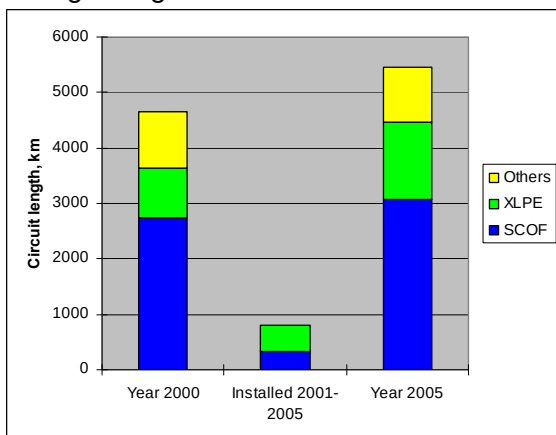
Voltage range

60-219 kV



Voltage range

220 kV and above



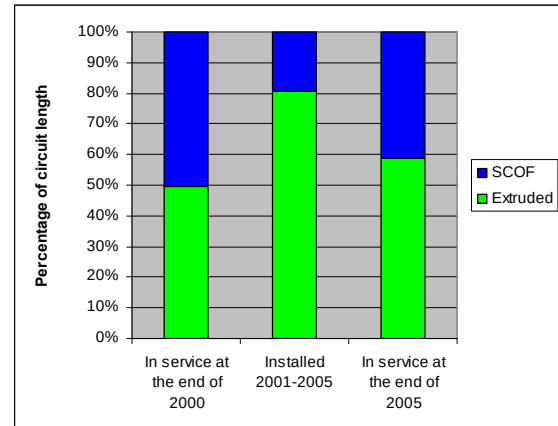
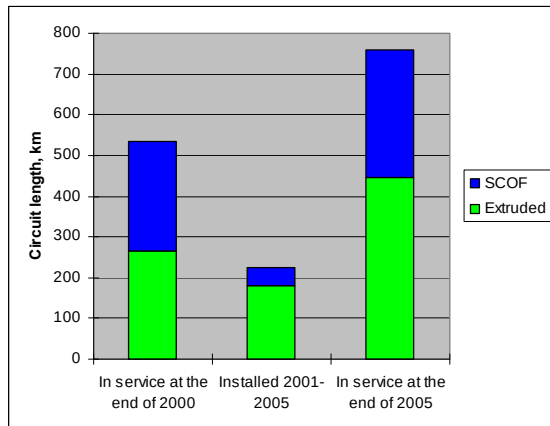
Since the year 2000;

- Almost all installed AC cables (98%) have been XLPE or SCOF cables with XLPE being the preferred cable type (87%).
- No PILC cables have been installed.
- PE insulated cables are no longer being utilised
- At voltages below 220 kV more than 93% of the cable circuit length installed from 2001 to 2005 was of the XLPE type.
- For voltage levels above 220 kV SCOF cables still account for 41% of the cables installed.
- The trend towards the use of XLPE will continue and its use will grow at the higher voltage level.

Figure 6 DC land cables installed between 2000 and 2005

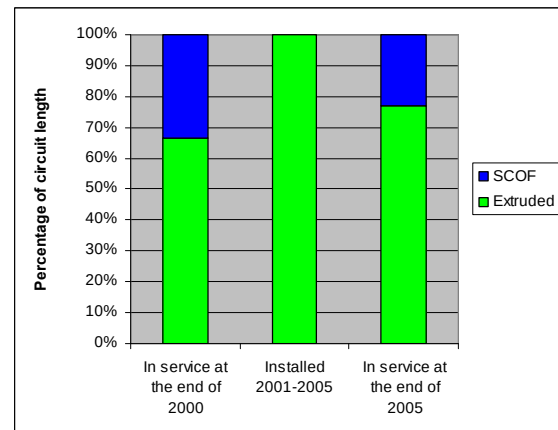
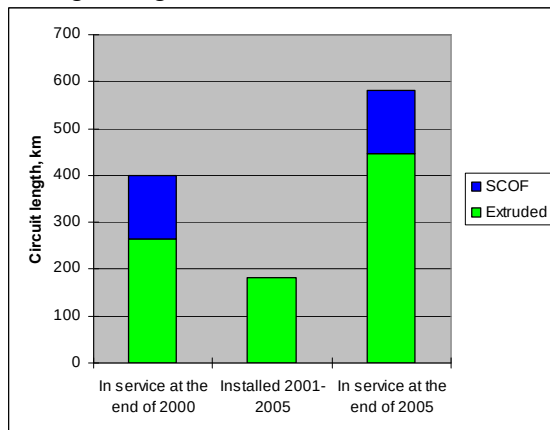
Voltage range

All voltages



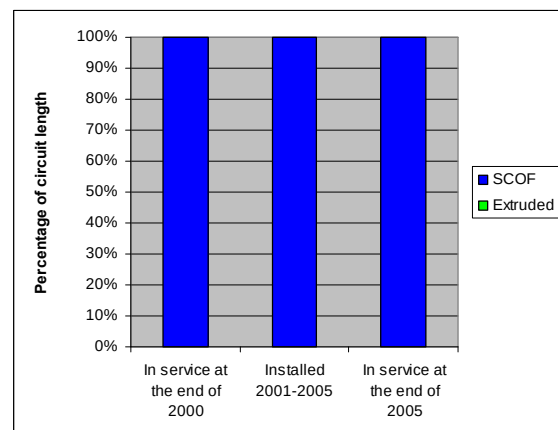
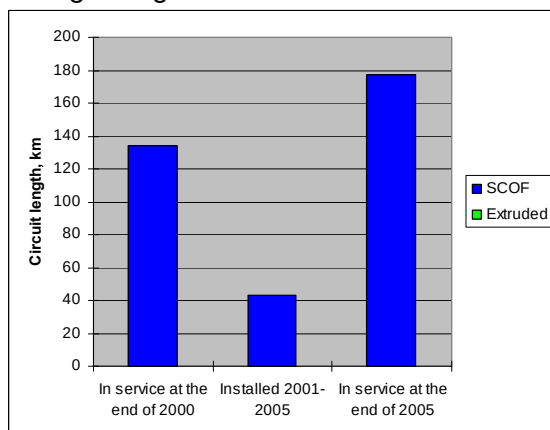
Voltage range

60-219 kV



Voltage range

220 kV and above



During the years 2001 to 2005, extruded cables have become the most widely used DC cable type for land applications.

- At voltages below 220 kV, all DC land cables installed are of the extruded type.
- At voltages above 220 kV, SCOF cables have been exclusively installed.

Table 7 AC land accessories installed between 2000 and 2005

	VOLTAGE RANGE kV		60 to 109					110 to 219					220 to 314					315 to 500						
	Joint Type	Year of Installation	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005		
Extruded cables (EPR, PE or XLPE)	Premoulded Straight joint		380	746	1005	1370	1286	182	429	836	633	559	60	117	264	162	62					96	56	
	Site Made Straight joint		1360	1142	558	1109	513	1221	1695	1609	1119	1217		27		3	3				150			
	Transition joint		19	36	41	86	11	48	39	43	67	60				3								
	Outdoor Termination - Fluid filled - Porcelain		531	753	513	483	600	267	282	546	226	187	135	63	102	66	60	12						28
	Outdoor Termination - Fluid filled - Composite insulator		27	15	21	24	21	131	128	163	190	285			6	9	3							12
	Outdoor Termination - Dry - Porcelain		12	27	15	24	51	159	216	51	63	162												
	Outdoor Termination - Dry - Composite insulator		75	69	96	186	138	32	35	83	32	41					12					36		
	GIS or Transformer Termination - Fluid filled			6	5	2	3	116	77	130	98	106	54	30		3	3							12
	GIS or Transformer Termination - Dry		311	296	225	190	225	394	565	447	366	389	135	12	42	27	42				12			
	SCOF Cables	Straight joint		17	32	21	90	84	552	249	453	144	132					15	255	348	266	18	12	
Stop joint			6	9		10	3	130	37	69	18	25						42	66	49	9	3		
Transition joint								33	27	27	30	27												
Outdoor Termination Porcelain			12	30		36	27	6	24		6	7					15	12		27	6			
Outdoor Termination Composite Insulator																		6	9		9	3		
GIS or Transformer Termination - Fluid filled			2	4	23	6	5	87	38	62	12	27					9	72	18	18		3		
HPOF Cables	Straight joint				27		5	12	16	18	1	2			2	1								
	Stop joint																							
	Trifurcating Straight joint																							
	Trifurcating Stop joint																							
	Outdoor Termination Porcelain				15		15	18	27		3													
	GIS or Transformer Termination - Fluid filled				3			3																
GC Cables	Straight joint																							
	Outdoor Termination Porcelain																							
	GIS or Transformer Termination																							
	Transition joint									24	12													
	Total number of installed AC accessories per year		2752	3165	2523	3661	2967	3378	3874	4586	3034	3228	386	249	414	275	225	399	441	522	174	129		

- 89% of all installed accessories are of extruded cable types.
- 11% of all installed accessories are of SCOF cable type.
- Among installed joints for extruded cables, 41% are of the pre-molded type and 59% are still site-made.
- Among all installed outdoor terminations, 24% are of the composite type and 76% are using a porcelain insulator.

Table 8 DC land accessories installed between 2000 and 2005

CABLE TYPE	VOLTAGE RANGE		60 to 109					110 to 219					220 to 314					315 to 500				
Extruded cables (EPR, PE or XLPE)	Joint Type	Year of Installation	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005	2001	2002	2003	2004	2005
	Premoulded Straight joint								400													
	Site Made Straight joint																					
	Outdoor Termination - Fluid filled - Porcelain																					
	Outdoor Termination - Fluid filled - Composite insulator																					
	Outdoor Termination - Dry - Porcelain																					
	Outdoor Termination - Dry - Composite insulator								60													
SCOF Cables	Straight joint																		50			
	Stop joint																		4			
	Outdoor Termination Porcelain																		2			
	Outdoor Termination Composite Insulator																					
	Total number of installed DC accessories per year								460										56			

Table 9 Summary of the total number of faults on land cable systems reported 2000 to 2005

Table of reported faults							
Cable type	Type of fault	Faulty Component					
		Cable	Joint	Termination	Other Component	Unspecified component	Total
XLPE	Internal	26	40	28	2		96
	External	47	13	17	2		79
	Unknown (int. or ext.)	3	6	5	0		14
	Total	76	59	50	4	0	189
SCOF	Internal	21	12	11	6		50
	External	53	5	9	1		68
	Unknown (int. or ext.)	3	3	4	0		10
	Total	77	20	24	7	0	128
PE	Internal	9	1	21	0		31
	External	33	3	6	0		42
	Unknown (int. or ext.)	3	0	5	0		8
	Total	45	4	32	0	0	81
HPOF	Internal	13	6	3	7		29
	External	19	7	2	7		35
	Unknown (int. or ext.)	1	0	1	2		4
	Total	33	13	6	16	0	68
GC	Internal	10	1	3	1		15
	External	4	0	6	4		14
	Unknown (int. or ext.)	0	0	2	2		4
	Total	14	1	11	7	0	33
EPR	Internal	0	0	2	0		2
	External	4	0	0	0		4
	Unknown (int. or ext.)	0	0	0	0		0
	Total	4	0	2	0	0	6
PILC	Internal	244	9	4	1	1	259
	External	49	1	2	4		56
	Unknown (int. or ext.)	0	0	1	0		1
	Total	293	10	7	5	1	316
DC - SCOF	Internal	0	18	0	0		18
	External	0	0	0	0		0
	Unknown (int. or ext.)	0	0	0	0		0
	Total	0	18	0	0	0	18
AC - Unspecified cable Type	Internal	0	0	1	0		1
	External	3	4	1	0		8
	Unknown (int. or ext.)	4	1	0	0	0	5
	Unspecified	0	0	0	0	2	2
	Total	7	5	2	0	2	16
Total per faulty component:		549	130	134	39	3	855
					Grand Total:		855

A total 855 faults were reported on land cable systems over the five years ending December 2005.

- Details of the faults for each cable type and component are given in Table 10.
- Two of the faults reported were not classified as cable or component.
- The faults (316) that were reported on PILC cables are related to the age of these cable systems. These cable systems have reached the end of their useful life.
- XLPE cable and accessories failed in 189 occasions whereas SCOF components failed in 128 occasions.
- For XLPE cables, 55% of the failures are internal whereas for SCOF 42% are internal.

- For AC cables (excluding PILC), internal failures account for 33% of all failures against 67% for external failures, i.e. 2 external faults for every internal fault when only cables are considered.
- In the case of GC and HPOF cables, the ratio between external faults and internal faults is about one to one, almost certainly as the result of a better inherent mechanical protection
- When all types of cables (excluding PILC) and all components are considered (cable and accessories), this ratio becomes almost one to one (48% internal and 52 % external).
- All faults on DC SCOF cable can be attributed to one project.

Table 10 Analysis of land cable faults

The following tables provide details of the origin of the faults, (an internal or external fault) and results of an analysis identifying the cause of the fault.

For the external faults, the reported faults reported are only external faults with an immediate breakdown or an unplanned outage of the cable system. External faults which do not lead to an immediate breakdown or an unplanned outage were not reported.

Due to the high number of reported faults on PILC cable systems, the PILC faults have been treated separately.

Table 10a PILC land cable faults

PILC Cables - Number of faults			
Voltage range [kV]	Cause of failure	Direct Burial	%
60 to 219	External - Abnormal System Conditions	2	1%
	External - Other Physical External Parameters	9	3%
	External - Third Party Mechanical	42	14%
	Internal	258	83%
	Total	311	100%

Table 10a gives us the number of reported faults on PILC cables by cause of failure. The majority of these faults are internal faults due to the age of this type of cable system.

This type of cable systems are used up to voltage levels of 90kV.

Table 10b AC land cables (excl PILC) internal and external faults

AC Land cables (PILC excluded) - Number of Internal and External Faults								
Voltage range [kV]	Mode of Installation	Bridges	Direct Burial	Ducts	In air	Troughs	Tunnels	Grand Total
60 to 219	External - Abnormal System Conditions		8	1	1			10
	External - Other Physical External Parameters		32	4	9			45
	External - Third Party Mechanical		111	11	1	8		131
	Internal		99	20	12		17	148
	Total	0	250	36	23	8	17	334
220 to 500	External - Abnormal System Conditions		3					3
	External - Other Physical External Parameters		14	2		2	2	20
	External - Third Party Mechanical	1	28	3		2		34
	Internal		59	5	1	2	7	74
	Total	1	104	10	1	6	9	131
60 to 500	Grand Total	1	354	46	24	14	26	465

Table 10b gives the number of faults for AC land cables (excluding PILC systems) as a function of the mode of installation.

Table 10c AC land cables (excl PILC) percentage of internal and external faults

AC Land cables (PILC excluded) - Percentage Internal and External Faults to total number of faults								
Voltage range [kV]	Mode of Installation	Bridges	Direct Burial	Ducts	In air	Troughs	Tunnels	Grand Total
60 to 219	External - Abnormal System Conditions	0%	2%	0%	0%	0%	0%	2%
	External - Other Physical External Parameters	0%	7%	1%	2%	0%	0%	10%
	External - Third Party Mechanical	0%	24%	2%	0%	2%	0%	28%
	Internal	0%	21%	4%	3%	0%	4%	32%
	Total	0%	54%	8%	5%	2%	4%	72%
220 to 500	External - Abnormal System Conditions	0%	1%	0%	0%	0%	0%	1%
	External - Other Physical External Parameters	0%	3%	0%	0%	0%	0%	4%
	External - Third Party Mechanical	0%	6%	1%	0%	0%	0%	7%
	Internal	0%	13%	1%	0%	0%	2%	16%
	Total	0%	22%	2%	0%	1%	2%	28%
60 to 500	Grand Total	0%	76%	10%	5%	3%	6%	100%

Two voltage classes, 60 to 219kV and above 220kV have been considered.

- Almost 50% of faults were internal failures and 50% were external faults.
- Of the internal faults, 60% of these were in the lower voltage class
- 77% of faults occurred in cables that were direct buried.
- There is no explanation why 36% of these were internal failures and caution is advised in drawing any conclusions.
- Unfortunately information relating to the quantities of cable installed in each mode of installation is not available.
- 70% of all faults occur at the lower voltage levels.
- Third party mechanical damage accounts for 34% of all faults.

Table 10d AC land cables number of external faults

AC Land cables (PILC excluded) - Number of External Faults								
Voltage range [kV]	Mode of Installation	Bridges	Direct Burial	Ducts	In air	Troughs	Tunnels	Grand Total
60 to 219	External - Abnormal System Conditions		8	1	1			10
	External - Other Physical External Parameters		32	4	9			45
	External - Third Party Mechanical		111	11	1	8		131
	External Total	0	151	16	11	8	0	186
220 to 500	External - Abnormal System Conditions		3					3
	External - Other Physical External Parameters		14	2		2	2	20
	External - Third Party Mechanical	1	28	3		2		34
	External Total	1	45	5	0	4	2	57
60 to 500	External Grand Total	1	196	21	11	12	2	243

Table 10d are the reported external faults referred to the mode of installation.

The questionnaire did not request information regarding installed circuit lengths as a function of mode of installation. However based on the information received, it can be concluded that the total length of direct buried cables and cables installed in ducts or tunnels is almost the same. Based on the reported faults it can be concluded that direct buried cable systems are about 10 times more likely to be damaged by external conditions than cable systems installed in ducts or tunnels.

Table 10e AC land cables percentage of external faults

AC Land cables (PILC excluded) - Percentage External Faults to total number of External faults								
Voltage range [kV]	Mode of Installation	Bridges	Direct Burial	Ducts	In air	Troughs	Tunnels	Grand Total
60 to 219	External - Abnormal System Conditions	0%	3%	0%	0%	0%	0%	4%
	External - Other Physical External Parameters	0%	13%	2%	4%	0%	0%	19%
	External - Third Party Mechanical	0%	46%	5%	0%	3%	0%	54%
	External Total	0%	62%	7%	5%	3%	0%	77%
220 to 500	External - Abnormal System Conditions	0%	1%	0%	0%	0%	0%	1%
	External - Other Physical External Parameters	0%	6%	1%	0%	1%	1%	8%
	External - Third Party Mechanical	0%	12%	1%	0%	1%	0%	14%
	External Total	0%	19%	2%	0%	2%	1%	23%
60 to 500	External Grand Total	0%	81%	9%	5%	5%	1%	100%

Table 10e gives the percentages related to the total number of reported external faults.

Almost 70% of external faults were third party mechanical damage. Directly buried cables are certainly more prone to external damage. However the effectiveness of the duct relies heavily on the design of the duct bank. Plastic pipes are not sufficient. The practice of patrolling cable routes to determine activities that may damage the cables remains an effective way to minimize damage to buried cables.

Table 11 Failure rates on the different types of AC land cable systems

		XLPE CABLES (AC)			SCOF CABLES (AC)		
A. Failure Rate - Internal Origin Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.027	0.067	0.030	0.014	0.107	0.041
Joint	Failure rate [fail./yr 100 comp.]	0.005	0.026	0.005	0.002	0.010	0.004
Termination	Failure rate [fail./yr 100 comp.]	0.006	0.032	0.007	0.005	0.015	0.009
B. Failure Rate - External Origin Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.057	0.067	0.058	0.095	0.141	0.108
Joint	Failure rate [fail./yr 100 comp.]	0.002	0.022	0.003	0.002	0.004	0.002
Termination	Failure rate [fail./yr 100 comp.]	0.005	0.018	0.006	0.009	0.013	0.010
C. Failure Rate - All Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.085	0.133	0.088	0.109	0.248	0.149
Joint	Failure rate [fail./yr 100 comp.]	0.007	0.048	0.008	0.004	0.014	0.006
Termination	Failure rate [fail./yr 100 comp.]	0.011	0.050	0.013	0.014	0.028	0.019

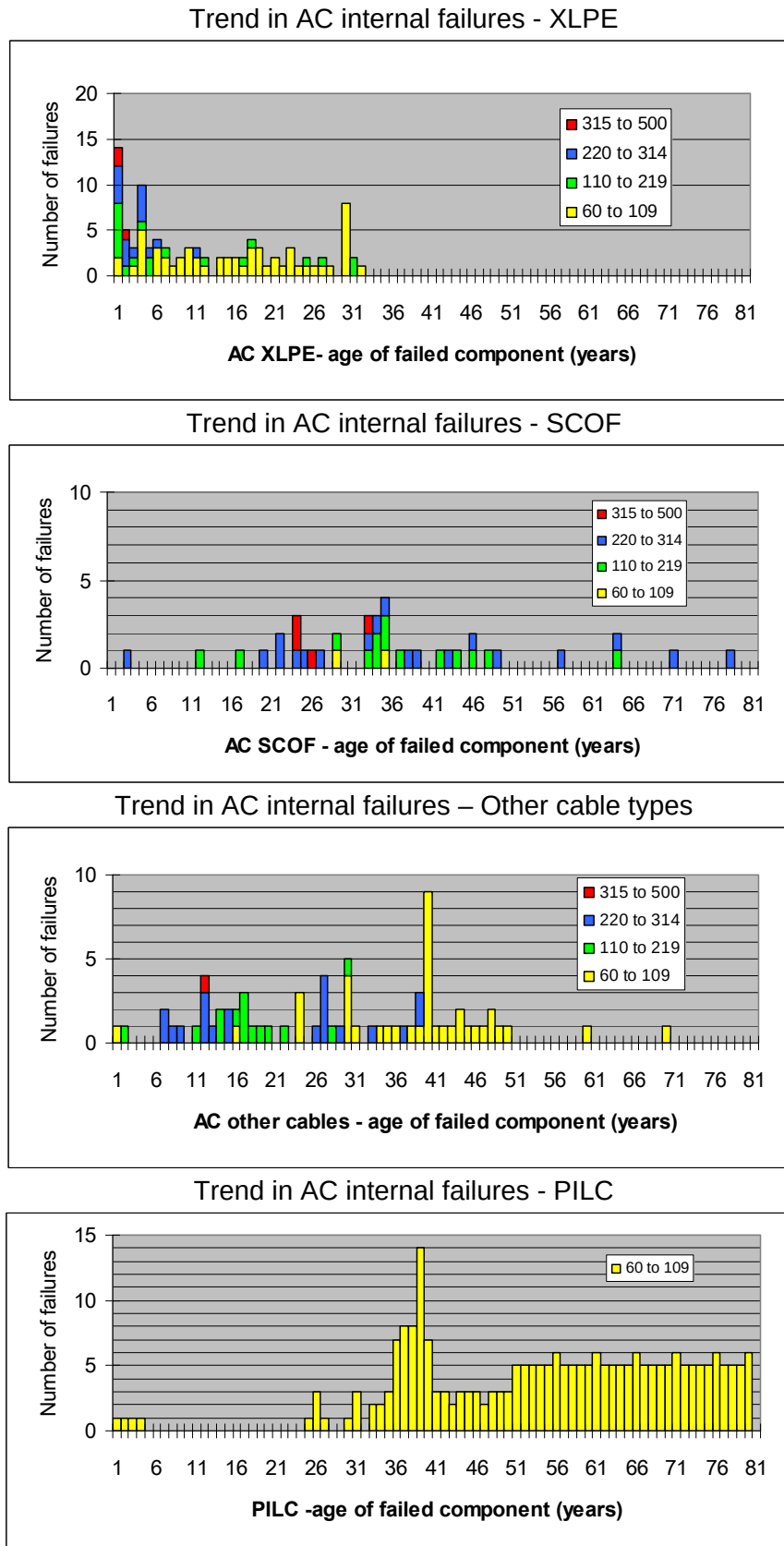
		HPOF, GC, EPR and PE CABLES (AC)			PILC CABLES (AC)		
A. Failure Rate - Internal Origin Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.299	0.020	0.208	9.387	NA	9.387
Joint	Failure rate [fail./yr 100 comp.]	0.053	0.020	0.044	0.058	NA	0.058
Termination	Failure rate [fail./yr 100 comp.]	0.218	0.907	0.366	0.070	NA	0.070
B. Failure Rate - External Origin Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.550	0.279	0.462	1.877	NA	1.877
Joint	Failure rate [fail./yr 100 comp.]	0.106	0.020	0.083	0.006	NA	0.006
Termination	Failure rate [fail./yr 100 comp.]	0.296	0.227	0.281	0.053	NA	0.053
C. Failure Rate - All Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.849	0.299	0.670	11.264	NA	11.264
Joint	Failure rate [fail./yr 100 comp.]	0.159	0.041	0.127	0.065	NA	0.065
Termination	Failure rate [fail./yr 100 comp.]	0.514	1.133	0.647	0.123	NA	0.123

Note; N/A not available

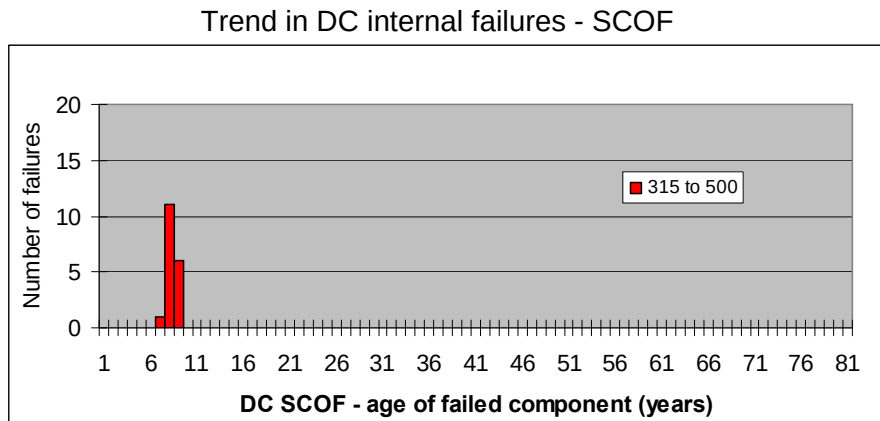
- The internal failure rates reflect the inherent performance of the cable system
- PILC cables have reached their end of life with a high level of internal failures.
- It is not possible to compare failure rates of cable and accessories due to different scaling factors
- Internal failure rates are greater at the higher voltage levels
- It should be noted that the average age of SCOF, HPOF and GC cable systems is significantly greater than extruded cable systems.
- Failure rates of SCOF include oil leaks reported as a failure.
- Internal failure rates of SCOF and XLPE cable are in line with previous data
- Further details regarding failure rates for different XPLE designs is given later

- Internal failure rates of accessories, particularly on XLPE cable, are of greater concern. Focus on quality control during jointing operations must be maintained.

Figure 12 Trends in internal failures of land cables as a function of the component age



- In terms of experience, XLPE cables have less service experience than the older pressurized insulation designs.
- Overall more failures are reported in AC XLPE cable than in AC SCOF cables.
- On the other hand there are also more XLPE cables installed than SCOF cables.
- XLPE cables operating in AC systems tend to fail at an earlier stage than the older technology designs.
- PILC cables have become problematic with a high failure rate after some 30 years.

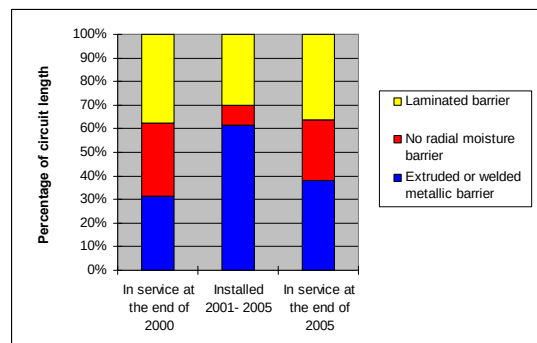
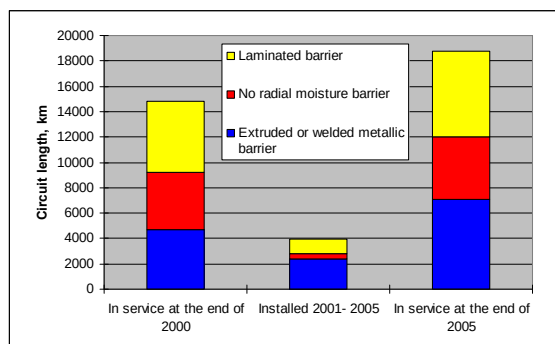


All faults on DC cables can be mainly attributed to one project.

Figure 13 Trends in design of XLPE AC land cables, moisture barriers

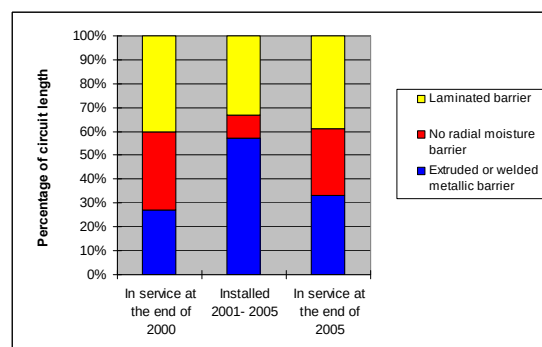
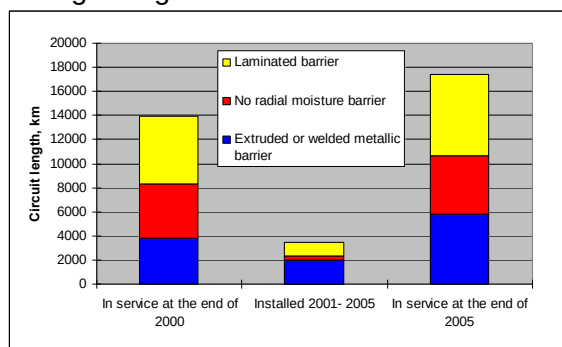
Voltage range

All voltages



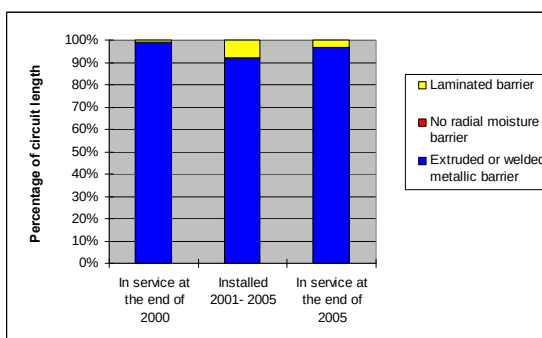
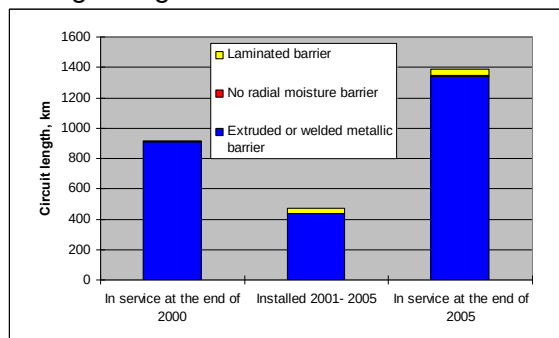
Voltage range

60-219 kV



Voltage range

220 kV and above



- In the period 2001 -2005 more than 90% of the installed XLPE cables had water barriers.
- Welded or extruded metallic barriers were chosen for around 60% of the cables.
- As cables in the voltage range 60-219 kV make up more than 90% of the total installed cable circuit length, the trend in this voltage range is almost the same as for the whole population.
- For voltages above 220 kV extruded or welded metallic barrier has been and still is the preferred solution.
- However, laminated barrier has now been introduced even at the highest voltage levels.

As regards failure rates a study was conducted to establish whether the cable design affected the failure rate. Considering the internal failure rates, the "barrier designs" demonstrate lower failure rates as expected, namely

0,046 for no metallic barrier;

0,016 for a laminated barrier

0,032 for extruded or welded metallic barrier;

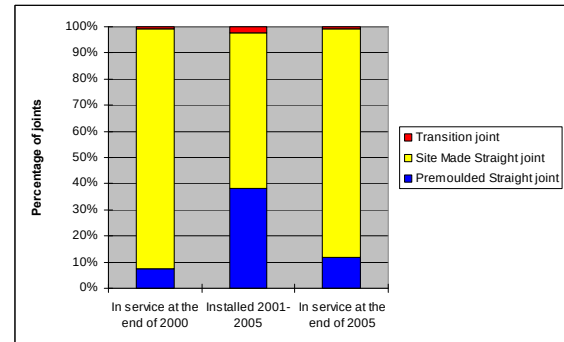
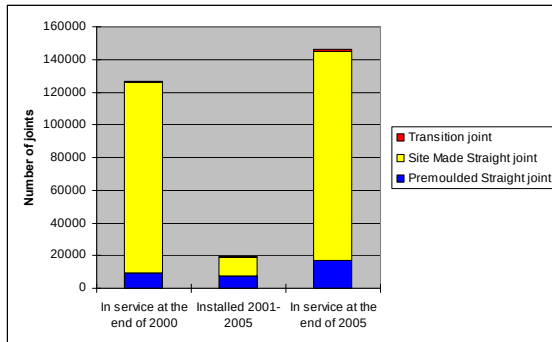
This analysis was based on 24000 circuit km of cable without a metallic barrier, 31000 circuit km for cables with a laminate sheath and 31000 circuit km with an extruded or welded metallic sheath.

Figure 14 Trends in design of XLPE AC land accessories

Figure 14a Joints

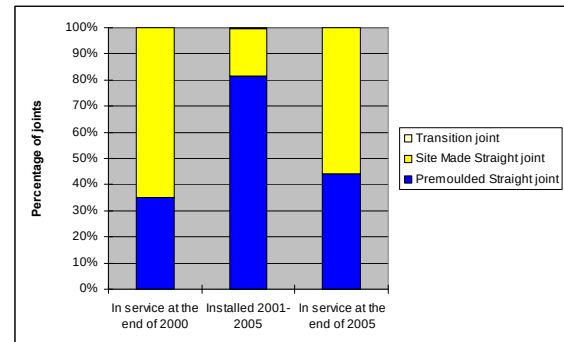
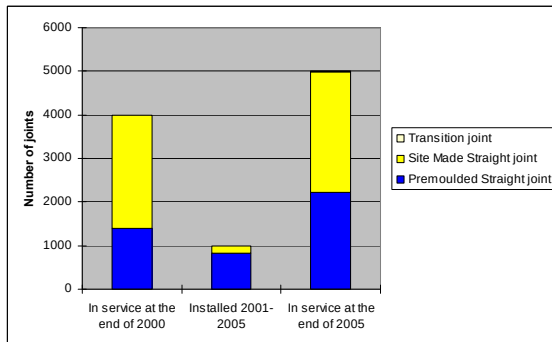
Voltage range

60-219 kV



Voltage range

220 kV and above

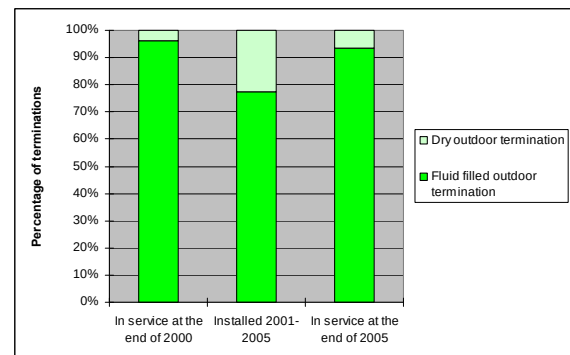
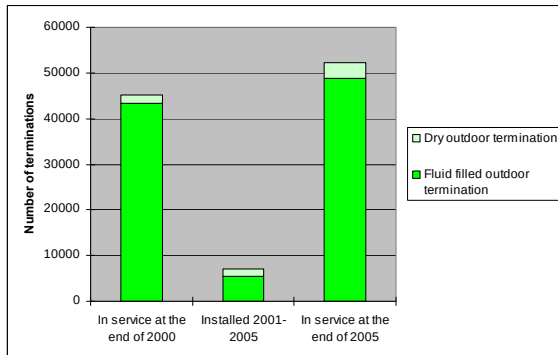


- The use of pre-moulded straight joints is increasing, but in the period 2001-2005 still only made up around 40% of the total number joints installed.
- Around 50% of the joints installed in that period were site made.
- For the highest voltage levels the trend towards using pre-moulded joints is very clear. More than 80% of the straight joints installed in 2001-2005 were of the pre-moulded type.
- There is some concern that there could have been some confusion regarding the definition and categorization of straight joints by some responders which may have affected the statistics presented.

Figure 14b Outdoor terminations

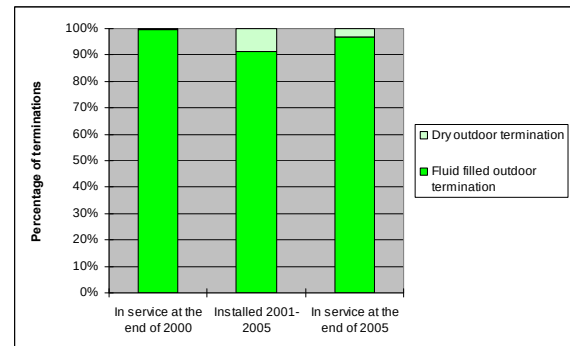
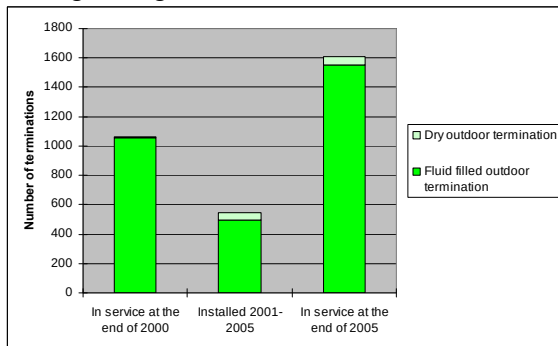
Voltage range

60-219 kV



Voltage range

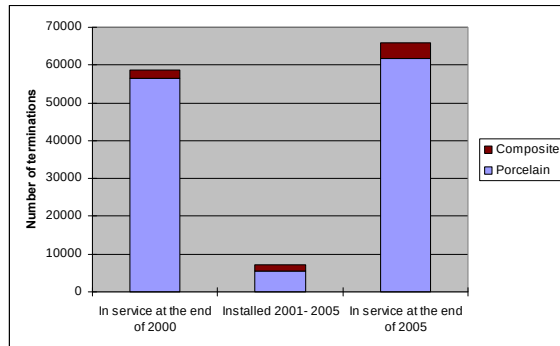
220 kV and above



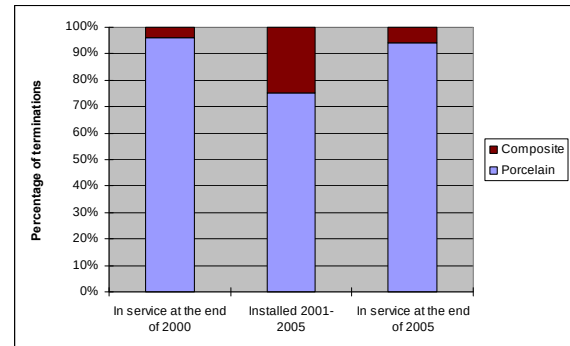
- For voltage levels below 220 kV, dry-type terminations make up more than 20% of the installed outdoor terminations in the period 2001-2005
- Around 94% of the outdoor terminations in service are fluid filled.

Figure 14c Insulators for outdoor terminations

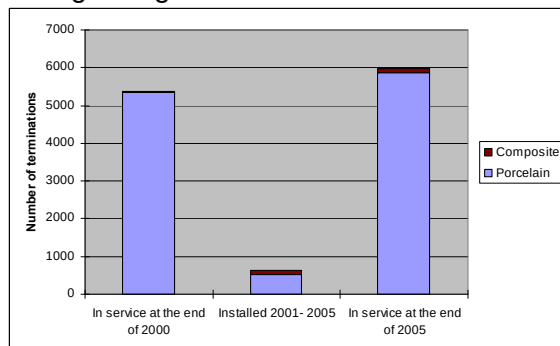
Voltage range



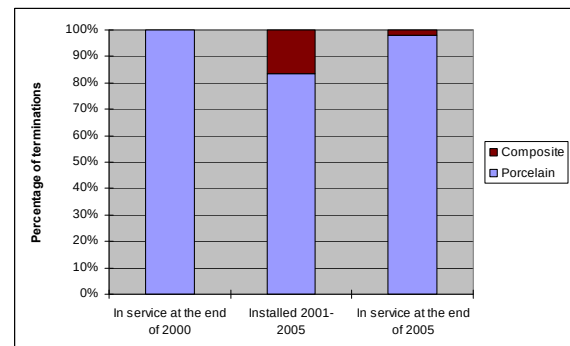
60-219 kV



Voltage range



220 kV and above

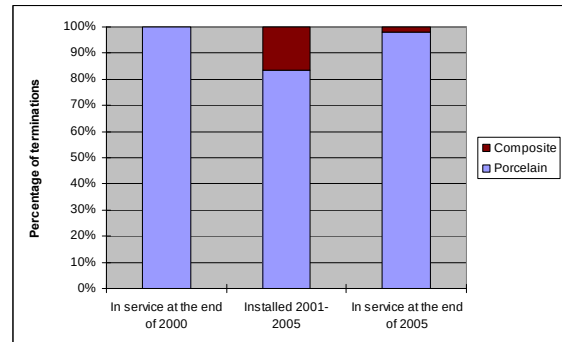
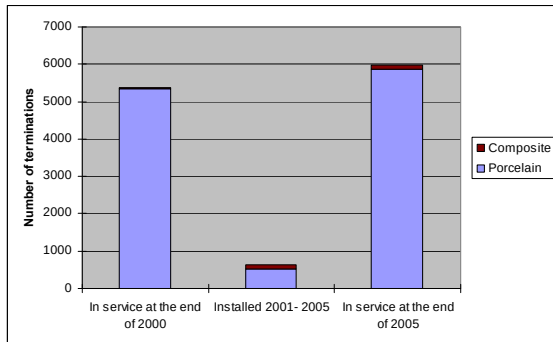


- The use of composite insulators is increasing in the voltage range 60 to 219 kV but porcelain was still preferred for around 75% of the terminations installed in 2001-2005.
- In 2000 no composite insulators had been installed at voltage levels above 315 kV, but this has now changed so that composite insulators are used at all voltages.

Figure 14d GIS terminations

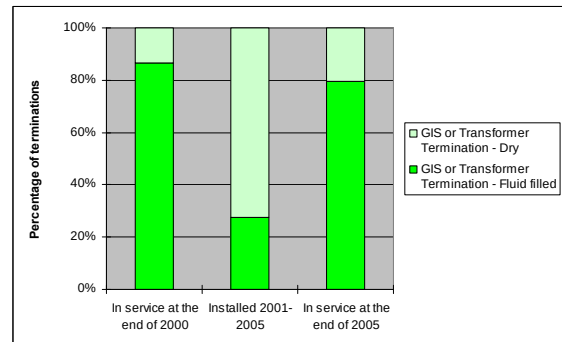
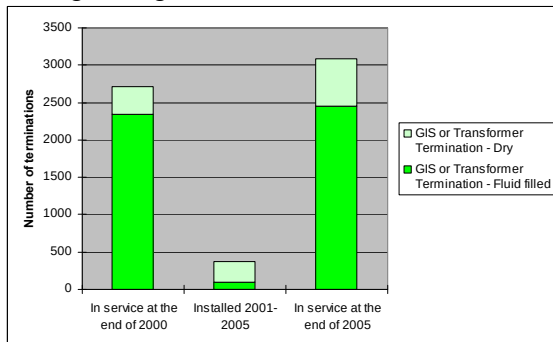
Voltage range

60-219 kV



Voltage range

220 kV and above



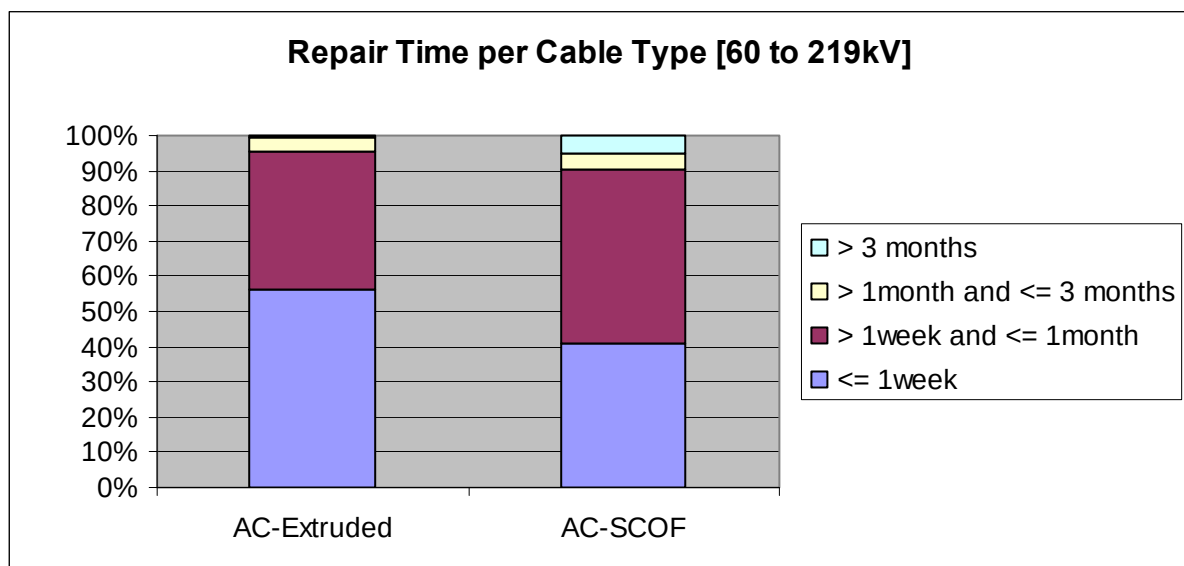
- There is little sign of change in the preferred design for 60-219 kV GIS or transformer terminations.
- Dry terminations accounted for more than 70% and are increasing.
- For voltages of 220 kV and above, dry GIS and transformer terminations are now superseding the fluid filled types

Figure 15 Outage times for AC land systems

The outage time of a system is defined as the period of time from the breakdown of the system (or unplanned outage) to the moment of re-energising the system. This includes the time of fault location, repair and testing.

Figure 15a and b shows the average repair time for the most common cable systems, extruded (XLPE, PE, EPR) and SCOF for the voltage ranges of 60 to 219kV and above 220kV.

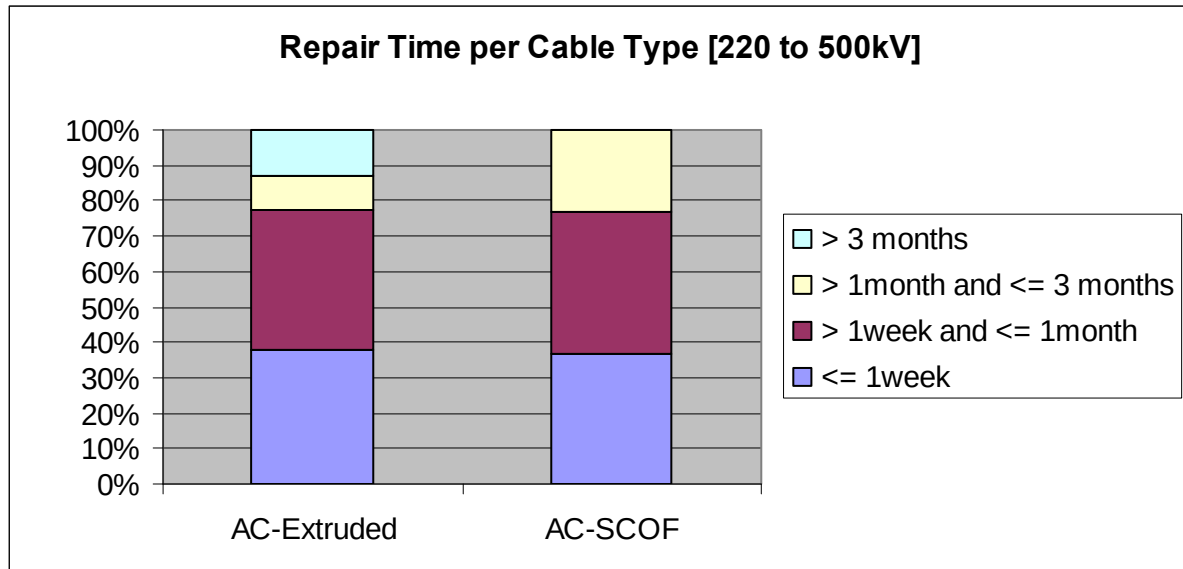
Figure 15a Repair times 60 to 219kV



For the voltage level of 60 to 219kV (figure 15a) it can be concluded that:

- 56% of AC extruded, 63% of AC-PILC cables are repaired within a week, compared to 41% for AC-SCOF cables
- 90% of all the cables are repaired within a month
- For 5% of the AC-SCOF cables, the repair takes longer than 3 months. (If the utility do not have spare cable in storage this may have major impact on outage time).

Figure 15b Repair times 220kV and above



For the voltage level of 220 to 500kV (figure 15b) it can be concluded that:

- There is practically no difference between AC-Extruded and AC-SCOF cables in terms of repair time
- Almost 80% of all the cables are repaired within a month
- All the AC-SCOF cables were repaired within 3 months
- The 13% of AC-Extruded cables which took more than 3 months for repair is probably due to a very low priority given to this repair.

Table 15c Average repairs times – type of land cable system

Average Repair time in Days per cable system type		
>1day and <6months	AC-Extruded	AC-SCOF
60 to 219 kV	15	20
220 to 500 kV	25	38

In table 15c you find the average repair time for Extruded and SCOF cable systems. In this calculation we have excluded the reported outage times less than 1 day and longer than 6 months.

For 60 to 219kV systems the difference in repair times is about 5 days, whereas for 220 to 500kV systems the difference is up to 14 days.

Table 15d Average repair time – mode of land installation

Average Repair time in Days per Mode of Installation		
>1day and <6months	Direct Burial	Ducts/Troughs/Tunnel
60 to 219 kV	14	15
220 to 500 kV	25	45

Table 15d gives the average repair time for the two most common modes of installation, direct burial and ducts/troughs/tunnels

For 60 to 219kV systems there is practically no difference, whereas for 220 to 500kV systems the difference is up to 20 days.

Table 16 Failure rates of AC land accessories

Voltage range kV	Cable type	Accessory tyoe	Total number of accessories in 2005	Total number of internal faults	Failure rate
60 to 219	Extruded (XLPE, PE or EPR)	Premoulded Straight joint	16995	13	0.028
		Site Made Straight joint	127711	13	0.002
		Transition joint	1336	2	0.035
		Outdoor Termination - Fluid filled - Porcelain	46226	7	0.003
		Outdoor Termination - Fluid filled - Composite insulator	2619	2	0.019
		Outdoor Termination - Dry - Porcelain	1954	2	0.024
		Outdoor Termination - Dry - Composite insulator	1353	0	0.000
		Outdoor Termination - Type not specified	0	6	
		Outdoor Terminations - Total	52152	17	0.007
		GIS or Transformer Termination - Fluid filled	4222	0	0.000
		GIS or Transformer Termination - Dry	20771	15	0.015
	SCOF	Straight joint	48843	1	0.000
		Stop joint	2949	4	0.028
		Transition joint	202	0	0.000
		Outdoor Termination Porcelain	13262	2	0.003
		Outdoor Termination Composite Insulator	22	0	0.000
	HPOF	GIS or Transformer Termination - Fluid filled	3306	2	0.012
		Straight joint	1359	4	0.060
		Stop joint	56	0	0.000
		Trifurcating Straight joint	45	0	0.000
		Trifurcating Stop joint	0	0	0.000
	GC	Outdoor Termination Porcelain	796	0	0.000
		GIS or Transformer Termination - Fluid filled	38	0	0.000
		Straight joint	1194	1	0.017
		Outdoor Termination Porcelain	380	2	0.105
		GIS or Transformer Termination	99	1	0.202
		Transition joint	41	0	0.000
220 to 500	Extruded (XLPE, PE or EPR)	Premoulded Straight joint	2212	4	0.044
		Site Made Straight joint	2780	2	0.015
		Transition joint	7	0	0.000
		Outdoor Termination - Fluid filled - Porcelain	1493	2	0.030
		Outdoor Termination - Fluid filled - Composite insulator	61	0	0.000
		Outdoor Termination - Dry - Porcelain	0	0	0.000
		Outdoor Termination - Dry - Composite insulator	53	0	0.000
		Outdoor Termination - Type not specified	0	13	
		Outdoor Terminations - Total	1607	15	0.215
		GIS or Transformer Termination - Fluid filled	2447	2	0.016
		GIS or Transformer Termination - Dry	637	2	0.071
	SCOF	Straight joint	13425	1	0.002
		Stop joint	1272	6	0.097
		Transition joint	13	0	0.000
		Outdoor Termination Porcelain	4142	5	0.024
		Outdoor Termination Composite Insulator	0	0	0.000
	HPOF	GIS or Transformer Termination - Fluid filled	3682	1	0.005
		Straight joint	923	1	0.022
		Stop joint	16	0	0.000
		Trifurcating Straight joint	38	0	0.000
		Trifurcating Stop joint	8	0	0.000
	GC	Outdoor Termination Porcelain	244	3	0.246
		GIS or Transformer Termination - Fluid filled	109	0	0.000
		Straight joint	0	0	0.000
		Outdoor Termination Porcelain	0	0	0.000
		GIS or Transformer Termination	0	0	0.000
		Transition joint	0	0	0.000

- The relatively poor performance of lower voltage pre-moulded joints is related to one installation.
- Within the data there are examples (approx 50% of cases where inadequate joiner training gives rise to a significant number of failures.
- In the case of transition joints the two failures represent a low statistical significance.
- The majority of reported problems with outdoor terminations are limited to one country.
- In the case of SCOF and GC cable accessories, the components with high failure rates are rather old.
- The failure rate of dry type GIS terminations is relatively high compared to the oil filled GIS terminations.

Table 17 Comparison of WG B1-10 data with earlier CIGRE Electra 137 publication

Component		CABLE SYSTEM										
		SCOF			XLPE				LDPE			
		ÉLECTRA	B1-10		ÉLECTRA	B1-10		ÉLECTRA				
		Voltage range (kV)	220 ≤ U ≤ 500	60 ≤ U ≤ 219	220 ≤ U ≤ 500	60 ≤ U ≤ 219	60 ≤ U ≤ 219	220 ≤ U ≤ 500	60 ≤ U ≤ 109	110 ≤ U ≤ 219		
Provisions against water penetration					No	Yes			No	Yes	No	Yes
Cable	Failure rate due to defects of internal origin (fail./100 ct.km.yr)	0.050	0.014	0.107	0.050	0.070	0.027	0.067				
	Failure rate due to defects of external origin (fail./100 ct.km.yr)	0.100	0.095	0.141	0.080	0.080	0.057	0.067				
	Failure rate due to defects of all origins (fail./100 ct.km.yr)		0.109	0.248	0.130	0.150	0.085	0.133				
	Average outage time (hours/fail.)	176			130							
Straight joint	Failure rate due to defects of internal origin (fail./100 ct.km.yr)	0.080	0.000	0.001	0.010					1.490		0.140
	Failure rate due to defects of external origin (fail./100 ct.km.yr)	0	0.001633813	0.00138303	0.003							
	Average outage time (hours/fail.)	420			93					315		190
Stop joint	Failure rate due to defects of internal origin (fail./100 ct.km.yr)	0.160	0.002	0.008					0.120		0.140	
	Failure rate due to defects of external origin (fail./100 ct.km.yr)	0	0	0.00276606								
	Average outage time (hours/fail.)	507									552	
Joint (All types)	Failure rate due to defects of internal origin (fail./100 ct.km.yr)		0.002	0.010			0.005	0.026				
	Failure rate due to defects of all origins (fail./100 ct.km.yr)		0.00367608	0.013830302			0.006809591	0.048358025				
	Average outage time (hours/fail.)											
Termination	Failure rate due to defects of internal origin (fail./100 ct.km.yr)	0.070	0.005	0.015	0.040		0.006	0.032	0.330		0.040	
	Failure rate due to defects of external origin (fail./100 ct.km.yr)	0.06	0.009033424	0.012873989	0.005		0.004942584	0.018252339				
	Average outage time (hours/fail.)	76			47				780		120	
Auxiliary oil equipmen	Failure rate due to defects of internal origin (fail./100 ct.km.yr)	0.320										
	Failure rate due to defects of external origin (fail./100 ct.km.yr)	0.07										
	Average outage time (hours/fail.)	39										
Other component	Failure rate due to defects of internal origin (fail./100 ct.km.yr)	0.190										
	Failure rate due to defects of external origin (fail./100 ct.km.yr)	0.08										
	Average outage time (hours/fail.)	59										
All components	Average outage time (hours/fail.)		478.0	917.0			351.0	594.0				

Summary of analysis of land cable

AC cable types

A total of almost 33000 circuit km of land AC cable was reported. This quantity compares to 6195 km in the last CIGRE survey.

57% of all cables in service are XLPE insulated and 32% of all cables are SCOF cable systems. SCOF and XLPE insulated cables account for 89% of all reported cables and are the predominant two technologies.

In the voltage range 60 to 219 kV, 63 % of cables are XLPE and 27% are SCOF. At 220 kV and above, 25 % of cables are XLPE whereas 43% are SCOF.

During the period 2001 to 2005, virtually all installed AC cables have been XLPE or SCOF with XLPE being the preferred cable type.

At voltages below 220 kV, more than 90% of the cable circuit length installed from 2001 to 2005 was of the XLPE type. For voltage levels above 220 kV SCOF cables still account for more than 40% of the cables installed.

PILC cables have reached their end of life with a high level of internal failures

Moisture barriers

In this period, more than 90% of the installed XLPE cables had water barriers. Welded or extruded metallic barriers were chosen for around 60% of these cables.

As cables in the voltage range 60-219 kV make up more than 90% of the total installed cable circuit length, the trend in this voltage range is almost the same as for the whole population.

For voltages above 220 kV extruded or welded metallic barrier has been and still is the preferred solution. However, laminated barrier has now been introduced even at the highest voltage levels, generally where cables are installed in air.

Accessories

Over 330,000 accessories were reported to be in service. 90% of all accessories are in the voltage range below 220 kV. 70% of all accessories are of extruded type and 30 % are of paper type. 67% of all accessories are joints and 33% are terminations.

The use of pre-moulded straight joints is increasing for extruded cables, but in the period 2001-2005 still only made up around 40 % of the total number joints installed. 50% of the joints installed in that period were site made. For the highest voltage levels the trend towards using pre-moulded joints is very clear and more than 80% of the joints installed were pre-molded at 220kV and above in the period 2001-2005.

DC cable types

There was 800cct km of DC land cable reported, with significant quantities of extruded insulated cables now installed at voltages up to 150kV. Only SCOF cables are reported for higher voltage levels. 59% percent of installed cable is now polymeric. *Reported polymeric dc cables are related to VSC type installations where the cables are not subjected to polarity reversals in operation.*

During the years 2001 to 2005, extruded cables have become the most widely used DC cable type with all installed DC land cables at voltages below 219 kV being the extruded type. At voltages of 220 kV and above, SCOF is still the only DC cable type used for land applications.

Fault analysis

A total 855 faults were reported on land cable systems over the five years ending December 2005. A high number of reported faults were associated with PILC cable systems.

In analyzing the faults, two voltage classes, 60 to 219 kV and above 220 kV were considered. Almost 50% of faults were internal failures and 50 % were attributed to external factors. Of the internal faults, 60% of these faults were in the lower voltage class and 77% of internal faults occurred in cables that were direct buried. There is no rational explanation why 36% of these faults were internal failures and caution is advised in drawing any conclusions.

70% of all faults occur at the lower voltage levels.

Third party mechanical damage accounts for 77% of “external faults” and 34% of “all faults”.

The questionnaire did not request information regarding installed circuit lengths as a function of mode of installation. However based on the results of this survey, the total length of direct buried cables and cables installed in ducts or tunnels was almost the same. Based on the reported faults, it can be concluded that direct buried cable systems are about 10 times more likely to be damaged by external conditions than cable systems installed in ducts or tunnels.

The internal failure rates best reflect the inherent performance of the cable system. PILC cables have reached their end of life with a high level of internal failures.

It is not possible to compare failure rates of cable and accessories due to different scaling factors. Internal failure rates are greater at the higher voltage levels. It should be noted that the average age of SCOF, HPOF and GC cable systems is significantly greater than extruded cable systems. Failure rates of SCOF include oil leaks reported as a failure. Internal failure rates of SCOF and XLPE cable are in line with expectations

Internal failure rates of accessories, particularly on XLPE cable, are of greater concern. Focus on quality control during jointing operations must be maintained

Comparing the recent data with that published previously and considering internal cable failures only, the new information appears to indicate that XLPE has a lower failure rate than SCOF. (The failure rate of XLPE cable has improved since the last published figures.) However in the case of joints SCOF tends to have a lower failure rate than XLPE. The failure rate of terminations on XLPE cable is slightly lower than on SCOF. Failure rates resulting from external failures appear to be tending to increase.

Outage times

Based on the data collected, it has been possible to estimate the outage times associated in carrying out repairs following a fault. Repairs on SCOF cables take on average 29 days whilst XLPE cable systems require 20 days.

8. ANALYSIS AND RESULTS - SUBMARINE CABLES

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Table 18 Quantities of AC submarine cable installed at the end of 2005

AC CABLES							
CABLE TYPE			VOLTAGE RANGE				Sum all voltages
			60 to 109 (kV)	110 to 219 (kV)	220 to 314 (kV)	315 to 500 (kV)	
SCOF	Single core		78	889	532	474	1974
	3-core		109	311			420
	Flat type (Mollerhoj)		30	40			70
HPOF	3-core		9	4	3	15	32
EPR	Single core	No radial moisture barrier	2	8			9
		Extruded or welded metallic barrier					
	3-core	No radial moisture barrier	19				19
		Extruded or welded metallic barrier					
XLPE	Single core	No radial moisture barrier	17				17
		Extruded or welded metallic barrier	108	306			414
	3-core	No radial moisture barrier	66				66
		Extruded or welded metallic barrier	348	328			676
Total installed AC circuit length to the end of 2005 (km) per voltage and sum all voltages			786	1887	535	489	3697

The quantity of cable in service at the end of 2005 was 3697circuit km. 67% were SCOF cables, mainly single core and 33% of cables were XLPE.

Table 19 Quantities of DC submarine cable installed at the end of 2005

DC CABLES							
CABLE TYPE			VOLTAGE RANGE				Sum all voltages
			60 to 109 (kV)	110 to 219 (kV)	220 to 314 (kV)	315 to 500 (kV)	
SCOF	Single core				239	108	347
	Flat type (Mollerhoj)				64	43	107
MI	Single core			739	404	1416	2559
	Integrated metallic return conductor				128		128
Extruded	Single core	No radial moisture barrier					
		Extruded or welded metallic barrier	143	83			226
Total installed DC circuit length to the end of 2005 (km) per voltage and sum all voltages			143	822	835	1567	3366

There were 3366 circuit km of DC cable reported to be in service at the end of 2005. 13% of cable installed was SCOF cable, 80% MIND and 7% XLPE.

The quantity of HVDC extruded cable reported in the period is covered by two HVDC VSC cable links.

Table 20 Quantities of AC submarine accessories / components installed at the end of 2005

AC ACCESSORIES		VOLTAGE RANGE kV			
CABLE TYPE	COMPONENT TYPE	60 to 109	110 to 219	220 to 314	315 to 500
SCOF cables	Flexible joints	64	97	15	
	Rigid joints	38	24		
	Transition joints at landfall	31	67	18	14
	Pumping plants	2	10	10	22
	Expansion tank stations	115	158	43	6
	Sealing ends (terminations)	443	644	166	152
HPOF cables	Straight joint		6	5	
	Stop joint				
	Trifurcating Straight joint			4	
	Trifurcating Stop joint				
	Outdoor Termination Porcelain	30	36	12	72
	GIS or Transformer Termination - Fluid filled			6	
Extruded cables with extruded or welded metallic radial moisture barrier	Flexible Cured joints	138	41		
	Rigid joints with Pre-moulded components		3		
	Transition joints	9	63		
	Terminations	300	338		
Extruded cables without extruded or welded metallic radial moisture barrier	Flexible Cured joints	14			
	Rigid joints with Pre-moulded components		12		
	Transition joints	2			
	Terminations	76			
Total number of installed AC accessories to the end of 2005	3306	1262	1499	279	266

It is thought that the number of accessories reported is probably understated. The number of factory joints on long submarine cables and the type and quantity of auxiliary equipment is not readily available information.

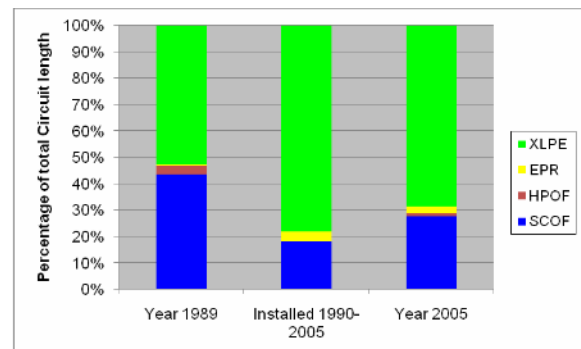
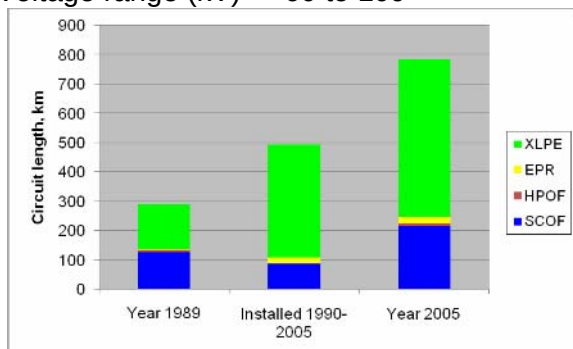
Table 21 Quantities of DC submarine accessories / components installed at the end of 2005

DC ACCESSORIES		VOLTAGE RANGE kV			
CABLE TYPE	COMPONENT TYPE	60 to 109	110 to 219	220 to 314	315 to 500
SCOF cables	Flexible joints			48	49
	Rigid joints			16	
	Transition joints at landfall			6	1
	Pumping plants			6	6
	Expansion tank stations			10	
	Sealing ends (terminations)			23	26
MI cables	Flexible joints		6	18	48
	Rigid joints		5		1
	Transition joints at landfall		8	6	2
	Terminations		20	14	16
Extruded cables with extruded or welded metallic radial moisture barrier	Flexible Cured joints	12	8		
	Rigid joints with Pre-moulded components				
	Transition joints	4	10		
	Terminations	24	14		
Extruded cables without extruded or welded metallic radial moisture barrier	Flexible Cured joints				
	Rigid joints with Pre-moulded components				
	Transition joints				
	Terminations				
Total number of installed DC accessories to the end of 2005	407	40	71	147	149

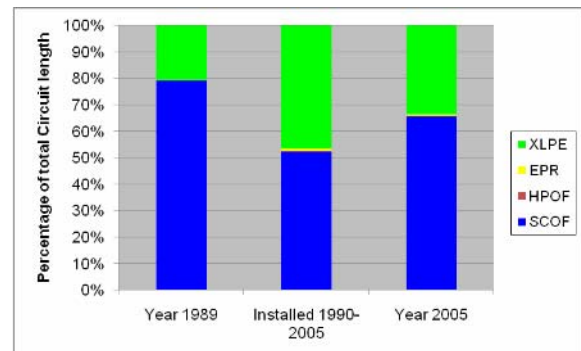
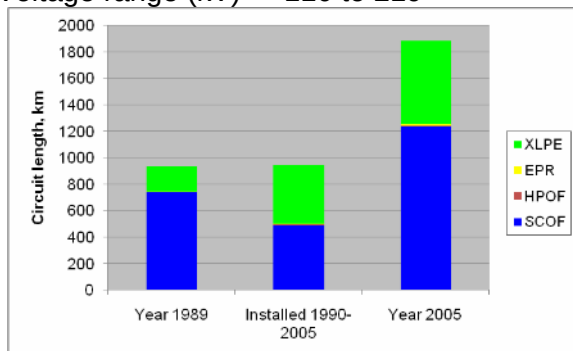
It is thought that the number of accessories reported is probably understated. The number of factory joints on long submarine cables and the type and quantity of auxiliary equipment is not readily available information.

Figure 22 AC submarine cable installed between 1990 and 2005

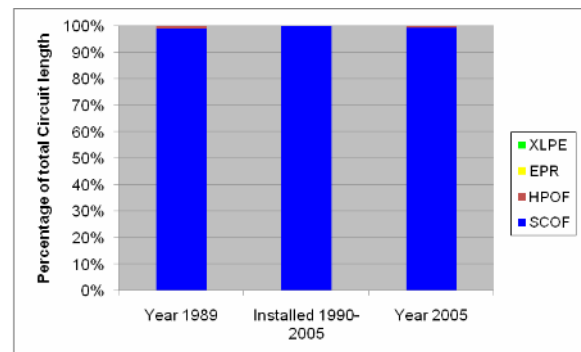
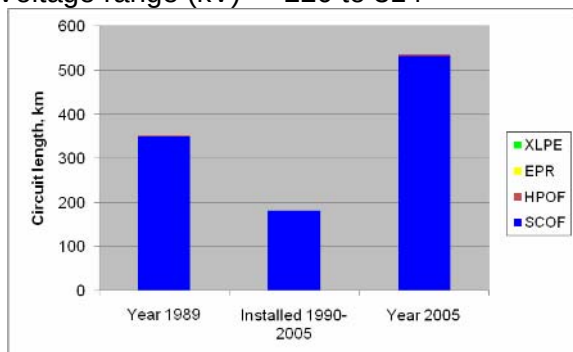
Voltage range (kV) 60 to 109



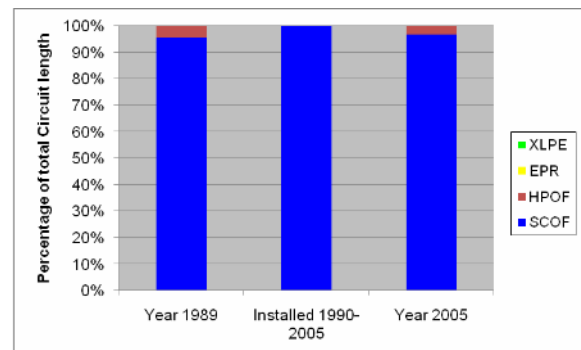
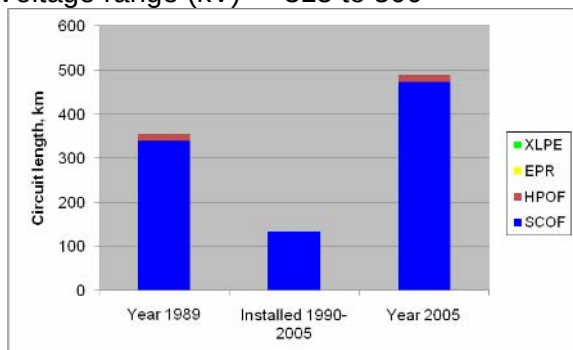
Voltage range (kV) 110 to 219



Voltage range (kV) 220 to 314



Voltage range (kV) 315 to 500



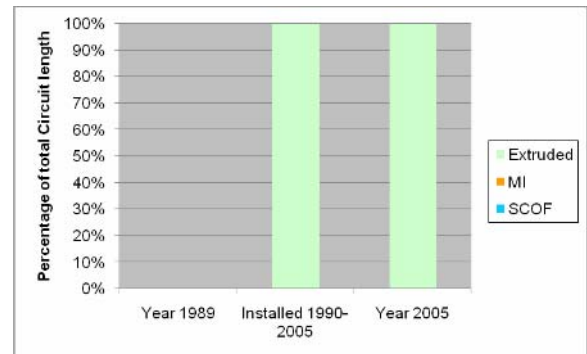
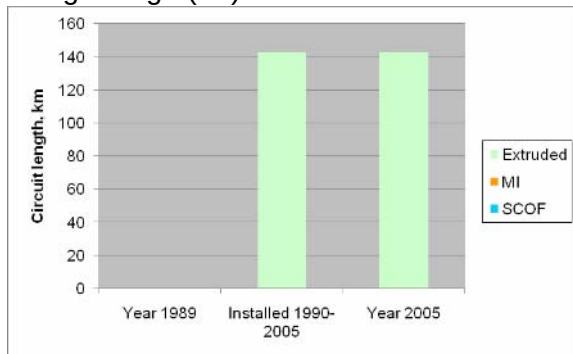
At 60 to 109kV, 80% of cables installed between 1990 and 2005 were XLPE cables. At 110 to 219kV 50% of cables installed were XLPE but no XLPE cables were installed at 220kV and above.

Table 23 AC submarine cable installed between 1990 and 2005

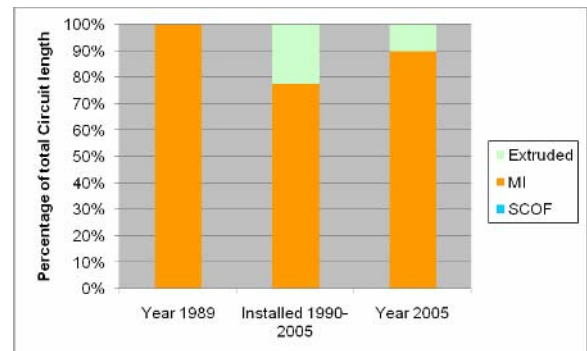
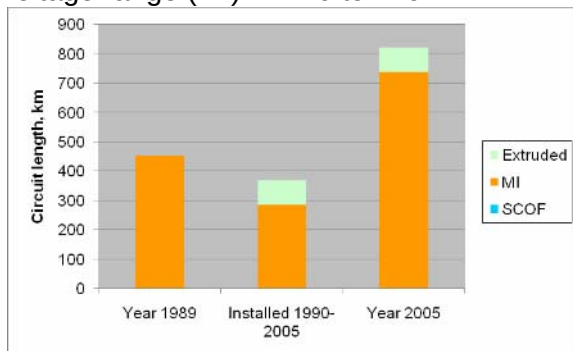
AC CABLES			VOLTAGE RANGE kV																															
CABLE TYPE			60 to 109							110 to 219							220 to 314							315 to 500										
YEAR OF INSTALLATION			1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005
SCOF	Single core		10.0				5.8				44.5	113.2	84.6	32.9	7.8	109.2	15.3			23.5	24.2	14.0	16.6		2.0	102.0	13.0			121.3				
	3-core			32.0	15.1	23.0	2.0		1.4	25.0		1.7	41.9	8.6			11.0																	
	Flat type (Mollerhoj)																3.0																	
HPOF	3-core															0.7																		
EPR	Single core	No radial moisture barrier														6.2																		
		Extruded or welded metallic barrier																																
	3-core	No radial moisture barrier						4.0		15.0																								
		Extruded or welded metallic barrier																																
XLPE	Single core	No radial moisture barrier																																
		Extruded or welded metallic barrier	3.1		9.1		4.8	39.5			15.8		99.8	11.5			30.7	10.7																
	3-core	No radial moisture barrier			5.3		2.4		1.7	1.5																								
		Extruded or welded metallic barrier	2.8	17.3	85.9	56.0	2.8	12.5	11.4	129.6					46.0	59.0	127.3	41.5																
Total installed AC circuit length per 2 year period (km)			15.9	49.3	115.5	79.0	17.8	56.0	13.1	147.5	85.3	113.2	186.0	86.4	62.4	175.0	173.3	66.2		23.5	24.2	14.0	16.6		2.0	102.0	13.0			121.3				

Figure 24 DC submarine cable installed between 1990 and 2005

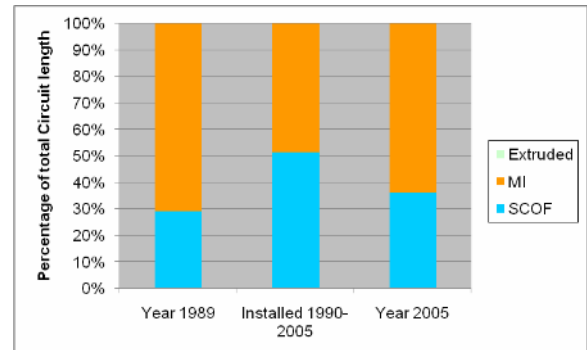
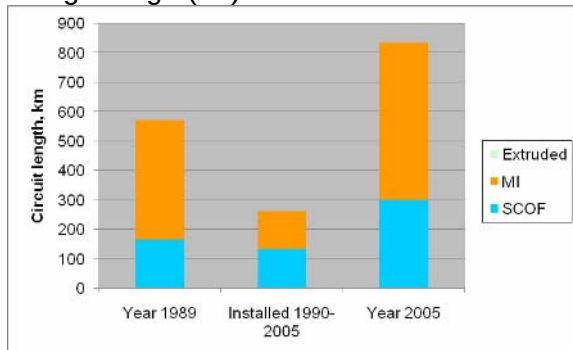
Voltage range (kV) 60 to 109



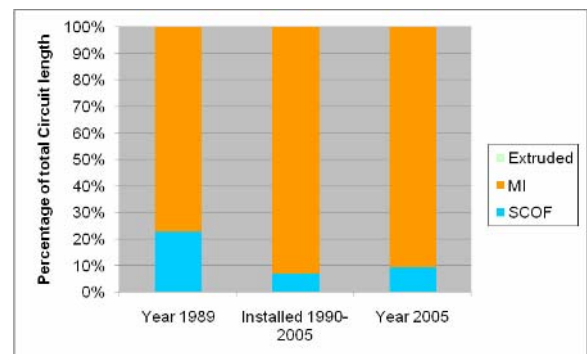
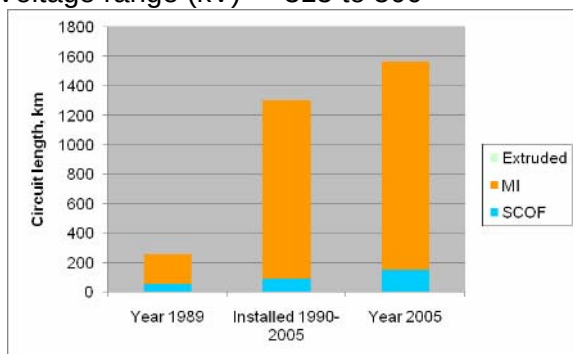
Voltage range (kV) 110 to 219



Voltage range (kV) 220 to 314



Voltage range (kV) 315 to 500



In the case of DC cables, there is HVDC VSC applications at 60 to 109 kV using only extruded insulated cable systems. In the 110kV to 219kV class 20% of cable was extruded insulated cable for HVDC VSC application with the remainder (80%) at this voltage level and at higher voltages being MIND cable.

Table 25 DC submarine cable installed between 1990 and 2005

DC CABLES			VOLTAGE RANGE kV																																
CABLE TYPE			60 to 109								110 to 219								220 to 314								315 to 500								
YEAR OF INSTALLATION			1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	
SCOF	Single core	Bipolar operation																						93.0						22.0	22.0			5.0	
		Monopolar operation																		42.5															
	Flat type (Mollerhoj)																													43.0					
MI	Single core	Bipolar operation											96.6	96.6																					
		Monopolar operation											94.0																				254.1	159.6	295.0
	Integrated metallic return conductor																							128.0											
Extruded	Single core	No radial moisture barrier																																	
		Extruded or welded metallic barrier							143.0									83.2																	
Total installed DC circuit length per 2 year period (km)									143.0				190.6	96.6			83.2			42.5					221.0			130.0	126.0	316.0	22.0		254.1	164.6	295.0

Table 26 AC submarine accessories installed between 1990 and 2005

AC ACCESSORIES		VOLTAGE RANGE kV																															
CABLE TYPE	COMPONENT TYPE	60 to 109								110 to 219								220 to 314								315 to 500							
YEAR OF INSTALLATION		1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005
SCOF cables	Flexible joints			2	28			3	2			3	6	3		6	4			8	4												
	Rigid joints				18																												
	Transition joints at landfall		12		16					6		8	22			3	6			6		12							8				
	Pumping plants				2								2								2			2		2							
	Expansion tank stations	1		2	6						2	4	7	8	4	2	1				2	5											
	Sealing ends (terminations)	6		12	24						8	16	12	30	26	25	3	12	8		8	18	18		6	12	8						
HPOF cables	Straight joint														4																		
	Stop joint																																
	Trifurcating Straight joint																																
	Trifurcating Stop joint																																
	Outdoor Termination Porcelain									12																							
	GIS or Transformer Termination - Fluid filled																																
Extruded cables with extruded or welded metallic radial moisture barrier	Flexible Cured joints			12			3	7		2				12	5	3	3																
	Rigid joints with Pre-moulded components																																
	Transition joints									3		6		6	9	12	6																
	Terminations	2	42	24	6	6	24	18	12	24		54	6	21	30	62	48																
Extruded cables without extruded or welded metallic radial moisture barrier	Flexible Cured joints								12																								
	Rigid joints with Pre-moulded components																																
	Transition joints																																
	Terminations	6		24		6		6	18																								
Total number of installed AC accessories per 2 year period		15	54	76	100	12	27	34	44	55	18	87	73	76	77	91	80	8		22	26	35		8	12	10			8				

Table 27 DC submarine accessories installed between 1990 and 2005

DC ACCESSORIES		VOLTAGE RANGE kV																																
CABLE TYPE	COMPONENT TYPE	60 to 109								110 to 219								220 to 314								315 to 500								
YEAR OF INSTALLATION		1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	
SCOF cables	Flexible joints																		3			6	4						42				1	
	Rigid joints																																	
	Transition joints at landfall																		2										1					
	Pumping plants																		2										3	2				
	Expansion tank stations																						8											
	Sealing ends (terminations)																			2				4					2	2				
MI cables	Flexible joints									3							2	3					2	2	2	6		12			10	4		
	Rigid joints												2	3														1						
	Transition joints at landfall												4					2				2						2						
	Terminations									6	2		4					2					2	2		2		2			2		2	
Extruded cables with extruded or welded metallic radial moisture barrier	Flexible Cured joints															6																		
	Rigid joints with Pre-moulded components																																	
	Transition joints							4								4	4																	
	Terminations							8								4	8																	
Extruded cables without extruded or welded metallic radial moisture barrier	Flexible Cured joints																																	
	Rigid joints with Pre-moulded components																																	
	Transition joints																																	
	Terminations																																	
Total number of Installed DC accessories per 2 year period								12		9	2		8	2	3	14	14	7	9			6	22	4	2	8		65	4		12	5	2	

Table 28 Total number of submarine faults reported 1990 to 2005

Failures 1990 to 2005 - overview and main classification						
	AC			DC		
	XLPE	SCOF	HPOF	MI	SCOF	Grand Total
Internal					4	4
External	2	7	2	11		22
Other	1	10		5		16
Unknown	1	4		2		7
Total	4	21	2	18	4	49

- The faults reported are mainly external faults, with immediate breakdown or an unplanned outage of the cable system.
- Six answers, classified as unknown, failed to specify whether the failure was instantaneous or not. These failures are reported to have been caused by anchor and trawling and as consequence are considered to be instantaneous. Therefore 40 cases may be classified as instantaneous failures and 9 cases may be classified as occurrence requiring unplanned outage.
- Eight of the nine cases requiring unplanned outage were reported on SCOF type cable. The remaining case was termination related (hydraulic system) on MI cable. Six of these failures were reported to be on terminations, joints and other components. Oil leaks are expected to be the main reason in these cases.
- Owing to the fact that few replies were received from utilities and that manufacturers may not be aware of all failures, the number of faults reported may be slightly understated. If so, this is most likely to be the case for the lowest voltage levels of XLPE and EPR cables installed in short lengths in shallow water.
- Repair joints for armoured submarine cables are not available off the shelf from accessory suppliers. Such accessories are designed and type tested by the submarine cable suppliers. Therefore it is rather unlikely that the submarine cable suppliers would not be informed about damage and repairs requiring joints. Installation of cable in long lengths and / or in deep water will require assistance from the supplier. Therefore, the reported number of failures, repairs and joints are assumed to be fairly accurate (information from the suppliers has been used to compensate for unsatisfactory response from utilities in parts of the world).
- In total 49 faults were reported, 55% on AC cable systems and 45% on DC cable.
- 7 cases (14%) are reported to have an unknown cause of failure.
- 16 faults (33%) are reported to have been caused by "other" reasons. This is rather higher than expected. "Other" was defined as physical external parameters excluding anchors, trawling or excavation and could include for example subsidence, increased burial depth resulting in overheating or an abnormal external system (e.g. lightning) condition.

- The origin of the undefined faults (reported as “Other” or “Unknown” has been investigated to try to clarify the type of fault, internal or external.

The following tables analyze the failures reported as “other or unknown”.

Tables 28a and 28b qualify the “other” categories of failures based on other information available.

Tables 28c and 28d qualify the “unknown” categories of failures based on other information available.

Table 28a Evaluation of “other” failures

Evaluation of cause of failure defined as Other			
Type of Cable	Number of cases	Protection at fault location	
All types	3	Landfall troughs	19%
	7	Unprotected	44%
	2	Direct burial	13%
	3	Other protection	19%
	1	No Information	6%
Grand Total	16		100%

- Failures reported as being caused by incidents other than trawling, anchoring and excavation may have not been specified.
- 63 % of these failures are reported on AC-SCOF cable and 31% on DC – MI cable.
- 19% of these failures have occurred in landfall troughs where wave induced movement and thermal effects may cause lead sheath fatigue and failure of paper insulated cables with lead sheath.
- 44 % of these failures are reported to have occurred at locations with unprotected cable.
- It is assumed that a significant part of this group is related corrosion, mechanical impact from wave action, unplanned thermal exposure etc in landfall area during time in operation.
- The major part of these failures occurred after nearly 10 years and more in operation.
- Supporting information regarding potential lightning and switching over voltages has not been given.

Table 28b Evaluation of “other” failures

Evaluation of cause of failure defined as Other					
Type of Cable	Protection at fault location	Age at time of failure			Σ Other
		0- 2 years	3 - 9 years	≥ 10 years	
All types	Landfall troughs		1	2	3
	Unprotected		3	4	7
	Direct burial	2			2
	Other protection			3	3
	No Information			1	1
	Grand Total	2	4	10	16
		13%	25%	63%	100%

- Some of these failures might have internal origin or be caused by mechanical impact during installation.
- However, taking into account the age at failure, it seems relevant to consider this group mainly as failures due to external impact; third party activity, unplanned thermal issues, landfall exposure etc.

Table 28c Evaluation of “unknown” failures

Evaluation of cause of failure defined as Unknown			
Type of Cable	Number of cases	Protection at fault location	
All types	0	Landfall troughs	0%
	2	Unprotected	29%
	1	Direct burial	14%
	2	Other protection	29%
	2	No Information	29%
Grand Total	7		100%

When the cause of failure is defined as “unknown” it could cover various cases including internal origin, a result of installation handling damage, external mechanical damage from dropped objects etc. The repairs may have been performed without examination of the fault or without agreed conclusion after examination as an electrical breakdown destroys a local section of the cable.

Table 28d Evaluation of “unknown” failures

Evaluation of cause of failure defined as Unknown					
Type of Cable	Protection at fault location	Age at time of failure			Σ Unknown
		0- 2 years	3 - 9 years	≥ 10 years	
ALL types	Landfall troughs				0
	Unprotected			2	2
	Direct burial			1	1
	Other protection	1		1	2
	No information	1	1		2
	Grand Total	2	1	4	7
		29%	14%	57%	100%

Some of these failures might have internal origin or be caused by mechanical impact during installation. However, taking into account the age at failure, it seems relevant to consider this group mainly as failures due to external impact.

Table 28e Evaluation of influence of age

Evaluation of trend of age regarding failures								
Type of Cable	Age at time of failure (Years)							Total
	0 – 5	6 – 10.	11 – 15.	16 – 20.	21 – 25.	26 - 30.	≥ 30	
AC - XLPE	2				2			4
AC - SCOF	4	3		1	5	3	5	21
AC - HPOF					2			2
DC - MI	5	2	2	3	3	2	1	18
DC - SCOF	1	2					1	4
Grand Total	12	7	2	4	12	5	7	49
	24%	14%	4%	8%	24%	10%	14%	100%

Only four internal faults were reported having no clear correlation with age. In the case of external failures the incidents are distributed and give no trend as a function of age.

Table 29 Number of submarine faults related to components

Reported failures 1990 to 2005 ref cable system components						
Type of Cable		Failed component				Total
		Cable	Joint	Termination	Other component	
AC - XLPE	Internal					0
	External	2				2
	Unknown/ Other	2				2
	Total	4	0	0	0	4
AC - SCOF	Internal					0
	External	7				7
	Unknown/ Other	11	1	1	1	14
	Total	18	1	1	1	21
AC - HPOF	Internal					0
	External	2				2
	Unknown/ Other					0
	Total	2	0	0	0	2
DC - MI	Internal					0
	External	11				11
	Unknown/ Other	6		1		7
	Total	17	0	1	0	18
DC - SCOF	Internal	1	3			4
	External					0
	Unknown/ Other					0
	Total	1	3	0	0	4
DC- Extruded	Internal					0
	External					0
	Unknown/ Other					0
	Total	0	0	0	0	0
	Grand Total	42	4	2	1	49

- 86% of failures were on cable rather than accessories. Based on the 26 defined faults, only 15% were internal faults with the remainder 85% being caused by external influences.
- There was insufficient data to quantify a fault rate for accessories.
- 51% of failures were on SCOF cables, with 84% of these being on AC systems. 8% of failures were on XLPE AC cable circuits, all XLPE failures being on dry design cable with a radial moisture barrier.
- The following graphs show the bi-annual number of failures per 100km over the 15 year period 1990 to 2005.

- Internal failures are reported on DC – SCOF cables only. Four faults were reported, two of which were on the same installation. The cables had been operating for 1, 7, 10 and 32 years respectively.
- It is possible that some of the 7 “unknown” cases reported as unknown could have internal origin.
- In the case of HPOF cables there were 2 failures, both a result of anchor damage on 23 and 25 year old cables.
- DC – MI submarine cables are generally used as interconnections in open sea crossing areas with extensive fishing activity and shipping

Table 30 Failure rates of submarine cable systems

		AC - HPOF cables			AC - SCOF cables			AC - XLPE cables			DC - MI cables			DC - SCOF cables		
A. Failure Rate - Internal Origin Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	NA	0.0000	0.0000	0.0000	0.0000	NA	0.0346	0.0346
B. Failure Rate - External Origin Failures or unknown		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	1.9183	0.0000	0.7954	0.1277	0.0738	0.1061	0.0705	NA	0.0705	0.1336	0.0998	0.1114	NA	0.0000	0.0000
C. Failure Rate - All Failures		60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES	60-219kV	220-500kV	ALL VOLTAGES
Cable	Failure rate [fail./yr 100cct.km]	1.9183	0.0000	0.7954	0.1277	0.0738	0.1061	0.0705	NA	0.0705	0.1336	0.0998	0.1114	NA	0.0346	0.0346

Note: NA – not available

Table 31 Number of submarine external faults as a function of installation

Failures related to mode of installation at failure location							
	AC				DC		
Mode of installation	XLPE	EPR	SCOF	HPOF	MI	SCOF	Grand Total
Unprotected	1		9	2	13		25
Buried	2		2		2	3	9
Other Protection	1		5		1	1	8
Landfall troughs			3		1		4
Unknown			1				1
Subsea Total	4		20	2	17	4	47
Termination related			1		1		2
Grand Total							49

Over 50% of faults occurred on unprotected cables. Buried cables are well protected against fishing gear, but can still be damaged by anchors penetrating deep into the seabed.

Table 31a Submarine faults as function of type of external impact

External and unidentified type of faults 1990 to 2005 ref cause of failure							
Type of Cable		Cause of failure					Total
		Trawling	Anchoring	Excavation	Other	Unknown	
AC - XLPE	External		2				2
	Unknown				1	1	2
	Total	0	2	0	1	1	4
AC - SCOF	External		5	2			7
	Unknown				10	4	14
	Total	0	5	2	10	4	21
AC - HPOF	External		2				2
	Unknown						0
	Total	0	2	0	0	0	2
DC - MI	External	7	3	1			11
	Unknown				5	2	7
	Total	7	3	1	5	2	18
DC - SCOF	External						0
	Unknown						0
	Total	0	0	0	0	0	0
DC - Extruded	External						0
	Unknown						0
	Total	0	0	0	0	0	0
	Grand Total	7	12	3	16	7	45

As already indicated, 85% of “26 defined” faults were due to external influences. Almost 50% of damage was known to be caused by anchors.

Table 31b Submarine faults as function of water depth

Failures locations related to water depth						Grand Total
	AC			DC		
Water depth	XLPE	SCOF	HPOF	MI	SCOF	
0 - 10 m	2	9		2	1	14
11 - 50 m	2	5	2	12	4	25
51 - 100 m		2		2		4
101- 200 m				1		1
> 200 m					3	3
Total	4	16	2	17	8	47

30% of faults occurred at water depths up to 10m and 52% at depths between 11 and 50m.

Table 32 Outage times of submarine cable systems

Reported cable repair duration						
	AC			DC		
Duration	XLPE	SCOF	HPOF	MI	SCOF	Grand Total
≤ 1 month	2	9		5	3	19
2 months	2	1		2	1	6
3 months		3	2	1		6
4 - 5 months		3		3		6
≥ 6 months		2				2
Unknown		3		7		10
Total	4	21	2	18	4	49

The questionnaire did not sufficiently specify regarding outage time and in some cases the outage time may have been longer than reported repair time.

However, excluding the extremes and unknowns, the average reported repair time of submarine cables is approx. 60 days.

It should be noted that repair times of submarine cables is affected by many factors (availability of spare cable and accessories, availability of appropriate vessel, weather conditions etc) that can lead to a wide spread in times to implement repairs.

Table 32a Submarine outage time at different voltage levels

Reported repair time duration								
Type of Cable		≤ 1 month	2 months	3 months	4 - 5 months	≥ 6 months	unknown/NN	Total
AC - XLPE	60 to 219	2	2					4
	220 to 500							
	Total	2	2					4
AC - EPR	60 to 219							
	220 to 500							
	Total							0
AC - SCOF	60 to 219	5	1	2	3	1	3	15
	220 to 500	4		1		1		6
	Total	9	1	3	3	2	3	21
AC - HPOF	60 to 219			2				2
	220 to 500							
	Total			2				2
DC - MI	60 to 219	1	1		1		4	7
	220 to 500	4	1	1	2		3	11
	Total	5	2	1	3		7	18
DC - SCOF	60 to 219	3	1					4
	220 to 500							
	Total	3	1					4
DC- Extruded	60 to 219							0
	220 to 500							0
	Total							0
	Grand Total	19	6	6	6	2	10	49

Of the 49 reported failures, 43% and 37% are reported on AC – SCOF and DC-MI cables respectively. Long outage time is more related to location of cable installation and type of cable than voltage level.

The very long repair times are assumed to be on long interconnections in open sea where weather conditions may be challenging and cases where replacement cable has been required.

Table 33 Comparison of data with earlier CIGRE publications

Reference	Cigre Paper 2- 07 -1991	Cigre Paper 2- 07 -1991	Cigre WG B1-10 -2008
Date of survey	1950 – 1980	1980 – 1990	1990 – 2005
Quantity of cable	3610	Not available	7100
Number of failures	154	116	49
Failure rate	0.32	Not available	0.12
Average outage time days	37	70	60

Table 33 summarises the latest data with that published in 1991.

- The number of reported faults is significantly lower.
- The number of failures is probably understated to a degree but some reduction would be expected.
- More focus on surveys and routing to find more suitable routes to both facilitate protection of the cables by burial and to ensure a more controlled installation has certainly led to a reduction in externally damage.
- The main reasons for reduced failure rate are assumed to be:
Improved methods for surveying and finding optimal routing
Improved methods for cable laying and protection
- Increased focus on protection by burial etc at installation
- Approx. 50 % of reported failures have occurred on installations of age 20 years and more. Consequently, the increased focus on protection on recent and new installations is expected to give improved failure rate in coming years.

Summary of analysis of submarine cable

AC cable types

The quantity of AC cable in service at the end of 2005 was almost 3700cct km. 67% were SCOF cables, mainly single core and 33% of cables were extruded. 13% of the 3400cct km of DC cable was SCOF cable, 80% MIND and 7% extruded.

At 60 to 109kV, 80% of AC cables installed between 1990 and 2005 were XLPE cables. At 110 to 219kV 50% of AC cables installed were XLPE but no XLPE cables were installed at 220kV and above.

DC cable types

In the case of DC cable systems, there is HVDC VSC applications at 60 to 109 kV based on the use of extruded insulated cable systems. In the 110 kV to 219 kV class 20% of cable was extruded insulated cable for HVDC VSC application with the remainder (80 %) at this voltage level and at higher voltages being MIND cable. *The polymeric DC cables are associated with VSC type installations where the cables are not subjected to polarity reversals in operation.*

Failure analysis

Owing to the fact that few replies were received from utilities and that manufacturers may not be aware of all failures, the number of faults reported may be slightly understated. If so, this is most likely to be the case for the lowest voltage levels of XLPE and EPR cables installed in short lengths in shallow water. Repair joints for armoured submarine cables are not available off the shelf from accessory suppliers. Therefore the reported number of failures, repairs and joints are assumed to be fairly accurate as information from the suppliers has been used compensate for unsatisfactory response from utilities in parts of the world.

7 faults (14%) are reported to have unknown cause of failure. 16 faults (33%) are reported to have been caused by other reason. "Other" was defined as physical external parameters, excluding anchors, trawling and excavation, but could be for example subsidence, increased burial depth resulting in overheating or an abnormal external system (e.g. lightning) condition.

The origin of the undefined faults (reported as "Other" or "Unknown") has been investigated to try to clarify the type of fault, internal or external. It has been concluded that the majority of these must be result of external caused impact.

Within the 49 faults, 55% were on AC cable systems and 45% on DC cable. The origin of the undefined faults has been investigated to try to clarify the type, internal or external, of fault. Only four internal faults were reported resulting in no clear correlation with age. In the case of external failures, the incidents are evenly distributed and give no trend as a function of age.

Protection modes

Over 50% of faults occurred on unprotected cables. Buried cables are well protected against fishing gear, but can still be damaged by anchors penetrating deep into the seabed.

The main risk for submarine cables is external damage. Compared to previous statistics the failure rate has improved from 0.32 to 0.12 failures /100 km years. Approx. 50 % of reported failures have occurred on installations of age 20 years and more. Consequently, the

increased focus on protection on recent and new installations is expected to give improved failure rates in coming years. This is considered to be an effect of increased effort on survey and routing to obtain a route with optimised conditions for natural protection, a seabed that is easier to excavate and trench and improved methods for laying and protection.

During the last two decades, utilities have conducted risk evaluation and have buried new submarine cable circuits in most strategic or risky locations.

Efficient protection against fishing gears may often be obtained at reasonable cost by trenching. Protection against damage by large anchors is more difficult and much more expensive. This seems to be reflected by a large share of unanimously reported as failures caused by anchoring.

Outage times

Based on the data collected, it has been possible to estimate the outage times associated with carrying out repairs following a fault as 60 days. It should be noted however that repair times of submarine cables is affected by many factors (availability of spare cable and accessories, availability of appropriate vessel, weather conditions etc) that can lead to a wide spread in times to implement repairs.

9. CONCLUSIONS

Significant changes have been made over the last two decades in terms of the introduction of new materials and technologies. Currently the demand for land and submarine cable systems is very high. Changes are being introduced in testing protocols in order to reduce costly testing programs and encourage innovation whilst retaining quality and reliability standards.

In the light of these changes, it is important to monitor service performance and ensure that the decisions to introduce such changes are being taken on the basis of proven and satisfactory service performance. The main aim of the work by WG B1-10 was to gather reliable service performance data and produce the information necessary to accomplish this task.

Some problems were encountered in collecting the data and it is suggested that it would be appropriate, at least in the case of land cables, to carry out a further survey within the next five years. However in order to have accurate and useful data, Utilities should review their processes of collecting the relevant information.

Eventually, reasonable responses were obtained for both land and submarine cable systems surveys. Replies from Utilities varied, several replies were incomplete and some geographical areas were non responsive. The low level of replies was probably the result of a rather demanding questionnaire, being by nature more detailed compared to other similar surveys. In light of the quality of the replies received and on the assumption that the information being generated is useful to the industry as a whole, it is recommended that utilities review their processes that collect data on quantities of cable installed and faults that occur in service. It would be useful if these findings could be made available for comparison purposes in a suitable forum (e.g. European Transmission System Operators).

The data collected was judged to be representative and following some exercises to check and validate the data, some analysis has been carried out. The results of the analysis are presented in sections 7 and 8. A commentary of the results of the analysis is included at the end of each section. Unfortunately the replies received recently have not been included.

Caution should be used when interpreting failure rates, particularly in cases when the size of the data population is small as in the case where smaller differentiation between cable designs is made such as in the case of submarine cables. The failure rate for components has been adopted from the previous publications and is expressed as the no. of faults per 100 units. Failure rates are mean failures rates and it is not appropriate to use them to calculate MTBF and availability of circuits.

10. APPENDIX 1

Land Cable Questionnaire Guidance Notes

Voltage Ranges

The voltages referred to are the nominal phase-to-phase system voltage. The voltage ranges have been chosen to group together similar design and operational principles.

Cable System Technologies

Both the older and newer technologies (namely Self Contained Oil Filled, High Pressure Pipe Type Cables, Gas Compression and Extruded cables) were considered. The circuit km reported are the lengths of circuit installed, ignoring the number of cables used for each phase. So a 5 km long double-circuit connection with 3 phases and two cables per phase should be reported as 10 circuit km even though it has 60 km of cable core.

Repair Time

Repair time is the cumulative period of time required to mobilize resources, locate and repair the failure. The repair time associated with a failure is of fundamental importance since the summation of repair times is required to obtain a measure of non-availability, which from a reliability viewpoint is of greater significance than fault rate.

Land Cable Systems -Tabulation of Data

A total of seven tables (Excel sheets) should be completed as far as possible in respect of various type of cables circuits (AC or DC) and accessories as well as faults statistics. These sheets are as follows:

1. AC & DC Cable Circuits - 2005 / Data on actual cable network installed to the end of 2005.
2. AC Cable Installed 2001-2005. / Amount and types of AC cables installed from year 2001 up to 2005.
3. DC Cable Installed 2001-2005. / Amount and types of DC cables installed from year 2001 up to 2005.
4. AC & DC Accessories - 2005. / Data on actual accessories installed to the end of 2005.
5. AC Accessory Inst. 2001-2005. / Amount and types of AC Accessories installed from year 2001 up to 2005.
6. DC Accessory Inst. 2001-2005 / Amount and types of DC Accessories installed from year 2001 up to 2005.
7. Faults 2001-2005. / Data on faults for statistics.

Definitions of the components listed in the tables and of the units used for components are given in Sections 8 and 9 respectively.

Age of Land Cable or Accessory

The age of the cable or Accessory is the period of time elapsed since the date of commissioning.

Land Cable Systems - Definition of Components

Cable - Three-core or single-core cable of the following types:

The following cable types are considered for AC Cable Systems:

1. SCOF: Self-contained oil-filled cables including Paper and PPL insulation. Flat-type cables (Mollerhoj) are also included.
2. HPOF High pressure oil or gas pipe type cables
3. GC Gas compression cables
4. EPR Extruded Ethylene Propylene Rubber with or without a water barrier
5. PE Extruded Polyethylene with or without a water barrier or with a laminated barrier
6. XLPE Extruded Cross Linked Polyethylene with or without a water barrier or with a laminated barrier
7. PILC Paper insulated, impregnated, lead covered (sheathed), non pressurized

Water Barrier: In this context water barrier refers to sheath constructions which provide an impermeable barrier to the radial flow of water and would cover for example cable designs incorporating an extruded lead or an extruded or welded aluminium, copper or stainless steel sheath. A cable having a copper wire screen under a PVC sheath on the other hand would be considered as a design without a water barrier.

Laminated Barrier: Laminated barrier refers to longitudinally applied metal foils glued to itself or not. This type of barrier is generally an integral part of the external plastic jacket/sheath.

For DC Cable Systems, SCOF and Extruded cables (XLPE or PE) are only considered.

Cable Tails (Risers)

Cable tails which are short lengths (less than about 50m) of single-core cable used in terminating 3-core self-contained or pipe-type cables from trifurcating joint to sealing ends must be considered for the sake of this survey as three-core cables.

Straight Joint

Straight joints are either three-core or single-core joints incorporating all elements enclosed within the outer corrosion protection box. For pipe-type cables the straight joint will incorporate all elements between and include the end collars on the pipe. This term should also include the semi-stop joint for pipe-type cables.

In the case of extruded cables, it is required to differentiate between the two following types:

1. Premoulded straight or
2. Site Made straight (taped, extruded)

Note that the joints could either be of sectionalised type or non-sectionalised type (with or without screen interruption)

Stop Joint (SCOF, HPOF)

Stop joints would incorporate all elements enclosed within the outer corrosion protection box for 3-core or single-core self contained oil-filled cables.

Transition Joint (between SCOF or GC cables and Extruded cables)

Transition joints would incorporate all elements enclosed within the outer corrosion protection box between 3-core or single-core oil-filled cables, gas compression cables and extruded cables.

Terminations (Sealing ends)

Three types of terminations are defined.

1. Outdoor/indoor (Pothead) termination
2. Oil-immersed (Transformer) termination
3. Gas-immersed (GIS) termination

The termination includes all elements from the sheath plumb to the top connector stalk, in the case of self-contained oil-filled cable and from the sealing end base plate to the top connector stalk in the case of pipe-type cables.

For cables with extruded insulation the sealing end will include all elements from where the outer corrosion protective sheath has been removed to the top connector stalk.

"Fluid filled" and "Dry type" terminations are distinguished as well as insulator types which could either be "Porcelain" or "Composite".

Other Components

This category will include the following items:

- Pilot Cable including Joints

All pilot and telephone cables including joints and spur joints associated with the alarm system on the transmission cable.

- Pilot Cable Terminations and Alarm System Circuitry

All electrical components of the pressure alarm systems from pilot cable terminations to alarm indication panel.

- Sheath Bonding Equipment

All link boxes, bonding leads, sheath surge diverters and earthing fittings for single-point bonding and cross-bonding of cable sheaths.

- Heat Exchanger and Monitoring Equipment

All equipment both mechanical and electrical associated with external or internal cable cooling systems. This item includes hot-spot thermal monitoring.

- Cathodic Protection Equipment

All equipment associated with cathodic protection on cable metallic sheath.

- Ancillary oil equipment

This item includes all oil tanks, oil pipes, fittings, isolation pieces, pressure gauges, etc. in the case of oil-filled cables and all pumps, valves, pressure switches and other oil and gas fittings in the case of pipe-type oil or gas cables.

Units of Land Cable Components

Voltage:	kV (nominal phase-to-phase value).
Cable:	Circuit km (3-core or 3 single core cables ignoring the number of cables used for each phase).
Straight Joint/Stop Joint /Transition Joint:	One single-core or one three-core joint.
Sealing End:	One single-core sealing end.
Ancillary Oil or Gas Equipment:	One set of equipment physically situated at one position with one single connection to a 3-core cable or one set of three connections to 3 single-core cables. It can be a feed point or alarm point.

Type of Land Cable System

The type of cable such as SCOF, EPR, XLPE etc. is also referred to as the type of cable system.

Mode of Installation of Land Cables

When completing the fault reporting table, the mode of installation at the fault position should be reported among the following:

1. Direct burial
2. Ducts
3. In air
4. Troughs
5. Tunnels
6. Shafts
7. Bridges
8. Unknown.

Cause of Failure of Land Cable Systems

When completing the cause of failure information, if the information is available the cause of the failure should be recorded as "internal" to the cable or component or as "external" and differentiating between whether the externally generated fault was as a result of "Third Party Mechanical damage", other physical external parameters (e.g. subsidence, increased burial depth resulting in overheating...) or an abnormal external system (e.g. lightning...) condition.

11. APPENDIX 2

Submarine Cable Questionnaire Guidance Notes

Submarine Cable Systems - Tabulation of Data

A total of seven tables (Excel sheets) should be completed as far as possible in respect of various type of cables circuits (AC or DC) and accessories as well as faults statistics. These sheets are as follows:

1. AC & DC Cable Circuits - 2005 / Data on actual submarine cable network installed to the end of 2005.
2. AC Cable Inst. 1990-2005 / Amount and types of AC submarine cables installed from 1990 onwards to the end of 2005.
3. DC Cable Inst. 1990-2005 / Amount and types of DC submarine cables installed from 1990 onwards to the end of 2005.
4. AC&DC Accessory - 2005 / Data on actual submarine accessories installed to the end of 2005.
5. AC Acc. Inst. 1990-2005 / Amount and types of AC submarine accessories installed from 1990 onwards to the end of 2005.
6. DC Acc. Inst. 1990-2005 / Amount and types of DC submarine accessories installed from 1990 onwards to the end of 2005.
7. Faults 1990-2005 / Data on faults for statistics.

Sheets are to be filled for each type of cable system, and for each system nominal voltage. One sheet is also used to record failures occurred on transmission circuits.

Definitions of the components listed in the tables and of the units used for components are given in Sections 8 and 9 respectively.

Submarine Cable Systems

Cable - Three-core or single-core cable including concentric designs, of the following types:

AC submarine cables

Self-contained oil-filled, including flat-type cables (Mollerhoj cables);
High pressure oil filled pipe type cables (HPOF);
Cross linked polyethylene with or without water barrier;
Ethylene propylene rubber with or without water barrier.

DC submarine cables

- Self-contained oil-filled (SCOF), including flat-type cables (Mollerhoj cables)
- Mass impregnated cables (MI) including integrated concentric return conductor
- Extruded DC insulation with or without water barrier

Water Barrier: In this context water barrier refers to sheath constructions, which provide an impermeable barrier to the radial flow of water and would cover for example cable designs incorporating an extruded lead or an extruded or welded aluminum, copper or stainless steel sheath. A cable having a copper wire screen under a PVC sheath on the other hand would be considered as a design without a water barrier.

Straight Joints

Three-core or single-core joint incorporating all elements enclosed within the outer corrosion protection in the case of self-contained oil-filled or extruded cables.

Flexible Joints (factory or site made):

A flexible joint of any of the following construction:

- Hand-applied or mechanically applied paper tapes; combined with lead tube and continuous armour layer across the joint.
- Hand-applied or mechanically applied tapes, which may be either self-amalgamating or heat/pressure vulcanized in the case of extruded-insulation cables; combined with continuous armour layer across the joint.
- Field-moulded by extrusion process, for extruded-insulation cables; combined with continuous armour layer across the joint.

Rigid Joints Pre-moulded Straight Joint (site made)

A straight joint which is substantially constructed of factory made rigid components with a pre-made body including field control (as for land joints) and an outer metal housing used to avoid bending of the pre-made joint body and serve as a base and continuation of the armour layers.

Transition Joint

Incorporating all elements enclosed within the outer corrosion protection (box) for jointing between different types of cables.

This term shall also include stop joints and anchor joints on self-contained oil filled cables. The term shall also include a transition joint between a submarine cable and a land cable at land fall.

Stop Joint (HPOF)

Stop joints would incorporate all elements enclosed within the outer corrosion protection box for 3-core or single-core self contained oil-filled cables.

Sealing Ends/Terminations

Outdoor/indoor (Pothead) termination, gas filled, oil filled or dry;
Oil-immersed (Transformer) termination;
Gas-immersed or oil-immersed (GIS) termination.

Incorporating all elements from the sheath plumb to the top connector stalk for SCOF, extruded and MI cables.

For cables with extruded insulation without a metal sheath the sealing end will include all elements from where the outer corrosion protective sheath has been removed to the top connector stalk.

Other Components

This category will include the following items:

- Pilot Cable including Joints

All pilot and telephone cables including joints and spur joints associated with the alarm system on the transmission cable.

- Pilot Cable Terminations and Alarm System Circuitry

All electrical components of the pressure alarm systems from pilot cable terminations to alarm indication panel.

- Sheath Bonding Equipment

All link boxes, bonding leads, sheath surge diverters and earthing (grounding) fittings for single-point bonding and cross-bonding of cable sheaths.

- Heat Exchanger and Monitoring Equipment

All equipment both mechanical and electrical associated with external or internal cable cooling systems. This item includes hot-spot thermal monitoring

- Cathodic Protection Equipment

All equipment associated with cathodic protection on cable metallic sheath.

- Ancillary oil equipment:

This item includes all oil tanks, oil pipes, fittings, isolation pieces, pressure gauges in the case of oil filled cables.

Units for Submarine Components in Questionnaire

Voltage:	kV (nominal phase-to-phase value for AC links and phase to ground for DC links)
AC Cable:	Route km (3-core or 3 single core cables ignoring the number of cables used for each phase)
DC Cable:	Route km (length between terminations independent of bipolar, monopolar with metallic return or electrodes) (parallel bipoles and parallel monopoles with metallic return or electrodes build to enable independent operation are regarded as two DC installations)
Straight Joint/Stop Joint /Transition Joint:	One single-core or one three-core joint
Sealing End:	One single-core sealing end
Ancillary (Oil) Equipment:	One set of equipment physically situated at one position with one single connection to a 3-core cable or one set of three connections to 3 single-core cables. It can be a feed point or alarm point.

Type of Submarine Cable System

The type of cable such as SCOF, HPOF, EPR, XLPE etc. is also referred to as the type of cable system.

Modes of Installation of Submarine Cables

Unprotected: Cable (or pipe with cables for HPOF) left unburied and without external protection on the seabed

Protected by direct burial into the sea bed: Water jetting, burial by ploughing, burial in pre-made trench, etc

Protection by additional surface applied measures: Rock dumping, half-shell pipes, concrete mattresses etc

Landfall protection: Direct burial, troughs, ducts, pre-installed pipes etc

Cause of Failure of Submarine Systems

When completing the cause of failure information, if the information is available the cause of the failure should be recorded as "internal" to the cable or component or as "external" and differentiating between whether the externally generated fault was as a result of "Third Party Mechanical damage such as anchor, trawling or excavation activities " or other physical external parameters (e.g. subsidence, increased burial depth resulting in overheating) or an abnormal external system (e.g. lightning) condition.

12. APPENDIX 3

Summary of Replies from Questionnaire

	Land	Submarine
Australia & New Zealand	0	1
Austria	1	0
Belgium	1	0
Brazil	3	0
Canada	3	2
China	0	0
Denmark	20	5
Finland	1	1
France	1	0
Germany	1	1
Ireland	1	1
Italy	3	1
Japan	10	1
Korea	1	1
Netherlands	5	0
Norway	3	11
Poland	1	1
Portugal	2	0
Russia	0	0
South Africa	0	0
Spain	1	1
Sweden	1	0
Switzerland	2	2
United Kingdom	3	1
United States	6	1
Gulf States	0	0
Argentina	0	0
Croatia	1	1
Egypt	0	0
Greece	0	0
India	0	0
Israel	1	0
Malaysia	0	0
Mexico	0	0
Romania	0	0
Singapore	1	0
Thailand	0	0
Vietnam	0	0

	Land	Submarine
Hong Kong	0	0
Taiwan	0	0
Qatar	0	0
Bahrain	0	0
Oman	0	0
Kuwait	0	0
Saudi Arabia	0	0
Abu Dhabi	0	0
Dubai	0	0
UAE	0	0
Lebanon	0	0
Replies from Utilities	73	32
Replies from Cable Suppliers		4

13. REFERENCES

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4. Commission of European Communities Background Paper "Undergrounding of Electricity Lines in Europe", December 2003
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7. Europacable Publication "European Industry Leading Edge in EHV Cable Systems Technology", 2005
8. "World Survey of 230kV and above XLPE Land Cable Installations" Personal document of R Mosier, December 2007
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